Ministry of Environment, Lands and Parks
Hydrology Branch

FLOODPLAIN MAPPING

Kettle River

MIDWAY - ROCK CREEK - WESTBRIDGE

Design Brief

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1 INTRODUCTION

1 Introduction

This Design Brief and associated Floodplain Maps for the Kettle River, West Kettle River and Boundary Creek were prepared under the Canada-British Columbia Floodplain Mapping Agreement by Acres International Limited. The Floodplain Mapping Program is a joint initiative by the federal and BC governments to provide information which will help minimize flood damage in British Columbia. The program identifies and maps areas that are highly susceptible to flooding. These areas may be designated as floodplains by the federal and provincial Environment Ministers. Designated floodplains are subject to development restrictions. Subdivisions within a floodplain require the approval of the regional water manager. Crown agencies such as the Canada Mortgage and Housing Corporation do not support development on designated floodplains unless adequate floodproofing measures are taken. As well, disaster assistance is available only if new developments have incorporated adequate floodproofing measures. Local governments may impose further restrictions.

The floodplain delineation study was conducted from July to November 1996, and encompassed a channel length of 46.5 km in the Kettle River basin located in the Kootenay region of British Columbia (see Figure 1-1). This Design Brief describes the data and analyses undertaken and summarizes the study findings.

The principal contact within the Victoria offices of B.C. Environment, Lands and Parks, Water Management Division for the study was Mr. R.W. Nichols, Head, Floodplain Mapping Program. The Water Management Division contact in the Regional Office in Penticton was Mr. B.J. Symonds, Head, Engineering Section. Valuable assistance and guidance were provided to the study by these staff members, and their contributions are gratefully acknowledged.

This floodplain delineation study comprised the following principal tasks:

- completion of a hydrology study to assess flooding characteristics and estimate design flood flows for the study reaches;

- calibration of a computer backwater model (HEC-2) to estimate flood profiles, using river cross-sectional data, high water mark data and topographic maps provided by the B.C. Ministry of Environment, Lands and Parks as input data;

- determination of 200- and 20-year flood levels for the study reaches, using the calibrated computer model with the design flood flows;

Fig. 1-1

Ministry of Environment, Lands and Parks
Floodplain Mapping Program - Upper Kettle River
Location Map

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- delineation of land areas with elevations lower than the 200-year flood levels plus freeboard as the "200-year floodplain", using topographic maps provided by the B.C. Ministry of Environment, Lands and Parks; and

- preparation of this Design Brief and associated Floodplain Maps.

2 Drainage Basin

2 Drainage Basin

2.1 Description of the Basin

The Kettle River basin lies within the Monashee (Columbia) mountains and is bounded by the Beaverdell (west) and Midway (east) ranges. The terrain is generally very rugged with mountain peaks rising to over 2000 m and ground slopes as high as 50%.

Most of the land usable for farming and housing lies in a narrow strip along the bottom of the valley. The study area is located in the Regional District of Kootenay Boundary. The principal community in the study area is the Village of Midway, with additional smaller unincorporated settlements at Westbridge and Rock Creek.

Generally, the basin is heavily forested and logging is the principal economic activity. Tourism is also an important component of the local economy.

2.2 Hydrological Characteristics

The Kettle River flows from north to south until it turns east at Rock Creek, where it then flows in a south-easterly direction to Midway at the downstream end of the study reach (see Figure 2-1). The West Kettle is a significant tributary of the Kettle River, combining with the Kettle River at Westbridge. Boundary Creek is a relatively steep mountain stream which joins the Kettle River just downstream of Midway in the United States.

The study reaches comprise:

- the Kettle River from the U.S. border at Midway to a point about 5 km upstream of its confluence with the West Kettle River (44.0 km)
- the West Kettle River near its confluence with the Kettle River (1.9 km)
- the lower portion of Boundary Creek close to Midway (0.6 km)

The drainage areas contributing to flows in the study reach are summarized in Table 2.1.

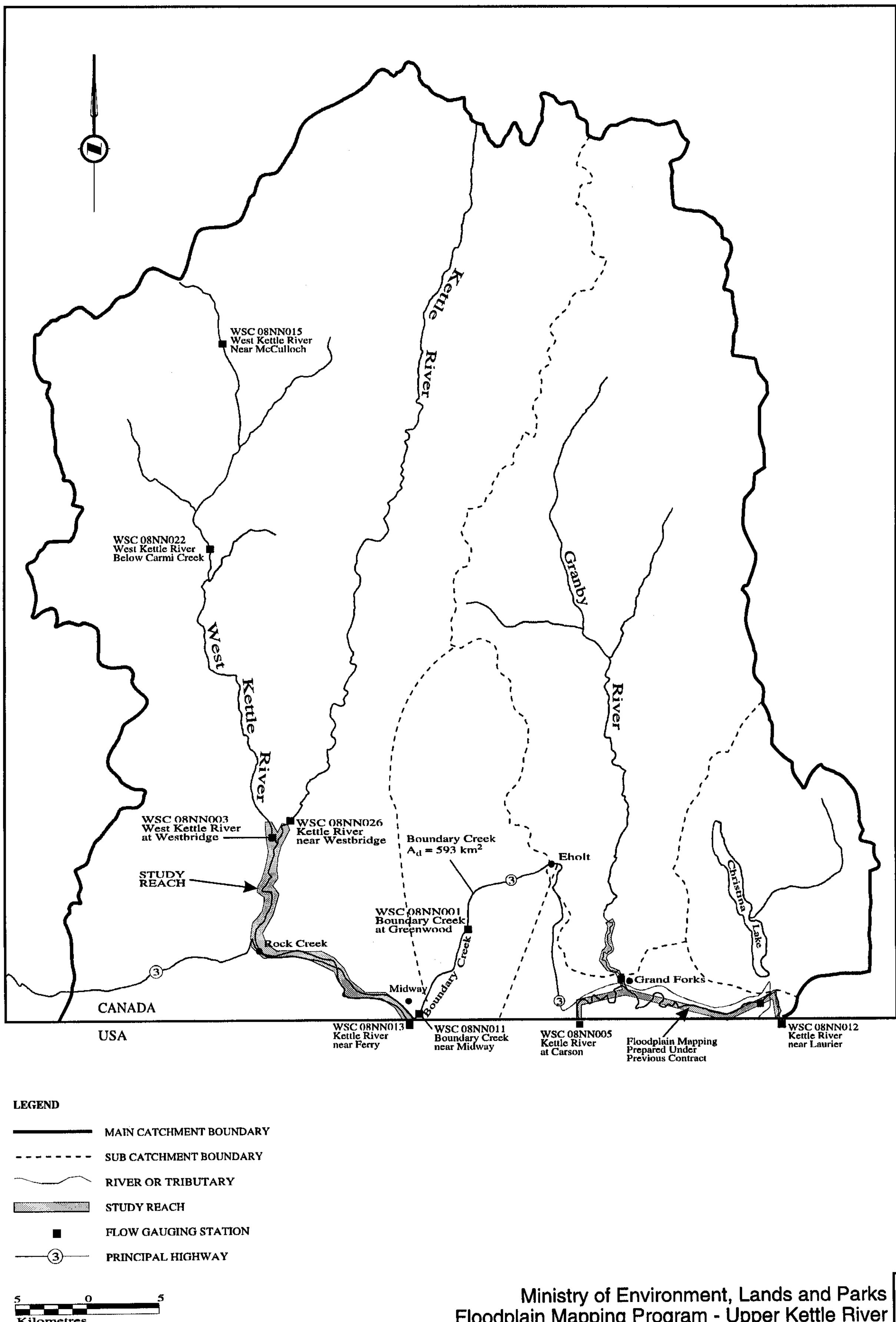

Fig. 2-1

Ministry of Environment, Lands and Parks
Floodplain Mapping Program - Upper Kettle River
Study Area

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TABLE 2.1 SUMMARY OF DRAINAGE AREAS

Location	Drainage Area (km^2)
Kettle River	
Upstream of confluence with West Kettle River	2,220
Upstream of Rock Creek	4,220
Upstream of U.S. border at Midway	5,150
West Kettle River	
At the mouth	1,870
Boundary Creek	
At the U.S. border	593

The mean daily temperature at Grand Forks ranges from -6.1°C in January to 19.6°C in July[1], with recorded temperature extremes of -38.9°C and 42.2°C. Of the total annual precipitation at Grand Forks of 460 mm, approximately two-thirds occurs as rain and one-third as snow.[2] The 100-year 24-hour maximum precipitation, as documented in the Atmospheric Environment Service Rainfall Frequency Atlas for Canada[3], is 45 mm.

There are seven streamflow gauging stations in the study basin with usable records (see Table 2.2). The mean annual runoff recorded at the long term station on the Kettle River near Ferry (WSC 08NN013) is 43.1 m^3/s. This is equivalent to a runoff depth of 236 mm, suggesting a runoff coefficient of 57%, which is in the normal range for a heavily forested catchment. The annual flood peak occurs from late April to mid-June. The annual runoff hygrograph is very much dominated by the spring freshet; on average, 78% of the annual flow is observed in April, May and June.

The snowmelt-dominated flow pattern observed for the Kettle River at Ferry is also evident in the flow records from the West Kettle and Boundary Creek. This has important implications for the flood frequency analysis. It appears that throughout the basin, the maximum annual flow is attributable to spring snowmelt supplemented by rainfall. No consideration needs to be given to rainfall-induced events at other times of the year.

While the annual flood peak is a snowmelt event, damaging floods usually require the occurrence of significant rainfall in addition to rapid snowmelt. These rains usually result from frontal systems moving in from the west coast which are subjected to significant orographic effects from the local topography. During the early summer, non-frontal "cold lows" occasionally pass through the area from the northwest, west or southwest, and sometimes produce significant amounts of rainfall before moving eastwards. Convective rainstorms typically occur in the summer months, but do not produce large floods, except on very small creeks.

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1 "Canadian Climatic Normals, Volume 2, Temperature, 1951- 1980", Atmospheric Environment Service, Environment Canada, 1982.

2 "Canadian Climatic Normals, Volume 3, Precipitation, 1951-1980," Atmospheric Environment Service, Environment Canada, 1982.

3 "Rainfall Frequency Atlas for Canada", Hogg, W.D. and D.A. Carr, Atmospheric Environment Service, Environment Canada, 1985.

TABLE 2.2 STREAMFLOW GAUGING STATIONS WITH USABLE RECORDS

Station Name	Kettle River Near Ferry	Kettle River Near Westbridge	W. Kettle River At Westbridge	West Kettle River Below Carmi Creek	West Kettle River Near McCulloch	Boundary Creek Near Midway	Boundary Creek at Greenwood
WSC No.	08NN013	08NN026	08NN003	08NN022	08NN015	08NN011	08NN001
Drainage Area (km^2)	5750	2150	1870	1170	230	593	479
Location	48-58-53N 118-45-55W	49-13-48N 118-55-39W	49-10-12N 118-58-28W	49-29-03N 119-06-30W	49-42-15N 119-05-31W	49-00-08N 118-45-42W	49-04-43N 118-41-12W
Period of Record	1929-date	1975-date	1917-19, 21 1979-date	1973-date	1949-57,64-date	1929-32,43-53, 71-77	1913-18,60-80
Notes	International gauging station operated by USGS	Manual gauge, seasonal operations, no instantaneous peak flows	Manual gauge, seasonal operation, no instantaneous peak flows	1973-74 RS 1975-date RC	Recording gauge since 1964	Manual gauge, seasonal operation, no instantaneous peak flows	Manual gauge, no instantaneous peak flows

2.3 Historical Floods

Over the years, the study area has been subjected to floods, some of which have caused significant damage. The following paragraphs describe the worst floods that have occurred since the late 1800's, based on information obtained from newspaper files, discussions with long-term residents of Midway and, when available, Water Survey of Canada flow data.

◇ **May 1894**

Although no flow records in the study area are available for 1894, the flood of 1894 was known to be a significant event in the general area. Discussions with staff of the USGS indicated that the flood was more severe than the flood of 1948.

The Midway Advance newspaper reported at the time that most bridges were destroyed in the flood. The lone exception, on the north fork of the Kettle (presumably the Kettle River north of Westbridge) was surrounded by water in "New Venice". Roads were washed out with the expectation that a month would elapse before they would be fully operable again.

In the Boundary Creek area, an "old timer" noted that the flood flows were the highest in twenty years. Several fields along the river were reported to be under water.

◇ **May 1942**

The flood peak as recorded at Ferry in 1942 was 507 m^3/s, and is the second largest flood peak in the 66-year flow record at this station. The estimated return period for this flood peak is 1 in 50 years. (see Section 4).

The Grand Forks Gazette reported that flooded areas near Westbridge stopped the Kettle Valley trains to the west and the Rock Creek highway was flooded, and "The Jackson ranch west of Midway was a lake except for the buildings". Flooding on Rock Creek washed out some timber cribbing and the highway became a temporary riverbed where it "cut straight through Olsen's old garage, and shot down either side of Wheeler's store, cutting deep gulleys". At one point, "the whole area between Rock Creek town and the high land at the CPR depot was virtually a lake". Soldiers on furlough were unable to return to their units.

◇ **May 1948**

The flood of 1948 was widespread in southern British Columbia. The recorded peak mean daily flow for the Kettle River at Ferry was 575 m^3/s, which is the flood of record for this station. The estimated return period for this flood peak is 1 in 200 years. The flood appears to have been caused by high snowmelt runoff exacerbated by a series of heavy thunderstorms.

No newspaper records could be found concerning flooding that occurred in the Midway-Rock Creek-Westbridge area in 1948. Mr. Dan Bolz, a long-time rancher near the confluence of Kettle River and Boundary Creek, indicated that some nearby fields, including his own, were inundated by the 1948 flood. Ms. Ludwar of Midway recalled that the local elementary school was under water. Available information suggests that flooding in the study area caused only nominal damage, especially when compared with the severe widespread damages that occurred elsewhere in the general area.

The review of past floods indicates that flooding in the study reach has not caused severe economic losses, due to rather limited development and population in the floodplain. This contrasts with the downstream town of Grand Forks, which has suffered substantial damage over the past 100 years. However, with increasing development pressures on flood-prone areas in the study reach, it is appropriate to delineate the floodplain in accordance with the standards of the Floodplain Mapping Program to provide information which will help to minimize future flood damages.

2.4 Field Investigations

During the course of the study, two reconnaissance trips to the Midway area were undertaken by the Principal Investigator -- July 8 to 10 and September 23 to 24, 1996. On the first trip, a reconnaissance of the accessible study reaches was undertaken to estimate the hydraulic roughness of the overbank portions of the river, and to make note of any features that would be relevant to the hydraulic analysis of floods. Photographs were taken of the river at representative points along the study reaches (see Photographs 2.1 to 2.4). Interviews were held with several long-term residents of the area concerning historic floods.

PHOTO 2.1
Junction of Kettle River and Boundary Creek, looking upstream

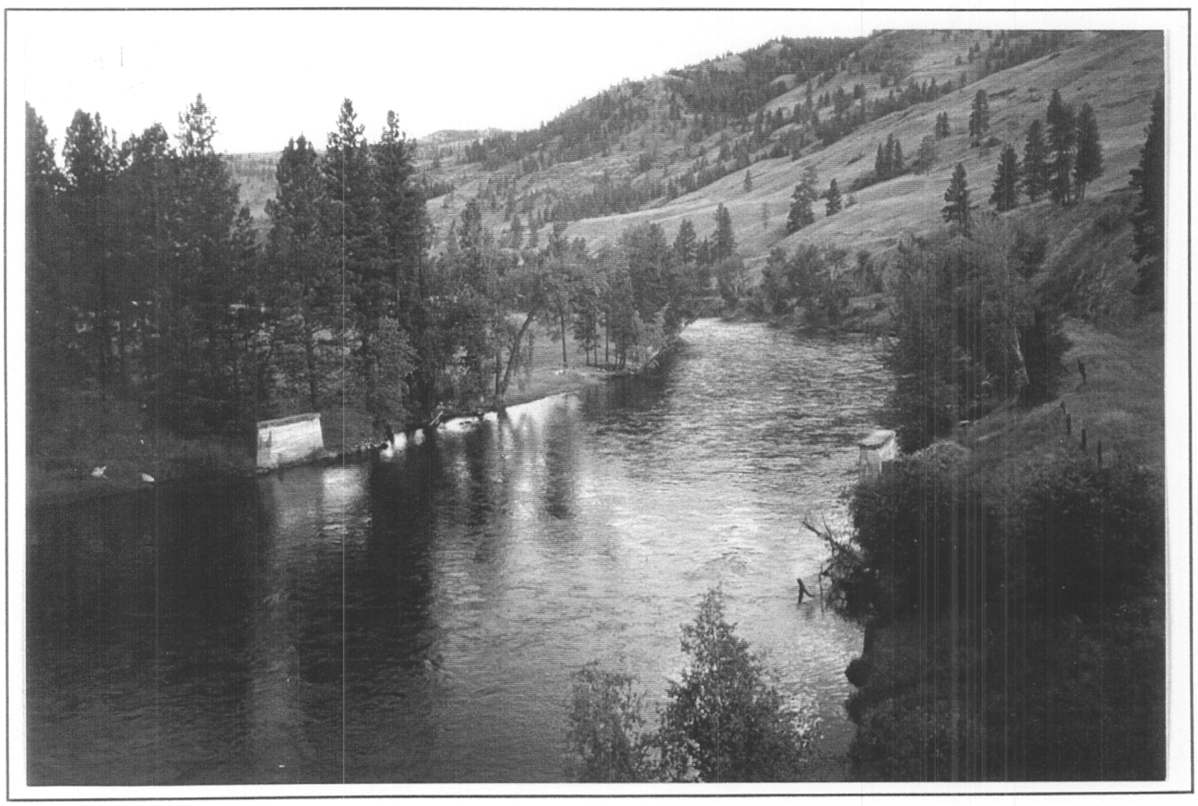

PHOTO 2.2
Kettle River at XS-24.5, including remnants of old bridge.

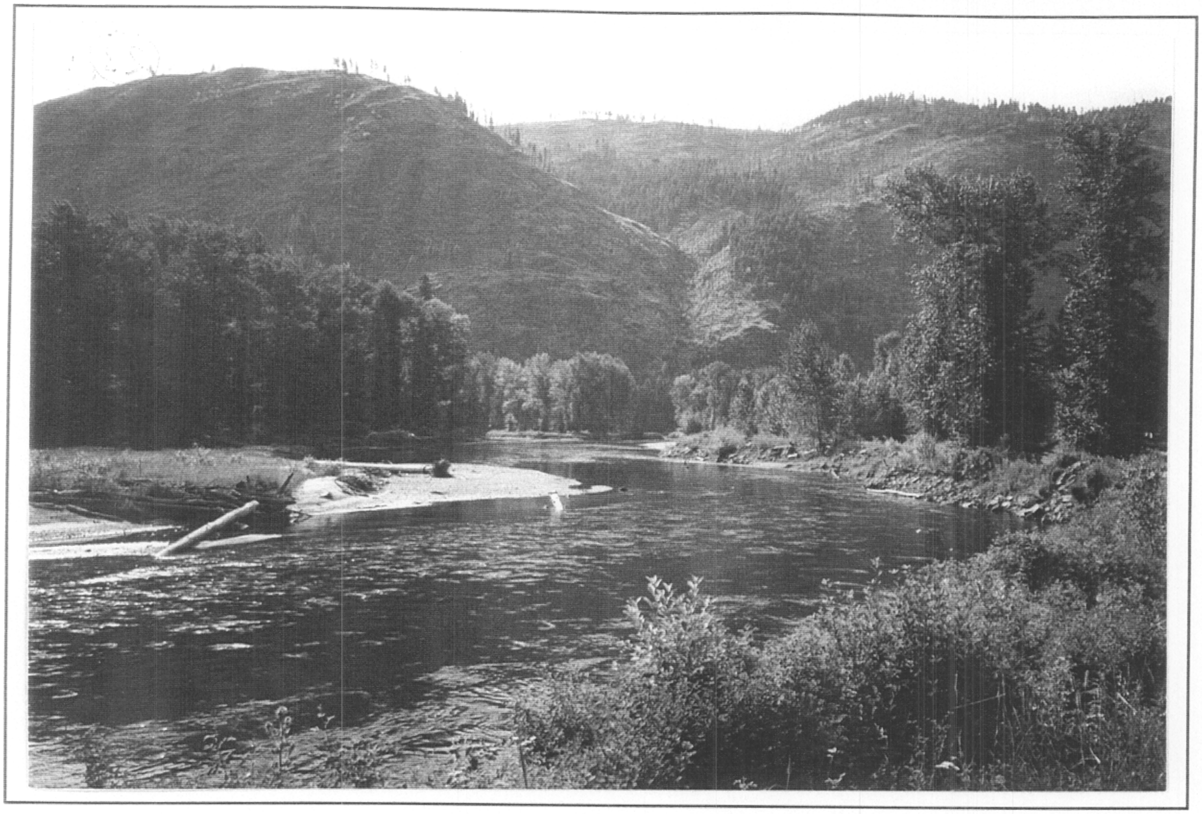

PHOTO 2.3
Kettle River at XS-77, looking downstream.

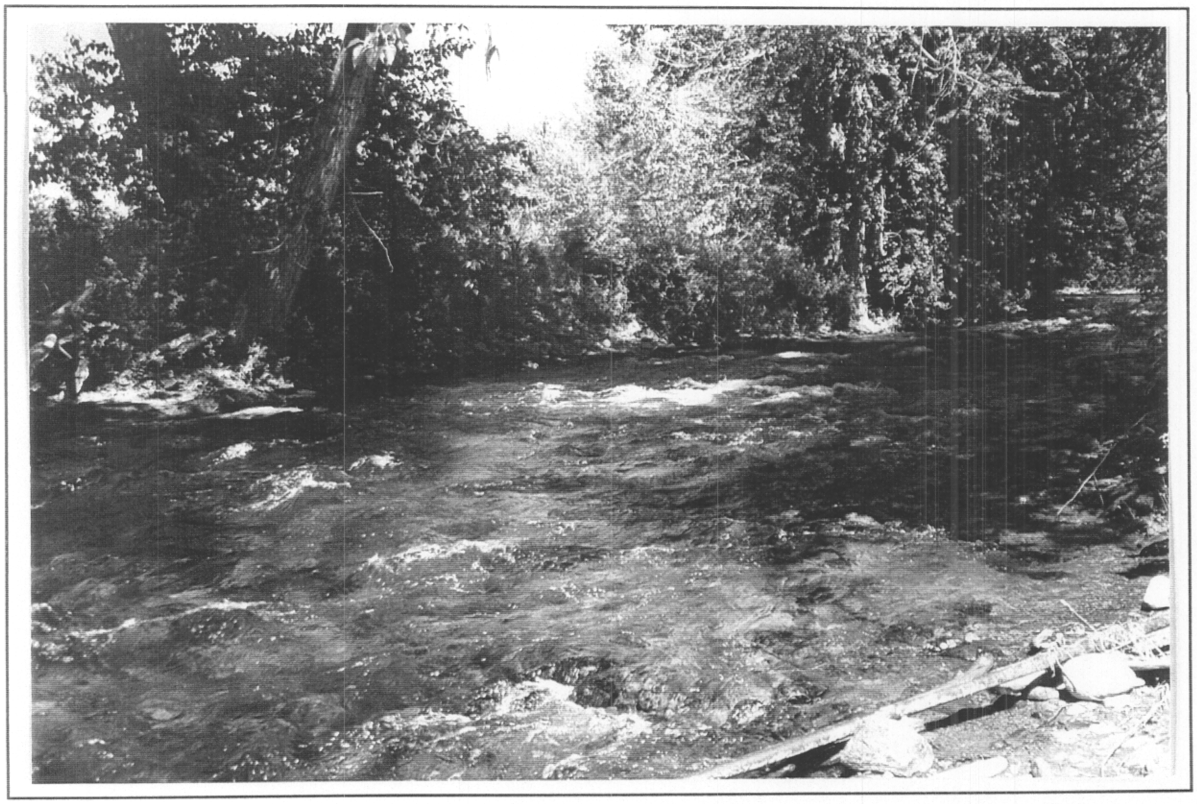

PHOTO 2.4
Boundary Creek, looking upstream at Customs Road Bridge.

At the start of the second field trip, a meeting was held in Penticton with Mr. Brian Symonds (Head, Engineering Section, Water Management Division), who provided background information on the study basin. Newspaper archives at Selkirk College in Castlegar were examined for accounts of historical floods in the study area. More interviews were held with long-term residents of the area concerning floods. Some uncertainties in the draft floodplain maps were reconciled in the field.

The assistance of the following individuals is gratefully acknowledged:

Ms. Gladys Brown	-	Midway Museum
Ms. Kathy Ludwar	-	Resident, Midway
Mr. Dan Bolz	-	Resident, Midway
Ms. Margarit Rotvold	-	Canada Customs, Midway
Mr. Wes Demchuk	-	Resident, Midway
Mr. Jim McMynn	-	Mayor, Midway
Mr. John Malloff	-	Building Inspector, Midway
Mr. Barry Alcock	-	B.C. Ministry of Environment, Lands & Parks (retired)

3 FLOOD FREQUENCY STUDIES

3 Flood Frequency Studies

3.1 Hydrological Data Sources

3.1.1 The Study Basin

Flood frequency analysis requires at least ten years of data at a site before a meaningful analysis may be undertaken. Over the years, Water Survey of Canada has operated a number of gauging stations in the Kettle River basin. The seven stations with usable records and the key characteristics of these stations are summarized in Table 2.2.

3.1.2 The Study Region

In 1989, the B.C. Ministry of Environment undertook a regional flood frequency analysis for the Kootenay (Nelson) region.[4] In that study, no regional curves or regional equations were developed for estimating peak flows for ungauged basins, due to the diverse characteristics of the gauged basins and the influence of this diversity on flood characteristics. The plots of unit mean annual flood (mean annual flood divided by drainage area) versus drainage area presented in the B.C. Environment report showed significant scatter on a sub-region basis, with a general trend of increasing unit flood peaks with drainage area. Such a trend is not normally expected, as small basins typically generate higher unit flood peaks than do larger basins. This demonstrates that other factors (e.g. basin elevation, orientation, natural storage) exert a significant influence on the flood characteristics of Kootenay region watersheds.

3.2 Flood Frequency

The mountainous terrain of the Kettle region makes conventional regional hydrology analysis difficult, as demonstrated in the B.C. Ministry of Environment regional hydrology study for the Kootenay (Nelson) region. Accordingly, the present study relied on the results of flood frequency analyses of the gauges in the study basin. This essentially complies with the recommended approach of the B.C. Ministry of Environment regional study.

The present study required water levels to be computed using the HEC-2 computer model for the following flow conditions:

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[4] "Guide to Peak Flow Estimation for Ungauged Watersheds in the Kootenay (Nelson Region)", Recksten, D.E. and Barr, L.J., B.C. Ministry of Environment, Water Management Branch 1989.

- 200-year Instantaneous Peak Flow
- 200-year Mean Daily Peak Flow
- 20-year Instantaneous Peak Flow
- 20-year Mean Daily Peak Flow

It is evident from Figure 2-1 and Table 2.1 that the catchment area of the Kettle River varies appreciably along the study reach. It was, therefore, necessary to derive the four desired flood flows at representative points along the study reach.

Flood frequency analyses were undertaken at the following locations:

- Kettle River near Ferry
- Kettle River near Westbridge
- West Kettle River at Westbridge
- West Kettle River below Carmi Creek
- West Kettle River near McCulloch
- Boundary Creek at Greenwood

Analyses were undertaken where possible using both instantaneous and daily peak flow data.

The Acres computer program used for the analysis, designated FDR, is based on Environment Canada's frequency analysis program "FDRPFFA". It incorporates slight modifications to the output format and the addition of graphics capabilities. The numerical results of FDR are identical to those of FDRPFFA. The program attempts to fit six different statistical distributions to the flood data:

- Gumbel (Extreme Value Type 1)
- Pearson Type III
- Three-Parameter Lognormal
- Log Pearson Type III
- Two-Parameter Lognormal
- Normal Distribution

For this study only the first three distributions were considered as candidates for analysis, as specified in the "Specification for Engineering Studies, Floodplain Mapping Program". The computer program output was reviewed and the most appropriate distribution for the data was selected, based on normally accepted statistically - based criteria. For many flood frequency analyses conducted in Canada, the sample sizes under consideration are too small to make a confident choice of distribution. However, there is often enough evidence to reject some of the choices, and the differences among the remaining candidates are quite small on many occasions.

In selecting a distribution and method fit for the various flow data sets, the following provided some guidance:

- it is preferable to adopt one frequency distribution and method of fit for a group of stations in an area (in particular, for a given station, one would want to choose the same distribution for the maximum instantaneous and daily series, to ensure consistency of results),
- it is often the case that no distribution can be demonstrated to be clearly superior to all other candidates, and
- a previous study[5] in the lower Kettle River basin resulted in selection of the Pearson Type III distribution.

a) Kettle River near Ferry

Both maximum instantaneous and maximum daily analyses were undertaken for this long-term station. For both sets, the Gumbel distribution provided a poor fit, whereas the Pearson Type III and Three-Parameter Lognormal distributions both appeared satisfactory and comparable in terms of estimated floods.

b) Kettle River near Westbridge

Only maximum daily flow series were available for analysis. The Pearson Type III and Three-Parameter Lognormal distributions provided adequate fits and similar results, whereas the Gumbel distribution provided a poorer fit to the data.

c) West Kettle River at Westbridge

Only daily flow data were available for analysis at this station. No solution was obtained for the Three-Parameter Lognormal distribution, probably because the flows exhibited negative skewness (with negative skewness there is no moments solution and seldom a maximum likelihood solution). The fit for the Pearson Type III distribution was reasonable and superior to that of the Gumbel distribution.

d) West Kettle River below Carmi Creek

Both maximum instantaneous and maximum daily analyses were undertaken for this station. For both data sets, no solution was obtained for the Three-Parameter Lognormal distribution (the flows exhibited negative skewness). The solutions for both the Pearson Type III and Gumbel distributions were adequate.

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[5] "Floodplain Mapping-Kettle and Granby Rivers, Design Brief", Acres International Limited, 1991.

e) West Kettle River near McCulloch

No solutions were obtained using the Three-Parameter Lognormal distributions for either the instantaneous or the daily series (the flows exhibited negative skewness). For both data sets, the fit for the Pearson Type III distribution was good, and clearly better than that of the Gumbel distribution.

f) Boundary Creek at Greenwood

Only maximum daily flow data were available for this station. The results for all three candidate distributions were fair and comparable.

Based on the above, it was decided to adopt the Pearson Type III distribution for all of the stations. Frequency plots for the Kettle River near Ferry are shown in Figures 3-1 and 3-2. Flood estimates for each of the stations are summarized in Table 3.1. Frequency plots for all stations and all candidate distributions are provided in Appendix A.

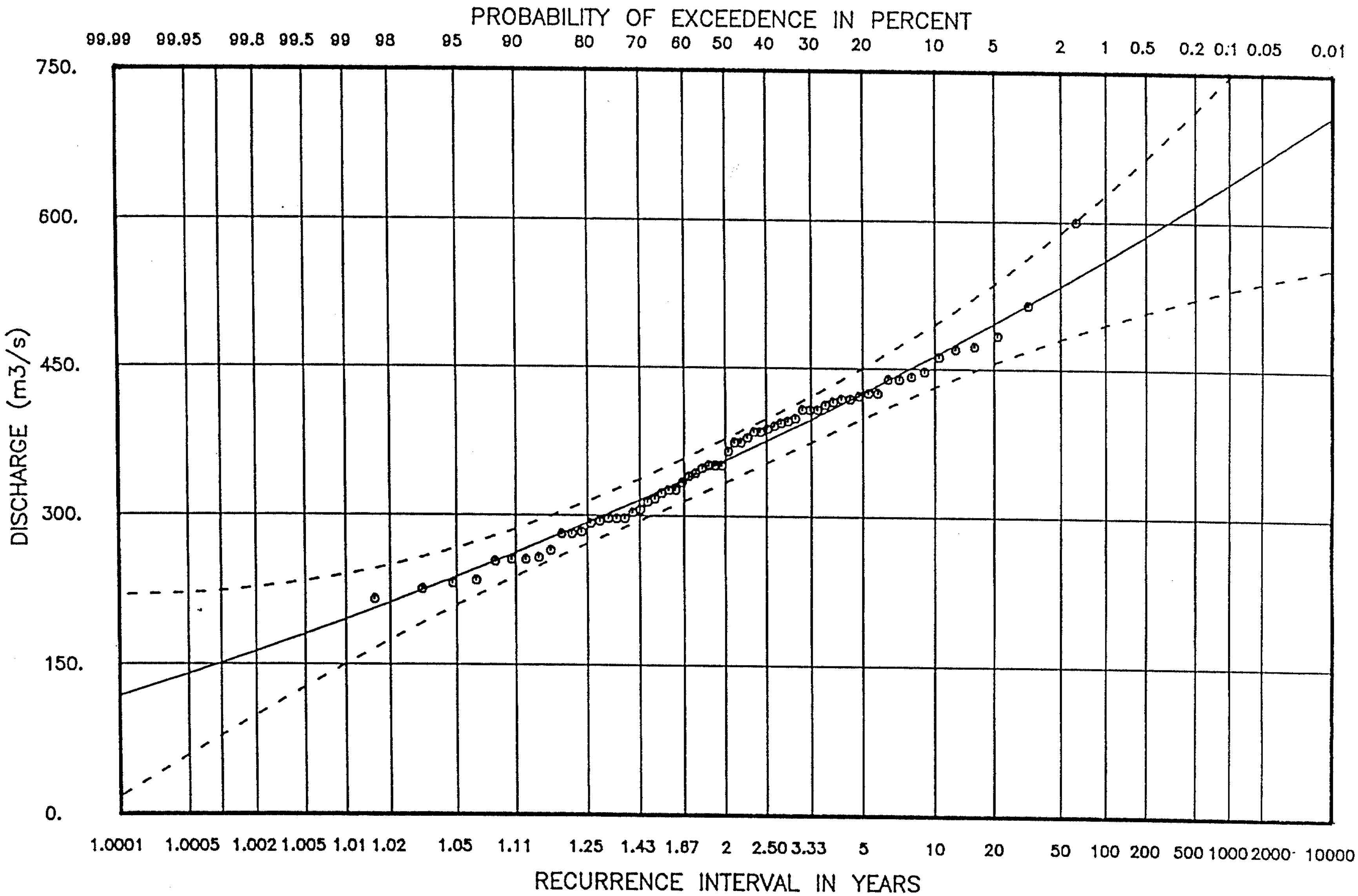
3.3 Derivation of Design Flows

The derivation of design flows for different parts of the study area, as summarized in Table 3.2, is described below.

a) Kettle River

Using the frequency results for the five stations on the Kettle and West Kettle rivers, a relationship was established for peak daily flow versus drainage area for return periods of 200 and 20 years. The relationship for T = 200 years is shown in Figure 3-3. The validity of the relationship for larger drainage areas was verified by comparing it with USGS flood estimates immediately downstream of Midway, and with flood estimates made at Laurier in an earlier floodplain mapping study (see footnote of Table 3.2). The pattern of the points from smaller drainage areas indicated that flood estimates for the short Kettle and West Kettle reaches above Westbridge would best be estimated directly from the records of the Kettle River near Westbridge, and the West Kettle at Westbridge.

To estimate instantaneous flows, the results for the three stations with both instantaneous and daily data were analyzed to derive a relationship between the peaking factor (Q inst/Q daily) and drainage area for return periods of 200 and 20 years (see Appendix B for derivation of these relationships). The relationship for T=200 years is shown in Figure 3-4.



PEARSON TYPE III DISTRIBUTION
Parameters Estimated by Moments

Ministry of Environment, Lands and Parks
Floodplain Mapping Program - Upper Kettle River
Flood Frequency Distribution - Kettle River Near Ferry - Instantaneous Peak Flows

Fig. 3-1

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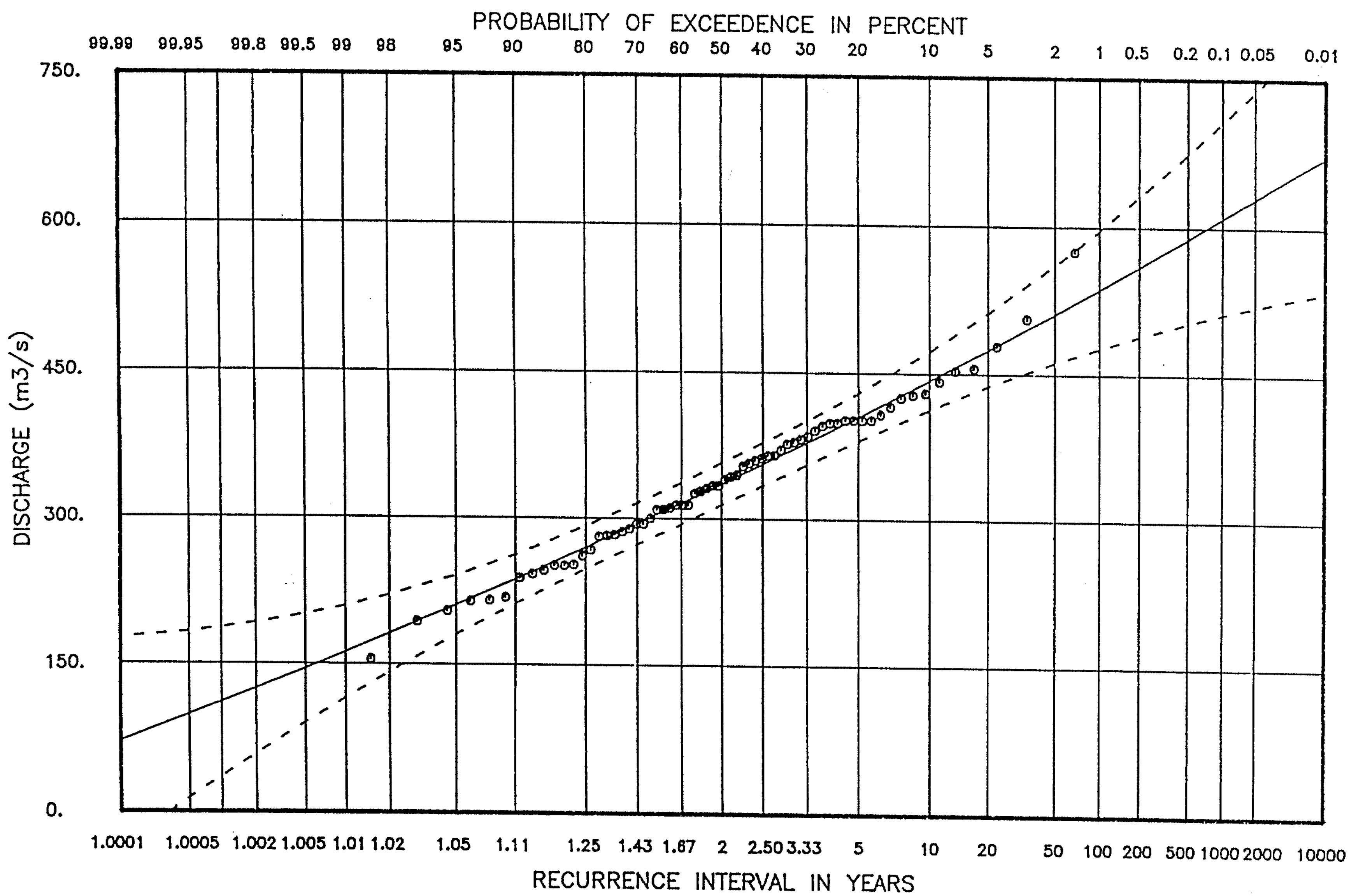

PEARSON TYPE III DISTRIBUTION
Parameters Estimated by Moments

Ministry of Environment, Lands and Parks
Floodplain Mapping Program - Upper Kettle River
Flood Frequency Distribution - Kettle River Near Ferry - Daily Peak Flows

Fig. 3-2

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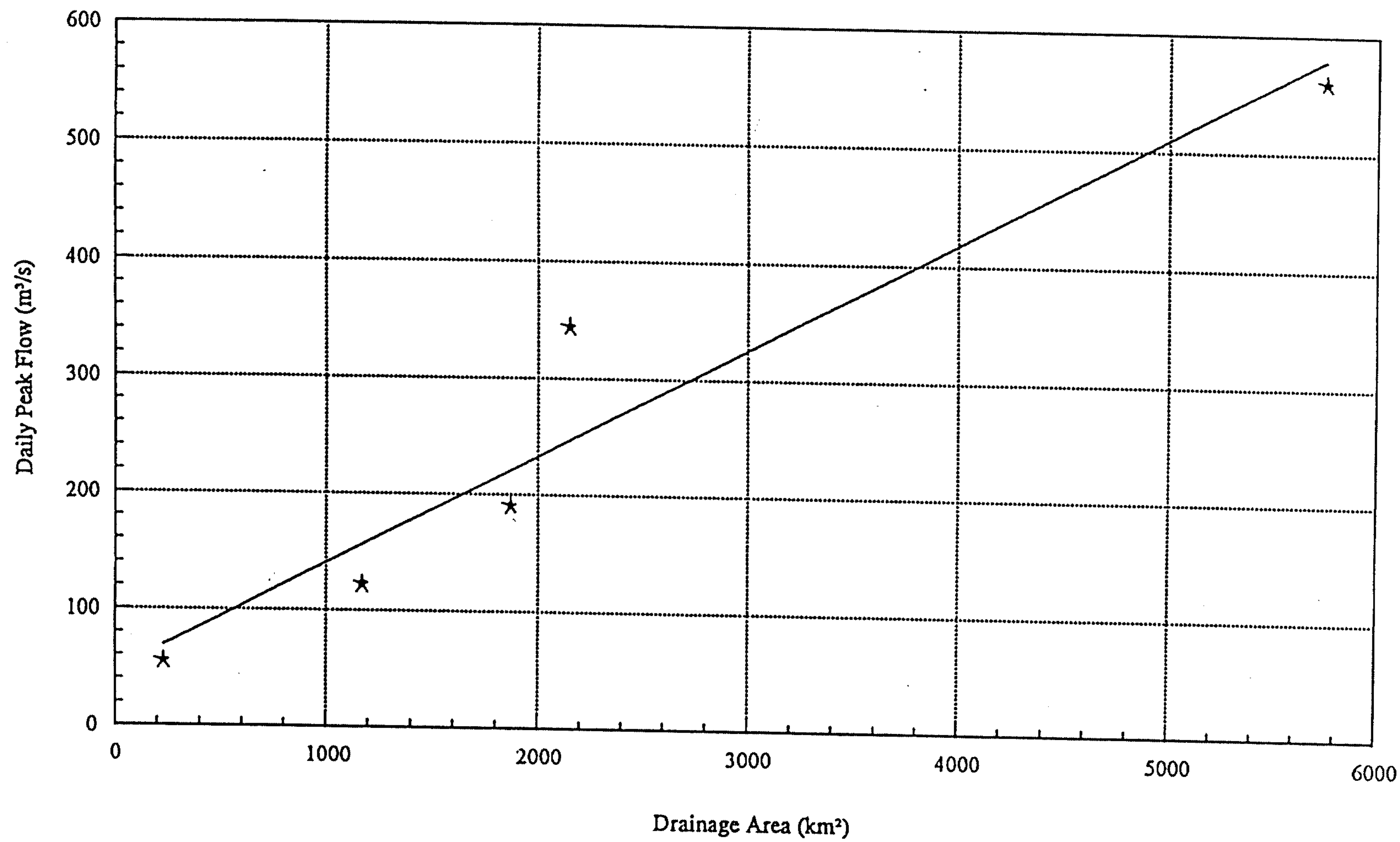

Fig. 3-3

Ministry of Environment, Lands and Parks
Floodplain Mapping Program - Upper Kettle River
200 Year Daily Peak Discharge vs. Drainage Area

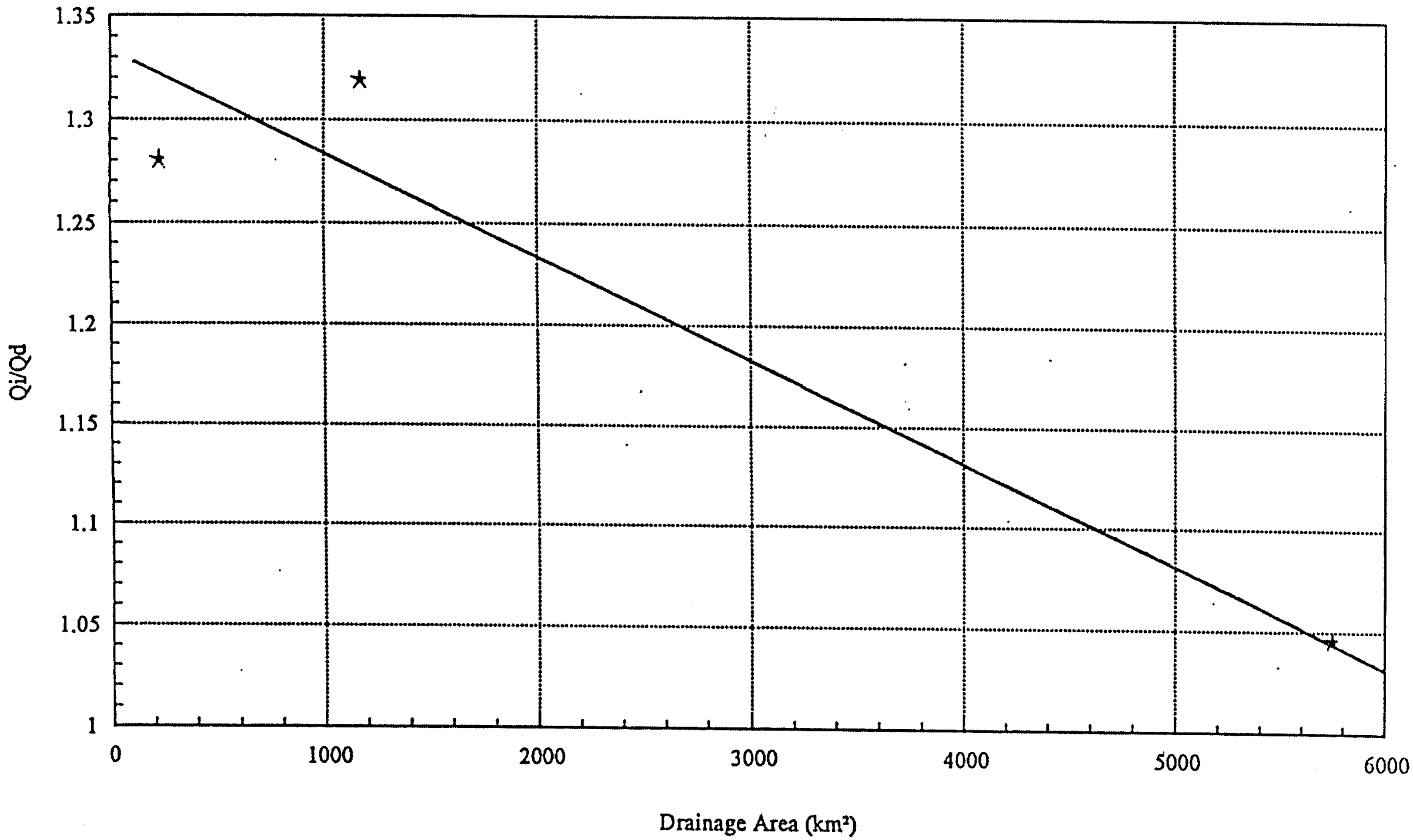

Fig. 3-4

Ministry of Environment, Lands and Parks
Floodplain Mapping Program - Upper Kettle River
Qi/Qd vs. Drainage Area for T=200

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TABLE 3.1 CALCULATED FLOOD PEAKS

Return Period (years)	Flood Peak (m^3/s)								
	Kettle River near Ferry		Kettle River Westbridge, Daily	W. Kettle River near Westbridge, Daily	W. Kettle River below Carmi Cr.		W. Kettle River near McCulloch		Boundary Creek near Greenwood, Daily
	Inst.	Daily			Inst.	Daily	Inst.	Daily	
10	463	443	281	156	134	110	59	46	37
20	496	475	298	166	142	114	62	49	42
50	535	512	317	177	150	118	66	52	49
100	561	537	331	184	156	120	69	54	54
200	586	561	344	190	161	122	71	55	59

Note - For further details, see Appendix A.

TABLE 3.2 DESIGN FLOWS FOR STUDY REACHES

Location	Q200 Inst. m³/s	Q200 Daily m³/s	Q20 Inst. m³/s	Q20 Daily m³/s
Kettle River Main Stem				
U.S. border to Rock Creek	562	524	477	446
Rock Creek to Westbridge	490	438	415	374
Westbridge to u/s end of study reach	422	344	357	298
West Kettle River	235	190	201	166
Boundary Creek	85.2	65.5	58.9	46.6
Kettle River at Grand Forks* (u/s of Granby R.)	604	584	512	493

* **Source:** Table 4.2, "Floodplain Mapping - Kettle and Granby Rivers, Design Brief", Acres International Limited, 1991. These figures, which represent the flood flows derived for use in floodplain mapping at a point a short distance downstream from Midway, lend support to the flood flows derived for the present study reach.

Using the drainage areas from Table 2.1 and the derived relationships, the design flows for the three subreaches of the Kettle River were established and are shown in Table 3.2.

b) West Kettle River

The frequency analysis results for the station at Westbridge were used directly to estimate the peak daily flow. The peaking factor relationships established for the Kettle River were used to estimate the instantaneous flood peaks for the West Kettle River. The results are provided in Table 3.2.

c) Boundary Creek

Mean daily flood peaks for Boundary Creek at Greenwood (drainage area 479 km^2) were adjusted to Midway (drainage area 593 km^2)using the peak flow versus drainage area relationship established for the Kettle River (Figure 3-3). The instantaneous flows were established using the peaking factor relationships developed for the Kettle River (Figure 3-4). The estimated flood flows are provided in Table 3.2.

It will be noted that the sum of the upper Kettle and West Kettle flows exceeds the estimated flow downstream from the West Kettle confluence[6]. The flow imbalance implied by these figures is explained by lack of coincidence of flood peaks, which has been observed in some years of record.

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[6] **For example, for T=20 years, mean daily flood peaks are 298+166=464 m^3/s, versus 374 m^3/s.**

4 HYDRAULIC ANALYSES

4 Hydraulic Analyses

4.1 River Backwater Modelling

The hydraulic analyses were undertaken using the HEC-2 standard-step backwater model developed by the U.S. Army Corps of Engineers[7]. Calculations were also performed using HEC-RAS (Hydrologic Engineering Center - River Analysis System), a graphical user-interface model intended as a replacement to HEC-2[8]. HEC-RAS introduces several computational modifications, most significantly to the bridge modelling approach and to the section conveyance calculations. Version 1.1 (1996) was found to be somewhat incomplete, in terms of limited optional capabilities and unexplained and unexpected error messages. Therefore, HEC-2 was used in all production runs of the present study. A comparison of computed water surface profiles showed the results of HEC-2 and HEC-RAS to be within $\pm$0.05 m.

The standard-step method assumes one-dimensional, gradually varied, steady flow. Starting with a known water level and flow, the model proceeds upstream (subcritical flow) or downstream (supercritical flow), calculating the unknown water levels in a channel. The model accounts for energy losses due to friction, flow contraction and expansion, and for various bridge losses.

4.2 Data Requirements

The standard step model requires the following input data for water surface profile computations:

- channel and floodplain geometry;
- detailed bridge descriptions;
- channel and floodplain surface roughness coefficients; and
- flow data with corresponding boundary conditions -- i.e., starting water levels.

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[7] U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-2 Water Surface Profiles, Generalized Computer Program, Davis, California, 1982, 1990 Revision.

[8] U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS River Analysis System User's Manual and Hydraulic Reference Manual, Version 1.0, July 1995.

In September and October, 1995, B.C. Environment surveyed 85 cross-sections on the Kettle River, 10 cross-sections on the West Kettle River and 7 cross-sections on Boundary Creek. As part of the survey, the cross-section locations were marked on 1:5,000 scale, 1 m contour maps produced by the B.C. Ministry of Environment, Lands and Parks in 1993, based on air photography flown in 1991. Thalweg and overbank distances between the sections were scaled from the maps. The maps were also used for extending the surveyed sections across the floodplain, where necessary.

Several bridges are located within the study area -- six on the Kettle River, one on the West Kettle River and one on Boundary Creek. As part of the cross-sectional survey, the B.C. Ministry of Environment, Lands and Parks provided detailed information on all bridges. The bridges were modelled using both HEC-2 and HEC-RAS.

Channel roughness values, represented by the Manning's roughness coefficient, "n"[9], were initially estimated based on photo documentation and site observations. Overbank roughness coefficients were evaluated from 1991 air photography and verified in the field. Roughness values were assumed not to vary with the discharge.

Flow data and boundary conditions for model calibration are discussed in Section 4.3, and for the production runs in Section 4.4.

4.3 Model Calibration

The accuracy of computed water surface profiles depends upon the successful calibration of the backwater model. A model should preferably be calibrated against several different flows, each having a series of known high-water marks. Calibration flows approaching the magnitude of the design flood ensure a more reliable model. The calibration process assists in:

- selecting appropriate channel roughness coefficients;
- eliminating data input errors; and
- accurately modelling flow through bridge openings.

In May 1995, B.C. Ministry of Environment, Lands and Parks staff undertook a water level survey for the three study reaches. The survey was carried out over a period of two days. Water levels were observed at a total of 35 locations and surveyed against local reference-points using a hand level and level rod. The exact time of each water level observation was also recorded. Reference-point elevations were obtained four months later, during the

[9] U.S. Department of the Interior, Geological Survey, Water Supply Paper 1849, Roughness Characteristics of Natural Channels, 1967.

cross-section survey. Flow conditions during the time of the water level survey corresponded to the 1995 maximum or near-maximum discharge for all three watercourses.

Other available calibration information included recorded water levels at the time of the cross-section survey, and published rating tables for two WSC stations within the study area as shown on Figures 4-4 and 4-5.

4.3.1 Estimation of Calibration Flows

Flow data recorded by WSC and USGS during the B.C. Ministry of Environment, Lands and Parks water level survey consisted of hourly flows obtained from the international station "Kettle River near Ferry" and daily flow data from the gauges "Kettle River near Westbridge" and "West Kettle River at Westbridge". The daily flows are based on a single gauge reading per day. For May 30 and 31, 1995, when the water level survey was carried out, the flow on the Kettle River near Ferry showed appreciable diurnal fluctuation, presumably in response to variation in snowmelt, the principal contributor to flow at that time of year. The survey was conducted under sunny conditions with no precipitation, yet measured flows varied by about ± 10% of the mean flow. One would expect at least this amount of variation at the upstream stations.

Calibration flows for the different study reaches were estimated as follows:

- Boundary Creek

  During the water level survey, B.C. Environment read the staff gauge at the discontinued stream gauging site "Boundary Creek near Midway". Based on the most recent rating curve for the station (dated 1977), the flow on Boundary Creek was estimated to be 15.7 m^3/s. In view of the channel-bed instability described in Section 5.4, this estimate should be considered approximate.

- West Kettle River

  The water-level survey included a reading at the "West Kettle River at Westbridge" gauge site, which according to the rating curve in effect at the time, corresponds to a flow of 68.1 m^3/s. The reading was taken on May 31, 1995 when the reported flow at the station was 61.2 m^3/s. Recognizing that both flow values correspond to instantaneous readings for a stream in which the daily flow range likely exceeds 25% of the mean, this difference does not cause concern.

- Kettle River

Over the time period of the surveys on May 30 and 31, the average flow observed at Ferry was 243.3 m^3/s (242.0 m^3/s from 8:35 am to 2:45 pm on May 30, 244.6 m^3/s from 8:30 am to 2:00 pm on May 31). Subtracting the estimated Boundary Creek flow yields an average discharge on the Kettle River at the US border of 227.7 m^3/s.

Above the West Kettle River confluence, the Kettle River flow recorded at the gauge just upstream of the study reach (Kettle River near Westbridge) averaged 186 m^3/s (185 m^3/s on May 30 and 187 m^3/s on May 31). The average flow on the West Kettle at Westbridge was 62.8 m^3/s (64.4 m^3/s on May 30 and 61.2 m^3/s on May 31).

The sum of the observed flows at Westbridge (186 m^3/s plus 62.8 m^3/s equals 249 m^3/s) exceeds the flow at the US border (227.7 m^3/s) by about 9%, ignoring any tributary inflows such as from Rock Creek. However, the inconsistency is not significant considering the variability of flows at all three measuring points. The exact time of each water level reading was recorded, but developing a flow model to compute instantaneous discharges corresponding to each water-level measurement was not feasible.

Based on the available data, a calibration flow of 228 m^3/s was adopted for the Kettle River reach between the Canada-US border and Westbridge. The discharge does not include an allowance for local inflow and represents a somewhat "low" estimate. However, calibrating the backwater model to a "low" flow estimate results in somewhat increased roughness coefficients, and therefore results in a slightly more conservative model. A calibration discharge of 186 m^3/s was adopted from Westbridge to the upstream end of the study area.

4.3.2 Detailed Model Calibration

The cross-section survey input files were modified as summarized in Table 4.1. The modifications included adjusting cross-sections, or parts of sections, for skewness and limiting the flow to the channel and overbank portions effective in transporting flow, that is; eliminating areas of ponding in dead-end channels, local depressions and areas sheltered by railroad or highway embankments. Bridges were programmed as listed in Table 4.2. according to either the Normal or Special Bridge Method. The crossings were adjusted for the tabulated skewness angles.

Initial estimates for the Manning's "n" channel roughness coefficients were fine-tuned to obtain the best possible match between observed and calculated water levels. The range of Manning's "n" for the Kettle River channel was 0.030 to 0.042, generally increasing in reaches with steeper channel slopes. For the West Kettle River, "n" varied from 0.038 to

TABLE 4.1 - SUMMARY OF CROSS-SECTION INPUT DATA MODIFICATIONS

KETTLE RIVER:

Cross-section	Modifications to HEC-2 GR-Data:	Cross-section	Artificial Levees Limiting Flow to Active Portion of Floodplain:
13	Right bank inactive back-channels removed.	9	Left bank encroachment at railroad.
18	Left bank back-channel adjusted for skewness.	16	Left bank encroachment at railroad.
22	Left bank inactive back-channel removed.	17	Left bank encroachment at railroad.
23	Left bank inactive back-channel removed.	18	Left bank encroachment at railroad.
45	Right bank inactive flow area (reservoir) removed.	19	Left bank encroachment at railroad.
48	Left bank section adjusted for skewness.	21	Left bank encroachment at railroad.
59.1	Left bank section adjusted for skewness.	23	Left bank encroachment at railroad.
68	Right bank inactive flow areas (swampy lake & dead-end channel) removed.	26	Left bank encroachment at railroad.
		27	Left bank encroachment at railroad.
69	Right bank back-channel adjusted for skewness.	28	Right bank encroachment at highway.
		39	Left bank encroachment at railroad.
		51	Left bank encroachment at railroad.
		54	Left bank encroachment at railroad.
		72	Right bank encroachment for modelling Kettle/West Kettle confluence.

WEST KETTLE RIVER:

Cross-section	Modifications to HEC-2 GR-Data:	Cross-section	Artificial Levees Limiting Flow to Active Portion of Floodplain:
8	Left bank inactive flow area removed.	1	Left bank encroachment for modelling Kettle/West Kettle confluence.
		5	Right bank encroachment at road.

BOUNDARY CREEK:

Cross-section	Modifications to HEC-2 GR-Data:	Cross-section	Artificial Levees Limiting Flow to Active Portion of Floodplain:
6	Right bank section adjusted for skewness.	1	Right bank encroachment.

TABLE 4.2 - SUMMARY OF BRIDGE INPUT DATA

Location	Type	No. of Piers	Method	Angle of Skewness (degrees)	Max. Elev. Low Chord (m)	Min. Elev. Top Road (m)	Clearance* (m)
KETTLE RIVER:							
XS-3.9/4 Florence St/Midway	Steel Girder	3 sets of 5 (Steel)	Special	17	575.61	575.64	1.93
XS-15 Footbridge	Wood& Cable		Not Modelled				
XS-24.5/24.9 HWY #3	Steel Girder & I-Beam Str.	3 (Concrete)	Special	22	596.41	597.34	9.6
XS-33/34 Kettle Valley S. Rd.	Bailey	1 Wood Cribbing	Normal	0	595.45	596.84	1.05
XS-43.9/44 Kettle Valley S. Rd.	Concrete	1 (Steel/ Concrete)	Special	12	605.28	605.4	3.33
XS-55.4/55.5 Kettle V. RR (aband.)	Steel Trestle	1 Concrete	Special	25	611.43	612.23	1.37
WEST KETTLE RIVER:							
XS-1.4/1.5 HWY #33 Westbridge	Steel Girder	0	Normal	28	627.46	627.35	1.98
BOUNDARY CREEK:							
XS-3/4 Dominion Street	Concrete	0	Normal	0	577.6	578.3	0.57

* Clearance = Low Chord - Flood Level (incl. Freeboard).

0.042 and from 0.046 to 0.050 for Boundary Creek. Overbank roughness coefficients were estimated between 0.08 and 0.15. These values could not be verified, since the calibration flows were entirely within the channel banks for all three watercourses.

The following starting conditions were assumed for the calibration of the models:

- The Kettle River model was started using the surveyed water surface elevation at the Canada-US border.

- The West Kettle River model was extended downstream to include one additional cross-section, XS-0.7, equal to the western portion of Kettle River XS-72 . This location was assumed to be the point of confluence for the calibration flows, and the water surface elevation computed at XS-72 using the Kettle River model was used as the starting level at XS-0.7 for the extended West Kettle model.

- The Boundary Creek model was started using the slope-area method assuming a slope of 0.0085.

In general, the agreement between calculated and observed water levels was good, as shown in Tables 4.3 to 4.5 and in the profile plots (Figures 4-1 to 4-3). A discrepancy of 1.07 m occurred at XS-70 on the Kettle River. However, nearby readings were well matched and it was concluded that the discrepancy was due to a combination of superelevation and error in recording the high water mark. The cross-section is located at a sharp bend in the river and the reading was taken on the outside of the bend. Excluding that value, the mean absolute error was 0.12 m for the Kettle River, 0.11 m for the West Kettle River and 0.09 m for Boundary Creek.

Water surface elevations were also recorded by B.C. Ministry of Environment, Lands and Parks staff in September and October, 1995, during the cross-section survey. Water surface readings were taken at XS-1 on the Kettle River and at the discontinued gauge site on Boundary Creek. However, discharge during the survey was very low (Kettle River near Ferry: 3.79 m^3/s to 6.29 m^3/s) and the water level information was not appropriate for model calibration. Typically, the relative channel roughness increases at low discharges and, in fact, the Kettle River model calibrated against the 1995 near-peak flows under-estimated water surface elevations by up to 0.15 m for the September-October flows.

Using the West Kettle River HEC-2 model, a rating curve was developed for the gauge site near Westbridge and compared with the WSC stage-discharge table. The model was found to under-estimate water levels at flows less than 24 m^3/s, and to over-estimate the level by up to 0.22 m at the top end of the WSC curve (113 m^3/s), Figure 4-4. The West Kettle

TABLE 4.3 -KETTLE RIVER CALIBRATION PROFILE

XS-No.	Station (m)	Min Elev. (m)	Flow (cms)	Rouhgness "n"	CWSEL (m)	HWM (m)	Error (m)
1.0	0.0	568.63	228.00	0.030	570.99	570.99	0.00
2.0	415.0	568.59	228.00	0.030	571.37	571.37	0.00
3.0	685.0	568.68	228.00	0.030	571.61		
3.9	695.4	568.87	228.00	0.030	571.61		
4.0	705.0	568.87	228.00	0.030	571.66		
5.0	715.0	569.17	228.00	0.030	571.67	571.61	0.06
6.0	1125.0	570.04	228.00	0.030	572.09		
7.0	1430.0	569.30	228.00	0.030	572.35	572.25	0.10
8.0	2245.0	569.74	228.00	0.033	573.04		
9.0	2865.0	571.12	228.00	0.034	573.77		
10.0	3510.0	571.48	228.00	0.034	574.49		
11.0	3910.0	572.30	228.00	0.035	574.95	574.89	0.06
12.0	4670.0	573.43	228.00	0.036	575.93		
13.0	4970.0	573.63	228.00	0.036	576.36	576.45	-0.09
14.0	5630.0	574.05	228.00	0.036	577.18		
15.0	6255.0	575.13	228.00	0.035	577.98	577.89	0.09
16.0	6870.0	575.29	228.00	0.034	578.68		
17.0	7390.0	576.90	228.00	0.036	579.44		
18.0	8160.0	577.96	228.00	0.035	580.66		
19.0	8825.0	578.26	228.00	0.034	581.22		
20.0	9715.0	579.94	228.00	0.034	582.16		
21.0	10285.0	580.33	228.00	0.034	582.81		
22.0	10960.0	581.67	228.00	0.033	583.66		
23.0	11665.0	582.15	228.00	0.033	584.67		
24.0	11955.0	582.75	228.00	0.033	585.04	584.88	0.16
24.5	11975.0	582.29	228.00	0.033	585.08		
24.9	11985.0	582.29	228.00	0.033	585.09		
25.0	12525.0	583.70	228.00	0.033	585.81		
26.0	13200.0	584.00	228.00	0.033	586.73	586.65	0.08
27.0	13930.0	585.17	228.00	0.036	587.63		
28.0	14495.0	585.37	228.00	0.036	588.34		
29.0	15350.0	586.83	228.00	0.036	589.31		
30.0	16000.0	587.56	228.00	0.036	590.10		
31.0	16410.0	588.68	228.00	0.037	590.70	590.64	0.06
32.0	17090.0	587.46	228.00	0.036	591.62		
33.0	17500.0	589.03	228.00	0.036	592.15		
34.0	17510.0	588.79	228.00	0.036	592.17	592.06	0.11
35.0	17980.0	590.28	228.00	0.036	592.83		
36.0	18450.0	590.50	228.00	0.036	593.41		
37.0	19270.0	591.08	228.00	0.036	594.49	594.21	0.28
38.0	19750.0	592.36	228.00	0.040	595.11	595.21	-0.10
39.0	20530.0	594.18	228.00	0.037	596.51	596.42	0.09
40.0	21215.0	594.44	228.00	0.036	597.56	597.43	0.13
41.0	21585.0	595.02	228.00	0.000	598.06		

continued

TABLE 4.3 -KETTLE RIVER CALIBRATION PROFILE

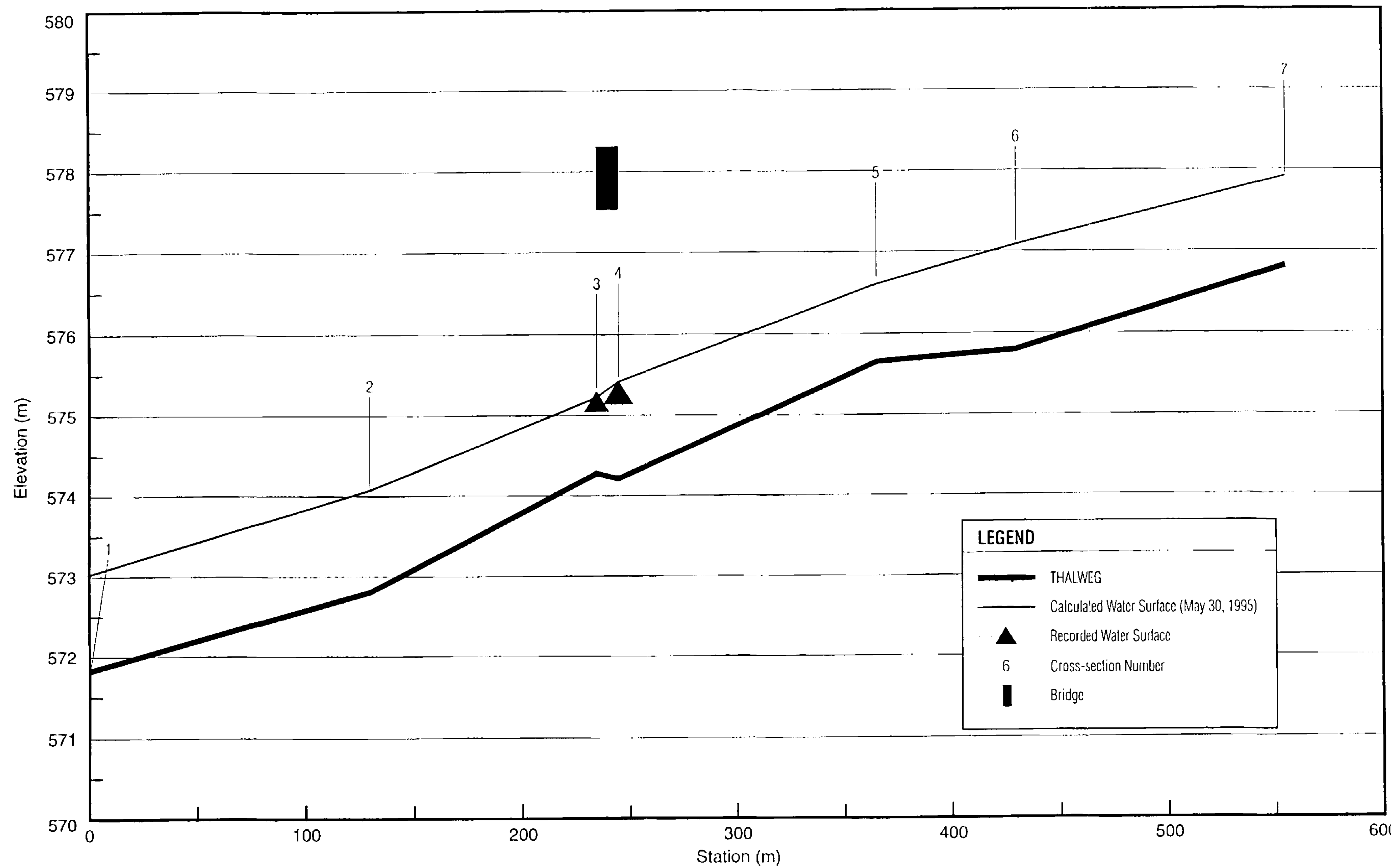
XS-No.	Station (m)	Min Elev. (m)	Flow (cms)	Rouhgness "n"	CWSEL (m)	HWM (m)	Error (m)
41.1	21870.0	595.96	228.00	0.000	598.63	598.58	0.05
42.0	22045.0	595.76	228.00	0.037	599.07	599.11	-0.04
43.0	22285.0	597.25	228.00	0.037	599.78		
43.9	22477.3	596.60	228.00	0.037	600.05		
44.0	22490.0	596.60	228.00	0.037	600.05	600.02	0.03
45.0	23040.0	594.87	228.00	0.037	600.68		
46.0	23550.0	599.09	228.00	0.036	601.34		
47.0	23970.0	599.04	228.00	0.036	602.01	601.82	0.19
48.0	24790.0	600.85	228.00	0.036	603.12	602.91	0.21
49.0	25370.0	601.02	228.00	0.036	603.89		
50.0	26000.0	600.79	228.00	0.036	604.49		
51.0	26705.0	603.29	228.00	0.036	605.32		
52.0	27230.0	604.22	228.00	0.036	606.29		
53.0	27935.0	602.87	228.00	0.036	607.15		
54.0	28575.0	604.86	228.00	0.036	607.85		
55.0	29015.0	603.73	228.00	0.036	608.22		
55.4	29038.5	604.59	228.00	0.036	608.21		
55.5	29045.0	604.59	228.00	0.036	608.25		
56.0	29065.0	605.35	228.00	0.036	608.26	608.17	0.09
57.0	29620.0	607.24	228.00	0.036	609.18	609.12	0.06
58.0	30195.0	607.60	228.00	0.036	610.15		
59.0	30685.0	608.38	228.00	0.036	610.97		
59.1	30855.0	607.65	228.00	0.036	611.24	611.14	0.10
60.0	31180.0	609.82	228.00	0.036	611.77		
61.0	31840.0	610.37	228.00	0.036	612.87	612.81	0.06
62.0	32510.0	610.61	228.00	0.036	613.64		
63.0	33165.0	612.15	228.00	0.036	614.54		
64.0	33965.0	613.17	228.00	0.036	616.61		
65.0	34370.0	614.01	228.00	0.036	617.08		
66.0	35355.0	615.69	228.00	0.036	618.09		
67.0	36105.0	615.97	228.00	0.036	619.16		
68.0	36670.0	616.77	228.00	0.036	619.93	619.55	0.38
69.0	37025.0	618.60	228.00	0.040	620.67	620.41	0.26
69/70	37202.5	618.60	228.00	0.041	621.07	621.21	-0.14
70.0	37380.0	618.61	228.00	0.042	621.47	622.54	-1.07
71.0	38145.0	620.50	228.00	0.042	622.85	622.78	0.07
72.0	38370.0	617.31	186.00	0.042	623.14		
73.0	38660.0	619.81	186.00	0.038	623.36		
74.0	39355.0	621.63	186.00	0.038	624.27		
75.0	40060.0	620.91	186.00	0.038	625.06		
76.0	40360.0	621.94	186.00	0.038	625.48		
77.0	40965.0	621.65	186.00	0.038	625.96	625.67	0.29
78.0	41315.0	623.37	186.00	0.040	626.25		
79.0	42435.0	624.06	186.00	0.040	627.34		
80.0	43040.0	624.64	186.00	0.040	627.92		
81.0	43970.0	625.73	186.00	0.042	629.04		
					Mean Absolute Error:		0.12

TABLE 4.4 - WEST KETTLE RIVER CALIBRATION PROFILE

XS-No.	Station (m)	Min Elev. (m)	Flow (cms)	Roughness "n"	CWSEL (m)	HWM (m)	Error (m)
0.7	0.0	621.34	68.10	0.038	623.14		
1.0	255.0	622.14	68.10	0.038	623.60	623.46	0.14
1.4	389.2	622.27	68.10	0.038	623.90		
1.5	400.0	622.27	68.10	0.038	623.92	623.79	0.13
2.0	415.0	622.05	68.10	0.038	623.95		
3.0	745.0	622.97	68.10	0.038	624.71		
4.0	965.0	623.47	68.10	0.038	625.36	625.29	0.07
5.0	1170.0	624.70	68.10	0.042	625.94		
6.0	1535.0	625.82	68.10	0.042	627.40		
7.0	1680.0	625.87	68.10	0.042	627.88		
8.0	1790.0	626.52	68.10	0.042	628.26		
9.0	1870.0	625.00	68.10	0.042	628.49		
						Mean Absolute Error:	0.11

TABLE 4.5 - BOUNDARY CREEK CALIBRATION PROFILE

XS-No.	Station (m)	Min Elev. (m)	Flow (cms)	Rouhgness "n"	CWSEL (m)	HWM (m)	Error (m)
1.0	0.0	571.83	15.70	0.046	573.03		
2.0	130.0	572.81	15.70	0.048	574.08		
3.0	235.0	574.28	15.70	0.048	575.22	575.18	0.04
4.0	245.0	574.22	15.70	0.048	575.42	575.29	0.13
5.0	365.0	575.65	15.70	0.048	576.61		
6.0	430.0	575.80	15.70	0.050	577.09		
7.0	555.0	576.82	15.70	0.050	577.91		
						Mean Absolute Error:	0.09

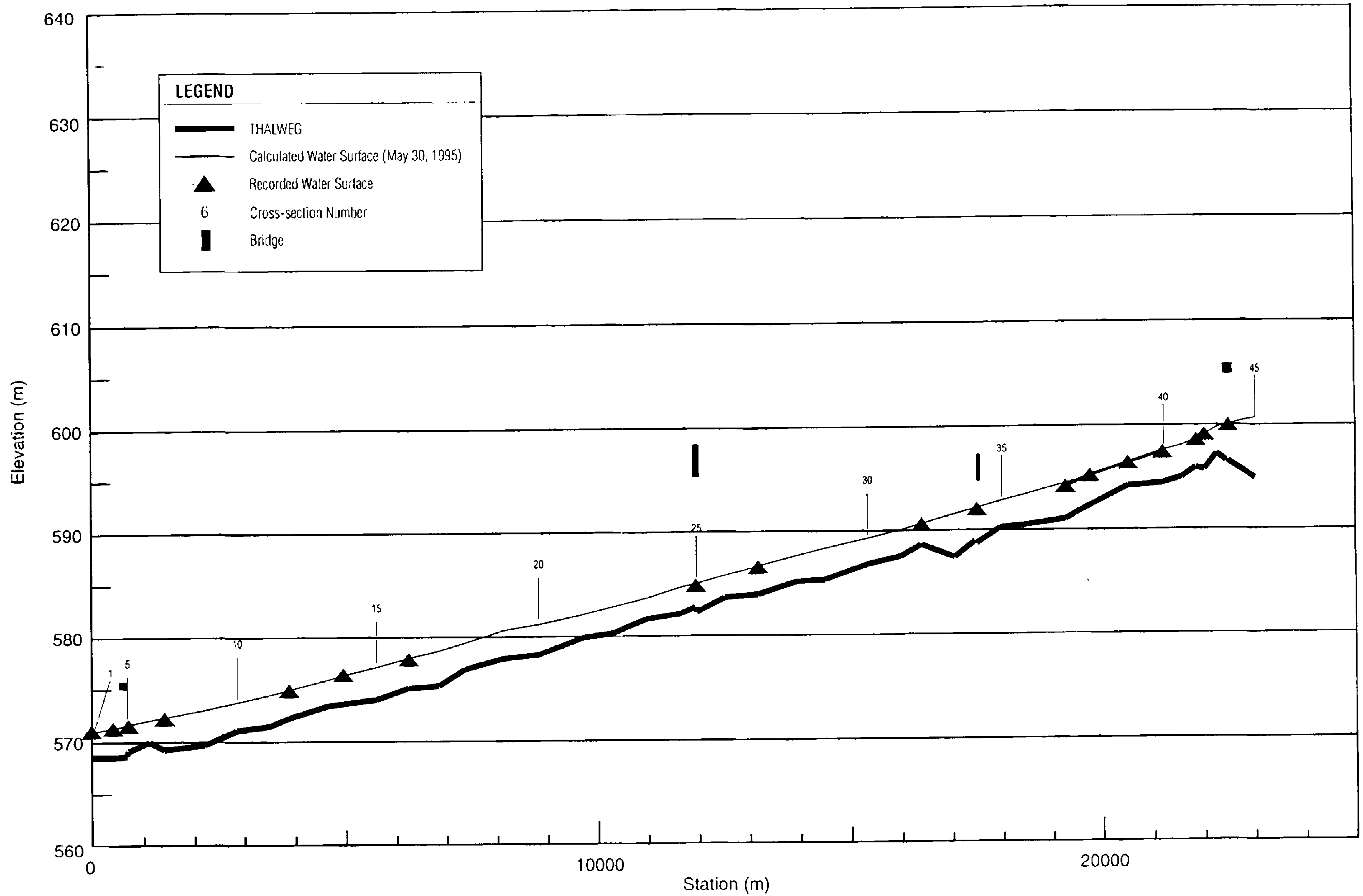


NOTE:
Cross-section locations shown on Drawing 93-13-1.

Fig. 4-1

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
Boundary Creek - Model Calibration

ACRES

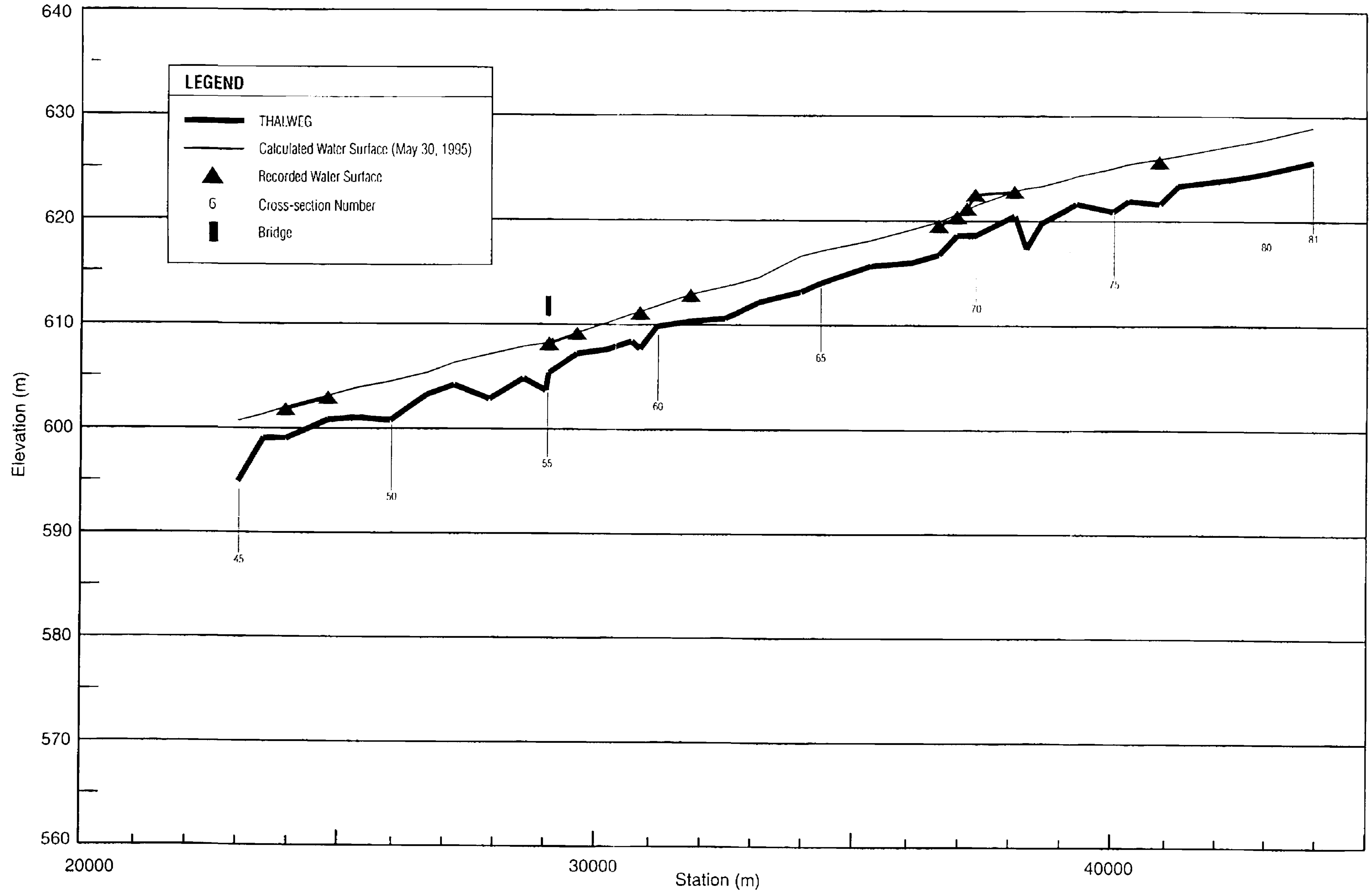


NOTE:
Cross-section locations shown on Drawing 93-13-1 to 93-13-8.

Fig. 4-2a

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
Kettle River - Model Calibration

ACRES

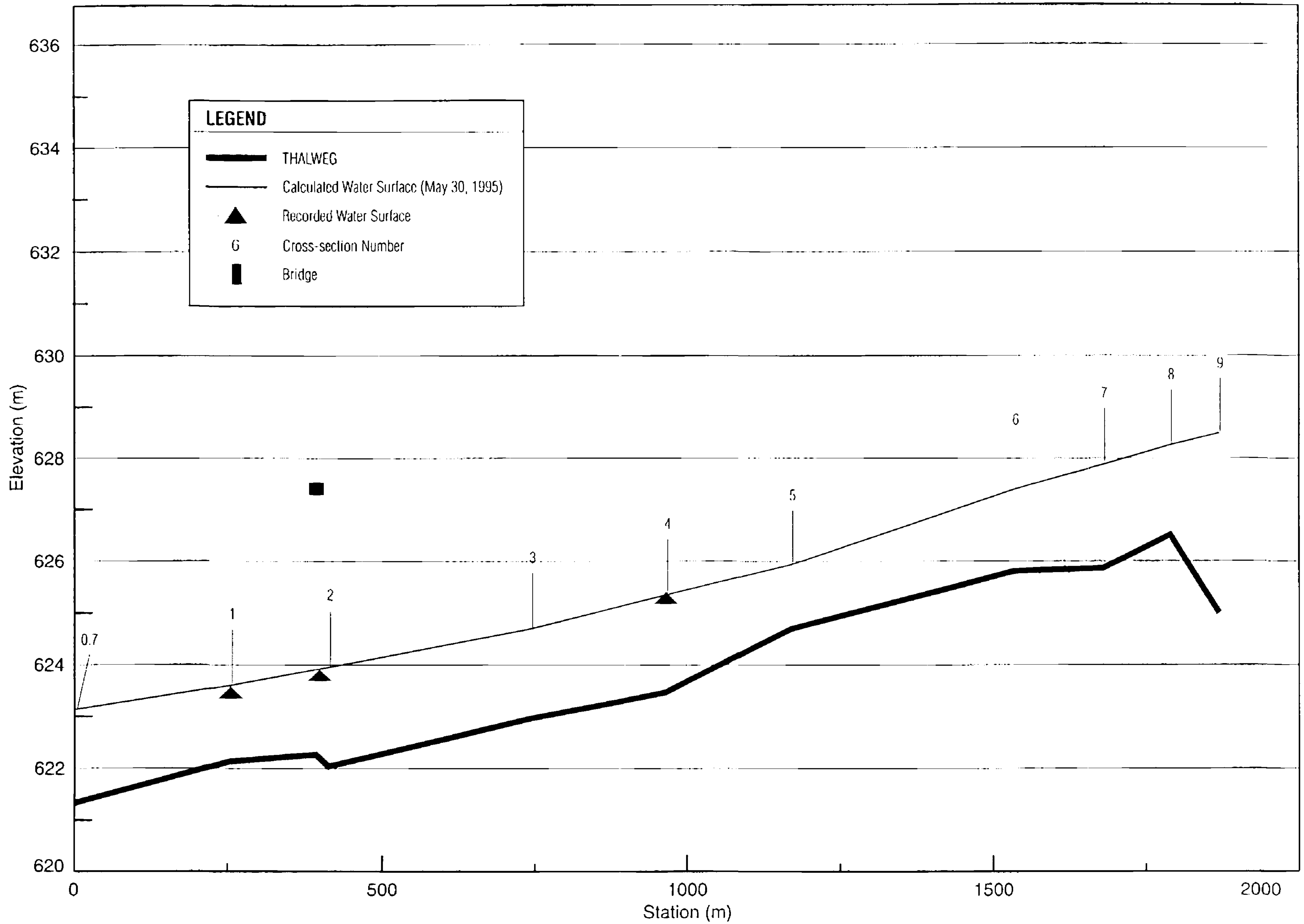


NOTE:
Cross-section locations shown on Drawing 93-13-1 to 93-13-8.

Fig. 4-2b

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
Kettle River - Model Calibration

ACRES



NOTE:
Cross-section locations shown on Drawing 93-13-7 and 93-13-8.

Fig. 4-3

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
West Kettle River - Model Calibration

ACRES

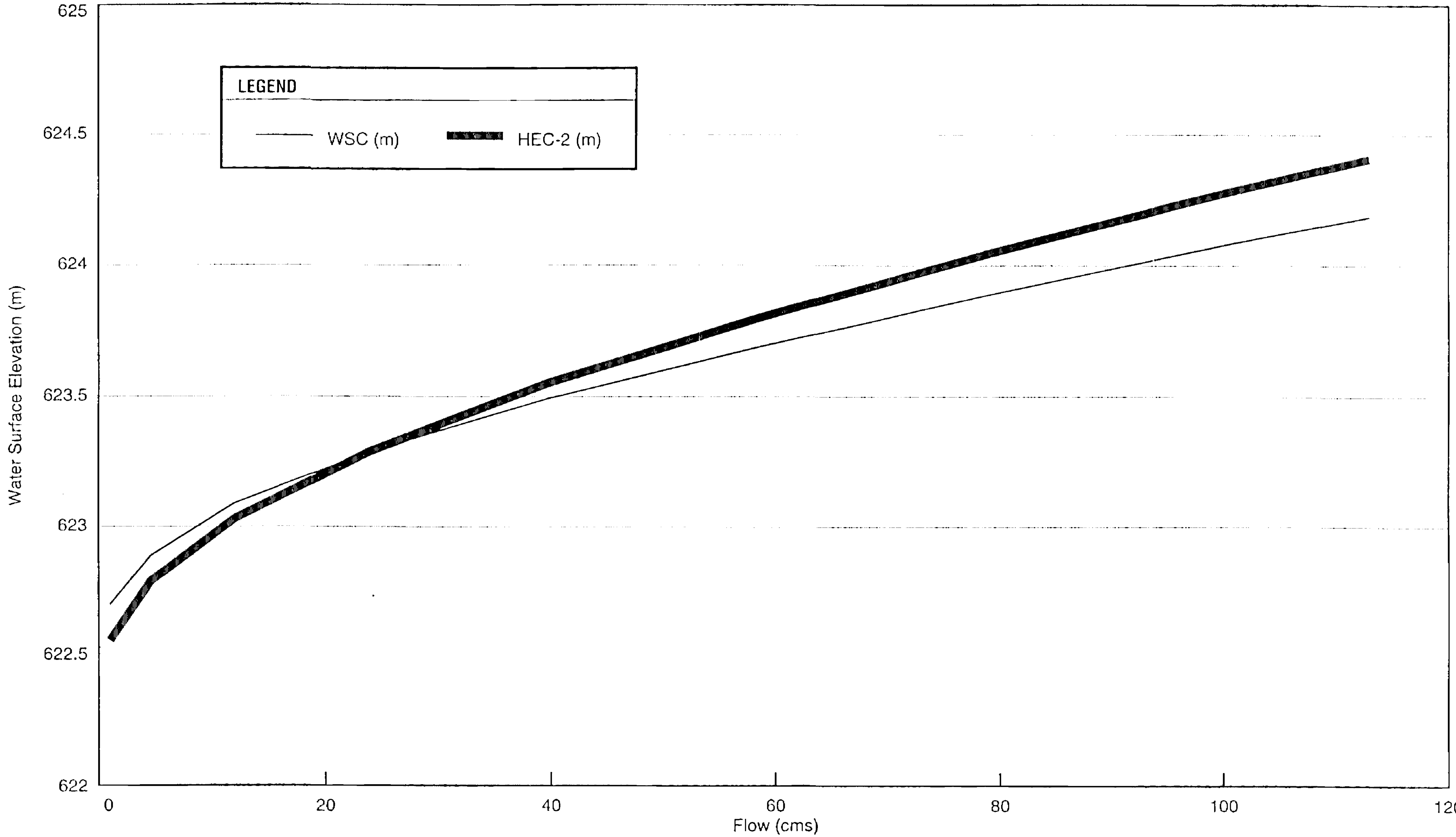


Fig. 4.4

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
West Kettle River at Westbridge Rating Curve Comparison

ACRES

River model suggests that water levels at the gauge are influenced by backwater from the Kettle River, and are therefore sensitive to the starting conditions assumed for the model.

A rating comparison was also performed for the Boundary Creek gauging site. The gauge is located between cross-sections 4 and 5, and water surface elevations were interpolated for the gauge site. Again, the model was seen to underestimate water levels at low flows, but was within 0.03 m at the top end of the WSC curve (38 m^3/s), as shown in Figure 4-5.

4.4 Model Starting Elevations and Related Sensitivity

Correct boundary conditions are essential for accurately computing flood profiles. The starting water levels on the Kettle and West Kettle Rivers were known for the calibration flows, but needed to be estimated for the 20-year and 200-year floods. The Boundary Creek starting levels were estimated for both the calibration and flood flows. Annual Kettle River, West Kettle River and Boundary Creek peak flows may coincide, but backwater effects caused by the Kettle River in either West Kettle River or Boundary Creek are limited to only short reaches due to the steep channel slopes.

4.4.1 Kettle River

The 20-year and 200-year instantaneous and maximum daily flood flows for the Kettle River were estimated as described in Section 3.3. Corresponding stage data for XS-1, the model starting point at the Canada-US border, were not available and had to be estimated. Two different approaches were taken, one using the slope-area option of HEC-2 and the other using a backwater model assembled for the Kettle River south of the border, near Ferry.

The slope-area method assumes normal flow at the model starting point and allows the user to input an estimate of the energy slope at the downstream end of a subcritical reach. The accuracy of this method was checked by re-running the calibration using the average longitudinal slope of the lower study reach as an estimate of the slope. This produced a computed water level at XS-1 only 0.04 m higher than that measured in the high water survey, lending confidence to the slope-area method. The difference reduced to 0.01 m at XS-3.

The slope of the energy grade-line varies with discharge, and an iterative process was used to estimate the slope at XS-1 for the 20-year and 200-year design floods. The input slope was adjusted until it equalled the average energy grade-line slope for the lower study reach. The slope increased slightly with increasing discharge as shown in Table 4.6. The sensitivity of the model to the selected slope was investigated by choosing the 200-year maximum daily flood as the base case. The starting slope was increased by a factor of 1.2 and reduced by a factor of 0.8. Corresponding computed water surface elevations are listed in Table 4.6.

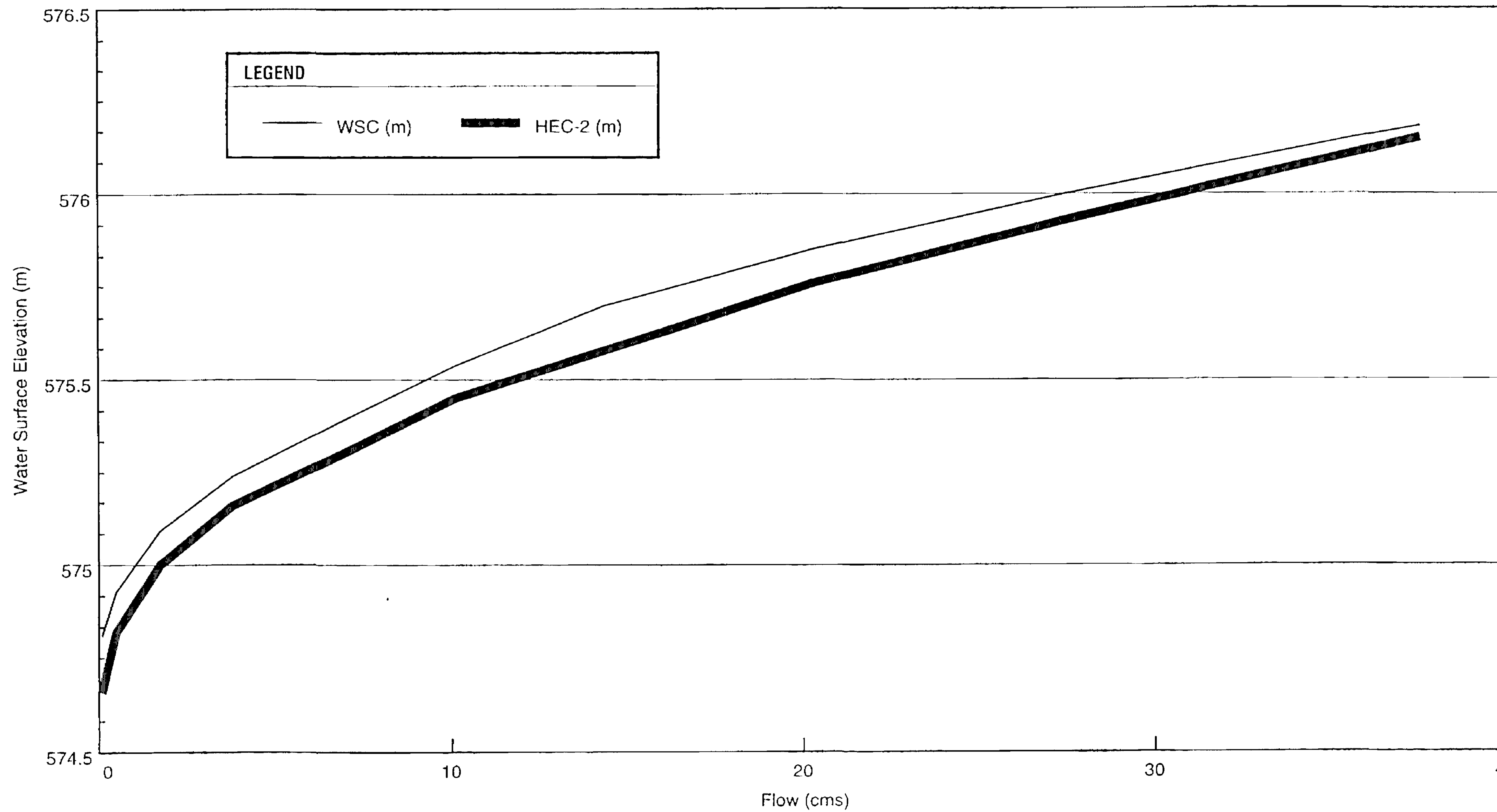


Fig. 4.5

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
Boundary Creek near Midway Rating Curve Comparison

ACRES

TABLE 4.6 - KETTLE RIVER STARTING CONDITIONS & RELATED SENSITIVITY

ESTIMATED STARTING WATER LEVELS AT CANADA-US BORDER (m):

Flood Level	200-year Inst.	200-year Max. Daily	20-year Inst.	20-year Max. Daily
Flow (m3/s)	562	524	477	446
Average Slope (Slope- Area Method)	0.001000	0.000975	0.000950	0.000950
Water Level at XS-1 (Slope- Area Method)	572.38	572.28	572.14	572.03
Water Level at XS-1 (Extended US Model)	572.19	572.11	571.91	571.84

STARTING LEVEL SENSITIVITY:

XS- No.	Station	200-yr Max Base Case	Elev. Diff (m) S*1.2=.00117	Elev. Diff (m) S*0.8=.00078	Elev. Diff (m) 0.5 m Reduction	Elev. Diff (m) 0.5 m Rise
1	0	572.28	-0.15	0.20	-0.50	0.50
2	415	572.69	-0.09	0.12	-0.23	0.33
3	685	573.00	-0.06	0.09	-0.15	0.24
3.9	695	573.00	-0.06	0.09	-0.14	0.25
4	705	573.08	-0.05	0.08	-0.12	0.23
5	715	573.09	-0.05	0.08	-0.12	0.22
6	1125	573.53	-0.03	0.05	-0.07	0.14
7	1430	573.73	-0.03	0.03	-0.06	0.11
8	2245	574.55	-0.01	0.01	-0.02	0.05
9	2865	575.32	0.00	0.01	-0.01	0.02

At XS-1 the increased slope lowered the water level by 0.15 m and the reduced slope raised the water level by 0.20 m. About 3 km upstream, the water surfaces converged with the base case.

The model sensitivity to more extreme starting level variations was checked by artificially raising and lowering the water surface elevation at XS-1 by 0.5 m. The resulting profiles still converged with the base case in about 3 km as shown in Table 4.6.

In 1993, the US Army Corps of Engineers prepared floodplain mapping for the Kettle River in Ferry County. The upstream limit of the study reach was about half way between the Canada-US border and the stream gauge near Ferry. The HEC-2 model for the study was obtained by the B.C. Ministry of Environment, Lands and Parks and provided to Acres. It was then extended upstream to XS-1 of the present study by inserting three interpolated cross-sections in the 1.3 km long intermediate reach. The extended model was run using the estimated calibration flows and the computed water level at XS-1 was found to be only 0.01 m different from the measured value.

Using the extended US-model, the 200-year and 20-year flood levels at XS-1 were computed as shown in Table 4.6 and found to average 0.20 m less than those obtained using the slope-area method. The extended US-model, based on several hand-interpolated cross-sections, is considered to be less accurate and the more conservative starting levels, based on normal flow, were used in the profile computations.

4.4.2 West Kettle River

At the 20-year and 200-year floods, the Kettle and West Kettle River confluence was assumed to be at Kettle River XS-73 and West Kettle River XS-1. The West Kettle River starting levels at XS-1 were assumed to be equal to the computed Kettle River water-levels at XS-73 for the equivalent flood magnitudes.

The model sensitivity to the starting level was investigated by varying the water level at XS-1 by ±0.5 m. The profiles for the 200-year maximum daily base case were found to converge within roughly 500 m (Table 4.7).

4.4.3 Boundary Creek

Stage-discharge information at the Boundary Creek downstream study limit was not available and rating tables for the WSC gauge (265 m upstream), go up to roughly the 10-year flood. The 20-year and 200-year starting elevations were estimated using the slope-area method, matching the starting slope to the average slope of the lower study reach. For the 200-year instantaneous flood, a stable slope could not be obtained and instead, critical

TABLE 4.7 - WEST KETTLE RIVER STARTING CONDITIONS & RELATED SENSITIVITY

ESTIMATED STARTING WATER LEVELS AT CROSS-SECTION 1 (m):

Flood Level	200-year Inst.	200-year Max. Daily	20-year Inst.	20-year Max. Daily
Flow (m3/s)	235	190	201	166
Water Level at XS-1 (XS-73 Kettle River)	624.62	624.42	624.32	624.15

STARTING LEVEL SENSITIVITY:

XS- No.	Station	200-yr Max Base Case	Elev. Diff (m) .5m Reduction	Elev. Diff (m) .5 m Rise
1	255	624.42	-0.50	0.50
1.4	389	624.84	0.05	0.28
1.5	400	624.88	0.06	0.27
2	415	624.91	0.05	0.25
3	745	625.92	0.00	0.03
4	965	626.46	0.00	0.00
5	1170	626.93	0.00	0.00

depth was used as the starting elevation. Starting levels and slopes are summarized in Table 4.8.

The sensitivity of the computed profiles to the starting level was checked by selecting the 200-year maximum daily flood as the base case and changing the slope at XS-1 by a factor of 1.2 and 0.8. Results are given in Table 4.8. Also tabulated is the 200-year maximum daily flood, assuming critical flow at XS-1 and with a starting level raised by 0.5 m. In either case the profiles converged within about 300 m or less, showing relative insensitivity to the model starting conditions.

In delineating the floodplain limits for Boundary Creek, for the western boundary it was assumed that avulsion of the creek could occur at the point where it exits the canyon. Its location must be considered approximate.

4.5 Roughness and Discharge Sensitivity Studies

The sensitivity of the computed water surface profiles to variations in channel roughness and design discharge was evaluated. The 200-year daily discharge was selected as the base flood profile. The discharge and roughness values were altered and each resulting profile compared to the base condition and the average variation computed.

The sensitivity to changes in the Manning's roughness coefficients was evaluated by varying the calibrated n-values by a factor of 0.9, 1.1 and 1.2. Compared to the base profile, the average drop in the computed water surface elevation for the Kettle River was 0.17 m for a 10% reduction in roughness. The average increases for respectively 10% and 20% higher roughness values were 0.16 m and 0.32 m. The equivalent variations for West Kettle River were -0.11 m, 0.11 m and 0.21 m; and for Boundary Creek -0.09 m, 0.07 m and 0.15 m. Results are summarized in Tables 4.9, 4.10, and 4.11.

The sensitivity of the computed water surface profiles to variations in the design flow was evaluated by reducing the discharge by 10% and increasing it by 10% and 20%. Compared to the base profile, the mean absolute differences were -0.18 m, 0.17 m and 0.33 m for the Kettle River; -0.12 m, 0.11 m and 0.22 m for West Kettle River and -0.9 m, 0.08 m and 0.16 m for Boundary Creek. Tables 4.9, 4.10 and 4.11 summarize the results of the discharge sensitivity analysis.

The relatively high Kettle River sensitivity to discharge variations is noteworthy, considering the uncertainties associated with the calibration flows. However, the flow equivalent to a 20% increase in design flow has a chance of occurrence of less than 2.5%. Furthermore, for a 20% increase in flow, the mean water level rise of 0.33 m is still less than the 0.6 m freeboard allowance for hydraulic and hydrological uncertainties.

TABLE 4.8 - BOUNDARY CREEK STARTING CONDITIONS & RELATED SENSITIVITY

ESTIMATED STARTING WATER LEVELS AT CROSS-SECTION (m):

Flood Level	200-year Inst.	200-year Max. Daily	20-year Inst.	20-year Max. Daily
Flow (m3/s)	85.2	65.5	58.9	46.6
Average Slope (Slope- Area Method)	- (Critical Flow)	0.009000	0.009000	0.008700
Water Level at XS-1 (Slope-Area Method)	574.15 (Critical Flow)	574.03	573.94	573.76

STARTING LEVEL SENSITIVITY:

XS-No.	Station	200-yr Max Base Case	Elev. Diff (m) S*1.2=.0108	Elev. Diff (m) S*0.8=.0072	Elev. Diff (m) Critical Flow	Elev. Diff (m) 0.5 m Rise
1	0	574.03	-0.08	0.10	-0.37	0.50
2	130	575.15	0.02	-0.27	0.17	-0.47
3	235	576.21	-0.02	0.15	-0.10	0.30
4	245	576.41	0.00	0.07	-0.02	0.17
5	365	577.60	0.00	0.00	0.00	-0.01
6	430	577.98	0.00	0.00	0.00	0.00
7	555	578.95	0.00	0.00	0.00	0.00

TABLE 4.9 - KETTLE RIVER ROUGHNESS & DISCHARGE SENSITIVITY

XS-No.	Base Case 200-yr Daily (m)	CWSEL Difference corresp. to: n*0.9 (m)	n*1.1 (m)	n*1.2 (m)	CWSEL Difference corresp. to: Q*0.9 (m)	Q*1.1 (m)	Q*1.2 (m)
1.0	572.28	-0.18	0.17	0.33	-0.18	0.17	0.33
2.0	572.69	-0.19	0.17	0.33	-0.19	0.16	0.32
3.0	573.00	-0.19	0.17	0.33	-0.20	0.17	0.34
3.9	573.00	-0.19	0.17	0.34	-0.20	0.18	0.35
4.0	573.08	-0.16	0.16	0.32	-0.20	0.19	0.37
5.0	573.09	-0.16	0.16	0.31	-0.20	0.19	0.36
6.0	573.53	-0.17	0.16	0.32	-0.21	0.19	0.38
7.0	573.73	-0.19	0.17	0.34	-0.20	0.18	0.36
8.0	574.55	-0.22	0.20	0.40	-0.22	0.21	0.40
9.0	575.32	-0.22	0.21	0.40	-0.23	0.22	0.43
10.0	575.96	-0.22	0.21	0.42	-0.22	0.22	0.42
11.0	576.44	-0.21	0.20	0.40	-0.23	0.22	0.43
12.0	577.28	-0.21	0.21	0.41	-0.21	0.21	0.41
13.0	577.75	-0.19	0.18	0.35	-0.22	0.21	0.41
14.0	578.31	-0.17	0.18	0.34	-0.18	0.18	0.36
15.0	579.11	-0.17	0.17	0.33	-0.16	0.16	0.32
16.0	579.92	-0.16	0.16	0.30	-0.17	0.17	0.32
17.0	580.55	-0.16	0.15	0.29	-0.16	0.16	0.31
18.0	581.38	-0.08	0.09	0.18	-0.09	0.10	0.20
19.0	581.99	-0.12	0.12	0.23	-0.11	0.10	0.19
20.0	583.32	-0.15	0.15	0.28	-0.16	0.15	0.29
21.0	584.05	-0.17	0.15	0.30	-0.18	0.16	0.32
22.0	584.78	-0.16	0.15	0.30	-0.16	0.16	0.31
23.0	585.67	-0.12	0.13	0.26	-0.11	0.12	0.23
24.0	586.15	-0.14	0.14	0.27	-0.15	0.14	0.27
24.5	586.17	-0.14	0.14	0.27	-0.14	0.14	0.27
24.9	586.21	-0.13	0.13	0.26	-0.15	0.14	0.28
25.0	587.02	-0.18	0.16	0.31	-0.18	0.16	0.32
26.0	587.98	-0.18	0.17	0.34	-0.18	0.18	0.34
27.0	589.00	-0.20	0.18	0.36	-0.20	0.18	0.36
28.0	589.82	-0.21	0.18	0.36	-0.22	0.19	0.37
29.0	590.87	-0.22	0.21	0.40	-0.22	0.21	0.41
30.0	591.62	-0.23	0.20	0.39	-0.23	0.21	0.41
31.0	592.12	-0.22	0.17	0.36	-0.23	0.18	0.38
32.0	593.02	-0.23	0.20	0.41	-0.22	0.19	0.39
33.0	593.79	-0.24	0.21	0.43	-0.25	0.22	0.45
34.0	593.80	-0.23	0.22	0.43	-0.24	0.23	0.45
35.0	594.47	-0.23	0.21	0.42	-0.25	0.24	0.47
36.0	594.95	-0.23	0.22	0.42	-0.23	0.22	0.43
37.0	596.08	-0.23	0.21	0.42	-0.24	0.22	0.43
38.0	596.70	-0.23	0.22	0.43	-0.23	0.22	0.44
39.0	597.90	-0.22	0.20	0.41	-0.22	0.21	0.41
40.0	598.96	-0.21	0.21	0.40	-0.21	0.20	0.39
41.0	599.55	-0.23	0.22	0.42	-0.23	0.21	0.41
41.1	600.10	-0.22	0.22	0.42	-0.23	0.22	0.42

continued

TABLE 4.9 - KETTLE RIVER ROUGHNESS & DISCHARGE SENSITIVITY

XS-No.	Base Case 200-yr Daily (m)	CWSEL Difference corresp. to: n*0.9 (m)	n*1.1 (m)	n*1.2 (m)	CWSEL Difference corresp. to: Q*0.9 (m)	Q*1.1 (m)	Q*1.2 (m)
42.0	600.43	-0.22	0.22	0.43	-0.20	0.21	0.40
43.0	601.23	-0.14	0.15	0.30	-0.23	0.21	0.42
43.9	601.34	-0.16	0.16	0.31	-0.21	0.20	0.39
44.0	601.35	-0.16	0.16	0.31	-0.21	0.20	0.40
45.0	601.99	-0.20	0.19	0.38	-0.23	0.22	0.42
46.0	602.65	-0.21	0.18	0.35	-0.24	0.21	0.39
47.0	603.11	-0.19	0.17	0.33	-0.21	0.18	0.36
48.0	604.06	-0.17	0.17	0.32	-0.17	0.17	0.33
49.0	604.83	-0.17	0.16	0.32	-0.17	0.16	0.31
50.0	605.58	-0.19	0.17	0.33	-0.19	0.18	0.34
51.0	606.41	-0.19	0.18	0.35	-0.19	0.19	0.36
52.0	607.20	-0.17	0.16	0.31	-0.17	0.16	0.32
53.0	608.14	-0.19	0.18	0.35	-0.18	0.17	0.33
54.0	608.99	-0.20	0.19	0.37	-0.21	0.20	0.39
55.0	609.41	-0.19	0.18	0.36	-0.22	0.21	0.40
55.4	609.39	-0.20	0.19	0.37	-0.21	0.20	0.39
55.5	609.46	-0.18	0.17	0.34	-0.22	0.21	0.40
56.0	609.47	-0.18	0.18	0.36	-0.22	0.21	0.42
57.0	610.18	-0.17	0.17	0.32	-0.20	0.19	0.37
58.0	610.92	-0.16	0.15	0.29	-0.14	0.14	0.28
59.0	611.85	-0.15	0.14	0.27	-0.16	0.15	0.28
59.1	612.10	-0.14	0.15	0.29	-0.15	0.15	0.29
60.0	612.66	-0.15	0.16	0.30	-0.15	0.16	0.30
61.0	613.77	-0.17	0.16	0.31	-0.17	0.16	0.31
62.0	614.65	-0.17	0.16	0.32	-0.18	0.17	0.34
63.0	615.49	-0.19	0.18	0.34	-0.18	0.17	0.33
64.0	617.37	-0.13	0.12	0.24	-0.15	0.13	0.26
65.0	617.91	-0.15	0.14	0.27	-0.15	0.14	0.27
66.0	619.08	-0.19	0.17	0.34	-0.18	0.16	0.32
67.0	620.21	-0.20	0.18	0.35	-0.20	0.18	0.35
68.0	621.00	-0.19	0.19	0.36	-0.19	0.19	0.36
69.0	621.70	-0.16	0.15	0.29	-0.18	0.17	0.33
70.0	622.25	-0.13	0.14	0.27	-0.14	0.14	0.28
71.0	623.60	-0.15	0.14	0.27	-0.13	0.12	0.24
72.0	624.01	-0.16	0.14	0.28	-0.16	0.14	0.27
73.0	624.42	-0.17	0.16	0.31	-0.18	0.17	0.34
74.0	625.12	-0.15	0.15	0.29	-0.16	0.16	0.32
75.0	625.81	-0.16	0.15	0.29	-0.14	0.14	0.27
76.0	626.33	-0.11	0.11	0.20	-0.15	0.14	0.26
77.0	626.68	-0.11	0.11	0.20	-0.12	0.12	0.23
78.0	626.91	-0.11	0.10	0.19	-0.12	0.11	0.21
79.0	627.83	-0.10	0.08	0.16	-0.09	0.08	0.15
80.0	628.47	-0.11	0.10	0.18	-0.10	0.09	0.17
81.0	629.88	-0.16	0.14	0.27	-0.15	0.13	0.25
Average:		-0.17	0.16	0.32	-0.18	0.17	0.33

TABLE 4.10 -WEST KETTLE RIVER ROUGHNESS & DISCHARGE SENSITIVITY

XS-No.	Base Case 200-yr Daily (m)	CWSEL Difference corresp. to:			CWSEL Difference corresp. to:		
		n*0.9 (m)	n*1.1 (m)	n*1.2 (m)	Q*0.9 (m)	Q*1.1 (m)	Q*1.2 (m)
1.0	624.42	0.00	0.00	0.00	0.00	0.00	0.00
1.4	624.84	-0.07	0.07	0.14	-0.07	0.07	0.15
1.5	624.88	-0.07	0.08	0.16	-0.07	0.08	0.16
2.0	624.91	-0.08	0.08	0.16	-0.07	0.08	0.16
3.0	625.92	-0.13	0.11	0.22	-0.15	0.12	0.25
4.0	626.46	-0.11	0.10	0.20	-0.12	0.11	0.22
5.0	626.93	-0.14	0.13	0.25	-0.13	0.12	0.23
6.0	628.43	-0.13	0.12	0.23	-0.14	0.12	0.24
7.0	628.95	-0.13	0.13	0.25	-0.14	0.13	0.26
8.0	629.37	-0.14	0.12	0.24	-0.14	0.12	0.24
9.0	629.68	-0.14	0.13	0.26	-0.15	0.13	0.25
Average:		-0.11	0.11	0.21	-0.12	0.11	0.22

TABLE 4.11 - BOUNDARY CREEK ROUGHNESS & DISCHARGE SENSITIVITY

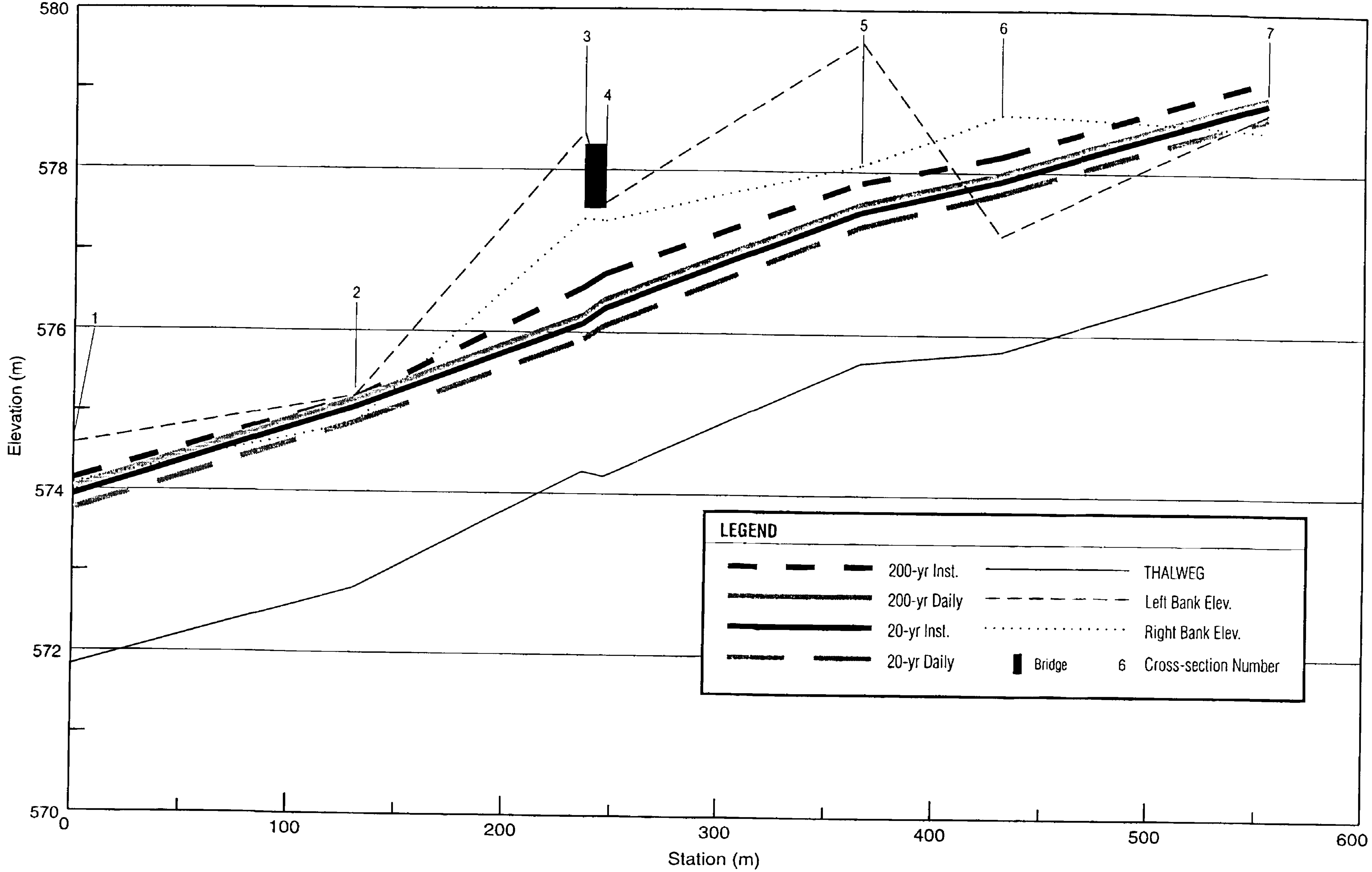
XS-No.	Base Case 200-yr Daily (m)	CWSEL Difference corresp. to:			CWSEL Difference corresp. to:		
		n*0.9 (m)	n*1.1 (m)	n*1.2 (m)	Q*0.9 (m)	Q*1.1 (m)	Q*1.2 (m)
1.0	574.03	-0.09	0.05	-0.01	-0.09	0.05	-0.01
2.0	575.15	-0.10	0.09	0.20	-0.09	0.09	0.23
3.0	576.21	-0.10	0.07	0.11	-0.09	0.07	0.07
4.0	576.41	-0.07	0.06	0.12	-0.10	0.10	0.18
5.0	577.60	-0.07	0.07	0.14	-0.09	0.09	0.18
6.0	577.98	-0.09	0.08	0.16	-0.08	0.08	0.15
7.0	578.95	-0.08	0.09	0.16	-0.08	0.08	0.15
Average:		-0.09	0.07	0.15	-0.09	0.08	0.16

4.6 Flood Profiles

Flood profiles were prepared to show the computed water surface elevations for the 20-year and 200-year daily and instantaneous floods (Figures 4-6 to 4-9.) The river thalweg, bridge crossings and bank profiles are also shown. The flood profiles do not include a freeboard allowance. The standard ministry freeboard allowance for hydraulic and hydrological uncertainties of either 0.3 m for the instantaneous flood level, or 0.6 m for the daily flood level, whichever gives the greater surface elevation, was applied to the computed water surface elevations. The computed elevations are tabulated in Tables 4.12 to 4.14, without and with freeboard. As indicated, the daily flood level plus prescribed freeboard was found to dominate.

The flood levels and floodplain limits shown on the floodplain mapping sheets are based on the selected 200-year flood levels listed in Table 4.12 to 4.14. The 20-year flood levels, including the freeboard allowance, are also shown on the mapping sheets for assistance in the administration of Health Act (septic tank) requirements.

The computed profiles assume unobstructed flow conditions and are only valid for the rivers in their present state.



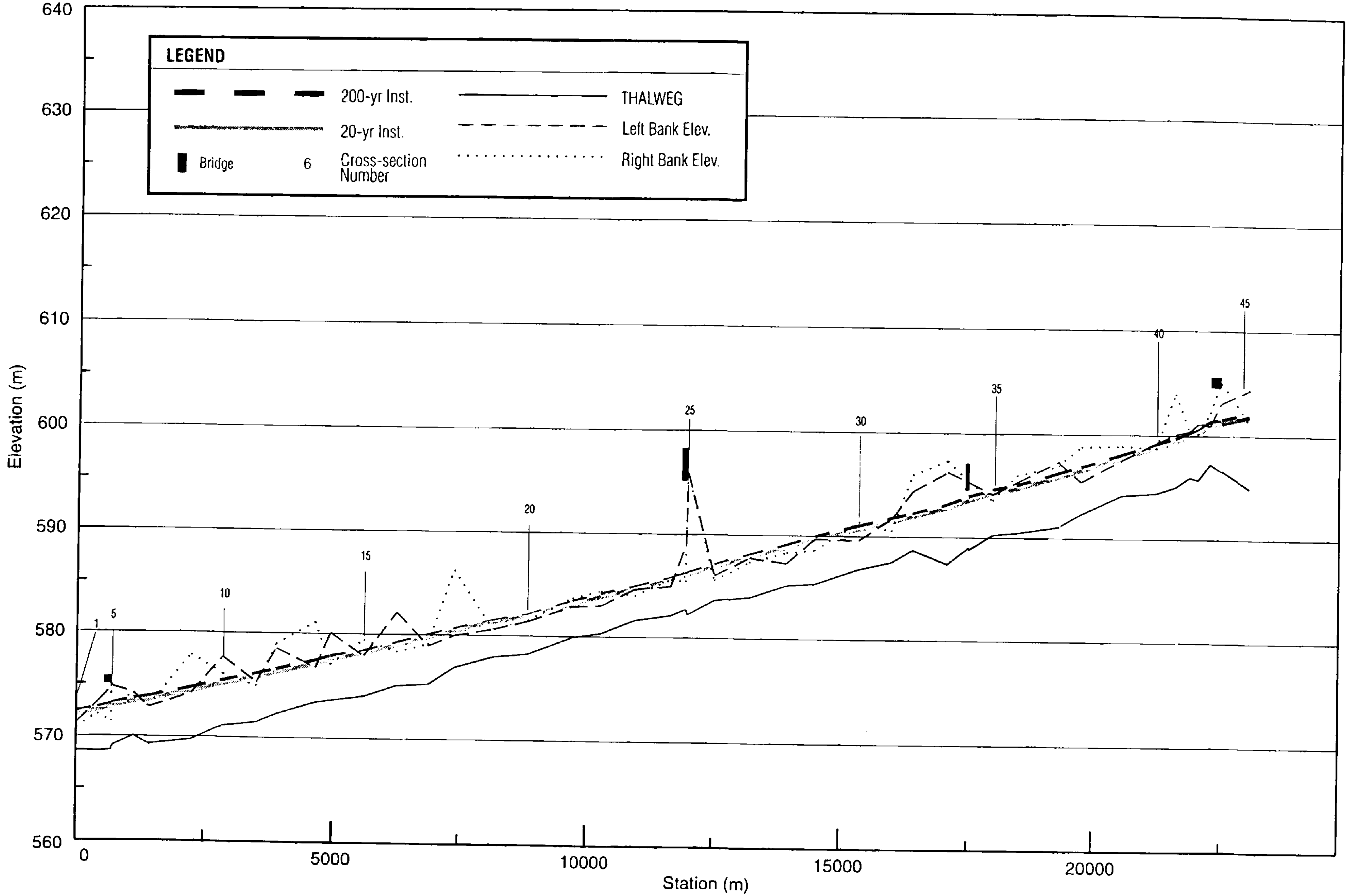
NOTE:

1. The water surface profiles were computed assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross-section locations shown on drawing 93-13-1.

Fig. 4-6

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
Boundary Creek - Computed Flood Profiles

ACRES



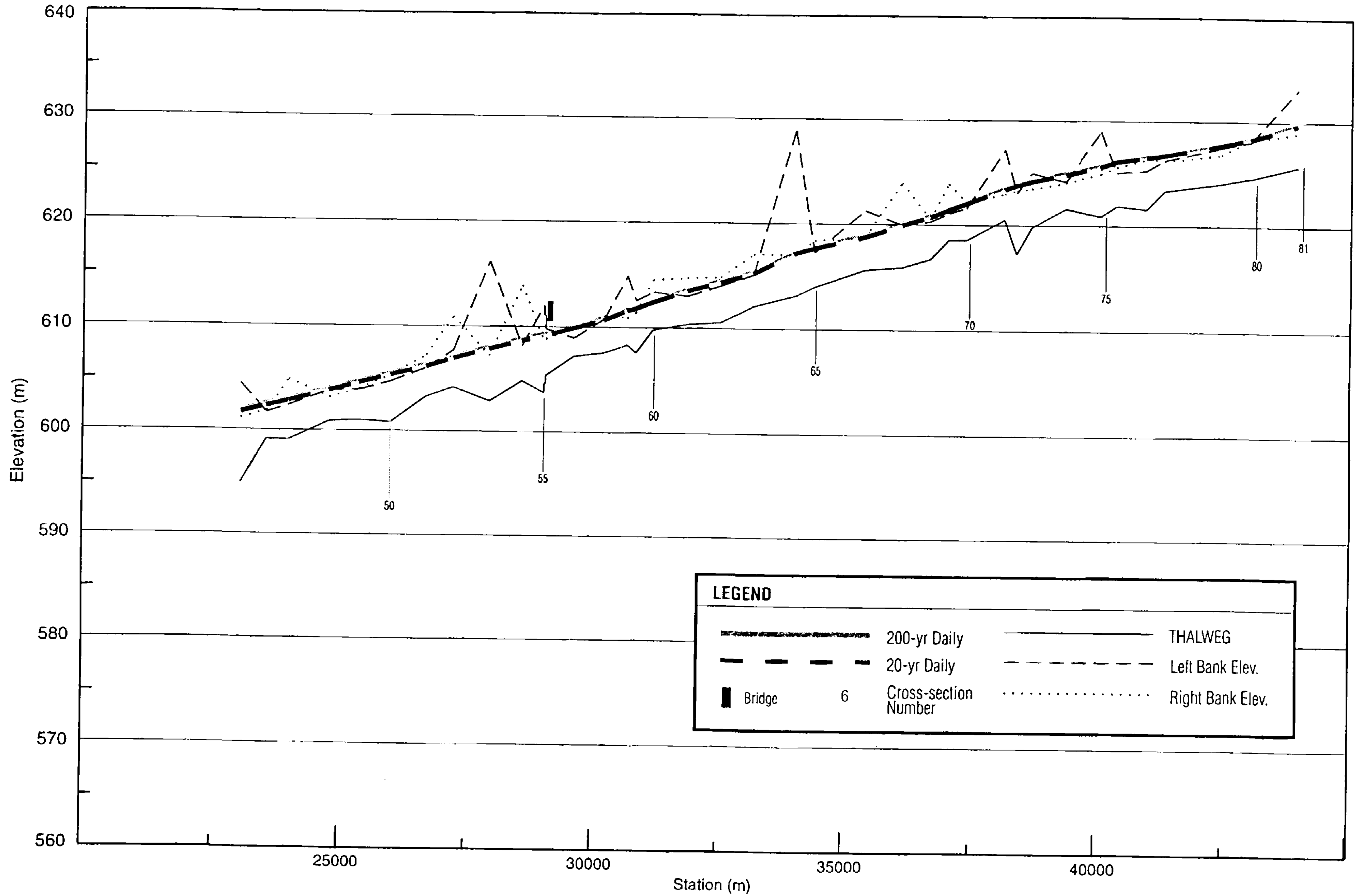
NOTE:

1. The water surface profiles were computed assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross-section locations shown on drawing 93-13-1 to 93-13-8.

Fig. 4-7a

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
Kettle River - Computed Flood Profiles (Instantaneous Flows)

ACRES



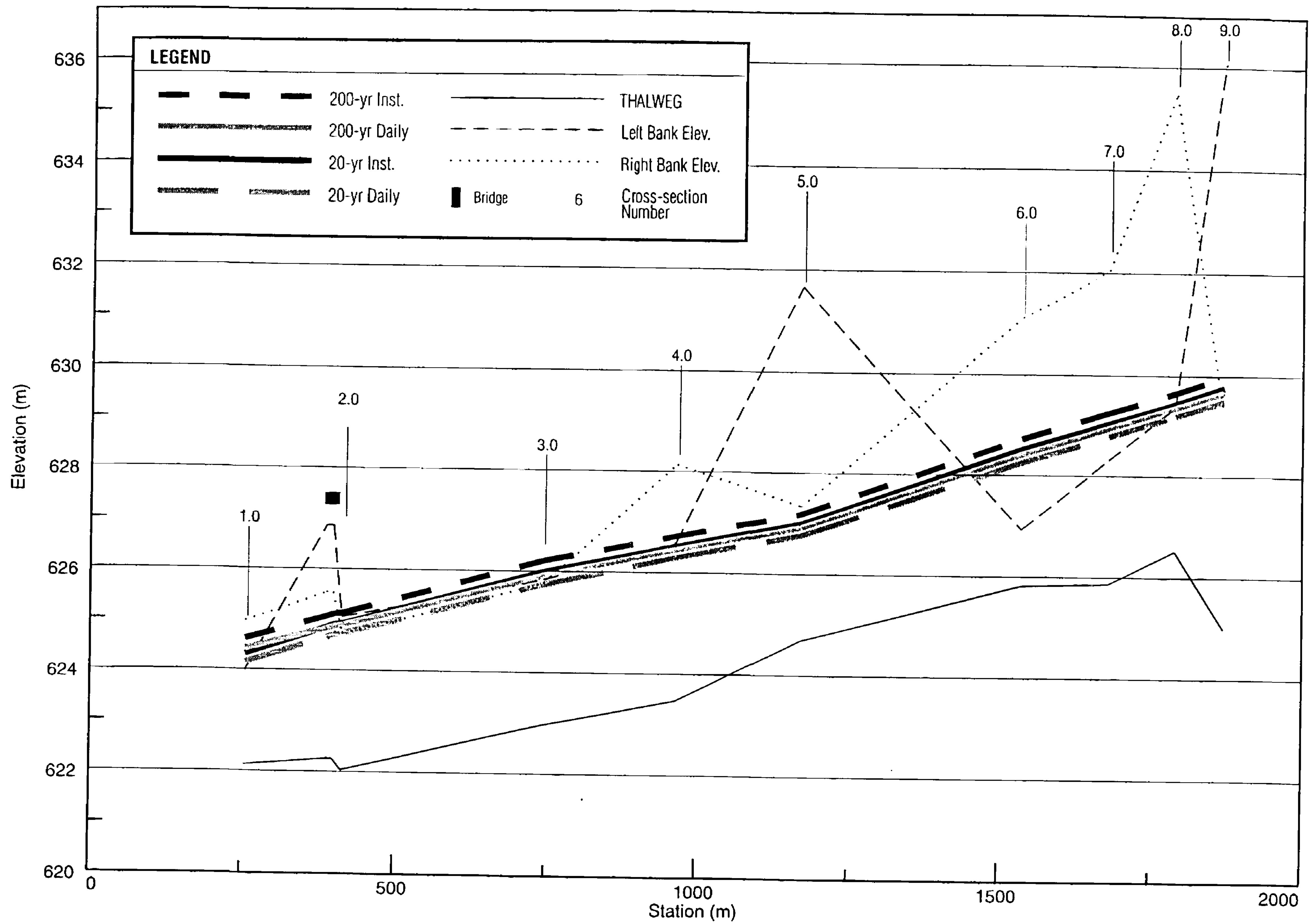
NOTE:

1. The water surface profiles were computed assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross-section locations shown on drawing 93-13-1 to 93-13-8.

Fig. 4-8b

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
Kettle River - Computed Flood Profiles (Daily Flows)

ACRES



NOTE:

1. The water surface profiles were computed assuming open water flow conditions.
2. The water surface profiles do not include an allowance for freeboard.
3. Cross-section locations shown on drawing 93-13-7 and 93-13-8.

Fig. 4-9

BC Environment
Floodplain Mapping Program - Kettle River and Tributaries
West Kettle River - Computed Flood Profiles

ACRES

TABLE 4.12 - KETTLE RIVER COMPUTED FLOOD PROFILES

XS-No.	Computed Flood Profiles - No Freeboard 200-yr Inst. (m)	200-yr Daily (m)	20-yr Inst. (m)	20-yr Daily (m)	Computed Flood Profiles - Including Freeboard 200-yr Inst. +0.3 (m)	200-yr Daily +0.6 (m)	20-yr Inst. +0.3 (m)	20-yr Daily +0.6 (m)
1.0	572.38	572.28	572.14	572.03	572.68	**572.88**	572.44	**572.63**
2.0	572.80	572.69	572.53	572.42	573.10	**573.29**	572.83	**573.02**
3.0	573.12	573.00	572.83	572.71	573.42	**573.60**	573.13	**573.31**
3.9	573.12	573.00	572.84	572.71	573.42	**573.60**	573.14	**573.31**
4.0	573.21	573.08	572.91	572.78	573.51	**573.68**	573.21	**573.38**
5.0	573.22	573.09	572.92	572.79	573.52	**573.69**	573.22	**573.39**
6.0	573.67	573.53	573.35	573.22	573.97	**574.13**	573.65	**573.82**
7.0	573.86	573.73	573.55	573.43	574.16	**574.33**	573.85	**574.03**
8.0	574.70	574.55	574.36	574.22	575.00	**575.15**	574.66	**574.82**
9.0	575.48	575.32	575.11	574.97	575.78	**575.92**	575.41	**575.57**
10.0	576.12	575.96	575.76	575.63	576.42	**576.56**	576.06	**576.23**
11.0	576.60	576.44	576.24	576.10	576.90	**577.04**	576.54	**576.70**
12.0	577.43	577.28	577.09	576.96	577.73	**577.88**	577.39	**577.56**
13.0	577.90	577.75	577.55	577.42	578.20	**578.35**	577.85	**578.02**
14.0	578.44	578.31	578.15	578.04	578.74	**578.91**	578.45	**578.64**
15.0	579.23	579.11	578.96	578.86	579.53	**579.71**	579.26	**579.46**
16.0	580.04	579.92	579.77	579.66	580.34	**580.52**	580.07	**580.26**
17.0	580.67	580.55	580.40	580.30	580.97	**581.15**	580.70	**580.90**
18.0	581.45	581.38	581.30	581.24	581.75	**581.98**	581.60	**581.84**
19.0	582.06	581.99	581.89	581.83	582.36	**582.59**	582.19	**582.43**
20.0	583.43	583.32	583.18	583.08	583.73	**583.92**	583.48	**583.68**
21.0	584.17	584.05	583.89	583.78	584.47	**584.65**	584.19	**584.38**
22.0	584.89	584.78	584.63	584.53	585.19	**585.38**	584.93	**585.13**
23.0	585.76	585.67	585.55	585.49	586.06	**586.27**	585.85	**586.09**
24.0	586.25	586.15	586.01	585.92	586.55	**586.75**	586.31	**586.52**
24.5	586.27	586.17	586.04	585.95	586.57	**586.77**	586.34	**586.55**
24.9	586.32	586.21	586.07	585.98	586.62	**586.81**	586.37	**586.58**
25.0	587.14	587.02	586.86	586.75	587.44	**587.62**	587.16	**587.35**
26.0	588.11	587.98	587.82	587.71	588.41	**588.58**	588.12	**588.31**
27.0	589.13	589.00	588.82	588.70	589.43	**589.60**	589.12	**589.30**
28.0	589.96	589.82	589.62	589.49	590.26	**590.42**	589.92	**590.09**
29.0	591.02	590.87	590.67	590.53	591.32	**591.47**	590.97	**591.13**
30.0	591.77	591.62	591.41	591.27	592.07	**592.22**	591.71	**591.87**
31.0	592.25	592.12	591.92	591.78	592.55	**592.72**	592.22	**592.38**
32.0	593.16	593.02	592.83	592.69	593.46	**593.62**	593.13	**593.29**
33.0	593.95	593.79	593.57	593.41	594.25	**594.39**	593.87	**594.01**
34.0	593.97	593.80	593.58	593.43	594.27	**594.40**	593.88	**594.03**
35.0	594.64	594.47	594.25	594.09	594.94	**595.07**	594.55	**594.69**
36.0	595.11	594.95	594.75	594.60	595.41	**595.55**	595.05	**595.20**
37.0	596.24	596.08	595.87	595.73	596.54	**596.68**	596.17	**596.33**
38.0	596.86	596.70	596.49	596.35	597.16	**597.30**	596.79	**596.95**
39.0	598.05	597.90	597.70	597.57	598.35	**598.50**	598.00	**598.17**
40.0	599.11	598.96	598.77	598.65	599.41	**599.56**	599.07	**599.25**
41.0	599.71	599.55	599.35	599.21	600.01	**600.15**	599.65	**599.81**
41.1	600.26	600.10	599.90	599.76	600.56	**600.70**	600.20	**600.36**
42.0	600.58	600.43	600.25	600.13	600.88	**601.03**	600.55	**600.73**
43.0	601.38	601.23	601.03	600.89	601.68	**601.83**	601.33	**601.49**
43.9	601.49	601.34	601.17	601.04	601.79	**601.94**	601.47	**601.64**
44.0	601.50	601.35	601.18	601.05	601.80	**601.95**	601.48	**601.65**

continued

TABLE 4.12 - KETTLE RIVER COMPUTED FLOOD PROFILES

XS-No.	Computed Flood Profiles - No Freeboard				Computed Flood Profiles - Including Freeboard			
	200-yr Inst. (m)	200-yr Daily (m)	20-yr Inst. (m)	20-yr Daily (m)	200-yr Inst. +0.3 (m)	200-yr Daily +0.6 (m)	20-yr Inst. +0.3 (m)	20-yr Daily +0.6 (m)
45.0	602.20	601.99	601.84	601.66	602.50	**602.59**	602.14	**602.26**
46.0	602.88	602.65	602.51	602.30	603.18	**603.25**	602.81	**602.90**
47.0	603.32	603.11	602.99	602.81	603.62	**603.71**	603.29	**603.41**
48.0	604.26	604.06	603.97	603.81	604.56	**604.66**	604.27	**604.41**
49.0	605.02	604.83	604.74	604.58	605.32	**605.43**	605.04	**605.18**
50.0	605.79	605.58	605.48	605.30	606.09	**606.18**	605.78	**605.90**
51.0	606.63	606.41	606.31	606.13	606.93	**607.01**	606.61	**606.73**
52.0	607.39	607.20	607.11	606.95	607.69	**607.80**	607.41	**607.55**
53.0	608.34	608.14	608.04	607.87	608.64	**608.74**	608.34	**608.47**
54.0	609.23	608.99	608.88	608.68	609.53	**609.59**	609.18	**609.28**
55.0	609.65	609.41	609.30	609.09	609.95	**610.01**	609.60	**609.69**
55.4	609.63	609.39	609.28	609.07	609.93	**609.99**	609.58	**609.67**
55.5	609.70	609.46	609.34	609.13	610.00	**610.06**	609.64	**609.73**
56.0	609.72	609.47	609.36	609.15	610.02	**610.07**	609.66	**609.75**
57.0	610.41	610.18	610.08	609.89	610.71	**610.78**	610.38	**610.49**
58.0	611.09	610.92	610.84	610.71	611.39	**611.52**	611.14	**611.31**
59.0	612.03	611.85	611.76	611.62	612.33	**612.45**	612.06	**612.22**
59.1	612.28	612.10	612.02	611.88	612.58	**612.70**	612.32	**612.48**
60.0	612.85	612.66	612.58	612.43	613.15	**613.26**	612.88	**613.03**
61.0	613.96	613.77	613.69	613.52	614.26	**614.37**	613.99	**614.12**
62.0	614.85	614.65	614.56	614.38	615.15	**615.25**	614.86	**614.98**
63.0	615.69	615.49	615.40	615.23	615.99	**616.09**	615.70	**615.83**
64.0	617.53	617.37	617.29	617.16	617.83	**617.97**	617.59	**617.76**
65.0	618.07	617.91	617.83	617.69	618.37	**618.51**	618.13	**618.29**
66.0	619.27	619.08	618.98	618.81	619.57	**619.68**	619.28	**619.41**
67.0	620.42	620.21	620.11	619.92	620.72	**620.81**	620.41	**620.52**
68.0	621.22	621.00	620.90	620.72	621.52	**621.60**	621.20	**621.32**
69.0	621.90	621.70	621.61	621.43	622.20	**622.30**	621.91	**622.03**
70.0	622.42	622.25	622.18	622.04	622.72	**622.85**	622.48	**622.64**
71.0	623.74	623.60	623.53	623.40	624.04	**624.20**	623.83	**624.00**
72.0	624.17	624.01	623.93	623.78	624.47	**624.61**	624.23	**624.38**
73.0	624.62	624.42	624.32	624.15	624.92	**625.02**	624.62	**624.75**
74.0	625.41	625.12	625.13	624.89	625.71	**625.72**	625.43	**625.49**
75.0	626.09	625.81	625.85	625.61	626.39	**626.41**	626.15	**626.21**
76.0	626.61	626.33	626.38	626.13	626.91	**626.93**	626.68	**626.73**
77.0	626.93	626.68	626.73	626.51	627.23	**627.28**	627.03	**627.11**
78.0	627.14	626.91	626.95	626.75	627.44	**627.51**	627.25	**627.35**
79.0	628.00	627.83	627.86	627.70	628.30	**628.43**	628.16	**628.30**
80.0	628.66	628.47	628.51	628.34	628.96	**629.07**	628.81	**628.94**
81.0	630.16	629.88	629.93	629.68	630.46	**630.48**	630.23	**630.28**

NOTE: Bold figures were used to derive floodplain limit s (same as TSB).

TABLE 4.13 - WEST KETTLE RIVER COMPUTED FLOOD PROFILES

XS-No.	Computed Flood Profiles - No Freeboard				Computed Flood Profiles - Including Freeboard			
	200-yr Inst. (m)	200-yr Daily (m)	20-yr Inst. (m)	20-yr Daily (m)	200-yr Inst. +0.3 (m)	200-yr Daily +0.6 (m)	20-yr Inst. +0.3 (m)	20-yr Daily +0.6 (m)
1.0	624.62	624.42	624.32	624.15	624.92	**625.02**	624.62	**624.75**
1.4	625.07	624.84	624.85	624.66	625.37	**625.44**	625.15	**625.26**
1.5	625.12	624.88	624.91	624.71	625.42	**625.48**	625.21	**625.31**
2.0	625.14	624.91	624.93	624.74	625.44	**625.51**	625.23	**625.34**
3.0	626.21	625.92	625.99	625.74	626.51	**626.52**	626.29	**626.34**
4.0	626.72	626.46	626.52	626.30	627.02	**627.06**	626.82	**626.90**
5.0	627.19	626.93	627.00	626.77	627.49	**627.53**	627.30	**627.37**
6.0	628.72	628.43	628.51	628.26	629.02	**629.03**	628.81	**628.86**
7.0	629.25	628.95	629.03	628.78	629.55	**629.55**	629.33	**629.38**
8.0	629.65	629.37	629.44	629.19	629.95	**629.97**	629.74	**629.79**
9.0	629.98	629.68	629.76	629.50	630.28	**630.28**	630.06	**630.10**

NOTE: Bold figures were used to derive floodplain limits.

TABLE 4.14 - BOUNDARY CREEK COMPUTED FLOOD PROFILES

XS-No.	Computed Flood Profiles - No Freeboard				Computed Flood Profiles - Including Freeboard			
	200-yr Inst. (m)	200-yr Daily (m)	20-yr Inst. (m)	20-yr Daily (m)	200-yr Inst. +0.3 (m)	200-yr Daily +0.6 (m)	20-yr Inst. +0.3 (m)	20-yr Daily +0.6 (m)
1.0	574.15	574.03	573.94	573.76	574.45	**574.63**	574.24	**574.36**
2.0	575.17	575.15	575.06	574.87	575.47	**575.75**	575.36	**575.47**
3.0	576.56	576.21	576.12	575.92	**576.86**	576.81	576.42	**576.52**
4.0	576.73	576.41	576.31	576.09	**577.03**	577.01	576.61	**576.69**
5.0	577.87	577.60	577.51	577.33	578.17	**578.20**	577.81	**577.93**
6.0	578.20	577.98	577.90	577.75	578.50	**578.58**	578.20	**578.35**
7.0	579.17	578.95	578.87	578.70	579.47	**579.55**	579.17	**579.30**

5 Channel Stability and Conditions

5 Channel Stability and Conditions

5.1 General

The channel stability within the study reaches was reviewed to assess what future changes may occur and how they might influence the computed flood profiles[10]. The present study discusses erosion prone areas and river instability, but is not intended to be used for risk management purposes. B.C. Ministry of Environment, Lands and Parks staff provided 1:31680 scale topographic maps of the study area entitled, "Columbia River Basin" based on surveys from 1952 and air photography of about the same time. These maps were compared with the 1993 maps to determine any changes in river configuration. Air photography flown in 1938, 1946 and 1991 was also reviewed. The early photography represented river conditions prior to the 1948 flood, the largest event on record. Unfortunately, the 1938 and 1946 coverage did not include Boundary Creek, or the downstream end of the Kettle River study reach. Available rating tables at the WSC stream gauges in the area were checked for vertical stability. Special conditions affecting flooding, such as log-jams and ice blockages, were also investigated. All three watercourses transport large amounts of logs and debris during high flows, but according to long term residents, neither log-jams nor ice-jams have historically caused problems.

5.2 Kettle River

The character of the Kettle River changes abruptly at the Canada-US border. Downstream of the study reach, the river flows through a series of tight meander loops at an average slope of 0.001. Large sand deposits are evident at the inside of the river bends. Upstream of the border, the channel is fairly straight, partially entrenched with some irregular meanders. The channel makes several sharp bends, generally at points of highly erosion resistant bank material or at bedrock outcrops. The banks are typically vegetated with trees or shrubs and are quite stable, with the few exceptions discussed below. The river bed is armoured with cobble-sized material and the average channel slope is about 0.001. There are a few mid-channel islands and numerous large gravel side- and point-bars.

Review of the historic material revealed the following areas of instability between the Canada-US border and Westbridge:

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[10] Kellerhals, R., Church, M. and Bray, D., Classification and Analysis of River Processes, Journal of the Hydraulics Division, ASCE, July 1976.

- The left bank, roughly between XS-11 and XS-13, appears to have been extended into the river, narrowing the channel and locally increasing flow velocities, which in turn have reduced the size of local gravel-bars and eroded a mid-channel island. The bank is partially protected by a wooden crib wall (Photo 5.1) and by rubble riprap (Photo 5.2). The wall is failing in some sections and the riprap is unstable.

- Just upstream of XS-17, the river makes a 90° turn and flow is directed straight towards the right bank. This steep bank consists of cobble and gravel sized fluvial material and is gradually slumping. Some of the eroded material is deposited a short distance downstream along the left bank, forming large gravel bars. At high flows, this gradually growing constriction will divert more flow across the left bank floodplain between XS-18 and XS-19. Conceivably, the main channel could cut through at one of the back channels, resulting in channel changes further downstream.

- Johnstone Creek (Rock Creek) flows into the Kettle River on the right bank between XS-42 and XS-43 (Photo 5.3). The air photography shows a gradual build-up of the creek fan over the last 50 years. The Kettle River left bank, across from the confluence, is vegetated and appears to be stable. A berm (Photo 5.4), built along the left bank roughly between XS-43 and XS-44, is not effective during large flood events. Due to the gradual fan build-up, upstream flood levels are likely to increase locally over time. In the future, Johnstone Creek may change its course across the fan, resulting in severe erosion and flooding.

- Erosion of the left bank downstream of XS-65 was noted. A protrusion in the right bank directs the flow to the opposite bank, causing erosion. The 1952 maps show the main channel near the right bank at XS-64, whereas the thalweg now follows near the left bank with vegetated islands having developed near the right bank.

- Louise Creek, a steep mountain creek, enters the Kettle River just upstream of XS-69 on the left bank. A gradual fan build-up has directed more of the Kettle River flow towards the right side of the channel, producing a large island that 30 years ago was part of the right bank. Louise Creek flows on the southernmost edge of the fan, and may change its course in the future.

- Throughout the study reach there are a number of other smaller streams, each with active fans at their outlets to the Kettle River including Bubar, Hulme, Ingram, James, Myers and Nicholson. Boundary Creek is discussed in Section 5.4.

The Kettle River below the West Kettle River confluence has remained essentially stable over the past 50 years. However, upstream of the confluence the character of the Kettle River changes and becomes laterally quite unstable. The irregularly meandering channel shows activity in terms of progression and numerous meander cut-offs. The bed material is mainly gravel-size and much finer than downstream of Westbridge. The average channel slope is 0.0009 and the channel contains large debris accumulations. The banks may be subject to severe erosion, resulting in relocation of the main channel. The channel movement is restricted by the terrace on the left side of the floodplain and by the highway embankment and terrace on the right side. Typically, the inactive historic channels shown on the 1993 maps were active 50 years ago (Photo 5.5). An extreme flood would likely substantially rearrange this reach, but within the confining terraces. Downstream of Westbridge, the configuration would likely stay mainly unaltered but extensive bedload transport would take place, shifting gravel bars and altering flood profiles locally.

5.3 West Kettle River

The West Kettle River has an irregular, slightly meandering channel with a narrow floodplain. The average channel slope is 0.0033 and the bed material is cobble-sized with some larger boulders (XS-5). The banks are heavily vegetated with large trees and shrubs. The study reach has remained stable over the period of investigation, although some irregular activity has taken place upstream of the study reach.

The fourteen WSC rating tables covering the period of record since 1979 for the stream gauge "West Kettle River near Westbridge" were reviewed. A specific rating table was produced, showing the variation in stage, over time, for a range of discharges. If the section was consistently aggrading, the table would show increasing stage levels for all discharges, and similarly, a decreasing stage would imply degradation. The section was found to be quite stable, with stage variations typically less than 0.05 m. At very low flows (less than 1 m^3/s) there appears to be a tendency for minor infilling of the channel.

5.4 Boundary Creek

The Boundary Creek channel bed has an average slope of 0.009 and is armoured with cobbles. The banks are heavily vegetated, and some large tree trunks lean into the creek. Minor build-up of gravel has taken place at the confluence with the Kettle River, but the fan is fairly small and does not constrict the Kettle River flows.

The 1952 map shows Boundary Creek as having three separate channels at the present Dominion Street Bridge, where the creek now is confined to a single channel. At extreme floods, there is a risk of the channel dividing or taking a different course. The Boundary Creek western flood boundary was delineated assuming avulsion of the creek at the point where it exits the canyon, resulting in extensive flooding. The location of this flood boundary should be considered approximate.

Bank erosion is taking place along the left bank at XS-5, at the outside of a bend (Photo 5.6). The bank, consisting of cobble-sized material overlain by gravel, is actively slumping, causing an abandoned building to be partly undermined. A specific rating table for the "Boundary Creek near Midway" gauge (based on 9 tables for 1971 to 1977) shows a tendency towards aggradation at low flows. Due to several shifts in the gauge reference, the results for higher discharges are inconclusive.

5.5 Accuracy of Computed Profiles

The models were calibrated to the available set of high water levels and the potential variation of roughness with flow was partially assessed. For the Kettle River, 200-yr flood flows were about 2.2 times the calibration flow, with a calculated increase in water level of about 1.5 m.

An extensive set of high water-levels were obtained by B.C. Ministry of Environment, Lands and Parks staff for the Kettle River, but some uncertainty is associated with the discharges corresponding to the recorded levels, due to diurnal fluctuations.

The Kettle River channel makes several abrupt bends, where substantial superelevation of the flow may occur. For the 200-year maximum daily flood, an elevation increase of over 0.5 m was estimated along the outside bank in some of the sharper bends.

Climate changes, logging activities and other man-made changes in the basins may alter the hydrology and consequently the flood profiles.

The B.C. Ministry of Environment, Lands and Parks standard 0.6 m freeboard allowance for hydraulic and hydrological uncertainties on the maximum daily flood level will envelope potential discrepancies in the computed water surface profiles for the three watercourses, based on the results of sensitivity studies presented in Section 4.

PHOTO 5.1
Kettle River Left Bank near Cross-section 13. Partly failing crib wall.

PHOTO 5.2
Kettle River Left Bank near Cross-section 11, riprap erosion protection.

PHOTO 5.3
Kettle River and Johnstone Creek confluence, looking downstream. Note stable left bank of the Kettle River and cobble-size material at the Johnstone Creek outlet.

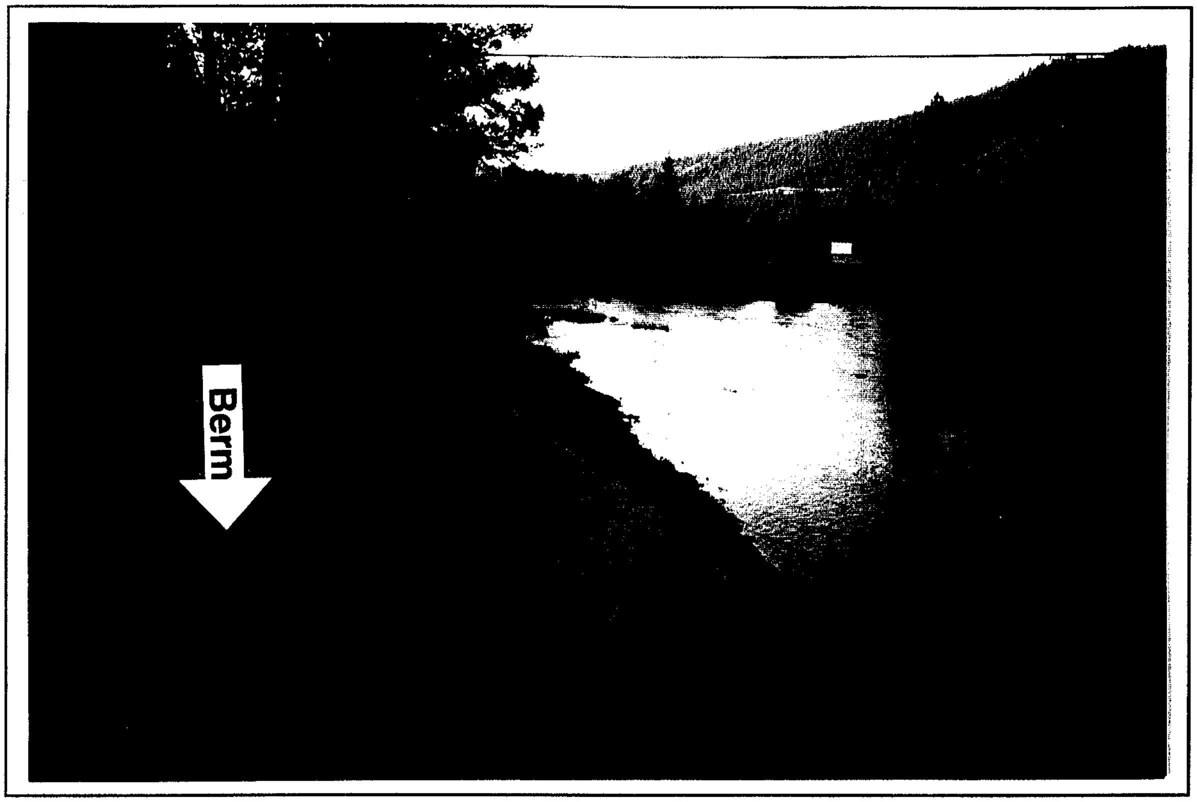


PHOTO 5.4
Kettle River Left Bank berm downstream of Cross-section 44.

PHOTO 5.5
Kettle and West Kettle River confluence, 1938. Note Kettle River configuration upstream of confluence.

PHOTO 5.6
Boundary Creek erosion of left bank near Cross-section 5.

6 CONCLUSIONS

6 Conclusions

This Design Brief presents an overview of the studies undertaken to produce the floodplain mapping sheets for the Kettle River from Midway to Westbridge. The floodplain limits shown on the maps correspond to the area which would be inundated by a flood having a 200-year recurrence interval, based on an analysis of historic flow records. The study area has a documented history of flooding dating back to large floods which occurred in 1894, 1942 and 1948.

The floodplain maps are administrative tools to provide information which will help to minimize future flood damages. They are not comprehensive floodplain mapping plans, nor do they provide solutions to site specific flood hazards such as land erosion or sudden shifts in the channel of a watercourse.

Flooding may occur outside the designated floodplain due to a variety of reasons including:

- tributary flooding
- jamming of ice or debris
- channel obstructions
- floods that exceed the design event

These limitations are noted on the maps where appropriate.

Regarding the floodplain maps, it can be seen that a significant part of the undeveloped land to the south east of Midway is within the floodplain limits. Also, some of the properties south of the Kettle River in Midway are in the floodplain. The floodplain in the reach east of Rock Creek (from about XS-42 to XS-30) is quite narrow as the river has become entrenched there with higher banks and larger cross-sectional area per unit of top width.

7 RECOMMENDATIONS

7 Recommendations

The maps (Drawings 93-13, Sheets 1 to 8) that were prepared together with this Design Brief depict the 200-year floodplain limits for the study reaches, based on technical standards established by the B.C. Ministry of Environment, Lands and Parks. It is recommended that these maps be designated under the terms of the joint Canada-British Columbia Floodplain Mapping Agreement.

The floodplain maps have been prepared based on the physical conditions as they existed in 1996. If any significant changes occur (e.g. construction of new bridges, filling in of floodplains to accommodate new development), the local authorities should report such changes to the B.C. Ministry of Environment, Lands and Parks, who are charged with the responsibility of monitoring the maps.

Floodproofing requirements in the bylaws of the Village of Midway and the Regional District of Kootenay Boundary should take cognizance of the information shown on the mapping sheets.

APPENDIX A - Statistical Data

APPENDIX A1 -
Kettle River Near Ferry - Instantaneous

STA. 08NN013 - KETTLE RIVER NEAR FERRY

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
31	255.	600.	1	.016	63.000
32	292.	515.	2	.032	31.500
33	396.	484.	3	.048	21.000
34	326.	473.	4	.063	15.750
35	314.	470.	5	.079	12.600
37	281.	462.	6	.095	10.500
39	294.	447.	7	.111	9.000
40	281.	442.	8	.127	7.875
41	264.	439.	9	.143	7.000
42	515.	439.	10	.159	6.300
43	225.	425.	11	.175	5.727
44	234.	425.	12	.190	5.250
45	365.	422.	13	.206	4.846
46	385.	419.	14	.222	4.500
47	257.	419.	15	.238	4.200
48	600.	416.	16	.254	3.938
49	408.	413.	17	.270	3.706
50	340.	408.	18	.286	3.500
51	425.	408.	19	.302	3.316
52	419.	408.	20	.317	3.150
53	334.	399.	21	.333	3.000
54	442.	396.	22	.349	2.864
55	408.	394.	23	.365	2.739
56	484.	391.	24	.381	2.625
57	462.	388.	25	.397	2.520
58	351.	385.	26	.413	2.423
59	351.	385.	27	.429	2.333
60	317.	379.	28	.444	2.250
61	425.	374.	29	.460	2.172
62	253.	374.	30	.476	2.100
63	297.	365.	31	.492	2.032
64	385.	351.	32	.508	1.969
65	303.	351.	33	.524	1.909
66	215.	351.	34	.540	1.853
67	413.	348.	35	.556	1.800
68	348.	343.	36	.571	1.750

69	408.	340.	37	.587	1.703
70	255.	334.	38	.603	1.658
71	473.	326.	39	.619	1.615
72	470.	326.	40	.635	1.575
73	297.	323.	41	.651	1.537
74	422.	317.	42	.667	1.500
75	388.	314.	43	.683	1.465
76	379.	306.	44	.698	1.432
77	283.	303.	45	.714	1.400
78	323.	297.	46	.730	1.370
79	306.	297.	47	.746	1.340
80	399.	297.	48	.762	1.313
81	416.	294.	49	.778	1.286
82	374.	292.	50	.794	1.260
83	447.	283.	51	.810	1.235
84	374.	281.	52	.825	1.212
85	394.	281.	53	.841	1.189
86	439.	264.	54	.857	1.167
87	391.	257.	55	.873	1.145

STA. 08NN013 - KETTLE RIVER NEAR FERRY

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
88	326.	255.	56	.889	1.125
89	297.	255.	57	.905	1.105
90	419.	253.	58	.921	1.086
91	351.	234.	59	.937	1.068
92	231.	231.	60	.952	1.050
93	439.	225.	61	.968	1.033
94	343.	215.	62	.984	1.016

STATISTICS OF DATA SERIES

SAMPLE SIZE = 62

MEAN =	359.8065	MIN. =	215.0000	MAX. =	600.0000
S.D. =	78.8085	C.S. =	.3166	C.K. =	3.1603

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 62

MEAN =	5.8615	MIN. =	5.3706	MAX. =	6.3969
S.D. =	.2231	C.S. =	-.2253	C.K. =	2.6348

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = 12.477

BETA = 39.894

GAMMA = -137.963

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	232.607	179.934	127.262	2633.612
1.050	264.859	236.088	207.318	1438.543
1.250	314.006	292.608	271.209	1069.924
2.000	377.424	355.658	333.892	1088.306
5.000	449.921	424.584	399.246	1266.886
10.000	494.532	463.075	431.619	1572.821
20.000	536.245	496.146	456.046	2004.963
50.000	588.732	534.781	480.830	2697.540
100.000	626.955	561.385	495.814	3278.521
200.000	664.180	586.336	508.493	3892.170
500.000	712.152	617.358	522.563	4739.723
1000.000	747.677	639.637	531.597	5402.023
10000.000	862.190	708.258	554.326	7696.599

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR PEARSON III

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

A = -389.600

M = 6.614

S = .105

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	238.137	179.142	134.762	14.233
1.050	266.852	236.041	208.788	6.134
1.250	314.869	292.747	272.178	3.643
2.000	378.031	355.696	334.680	3.045
5.000	450.567	424.454	399.855	2.985
10.000	495.389	462.922	432.584	3.389
20.000	537.888	496.047	457.461	4.049
50.000	592.488	534.859	482.836	5.116
100.000	633.129	561.669	498.275	5.988
200.000	673.458	586.883	511.438	6.880
500.000	726.571	618.333	526.220	8.065
1000.000	766.758	640.995	535.860	8.957
10000.000	901.502	711.225	561.109	11.854

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = -240.138

M = 6.388

S = .131

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	235.779	184.015	143.616	12.394
1.050	266.521	237.762	212.107	5.709
1.250	314.163	292.564	272.450	3.561

2.000	376.802	354.752	333.993	3.015
5.000	450.840	424.203	399.139	3.045
10.000	497.255	463.714	432.436	3.492
20.000	541.360	498.100	458.296	4.164
50.000	598.155	538.801	485.336	5.225
100.000	640.574	567.168	502.174	6.085
200.000	682.814	594.031	516.793	6.964
500.000	738.672	627.783	533.541	8.133
1000.000	781.112	652.269	544.679	9.013
10000.000	924.462	729.002	574.868	11.877

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .016

U = 324.343

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	252.651	221.825	191.000	6.948
1.050	279.667	255.929	232.190	4.638
1.250	313.068	295.100	277.132	3.044
2.000	365.265	346.865	328.464	2.652
5.000	447.485	416.513	385.540	3.718
10.000	504.444	462.626	420.808	4.520
20.000	559.673	506.859	454.044	5.210
50.000	631.555	564.113	496.672	5.978
100.000	685.574	607.018	528.461	6.471
200.000	739.474	649.766	560.057	6.903
500.000	810.661	706.163	601.666	7.399
1000.000	864.501	748.787	633.074	7.727
10000.000	1043.402	890.307	737.212	8.598

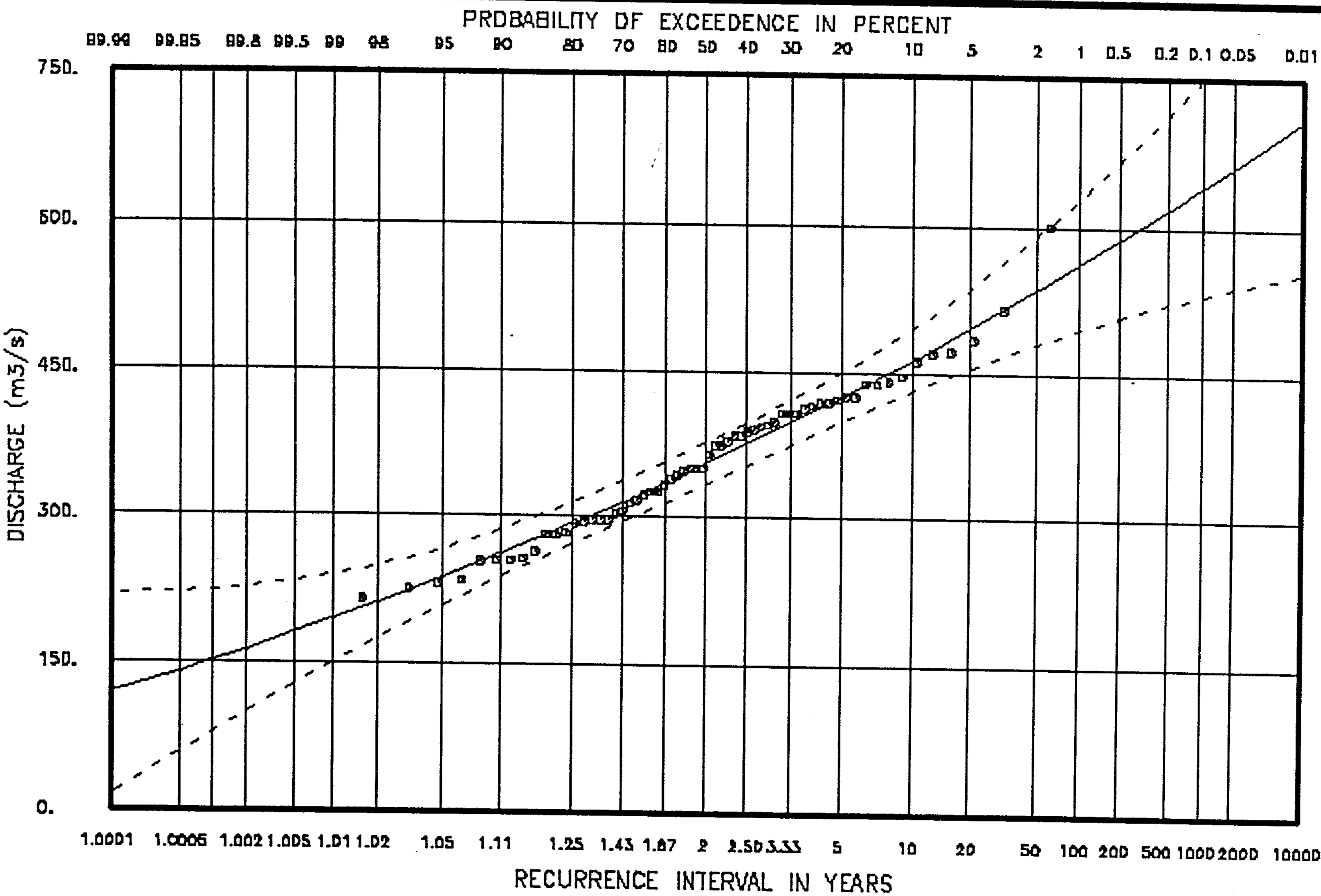
GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .014

U = 321.711

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	229.703	204.915	180.128	6.048
1.050	263.964	243.769	223.573	4.142
1.250	306.192	288.395	270.598	3.086
2.000	368.249	347.369	326.490	3.005
5.000	458.761	426.717	394.673	3.755

10.000	520.360	479.253	438.146	4.289
20.000	579.936	529.646	479.355	4.748
50.000	657.416	594.875	532.333	5.257
100.000	715.629	643.754	571.879	5.582
200.000	773.711	692.456	611.201	5.867
500.000	850.421	756.708	662.995	6.192
1000.000	908.440	805.268	702.097	6.406
10000.000	1101.234	966.498	831.761	6.970

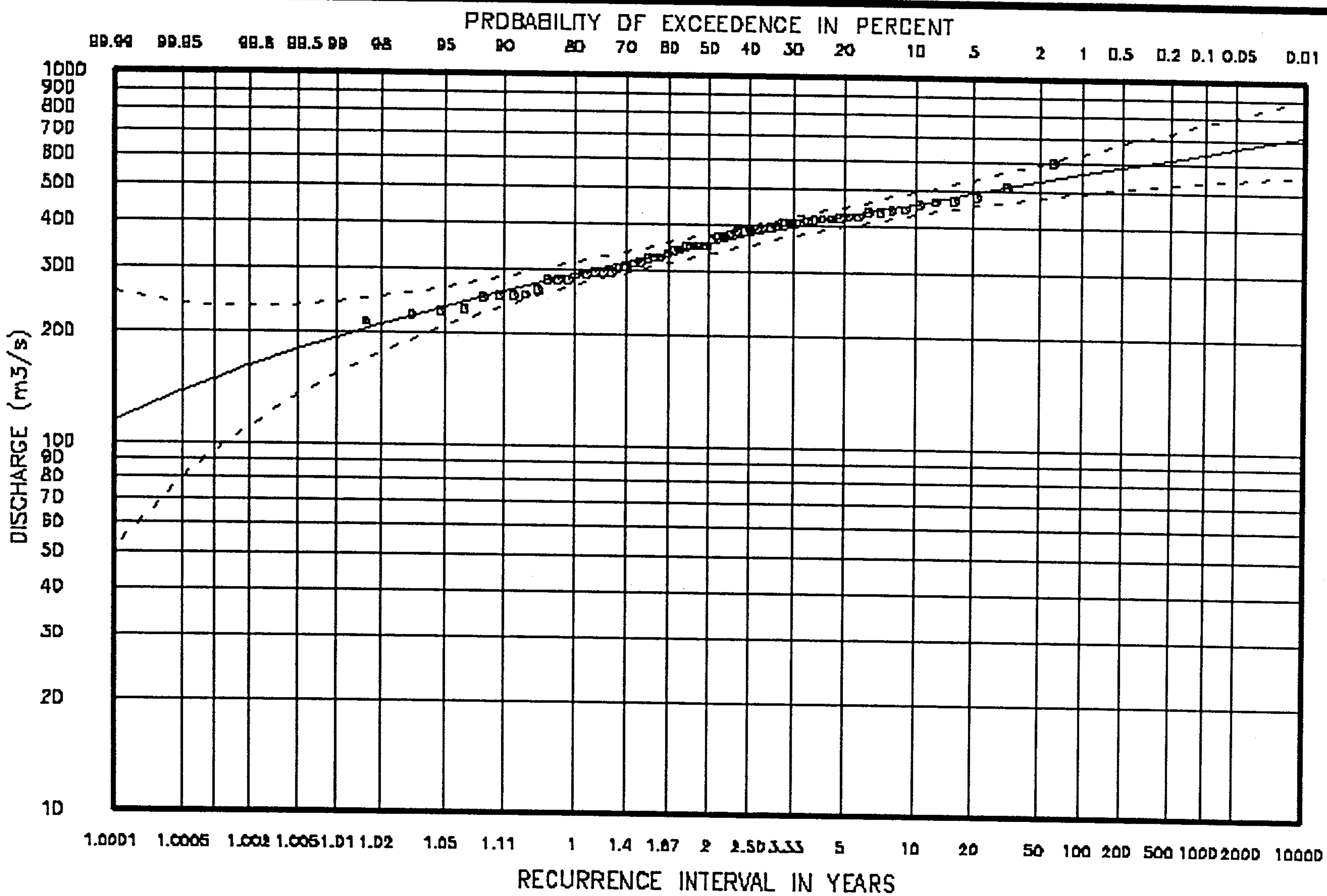


STA. 08NN013 – KETTLE RIVER NEAR FERRY

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

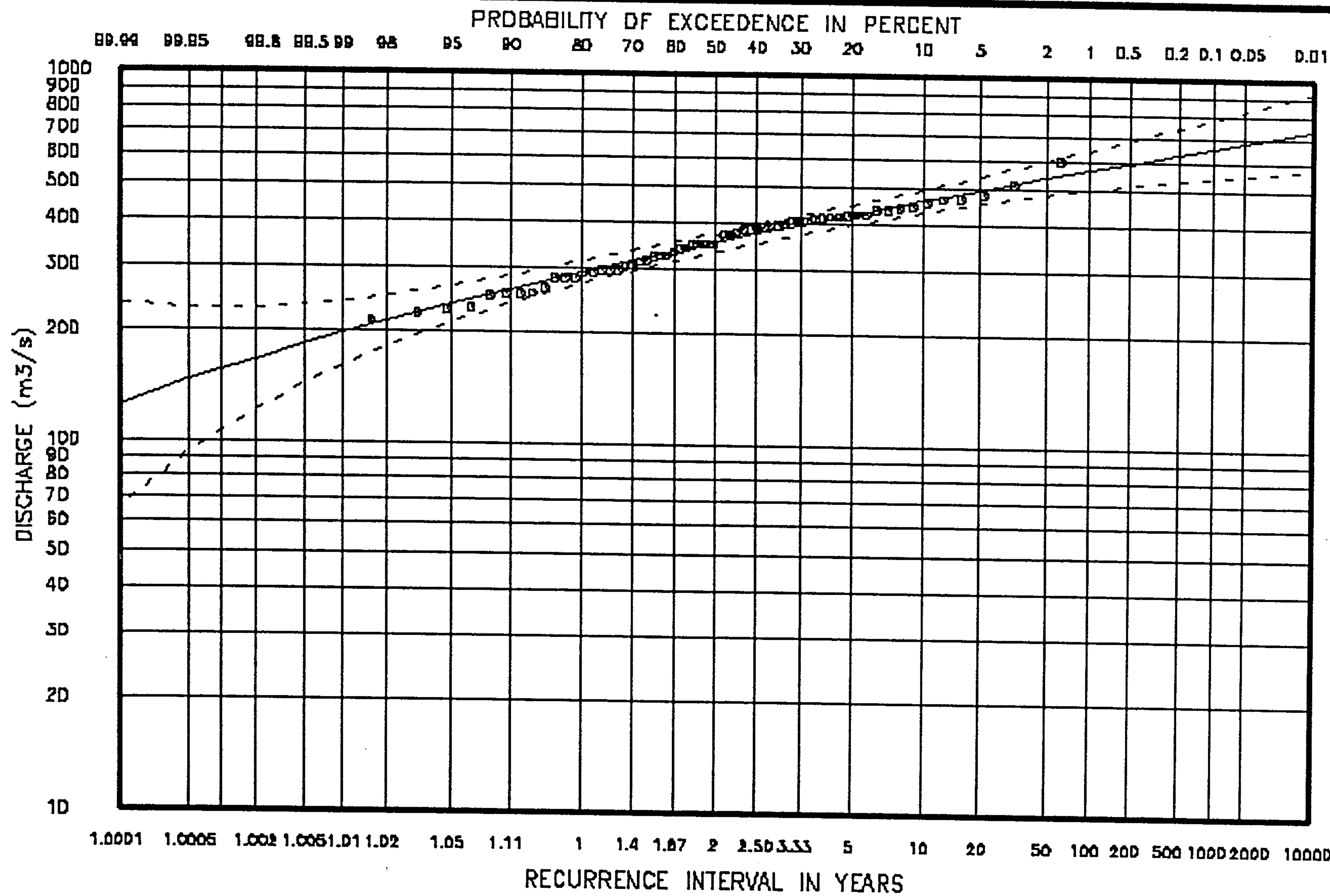


STA. 08NN013 – KETTLE RIVER NEAR FERRY

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

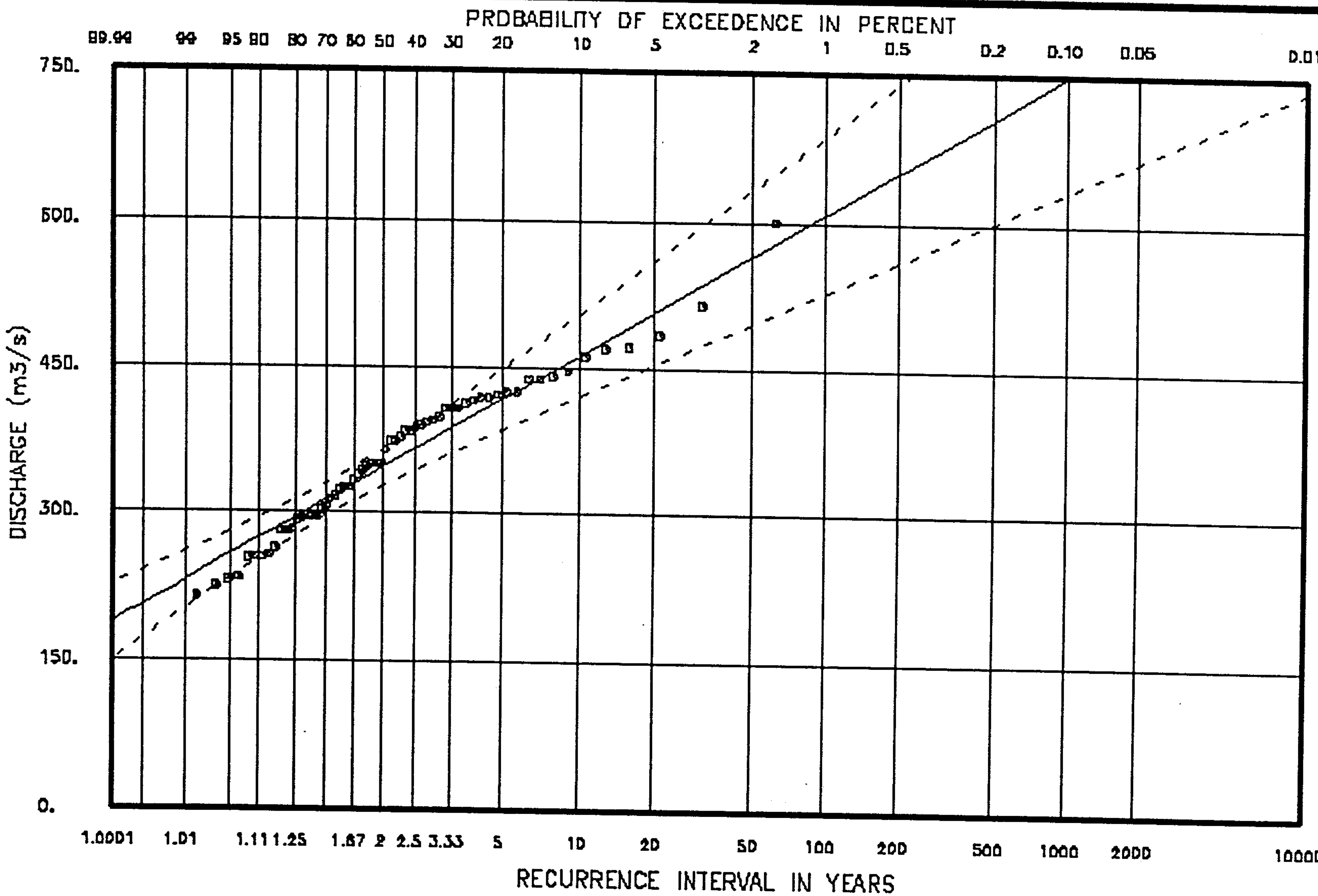


STA. 08NN013 – KETTLE RIVER NEAR FERRY

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

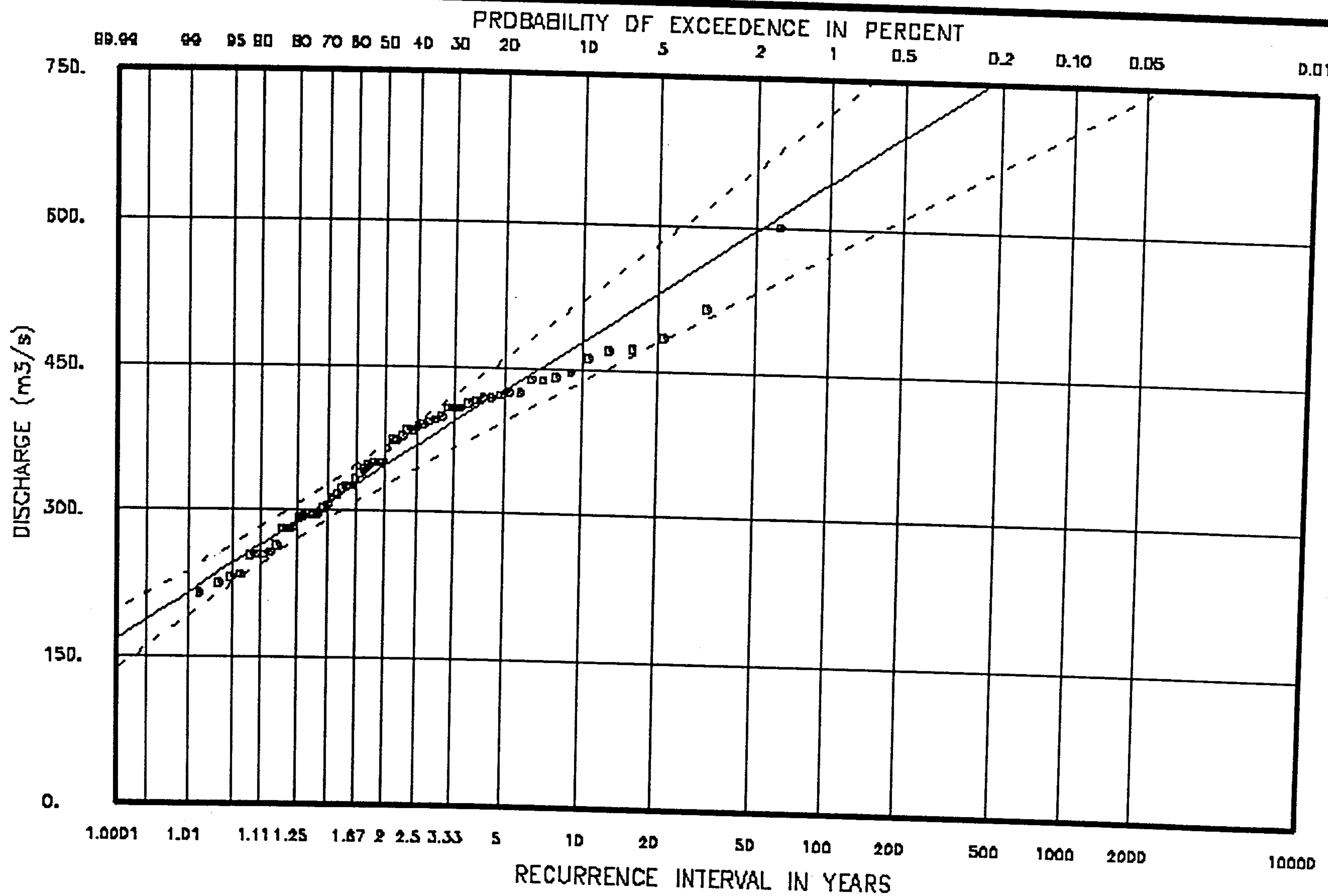


STA. 08NN013 – KETTLE RIVER NEAR FERRY

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN013 – KETTLE RIVER NEAR FERRY

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A2 -
Kettle River Near Ferry - Daily

STA. 08NN013 - KETTLE RIVER NEAR FERRY

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
29	193.	575.	1	.015	67.000
30	155.	507.	2	.030	33.500
31	242.	479.	3	.045	22.333
32	286.	456.	4	.060	16.750
33	391.	453.	5	.075	13.400
34	314.	442.	6	.090	11.167
35	300.	430.	7	.104	9.571
36	314.	428.	8	.119	8.375
37	252.	425.	9	.134	7.444
38	326.	416.	10	.149	6.700
39	281.	408.	11	.164	6.091
40	261.	402.	12	.179	5.583
41	251.	402.	13	.194	5.154
42	507.	402.	14	.209	4.786
43	214.	402.	15	.224	4.467
44	218.	399.	16	.239	4.188
45	360.	399.	17	.254	3.941
46	354.	396.	18	.269	3.722
47	251.	391.	19	.284	3.526
48	575.	385.	20	.299	3.350
49	402.	382.	21	.313	3.190
50	334.	379.	22	.328	3.045
51	396.	377.	23	.343	2.913
52	402.	371.	24	.358	2.792
53	314.	365.	25	.373	2.680
54	425.	365.	26	.388	2.577
55	402.	362.	27	.403	2.481
56	479.	360.	28	.418	2.393
57	442.	357.	29	.433	2.310
58	340.	354.	30	.448	2.233
59	343.	345.	31	.463	2.161
60	309.	343.	32	.478	2.094
61	385.	340.	33	.493	2.030
62	246.	334.	34	.507	1.971
63	289.	334.	35	.522	1.914
64	371.	331.	36	.537	1.861

65	294.	328.	37	.552	1.811
66	204.	326.	38	.567	1.763
67	399.	314.	39	.582	1.718
68	331.	314.	40	.597	1.675
69	399.	314.	41	.612	1.634
70	238.	311.	42	.627	1.595
71	453.	309.	43	.642	1.558
72	456.	309.	44	.657	1.523
73	283.	300.	45	.672	1.489
74	408.	294.	46	.687	1.457
75	377.	294.	47	.701	1.426
76	365.	289.	48	.716	1.396
77	267.	286.	49	.731	1.367
78	309.	283.	50	.746	1.340
79	294.	282.	51	.761	1.314
80	379.	281.	52	.776	1.288
81	382.	267.	53	.791	1.264
82	365.	261.	54	.806	1.241
83	430.	252.	55	.821	1.218

STA. 08NN013 - KETTLE RIVER NEAR FERRY

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
84	362.	251.	56	.836	1.196
85	357.	251.	57	.851	1.175
86	428.	246.	58	.866	1.155
87	345.	242.	59	.881	1.136
88	311.	238.	60	.896	1.117
89	282.	218.	61	.910	1.098
90	402.	215.	62	.925	1.081
91	334.	214.	63	.940	1.063
92	215.	204.	64	.955	1.047
93	416.	193.	65	.970	1.031
94	328.	155.	66	.985	1.015

STATISTICS OF DATA SERIES

SAMPLE SIZE = 66

MEAN =	338.4394	MIN. =	155.0000	MAX. =	575.0000
S.D. =	80.5923	C.S. =	.1909	C.K. =	3.2309

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 66

MEAN =	5.7948	MIN. =	5.0434	MAX. =	6.3544
S.D. =	.2503	C.S. =	-.5370	C.K. =	3.3876

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = 7.694

BETA = 109.721

GAMMA = -505.748

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	200.174	145.096	90.017	2753.935
1.050	239.154	208.669	178.184	1524.245
1.250	292.013	269.998	247.983	1100.745
2.000	357.358	335.876	314.395	1074.083
5.000	429.751	405.385	381.018	1218.338
10.000	472.861	443.231	413.602	1481.474
20.000	512.410	475.256	438.101	1857.704
50.000	561.438	512.140	462.843	2464.878
100.000	596.740	537.232	477.723	2975.445
200.000	630.845	560.551	490.256	3514.713
500.000	674.443	589.270	504.098	4258.626
1000.000	706.497	609.719	512.941	4838.883
10000.000	808.659	671.840	535.021	6840.961

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR PEARSON III

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

A = -929.547

M = 7.143

S = .063

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	210.318	144.814	99.712	18.658
1.050	241.580	208.663	180.231	7.324
1.250	292.942	270.051	248.949	4.068
2.000	358.028	335.885	315.112	3.192
5.000	430.466	405.334	381.670	3.008
10.000	473.771	443.178	414.560	3.338
20.000	513.889	475.228	439.475	3.911
50.000	564.346	512.185	464.845	4.849
100.000	601.237	537.356	480.263	5.616
200.000	637.350	560.776	493.401	6.400
500.000	684.227	589.655	508.155	7.438
1000.000	719.220	610.245	517.782	8.215
10000.000	833.903	672.946	543.056	10.723

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = -914.360

M = 7.131

S = .064

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	209.040	144.990	100.564	18.293
1.050	241.404	208.739	180.494	7.269
1.250	292.947	270.074	248.986	4.065

2.000	357.948	335.893	315.196	3.180
5.000	430.513	405.372	381.699	3.009
10.000	473.855	443.250	414.622	3.338
20.000	513.898	475.340	439.675	3.900
50.000	564.140	512.354	465.321	4.814
100.000	600.815	537.571	480.984	5.561
200.000	636.680	561.037	494.381	6.324
500.000	683.191	589.981	509.487	7.334
1000.000	717.884	610.620	519.384	8.092
10000.000	831.441	673.494	545.551	10.534

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .016

U = 302.173

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	227.888	197.335	166.782	7.741
1.050	255.739	232.210	208.682	5.066
1.250	290.077	272.268	254.459	3.270
2.000	343.442	325.205	306.967	2.804
5.000	427.128	396.429	365.731	3.872
10.000	485.034	443.586	402.138	4.672
20.000	541.167	488.820	436.472	5.354
50.000	614.216	547.371	480.525	6.106
100.000	669.108	591.246	513.384	6.585
200.000	723.877	634.962	546.046	7.002
500.000	796.209	692.636	589.062	7.477
1000.000	850.915	736.225	621.534	7.789
10000.000	1032.689	880.947	729.206	8.612

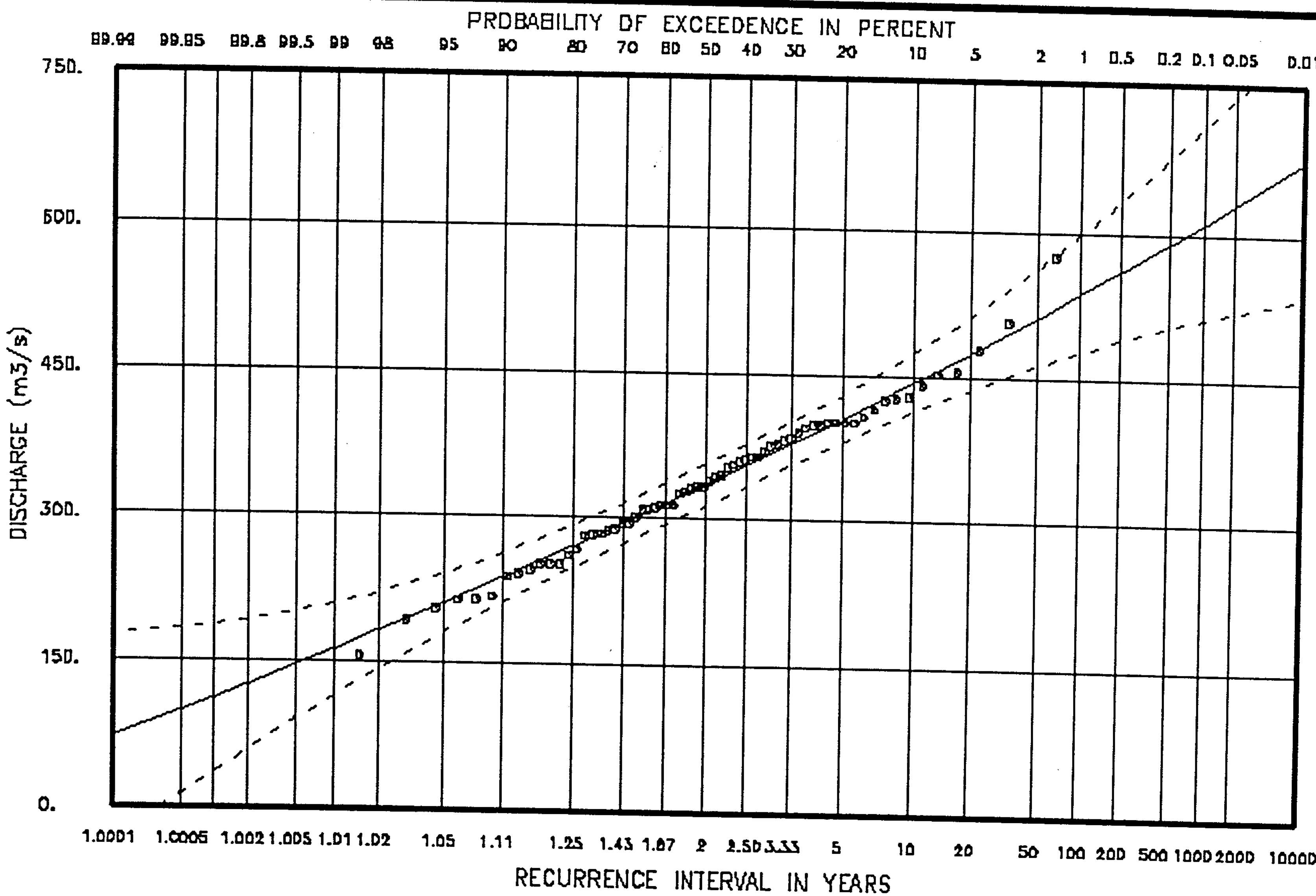
GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .013

U = 298.997

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	199.126	173.263	147.400	7.463
1.050	236.161	215.089	194.018	4.898
1.250	281.701	263.132	244.562	3.529
2.000	348.405	326.619	304.833	3.335
5.000	445.475	412.040	378.605	4.057

10.000	511.487	468.596	425.705	4.577
20.000	575.320	522.846	470.373	5.018
50.000	658.323	593.067	527.811	5.502
100.000	720.682	645.688	570.694	5.807
200.000	782.898	698.117	613.335	6.072
500.000	865.067	767.286	669.506	6.372
1000.000	927.213	819.563	711.914	6.567
10000.000	1133.716	993.132	852.548	7.078

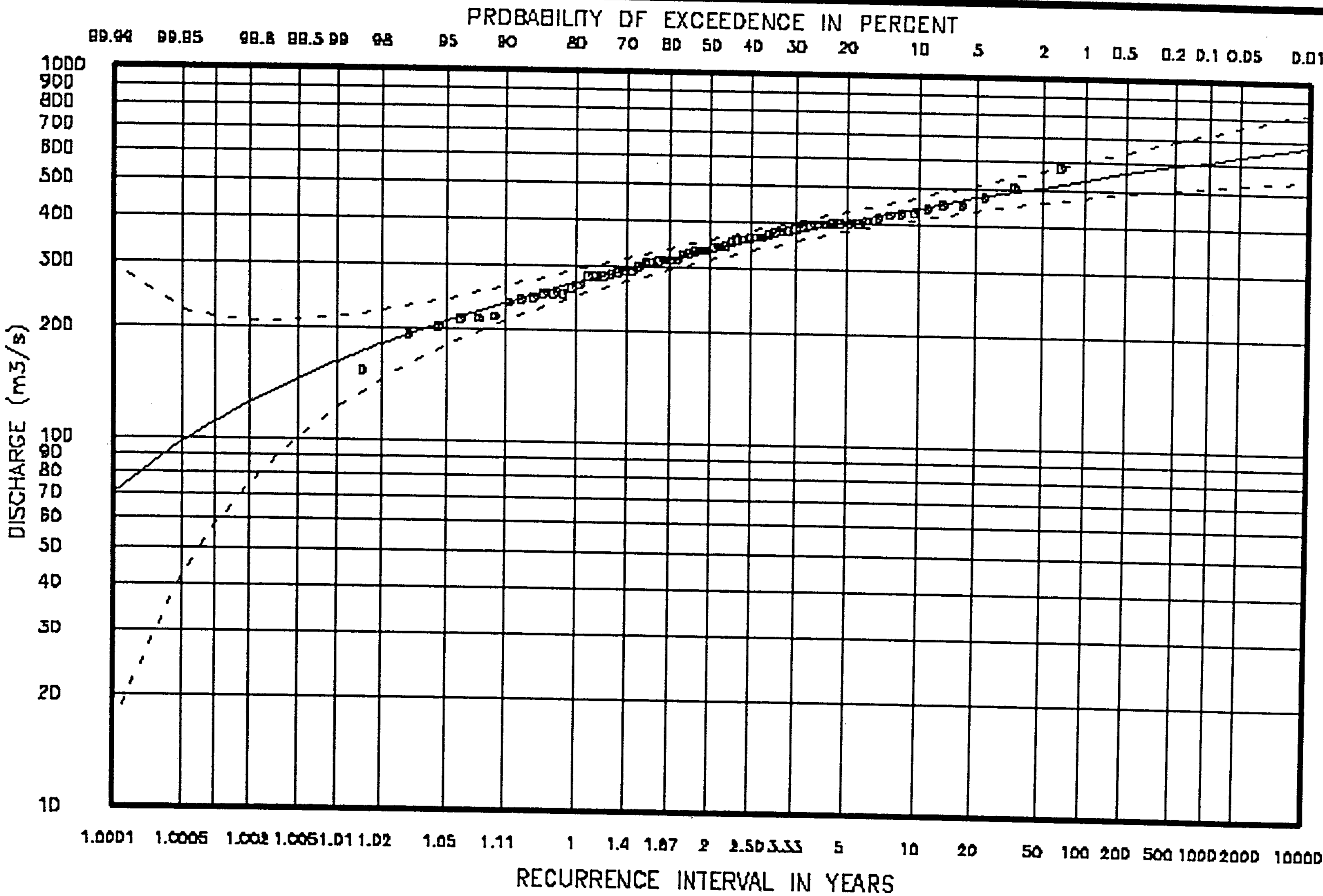


STA. 08NN013 – KETTLE RIVER NEAR FERRY

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

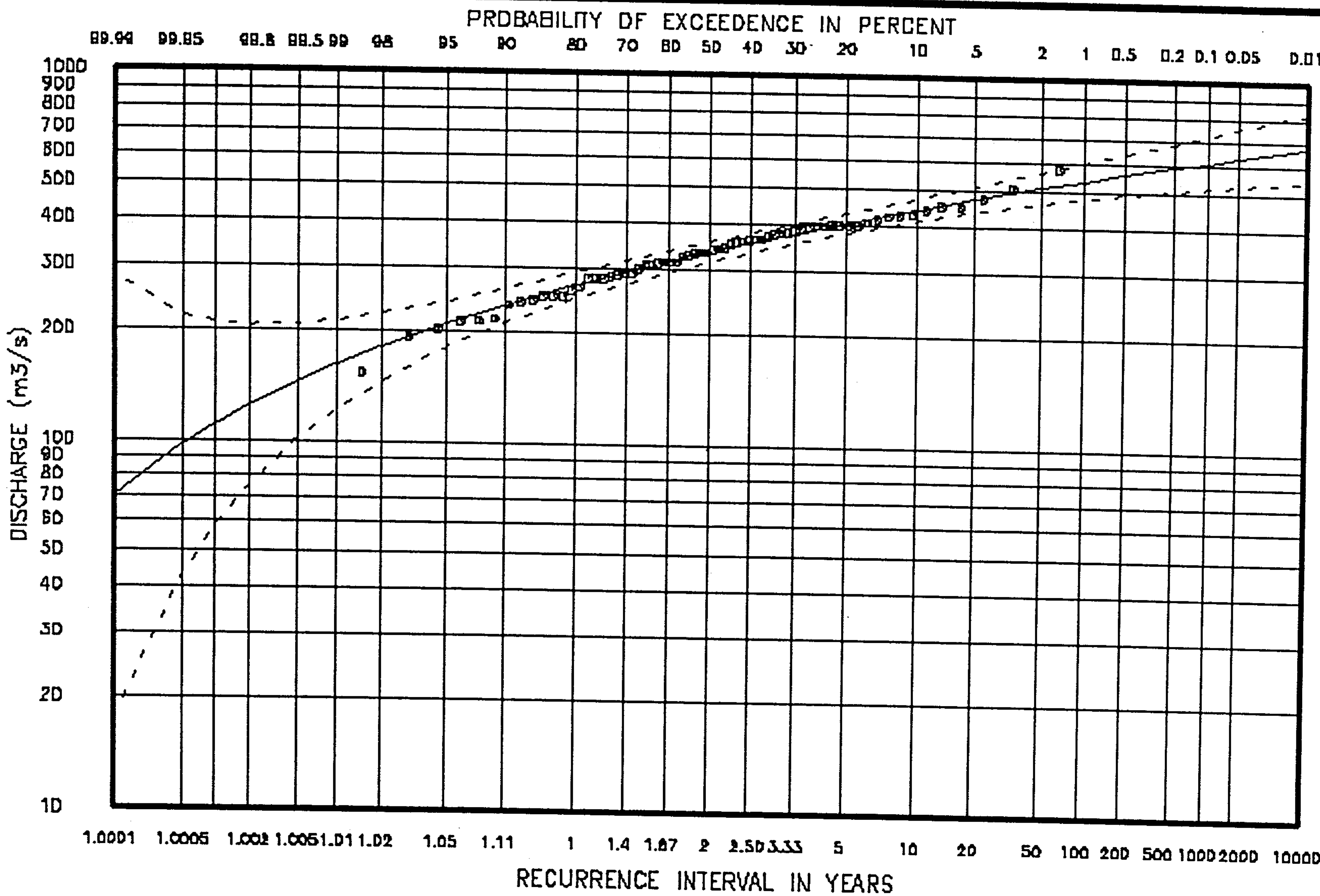


STA. 08NN013 – KETTLE RIVER NEAR FERRY

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

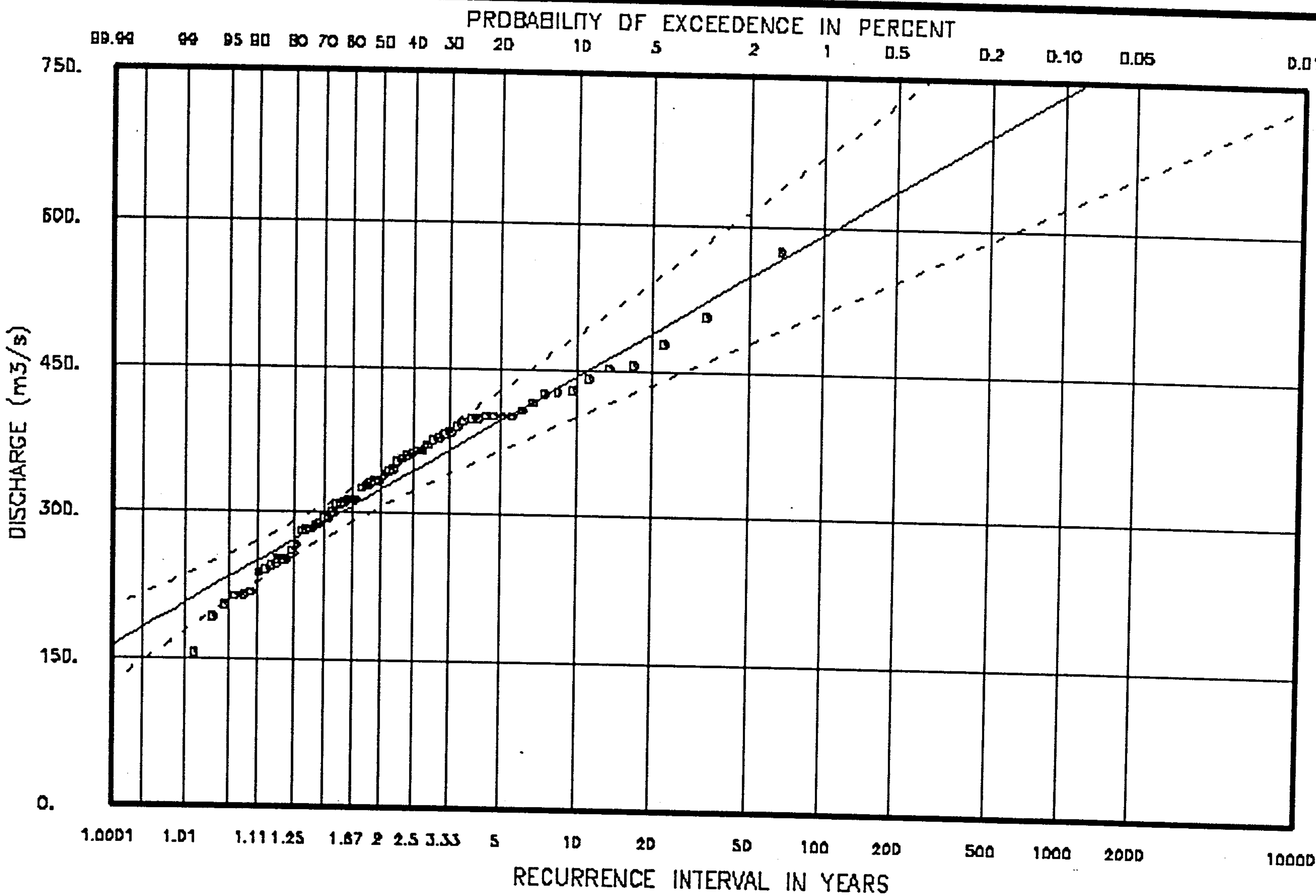


STA. 08NN013 — KETTLE RIVER NEAR FERRY

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

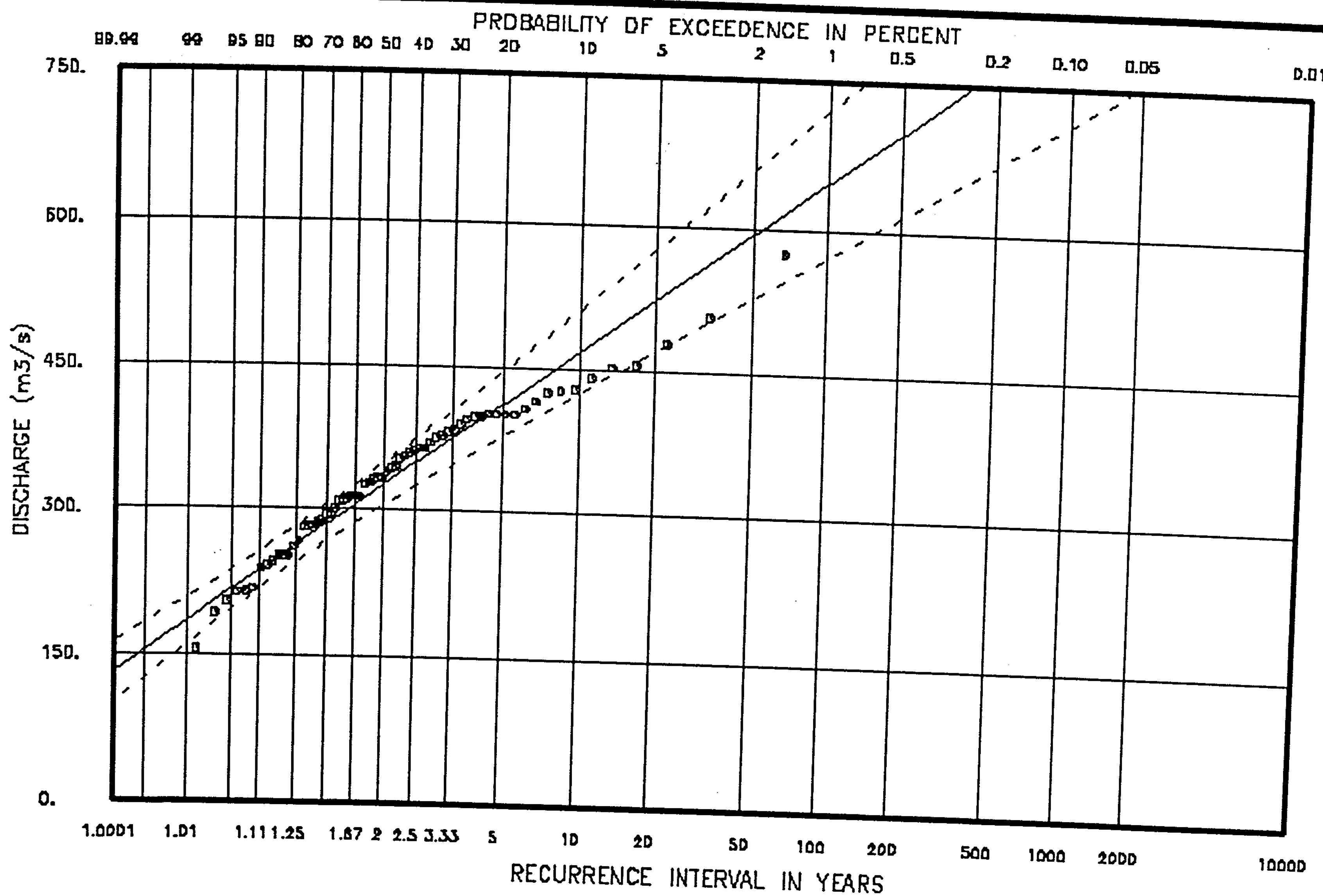


STA. 08NN013 — KETTLE RIVER NEAR FERRY

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN013 – KETTLE RIVER NEAR FERRY

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A3 -
Kettle River Near Westbridge - Daily

STA. 08NN026 - KETTLE RIVER NEAR WESTBRIDGE

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
79	199.	309.	1	.056	18.000
80	250.	291.	2	.111	9.000
81	247.	273.	3	.167	6.000
82	228.	259.	4	.222	4.500
83	259.	250.	5	.278	3.600
84	235.	247.	6	.333	3.000
85	273.	245.	7	.389	2.571
86	291.	235.	8	.444	2.250
87	229.	229.	9	.500	2.000
88	204.	228.	10	.556	1.800
89	196.	225.	11	.611	1.636
90	245.	208.	12	.667	1.500
91	225.	204.	13	.722	1.385
92	181.	199.	14	.778	1.286
93	309.	196.	15	.833	1.200
94	208.	187.	16	.889	1.125
95	187.	181.	17	.944	1.059

STATISTICS OF DATA SERIES

SAMPLE SIZE = 17

MEAN =	233.2941	MIN. =	181.0000	MAX. =	309.0000
S.D. =	36.1970	C.S. =	.5047	C.K. =	2.9960

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 17

MEAN =	5.4412	MIN. =	5.1985	MAX. =	5.7333
S.D. =	.1529	C.S. =	.2112	C.K. =	2.6928

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = 9.135

BETA = 15.701

GAMMA = 89.865

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	203.971	156.903	109.835	2220.182
1.050	203.302	178.741	154.181	1158.506
1.250	221.065	202.332	183.599	883.632
2.000	250.725	230.270	209.815	964.856
5.000	287.080	262.491	237.901	1159.895
10.000	312.554	281.157	249.761	1480.952
20.000	338.594	297.546	256.497	1936.249
50.000	373.612	317.075	260.538	2666.840
100.000	400.306	330.749	261.193	3280.965
200.000	427.078	343.734	260.389	3931.344
500.000	462.539	360.082	257.626	4832.863
1000.000	489.407	371.959	254.511	5540.000
10000.000	578.957	409.205	239.454	8007.144

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR PEARSON III

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

A = 16.158

M = 5.367

S = .166

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	207.469	155.930	117.194	13.471
1.050	205.385	178.636	155.370	6.582
1.250	222.019	202.486	184.671	4.344
2.000	251.472	230.338	210.980	4.141
5.000	288.073	262.355	238.932	4.411
10.000	314.025	280.970	251.396	5.246
20.000	341.616	297.396	258.900	6.539
50.000	380.807	317.098	264.048	8.636
100.000	412.385	330.991	265.662	10.371
200.000	445.598	344.266	265.977	12.170
500.000	492.067	361.103	264.995	14.597
1000.000	529.238	373.426	263.487	16.449
10000.000	666.250	412.612	255.532	22.602

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = 121.825

M = 4.664

S = .330

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	195.354	167.150	143.018	7.355
1.050	201.328	182.986	166.316	4.506
1.250	218.892	202.158	186.703	3.751

2.000	247.938	227.832	209.356	3.989
5.000	290.818	261.712	235.519	4.974
10.000	324.218	283.557	247.996	6.321
20.000	360.692	304.141	256.456	8.044
50.000	414.201	330.449	263.632	10.656
100.000	458.941	350.060	267.011	12.774
200.000	507.611	369.618	269.138	14.964
500.000	578.435	395.575	270.523	17.924
1000.000	637.299	415.388	270.748	20.190
10000.000	870.013	482.967	268.107	27.762

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .035

U = 217.005

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	198.580	169.919	141.258	7.956
1.050	207.654	185.583	163.511	5.610
1.250	220.280	203.574	186.868	3.871
2.000	244.458	227.350	210.242	3.549
5.000	288.137	259.339	230.542	5.238
10.000	319.400	280.519	241.638	6.538
20.000	349.941	300.836	251.730	7.700
50.000	389.838	327.133	264.428	9.042
100.000	419.879	346.839	273.799	9.933
200.000	449.881	366.473	283.065	10.736
500.000	489.536	392.377	295.218	11.680
1000.000	519.541	411.954	304.367	12.319
10000.000	619.298	476.954	334.611	14.077

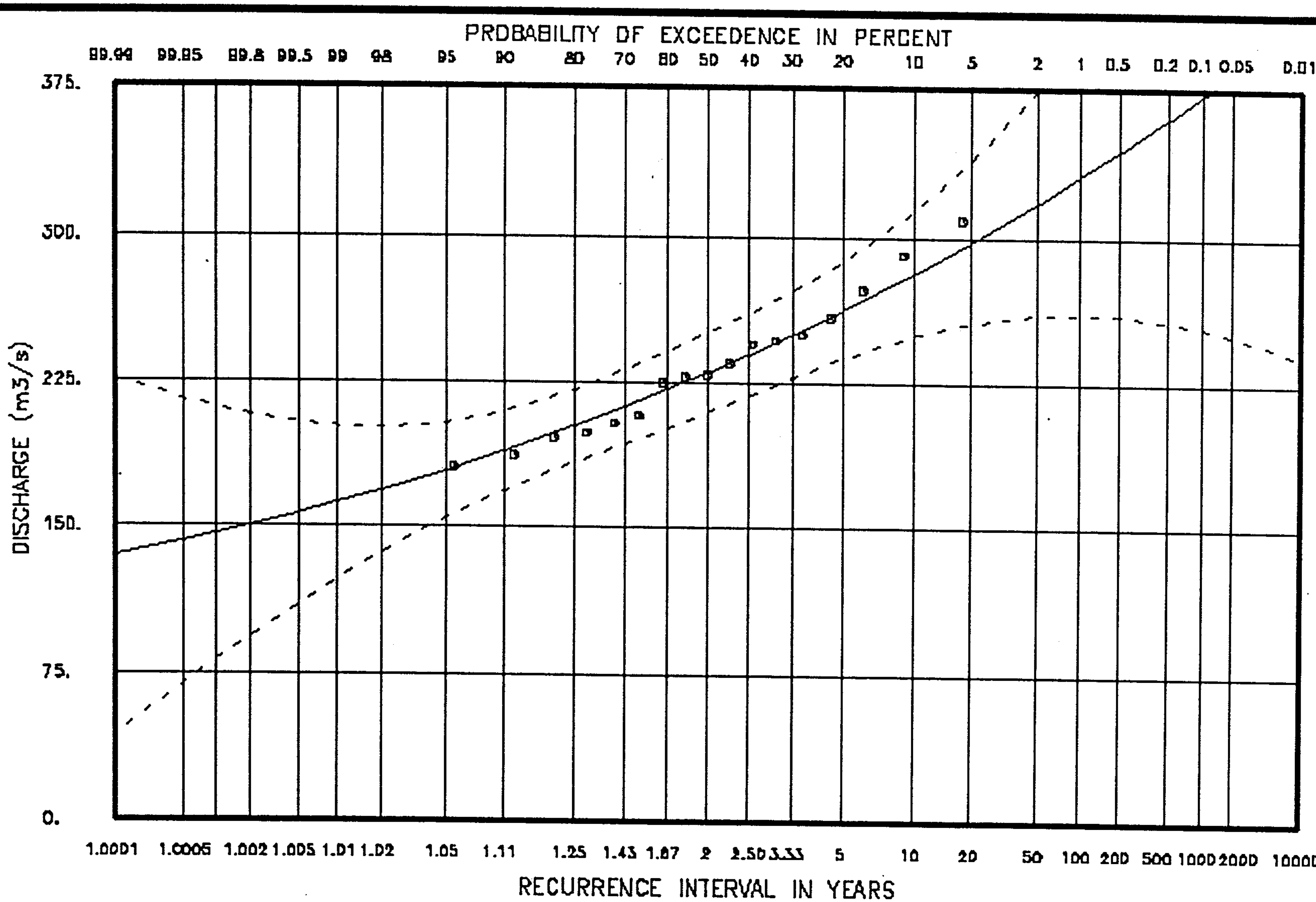
GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .034

U = 216.568

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	188.713	167.734	146.754	5.900
1.050	201.072	183.979	166.885	4.383
1.250	217.701	202.638	187.574	3.506
2.000	244.968	227.296	209.623	3.667
5.000	287.595	260.473	233.350	4.912

10.000	317.231	282.438	247.645	5.811
20.000	346.075	303.509	260.943	6.615
50.000	383.717	330.782	277.847	7.549
100.000	412.054	351.219	290.385	8.170
200.000	440.356	371.582	302.808	8.730
500.000	477.765	398.447	319.129	9.390
1000.000	506.075	418.751	331.427	9.837
10000.000	600.204	486.164	372.123	11.065

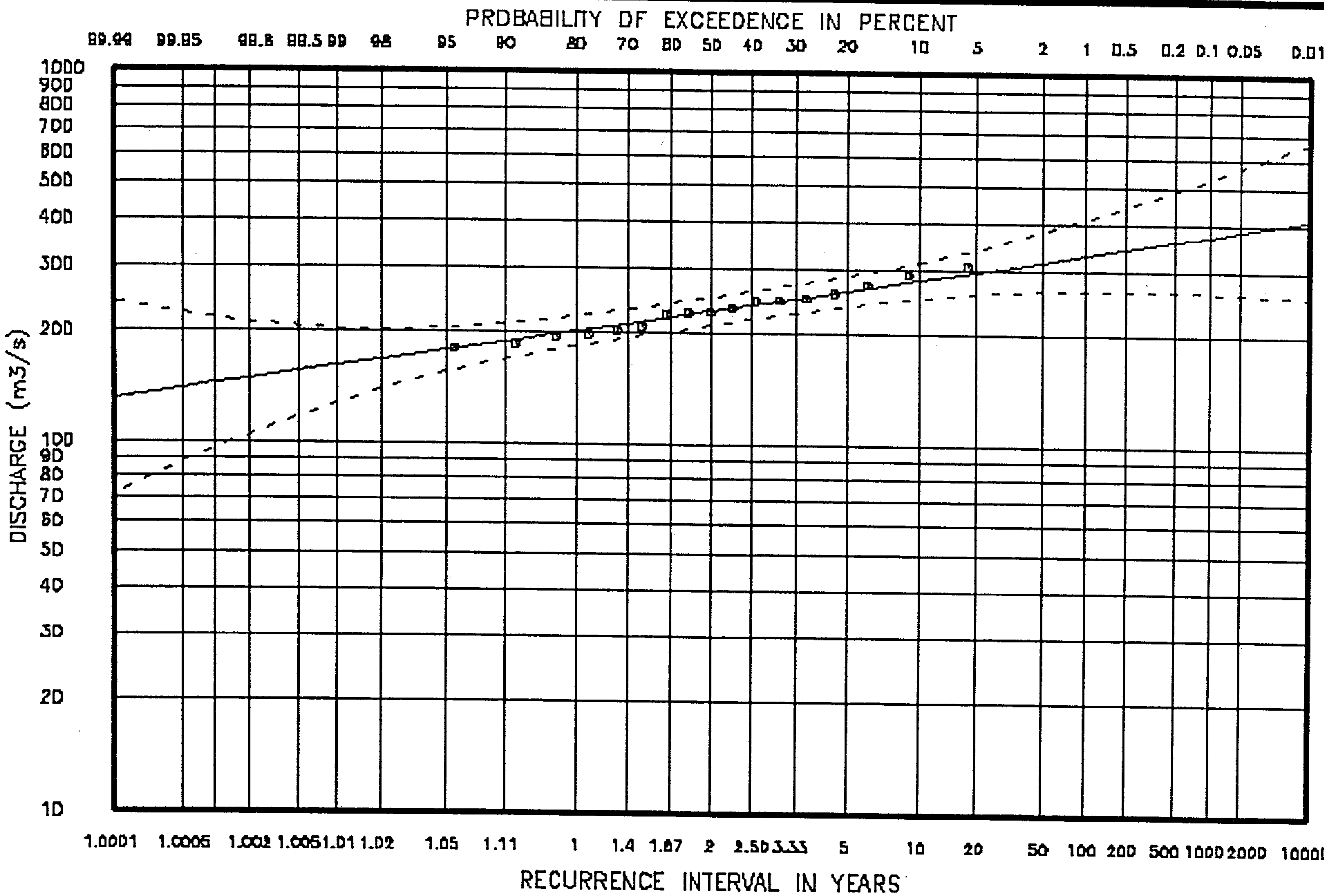


STA. 08NN026 – KETTLE RIVER NEAR WESTBRIDGE

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

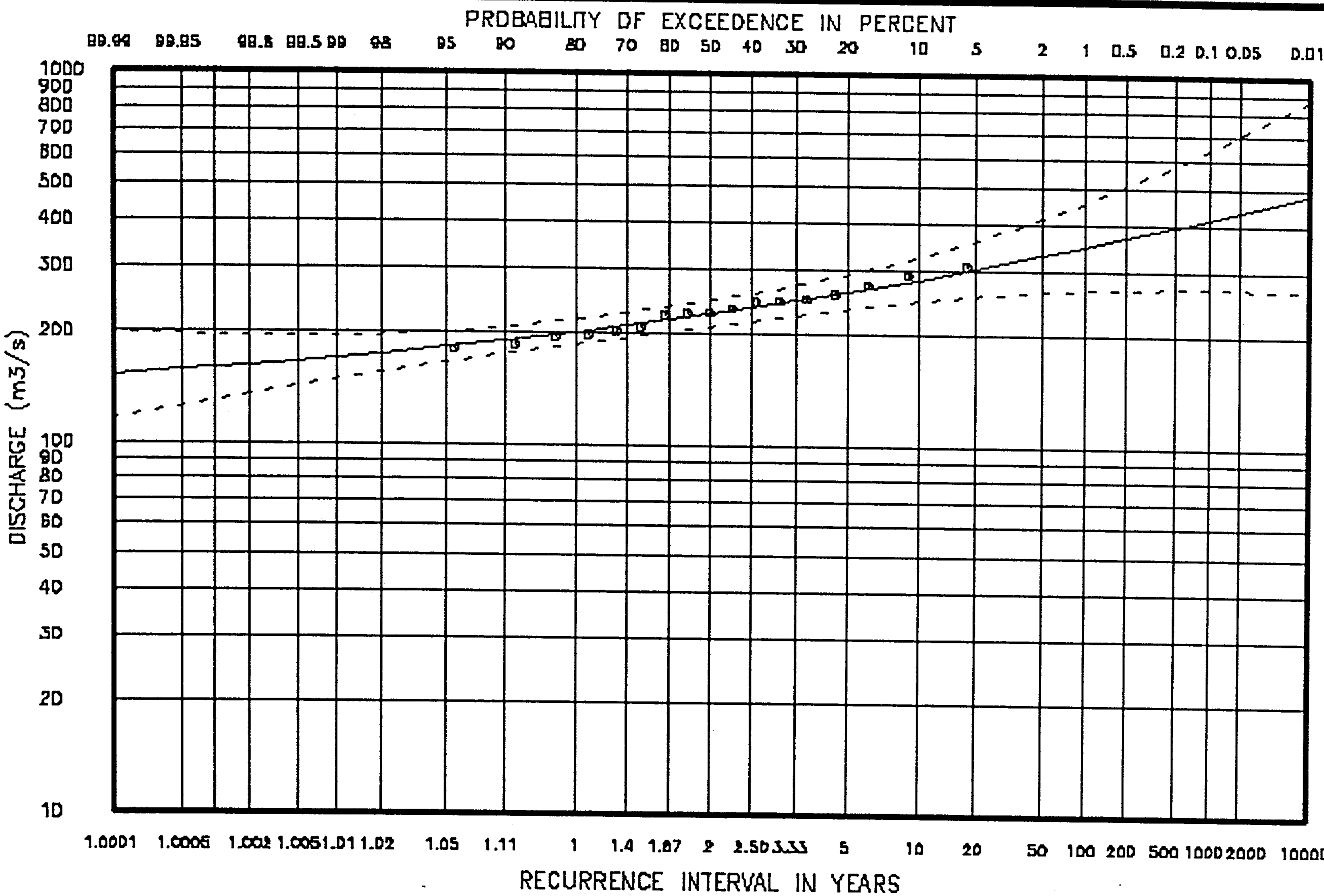


STA. 08NN026 – KETTLE RIVER NEAR WESTBRIDGE

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

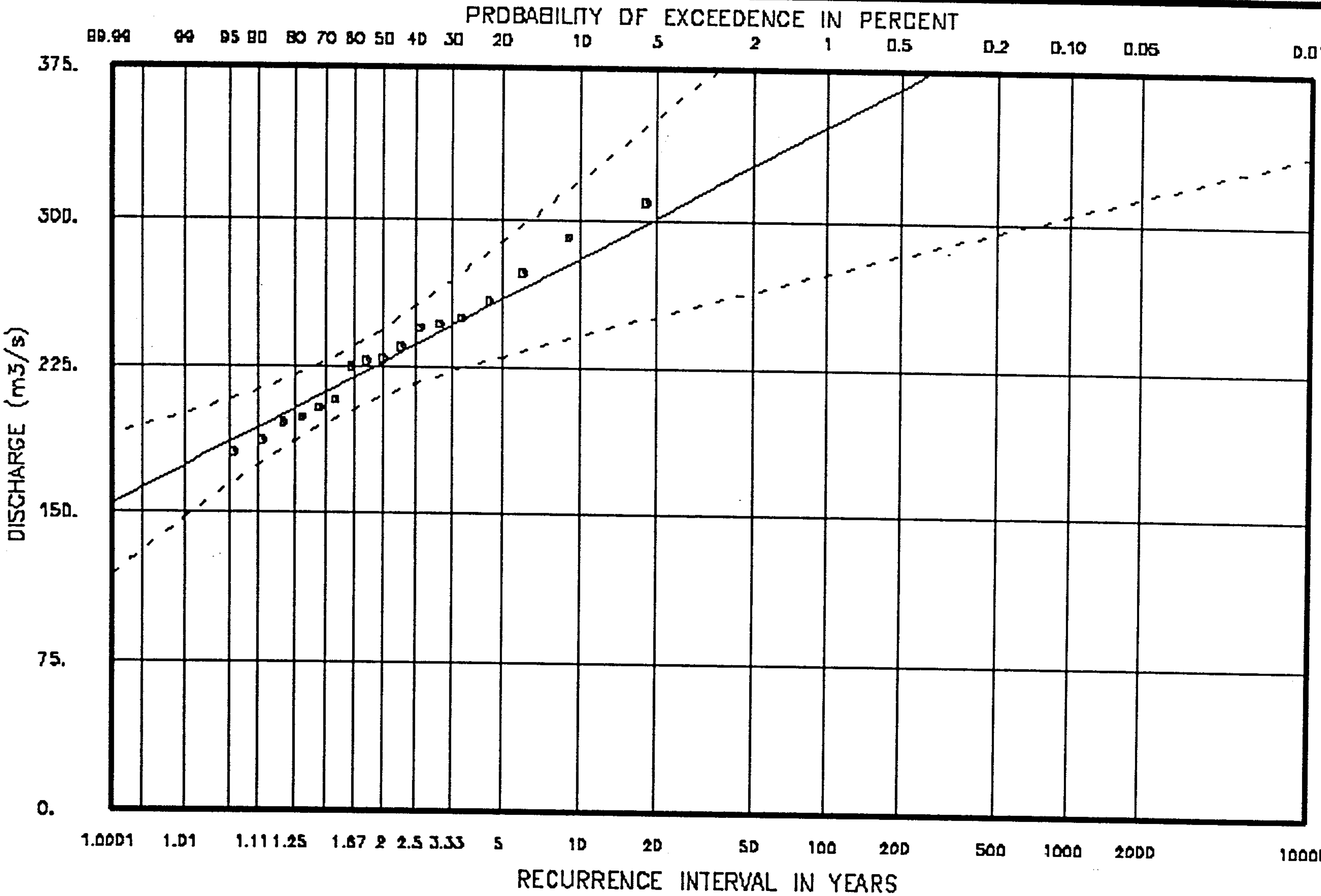


STA. 08NN026 – KETTLE RIVER NEAR WESTBRIDGE

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

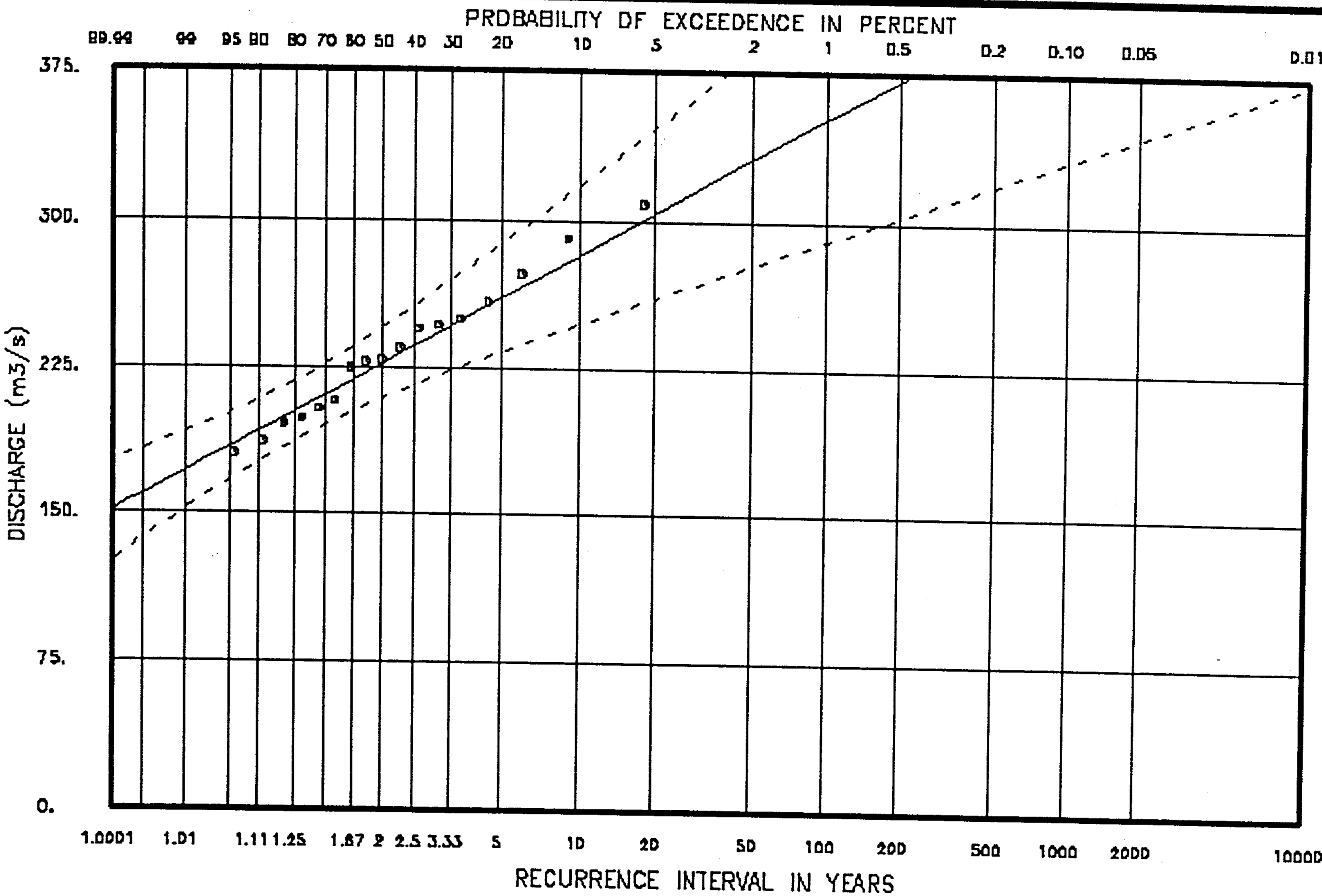


STA. 08NN026 – KETTLE RIVER NEAR WESTBRIDGE

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN026 – KETTLE RIVER NEAR WESTBRIDGE

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A4 -
West Kettle River Near Westbridge - Daily

STA. 08NN003 - WEST KETTLE RIVER AT WESTBRIDGE

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
17	85.	164.	1	.045	22.000
18	62.	162.	2	.091	11.000
19	85.	161.	3	.136	7.333
21	135.	154.	4	.182	5.500
79	111.	137.	5	.227	4.400
80	118.	135.	6	.273	3.667
81	110.	134.	7	.318	3.143
82	120.	133.	8	.364	2.750
83	164.	120.	9	.409	2.444
84	133.	118.	10	.455	2.200
85	112.	113.	11	.500	2.000
86	154.	112.	12	.545	1.833
87	162.	111.	13	.591	1.692
88	93.	110.	14	.636	1.571
89	80.	109.	15	.682	1.467
90	161.	93.	16	.727	1.375
91	113.	85.	17	.773	1.294
92	52.	85.	18	.818	1.222
93	137.	80.	19	.864	1.158
94	134.	62.	20	.909	1.100
95	109.	52.	21	.955	1.048

STATISTICS OF DATA SERIES

SAMPLE SIZE = 21

MEAN =	115.7619	MIN. =	52.2000	MAX. =	164.0000
S.D. =	31.7281	C.S. =	-.2379	C.K. =	2.7269

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 21

MEAN =	4.7103	MIN. =	3.9551	MAX. =	5.0999
S.D. =	.3069	C.S. =	-.9071	C.K. =	3.7327

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = -3.773

BETA = 70.700

GAMMA = 382.543

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	79.876	26.850	-26.176	2541.991
1.050	88.858	60.663	32.468	1351.637
1.250	107.447	89.505	71.563	860.097
2.000	132.676	117.017	101.359	750.644
5.000	158.560	142.752	126.944	757.822
10.000	173.298	155.529	137.759	851.858
20.000	187.062	165.728	144.394	1022.726
50.000	204.534	176.833	149.133	1327.932
100.000	217.273	184.021	150.768	1594.078
200.000	229.619	190.449	151.280	1877.750
500.000	245.381	198.051	150.722	2268.907
1000.000	256.920	203.262	149.604	2572.276
10000.000	293.251	218.133	143.014	3601.094

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

ALPHA = -45.840

BETA = 1.055

GAMMA = 164.142

MEAN = 115.762

S.D. = 47.093

C.S. = -1.947

RETURN PERIOD	UPPER CONFIDENCE	FLOOD ESTIMATE	LOWER CONFIDENCE	STANDARD ERROR

	LIMIT		LIMIT	PERCENT
1.005	27.046	-86.869	-200.783	5460.909
1.050	85.126	20.828	-43.469	3082.324
1.250	121.291	87.103	52.916	1638.913
2.000	144.966	129.489	114.013	741.915
5.000	158.606	152.516	146.427	291.926
10.000	162.668	158.830	154.992	184.012
20.000	164.576	161.868	159.159	129.852
50.000	165.205	163.567	161.929	78.520
100.000	164.779	164.010	163.241	36.851
200.000	166.218	164.132	162.046	100.000
500.000	166.231	164.145	162.059	100.000
1000.000	164.681	164.203	163.725	22.901
10000.000	168.846	165.611	162.376	155.082

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

NO MOMENT SOLUTION FOR THREE PARAMETER LOGNORMAL

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .040

U = 101.484

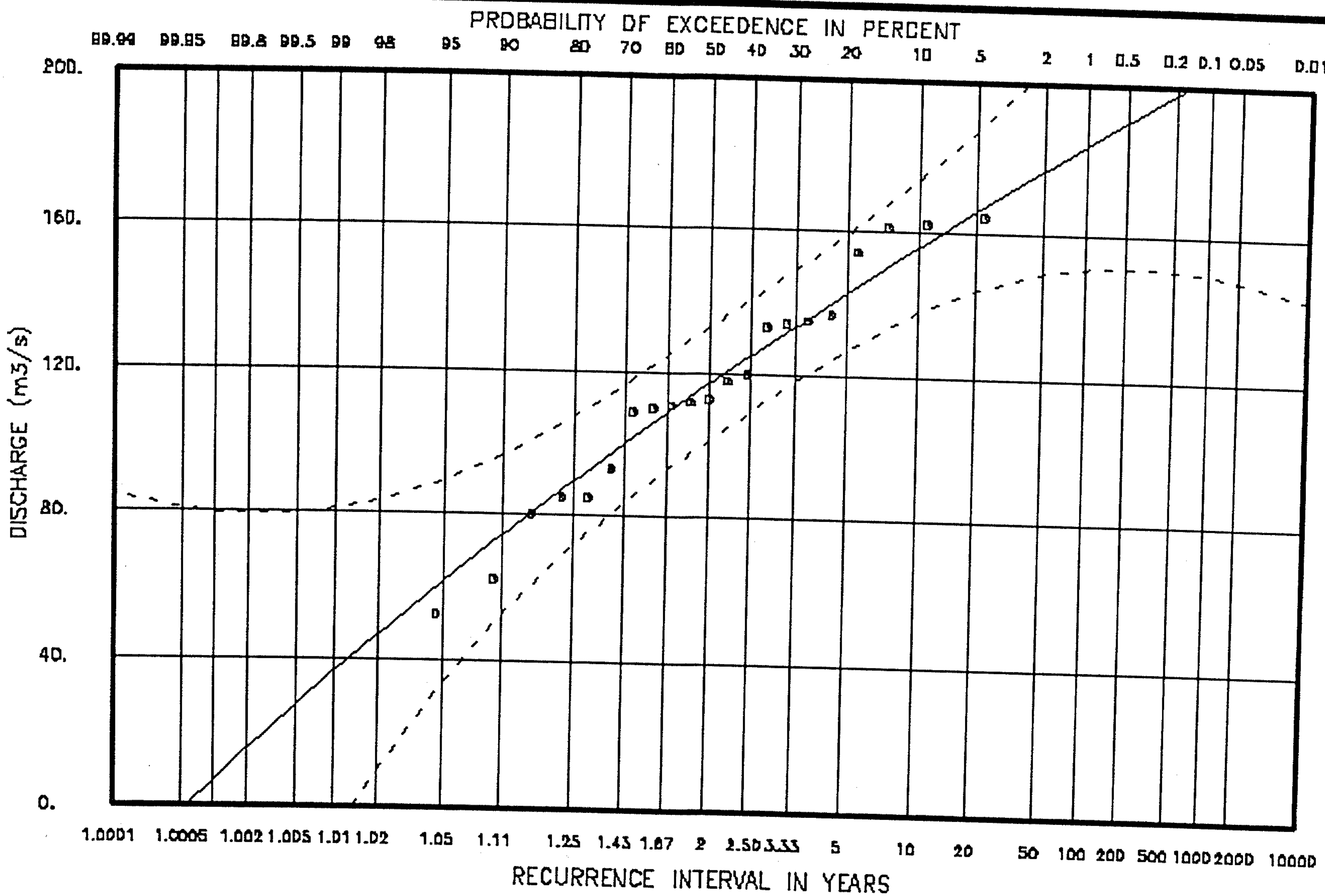
RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	82.452	60.211	37.970	17.708
1.050	91.068	73.941	56.813	11.104
1.250	102.675	89.711	76.747	6.928
2.000	123.827	110.552	97.276	5.757
5.000	160.939	138.592	116.245	7.730
10.000	187.329	157.157	126.985	9.204
20.000	213.071	174.965	136.859	10.441
50.000	246.675	198.015	149.356	11.780
100.000	271.968	215.289	158.609	12.621
200.000	297.224	232.499	167.773	13.346
500.000	330.600	255.205	179.809	14.163
1000.000	355.853	272.365	188.876	14.695
10000.000	439.800	329.340	218.881	16.078

GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .033

U = 99.988

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	68.262	48.789	29.316	19.134
1.050	81.687	65.821	49.955	11.555
1.250	99.366	85.384	71.402	7.850
2.000	127.640	111.236	94.833	7.069
5.000	171.195	146.020	120.846	8.265
10.000	201.344	169.050	136.756	9.158
20.000	230.650	191.141	151.632	9.909
50.000	268.868	219.735	170.602	10.719
100.000	297.628	241.162	184.696	11.224
200.000	326.347	262.512	198.676	11.657
500.000	364.300	290.678	217.056	12.142
1000.000	393.018	311.965	230.912	12.455
10000.000	488.494	382.643	276.792	13.261

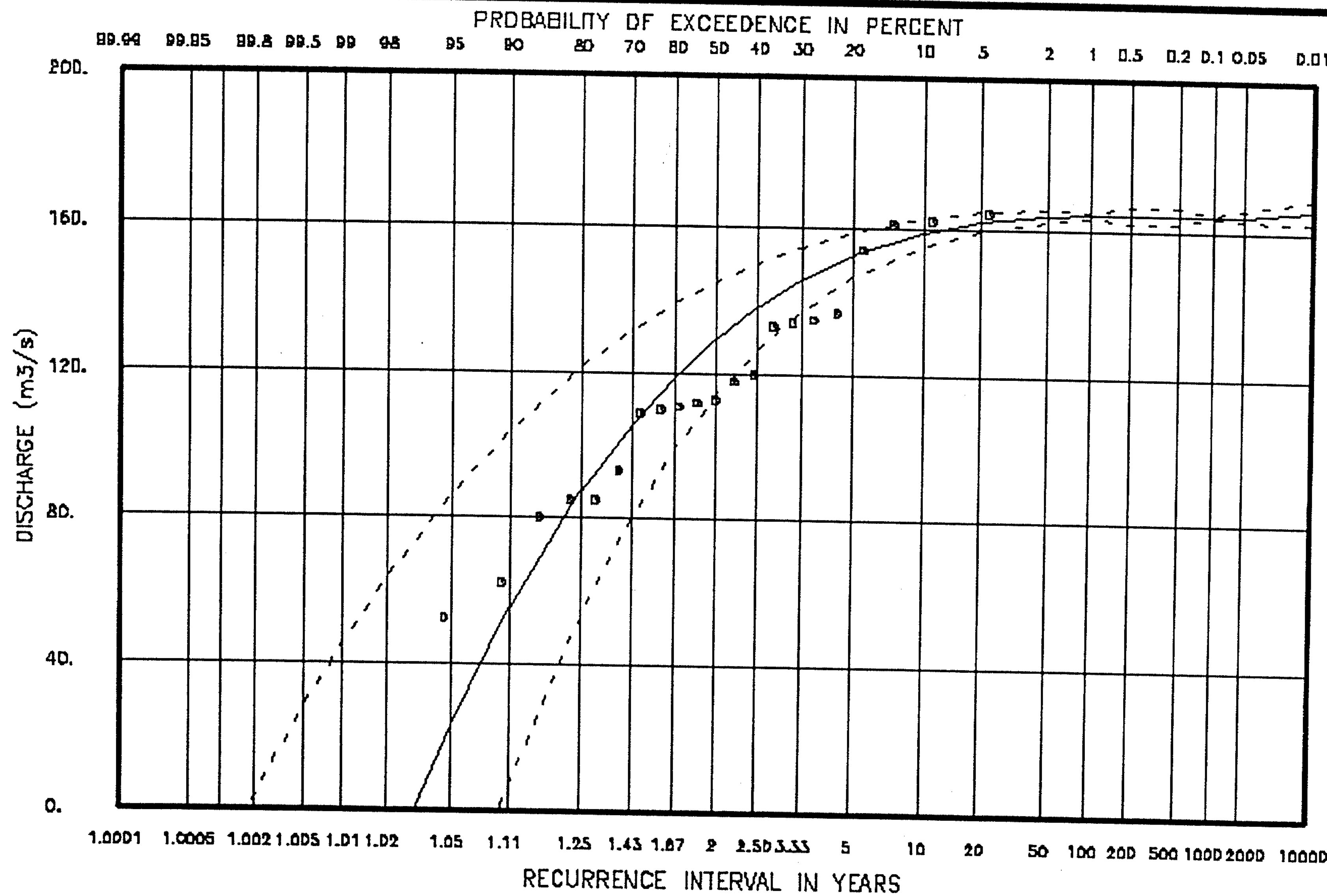


STA. 08NN003 – WEST KETTLE RIVER AT WESTBRIDGE

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

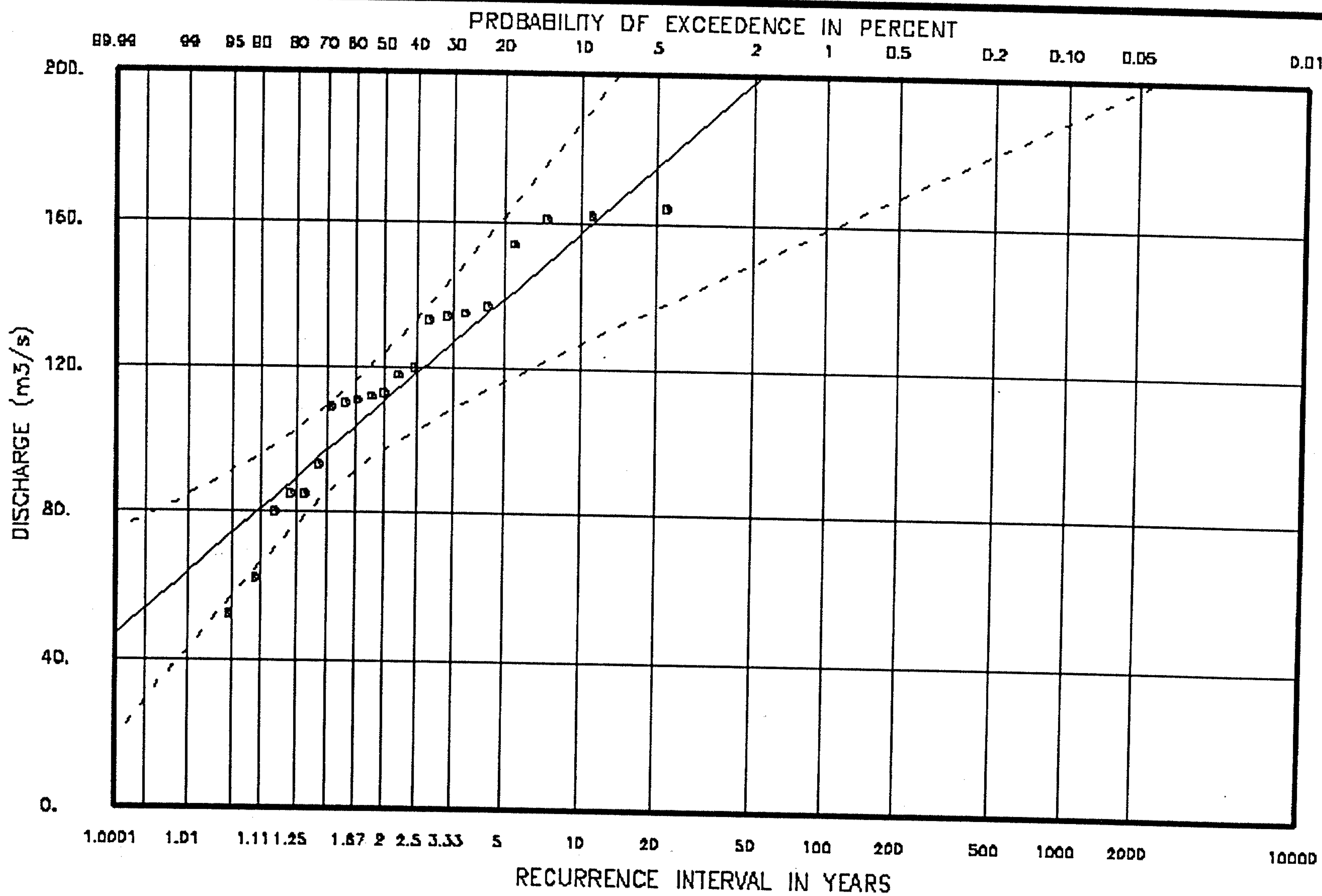


STA. 08NN003 – WEST KETTLE RIVER AT WESTBRIDGE

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

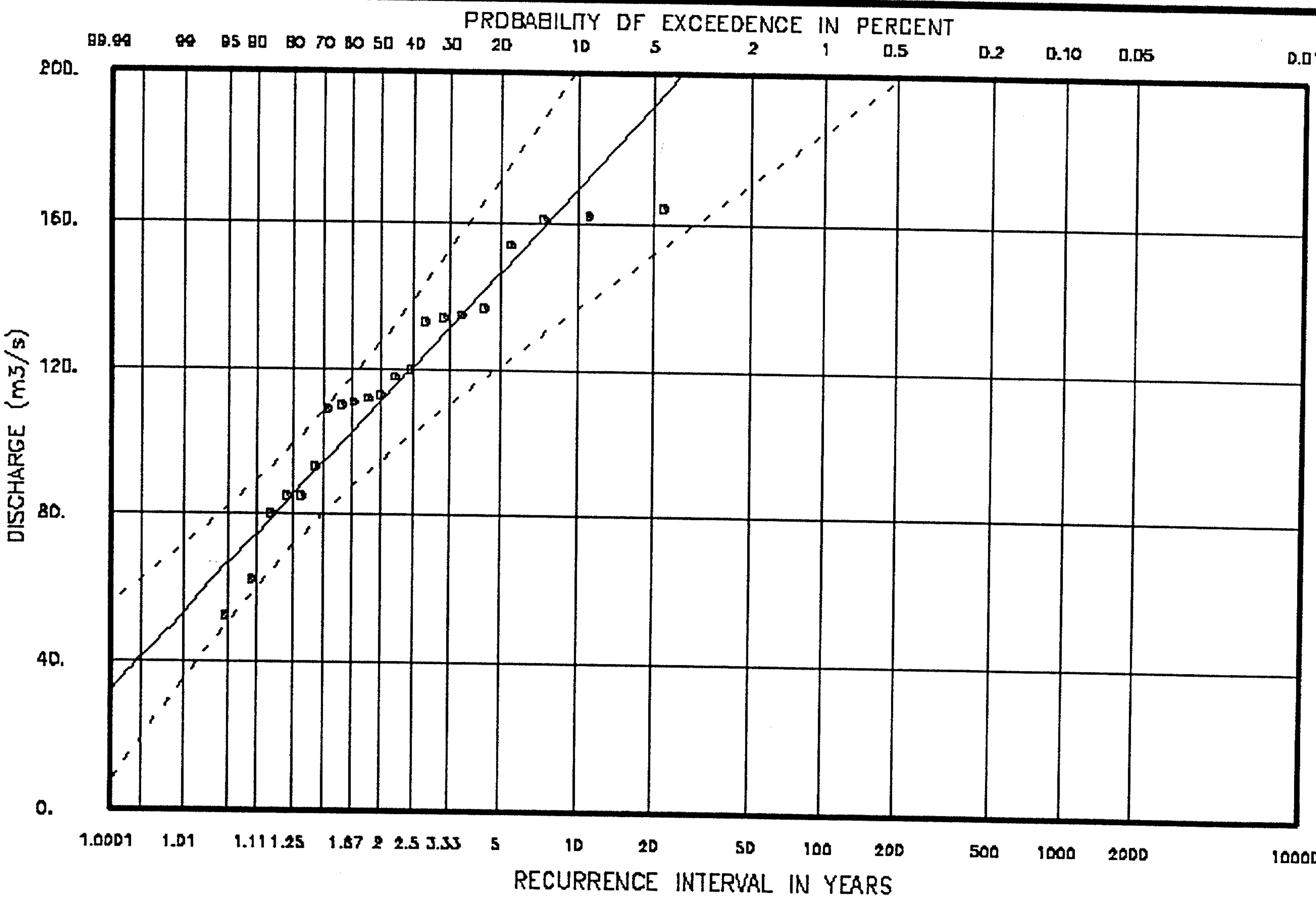


STA. 08NN003 – WEST KETTLE RIVER AT WESTBRIDGE

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN003 — WEST KETTLE RIVER AT WESTBRIDGE

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A5 -
West Kettle River Below Carmi Creek - Instantaneous

STA. 08NN022 - WEST KETTLE RIVER BELOW CARMI CREEK

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
75	111.	150.	1	.048	21.000
76	113.	146.	2	.095	10.500
77	86.	131.	3	.143	7.000
78	88.	118.	4	.190	5.250
79	96.	116.	5	.238	4.200
80	118.	113.	6	.286	3.500
81	150.	112.	7	.333	3.000
83	112.	111.	8	.381	2.625
84	110.	110.	9	.429	2.333
85	98.	108.	10	.476	2.100
86	131.	103.	11	.524	1.909
87	146.	98.	12	.571	1.750
88	93.	98.	13	.619	1.615
89	75.	96.	14	.667	1.500
90	108.	93.	15	.714	1.400
91	103.	88.	16	.762	1.313
92	46.	86.	17	.810	1.235
93	116.	81.	18	.857	1.167
94	98.	75.	19	.905	1.105
95	81.	46.	20	.952	1.050

STATISTICS OF DATA SERIES

SAMPLE SIZE = 20

MEAN =	103.9100	MIN. =	45.9000	MAX. =	150.0000
S.D. =	23.8372	C.S. =	-.1933	C.K. =	4.2005

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 20

MEAN =	4.6148	MIN. =	3.8265	MAX. =	5.0106
S.D. =	.2580	C.S. =	-1.3414	C.K. =	6.5898

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = -2.303

BETA = 107.096

GAMMA = 350.595

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	77.752	38.115	-1.523	1893.811
1.050	84.059	62.807	41.555	1015.401
1.250	97.822	84.113	70.404	654.991
2.000	116.756	104.677	92.597	577.143
5.000	136.525	124.155	111.785	591.037
10.000	147.947	133.924	119.901	669.991
20.000	158.655	141.773	124.891	806.595
50.000	172.280	150.376	128.473	1046.501
100.000	182.237	155.977	129.717	1254.664
200.000	191.910	161.010	130.110	1476.354
500.000	204.293	166.992	129.690	1782.209
1000.000	213.383	171.111	128.839	2019.698
10000.000	242.139	182.962	123.784	2827.413

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR PEARSON III

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

NO MOMENT SOLUTION FOR THREE PARAMETER LOGNORMAL

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .054

U = 93.183

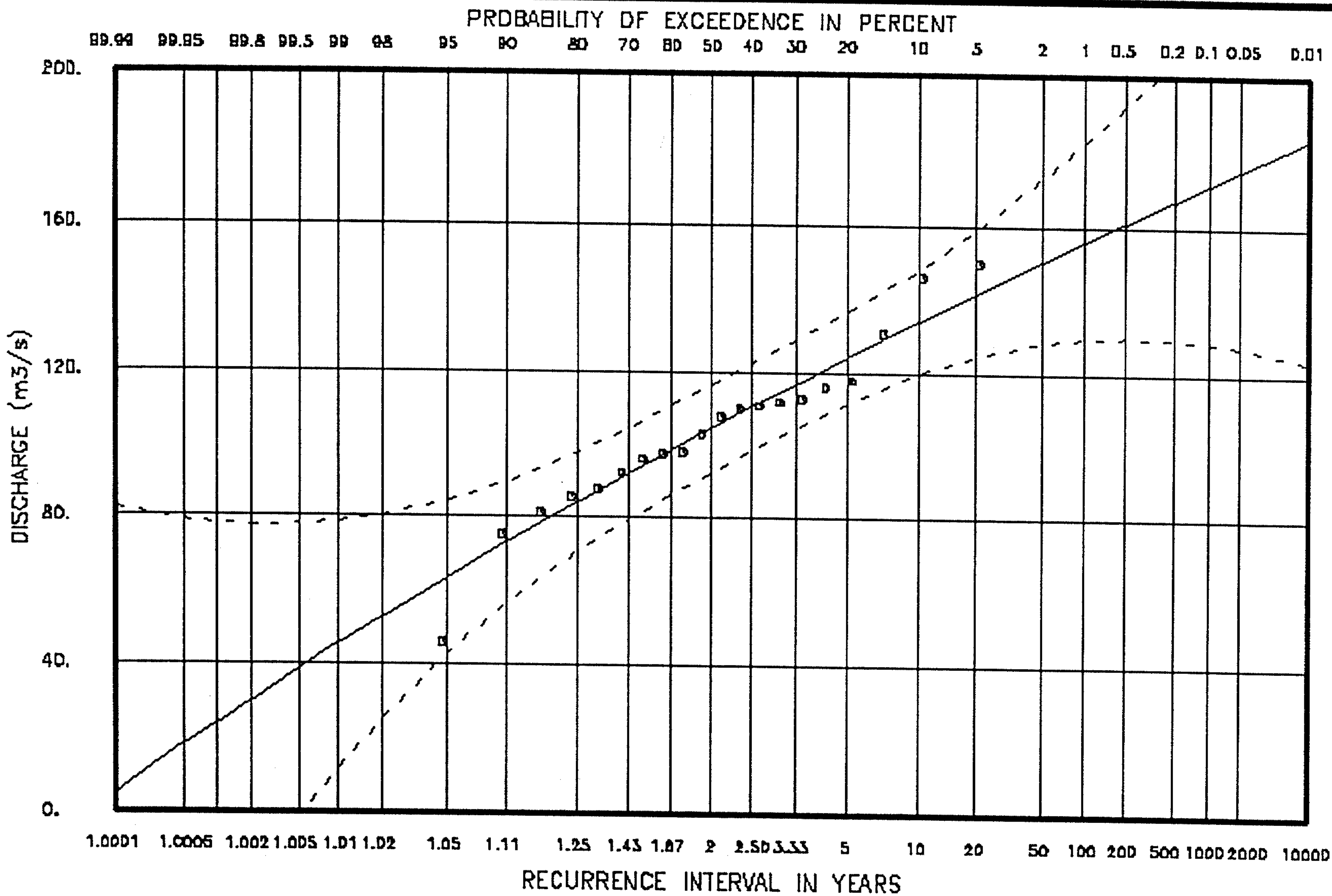
RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	79.354	62.175	44.995	13.202
1.050	85.720	72.490	59.260	8.720
1.250	94.352	84.338	74.324	5.673
2.000	110.250	99.995	89.741	4.900
5.000	138.323	121.062	103.801	6.812
10.000	158.316	135.010	111.704	8.248
20.000	177.823	148.389	118.954	9.477
50.000	203.293	165.707	128.121	10.837
100.000	222.465	178.684	134.903	11.707
200.000	241.610	191.614	141.618	12.466
500.000	266.911	208.673	150.434	13.334
1000.000	286.054	221.565	157.076	13.906
10000.000	349.693	264.371	179.048	15.420

GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .040

U = 92.051

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	66.864	50.690	34.516	15.245
1.050	77.627	64.449	51.271	9.769
1.250	91.866	80.253	68.640	6.914
2.000	114.762	101.138	87.514	6.436
5.000	150.147	129.238	108.328	7.730
10.000	174.665	147.842	121.019	8.668
20.000	198.504	165.688	132.873	9.463
50.000	229.597	188.788	147.979	10.328
100.000	252.998	206.098	159.199	10.872
200.000	276.365	223.345	170.325	11.342
500.000	307.248	246.099	184.950	11.872
1000.000	330.617	263.296	195.975	12.216
10000.000	408.310	320.393	232.476	13.111

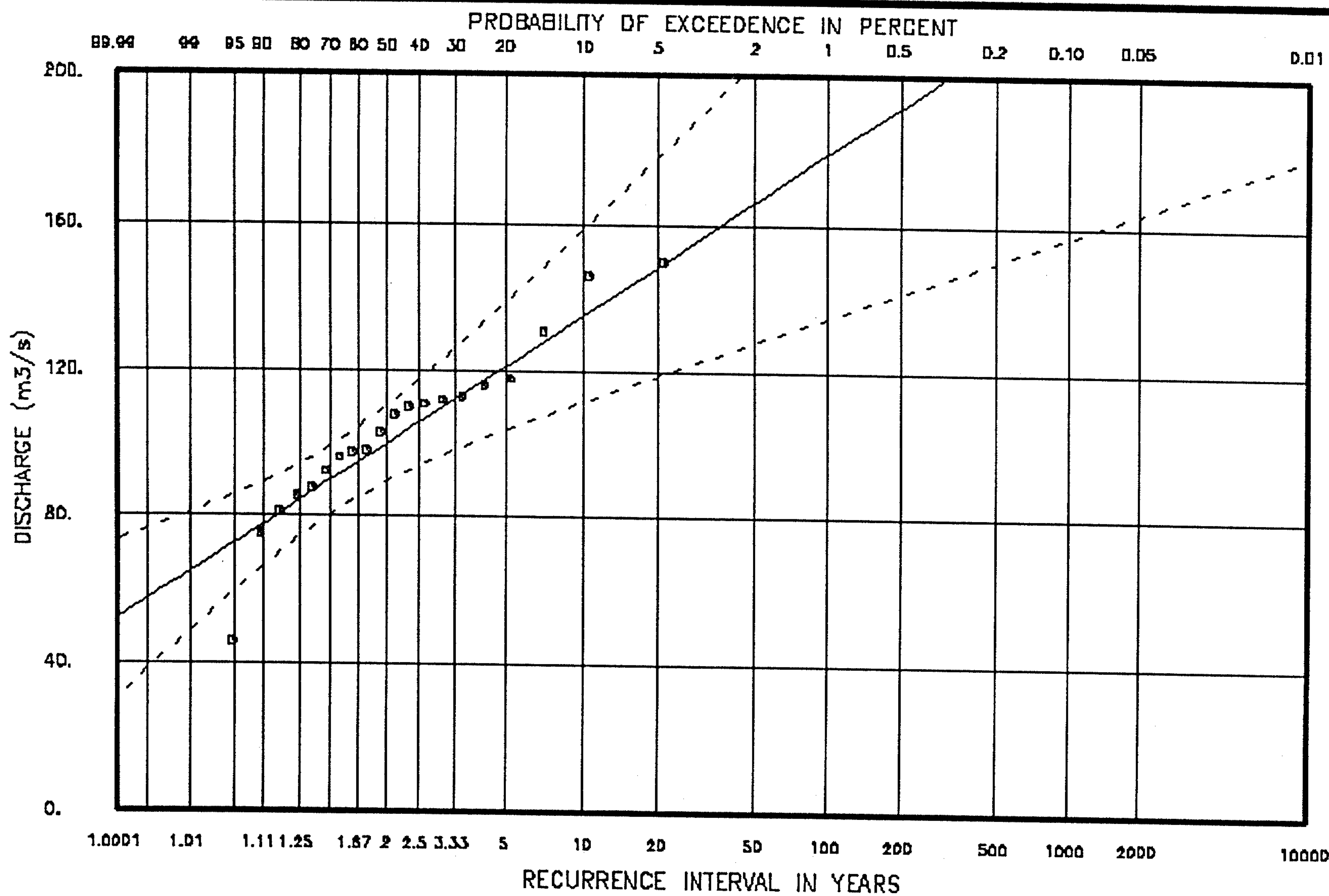


STA. 08NN022 – WEST KETTLE RIVER BELOW CARMI CREEK

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

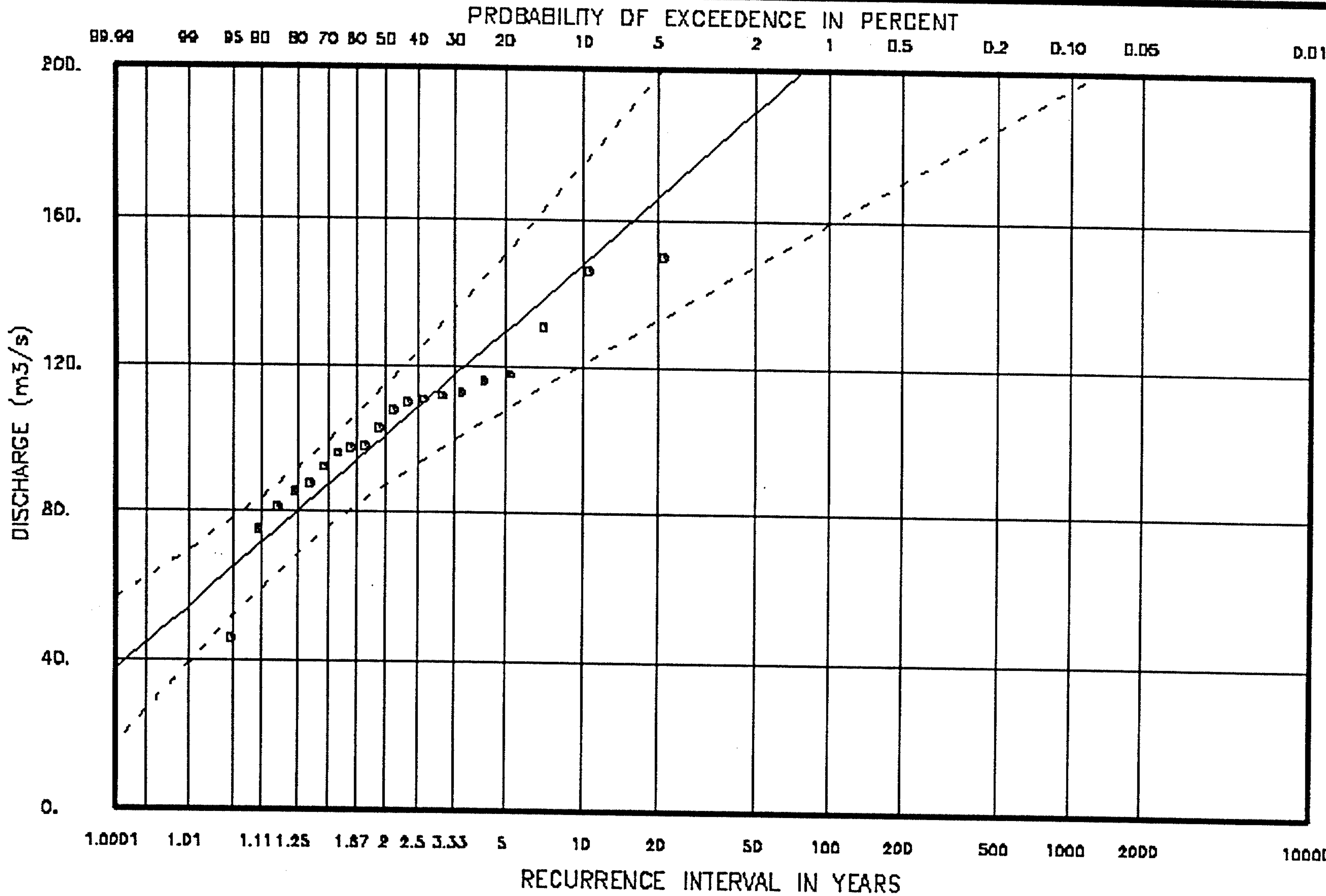


STA. 08NN022 – WEST KETTLE RIVER BELOW CARMI CREEK

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN022 – WEST KETTLE RIVER BELOW CARMI CREEK

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A6 -
West Kettle River Below Carmi Creek - Daily

STA. 08NN022 - WEST KETTLE RIVER BELOW CARMI CREEK

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
74	97.	121.	1	.043	23.000
75	97.	113.	2	.087	11.500
76	100.	109.	3	.130	7.667
77	79.	100.	4	.174	5.750
78	75.	100.	5	.217	4.600
79	82.	99.	6	.261	3.833
80	97.	98.	7	.304	3.286
81	113.	97.	8	.348	2.875
82	87.	97.	9	.391	2.556
83	95.	97.	10	.435	2.300
84	99.	95.	11	.478	2.091
85	80.	91.	12	.522	1.917
86	109.	87.	13	.565	1.769
87	121.	84.	14	.609	1.643
88	75.	82.	15	.652	1.533
89	64.	80.	16	.696	1.438
90	100.	79.	17	.739	1.353
91	91.	75.	18	.783	1.278
92	40.	75.	19	.826	1.211
93	98.	71.	20	.870	1.150
94	84.	64.	21	.913	1.095
95	71.	40.	22	.957	1.045

STATISTICS OF DATA SERIES

SAMPLE SIZE = 22

MEAN =	88.7500	MIN. =	39.5000	MAX. =	121.0000
S.D. =	17.8190	C.S. =	-.7784	C.K. =	4.6412

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 22

MEAN =	4.4624	MIN. =	3.6763	MAX. =	4.7958
S.D. =	.2351	C.S. =	-1.7951	C.K. =	7.8530

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = -6.935

BETA = 6.602

GAMMA = 134.535

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	73.104	29.803	-13.498	2081.776
1.050	75.711	55.487	35.262	972.341
1.250	85.936	74.861	63.786	532.466
2.000	99.932	91.023	82.113	428.331
5.000	111.169	103.967	96.765	346.251
10.000	117.121	109.576	102.031	362.739
20.000	123.282	113.654	104.026	462.872
50.000	131.386	117.681	103.976	658.907
100.000	137.190	120.055	102.919	823.825
200.000	142.653	122.022	101.391	991.874
500.000	149.366	124.156	98.946	1212.029
1000.000	154.091	125.498	96.905	1374.645
10000.000	167.910	128.788	89.666	1880.869

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

ALPHA = -4.986

BETA = 12.035

GAMMA = 148.752

MEAN = 88.750

S.D. = 17.296

C.S. = -.577

RETURN	UPPER	FLOOD	LOWER	STANDARD
PERIOD	CONFIDENCE	ESTIMATE	CONFIDENCE	ERROR

	LIMIT		LIMIT	PERCENT
1.005	66.465	34.774	3.082	1523.638
1.050	74.315	57.232	40.150	821.278
1.250	85.163	74.913	64.663	492.772
2.000	98.422	90.396	82.371	385.841
5.000	111.052	103.549	96.046	360.720
10.000	117.362	109.565	101.767	374.877
20.000	122.782	114.109	105.436	416.977
50.000	129.323	118.786	108.249	506.569
100.000	133.946	121.657	109.368	590.819
200.000	138.329	124.118	109.907	683.209
500.000	143.787	126.894	110.002	812.137
1000.000	147.685	128.712	109.739	912.174
10000.000	159.420	133.503	107.586	1246.028

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

NO MOMENT SOLUTION FOR THREE PARAMETER LOGNORMAL

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR THREE PARAMETER LOGNORMAL

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .072

U = 80.731

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	69.720	57.552	45.383	10.165
1.050	74.634	65.263	55.892	6.903
1.250	81.212	74.120	67.027	4.601
2.000	93.087	85.824	78.560	4.069
5.000	113.798	101.572	89.345	5.787
10.000	128.506	111.998	95.490	7.086
20.000	142.848	121.999	101.150	8.216
50.000	161.567	134.945	108.322	9.485
100.000	175.656	144.646	113.635	10.307
200.000	189.724	154.311	118.898	11.033
500.000	208.314	167.063	125.812	11.871
1000.000	222.379	176.700	131.022	12.428
10000.000	269.133	208.698	148.264	13.922

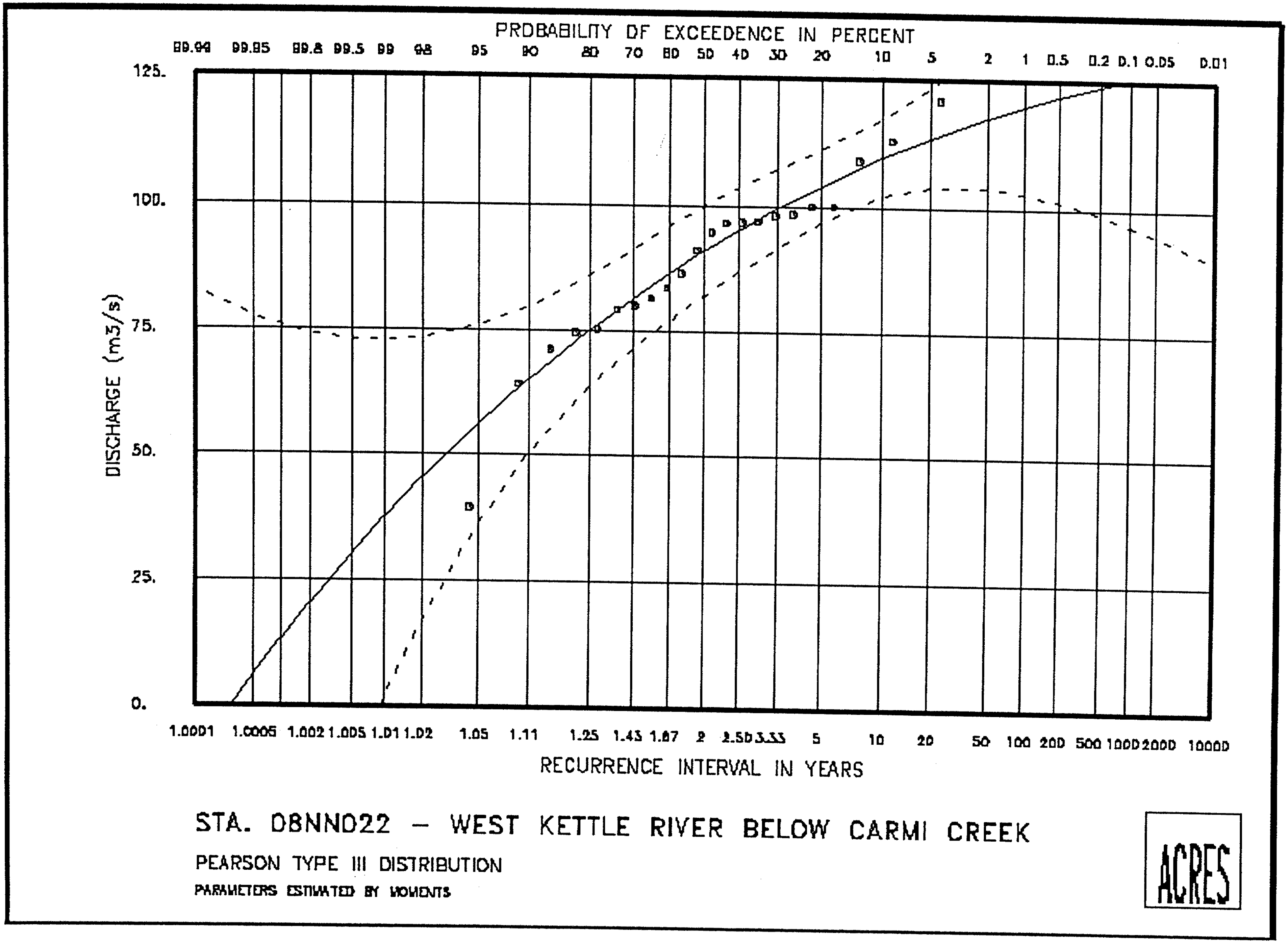
GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

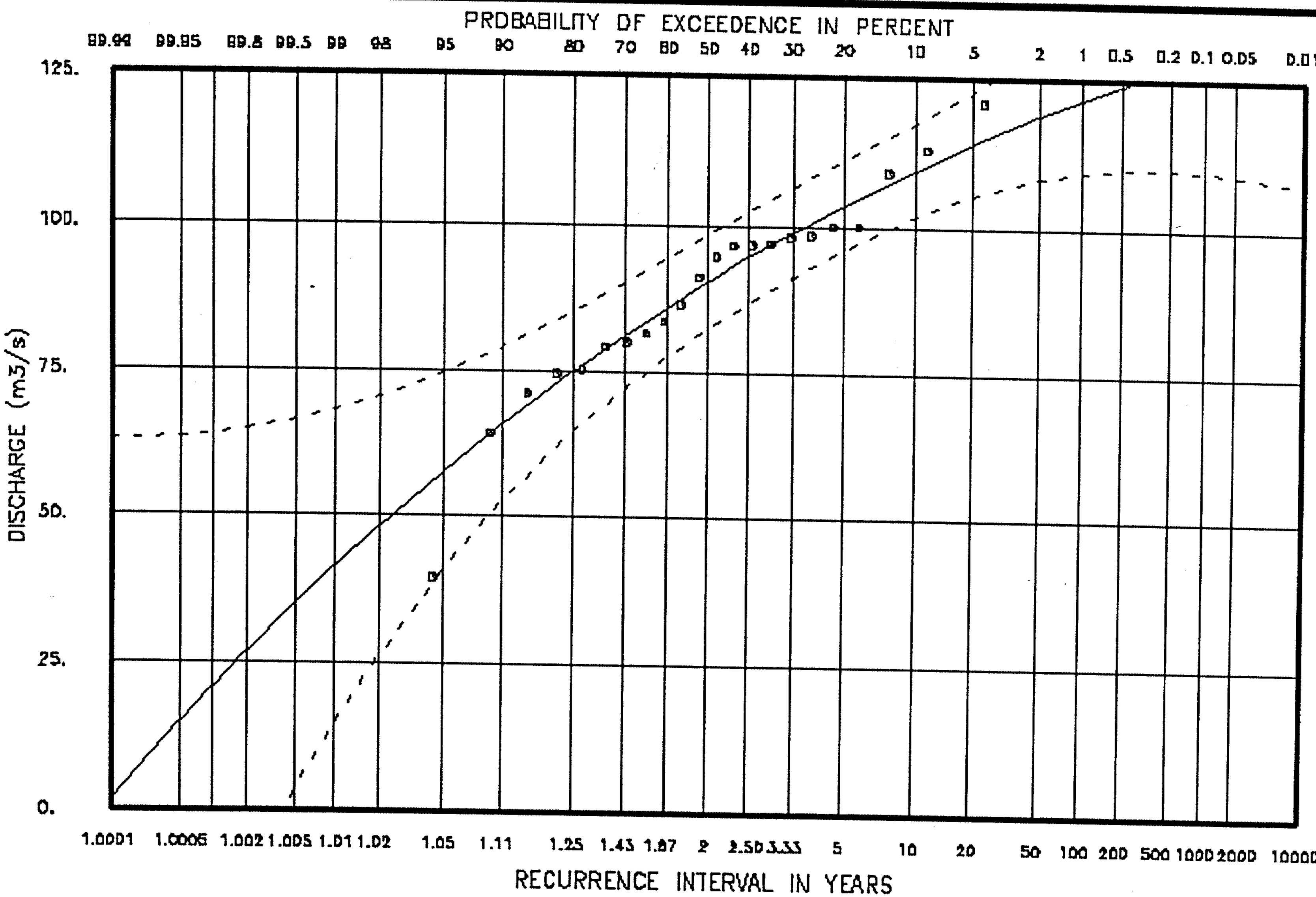
A = .049

U = 79.475

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	58.077	45.482	32.887	13.314
1.050	67.052	56.790	46.528	8.688
1.250	78.822	69.778	60.735	6.231
2.000	97.552	86.942	76.333	5.867
5.000	126.319	110.036	93.754	7.114

10.000	146.214	125.326	104.438	8.013
20.000	165.547	139.993	114.439	8.776
50.000	190.757	158.977	127.198	9.610
100.000	209.726	173.204	136.682	10.138
200.000	228.666	187.378	146.090	10.594
500.000	253.697	206.078	158.460	11.109
1000.000	272.636	220.211	167.787	11.445
10000.000	335.600	267.136	198.672	12.322


PROBABILITY OF EXCEEDENCE IN PERCENT
99.99 99.95 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
125.
100.
75.
50.
25.
0.
DISCHARGE (m3/s)
1.0001 1.0005 1.002 1.005 1.01 1.02 1.05 1.11 1.25 1.43 1.67 2 2.50 3.33 5 10 20 50 100 200 500 1000 2000 10000
RECURRENCE INTERVAL IN YEARS
STA. 08NN022 – WEST KETTLE RIVER BELOW CARMI CREEK
PEARSON TYPE III DISTRIBUTION
PARAMETERS ESTIMATED BY MOMENTS
ACRES

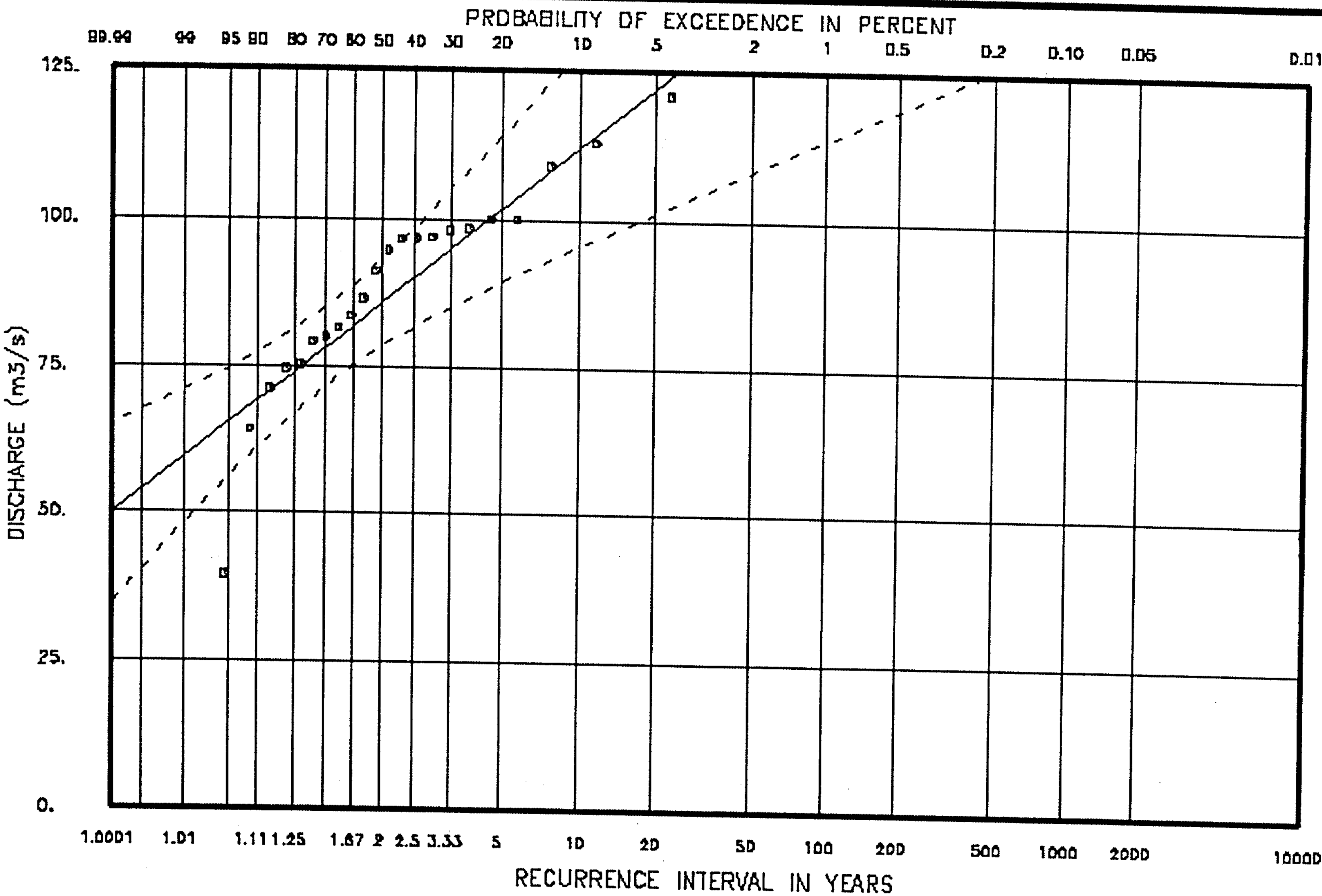


STA. 08NN022 – WEST KETTLE RIVER BELOW CARMI CREEK

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

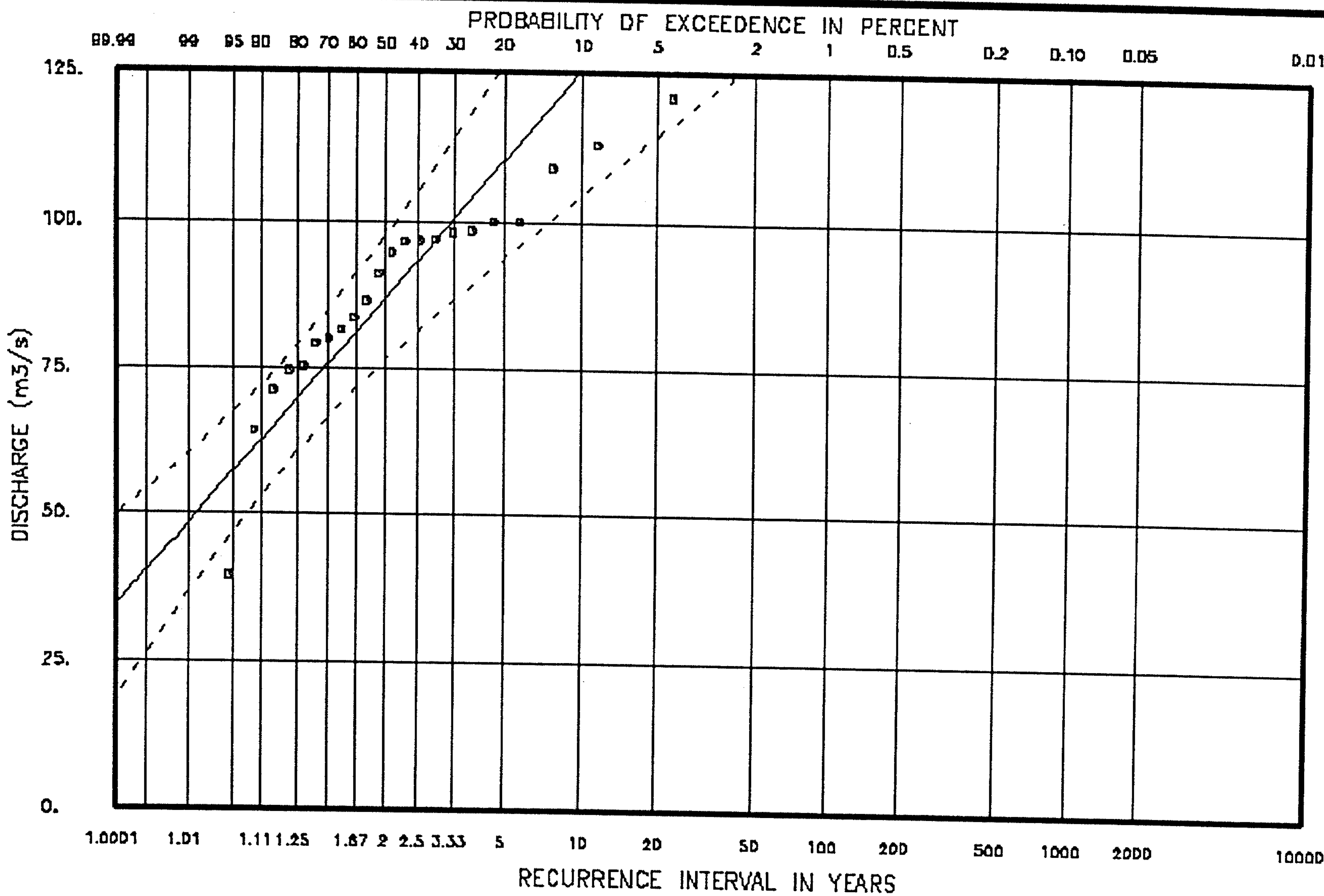


STA. 08NN022 – WEST KETTLE RIVER BELOW CARMI CREEK

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN022 – WEST KETTLE RIVER BELOW CARMI CREEK

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A7 - West Kettle River Near McCulloch - Instantaneous

STA. 08NN015 - WEST KETTLE RIVER NEAR MCCULLOCH

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
65	31.	63.	1	.032	31.000
66	23.	63.	2	.065	15.500
67	40.	60.	3	.097	10.333
68	38.	57.	4	.129	7.750
69	31.	57.	5	.161	6.200
70	35.	56.	6	.194	5.167
71	51.	55.	7	.226	4.429
72	57.	54.	8	.258	3.875
73	38.	54.	9	.290	3.444
74	63.	53.	10	.323	3.100
75	53.	51.	11	.355	2.818
76	57.	50.	12	.387	2.583
77	32.	50.	13	.419	2.385
78	43.	50.	14	.452	2.214
79	40.	47.	15	.484	2.067
80	60.	44.	16	.516	1.938
81	55.	44.	17	.548	1.824
82	44.	44.	18	.581	1.722
83	56.	43.	19	.613	1.632
84	47.	40.	20	.645	1.550
85	63.	40.	21	.677	1.476
86	54.	38.	22	.710	1.409
87	54.	38.	23	.742	1.348
88	50.	36.	24	.774	1.292
89	44.	35.	25	.806	1.240
90	50.	32.	26	.839	1.192
91	44.	31.	27	.871	1.148
92	27.	31.	28	.903	1.107
93	50.	27.	29	.935	1.069
94	36.	23.	30	.968	1.033

STATISTICS OF DATA SERIES

SAMPLE SIZE = 30

MEAN =	45.4400	MIN. =	22.9000	MAX. =	63.1000
S.D. =	10.8854	C.S. =	-.2677	C.K. =	2.3559

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 30

MEAN =	3.7855	MIN. =	3.1311	MAX. =	4.1447
S.D. =	.2609	C.S. =	-.7315	C.K. =	3.0461

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = -1.457

BETA = 55.821

GAMMA = 126.769

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	29.885	14.629	-.626	745.990
1.050	34.513	26.449	18.385	394.328
1.250	41.539	36.454	31.369	248.662
2.000	50.335	45.925	41.514	215.686
5.000	59.118	54.709	50.300	215.615
10.000	63.969	59.040	54.111	241.017
20.000	68.391	62.483	56.574	288.941
50.000	73.894	66.214	58.533	375.569
100.000	77.849	68.619	59.389	451.349
200.000	81.646	70.763	59.881	532.147
500.000	86.450	73.290	60.131	643.495
1000.000	89.940	75.016	60.093	729.770
10000.000	100.809	79.915	59.021	1021.711

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

ALPHA = -4.213

BETA = 6.885

GAMMA = 74.446

MEAN = 45.440

S.D. = 11.054

C.S. = -.762

RETURN PERIOD	UPPER CONFIDENCE	FLOOD ESTIMATE	LOWER CONFIDENCE	STANDARD ERROR

	LIMIT		LIMIT	PERCENT
1.005	27.155	9.036	-9.084	886.035
1.050	34.633	24.842	15.050	478.796
1.250	42.519	36.804	31.090	279.440
2.000	51.038	46.822	42.605	206.183
5.000	58.641	54.883	51.124	183.792
10.000	62.127	58.392	54.657	182.631
20.000	64.908	60.951	56.995	193.458
50.000	68.069	63.488	58.906	224.038
100.000	70.219	64.988	59.758	255.765
200.000	72.204	66.236	60.267	291.879
500.000	74.612	67.593	60.575	343.184
1000.000	76.286	68.451	60.615	383.165
10000.000	81.098	70.567	60.035	514.998

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

NO MOMENT SOLUTION FOR THREE PARAMETER LOGNORMAL

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR THREE PARAMETER LOGNORMAL

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .118

U = 40.542

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	32.640	26.381	20.123	11.601
1.050	35.912	31.092	26.272	7.580
1.250	40.151	36.502	32.854	4.887
2.000	47.388	43.652	39.917	4.185
5.000	59.561	53.273	46.984	5.772
10.000	68.132	59.642	51.151	6.961
20.000	76.475	65.752	55.028	7.975
50.000	87.353	73.660	59.967	9.090
100.000	95.536	79.586	63.636	9.800
200.000	103.705	85.491	67.277	10.418
500.000	114.497	93.281	72.064	11.122
1000.000	122.662	99.168	75.674	11.585
10000.000	149.799	118.715	87.632	12.804

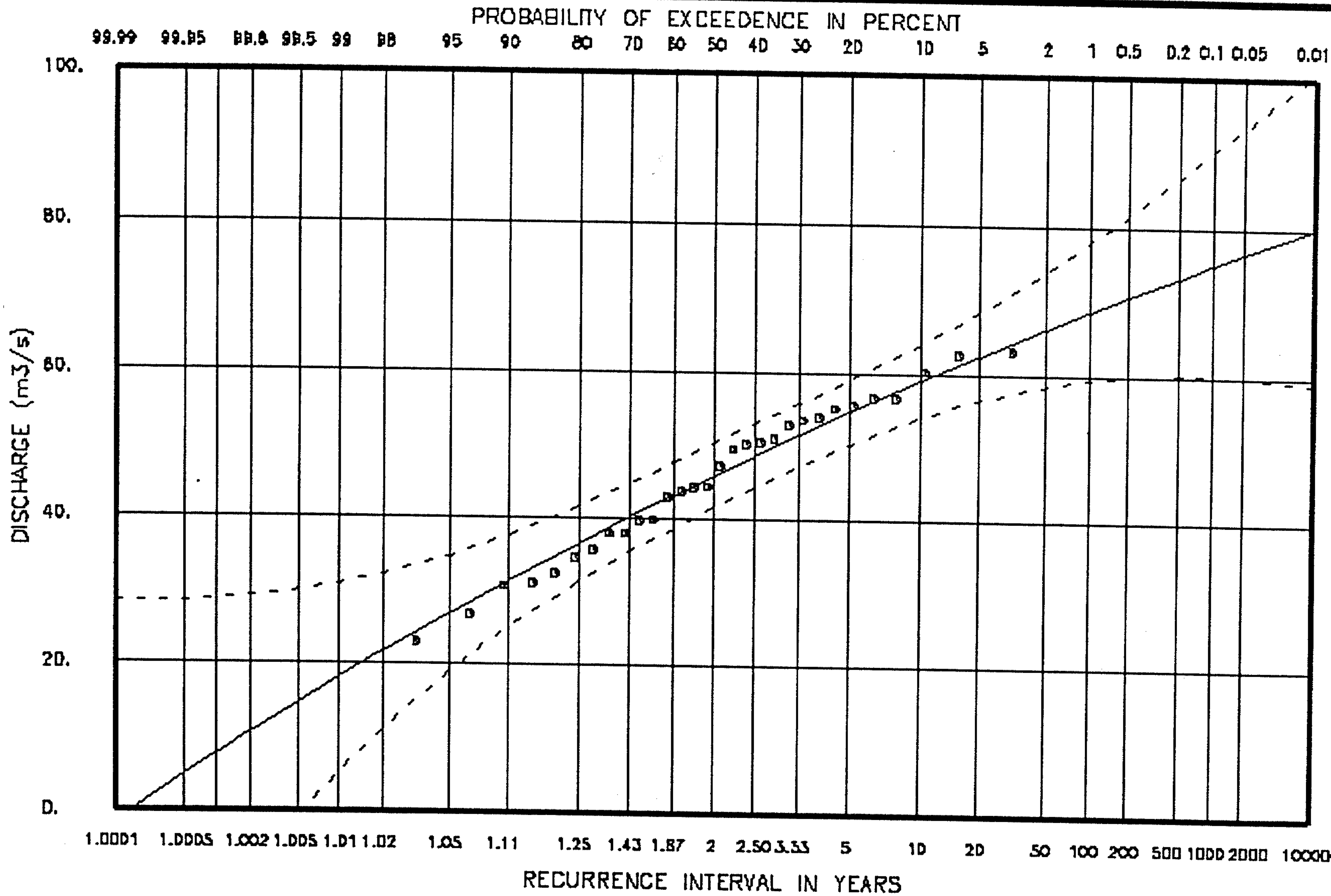
GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .095

U = 39.979

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	27.909	22.437	16.964	11.927
1.050	32.731	28.272	23.814	7.712
1.250	38.905	34.975	31.046	5.494
2.000	48.443	43.833	39.223	5.143
5.000	62.826	55.751	48.677	6.205

10.000	72.718	63.642	54.566	6.973
20.000	82.315	71.211	60.108	7.625
50.000	94.817	81.009	67.201	8.335
100.000	104.220	88.351	72.482	8.783
200.000	113.606	95.666	77.726	9.170
500.000	126.007	105.316	84.626	9.607
1000.000	135.389	112.610	89.831	9.891
10000.000	166.575	136.827	107.079	10.631

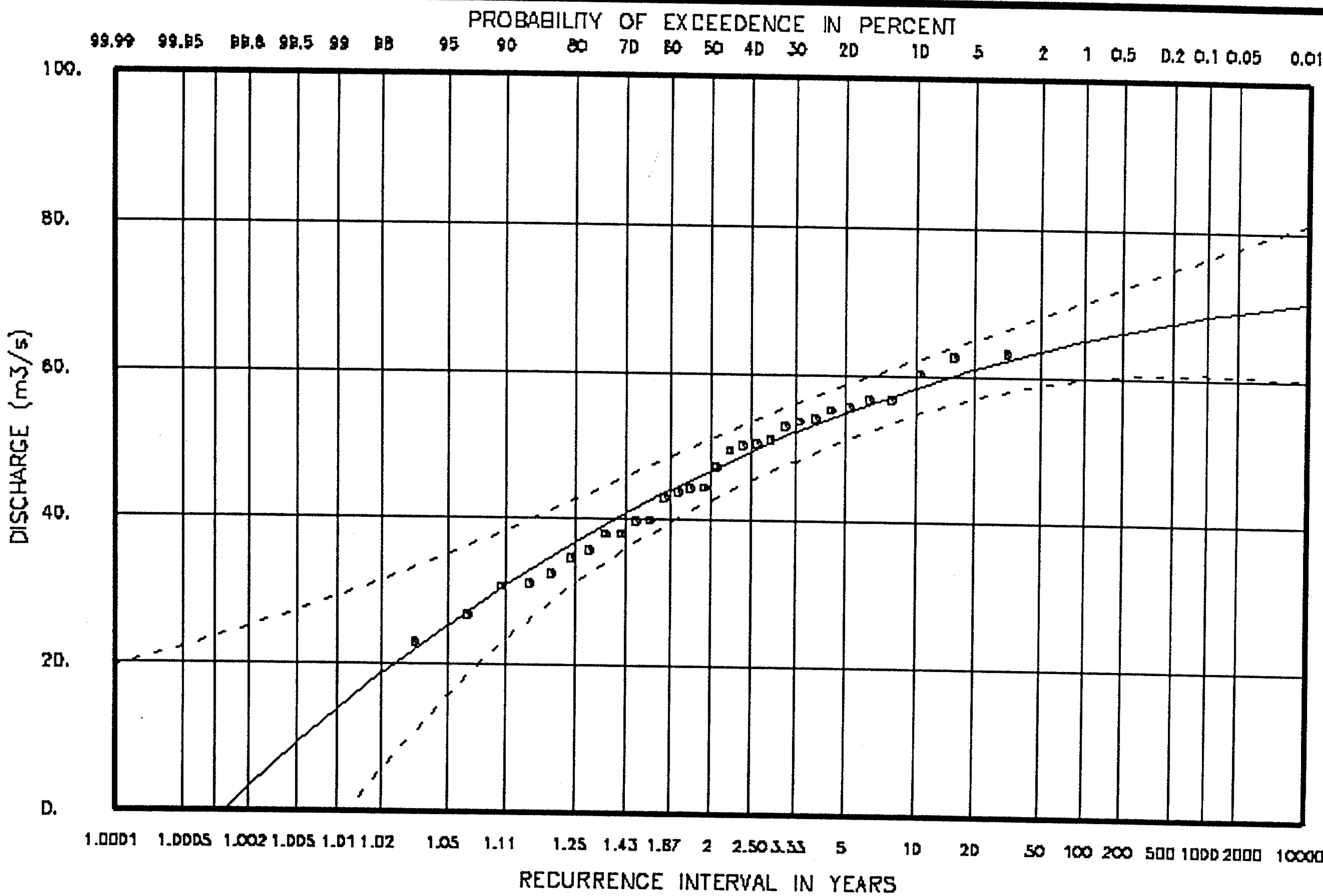


STA. 08NN015 – WEST KETTLE RIVER NEAR MCCULLOCH

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

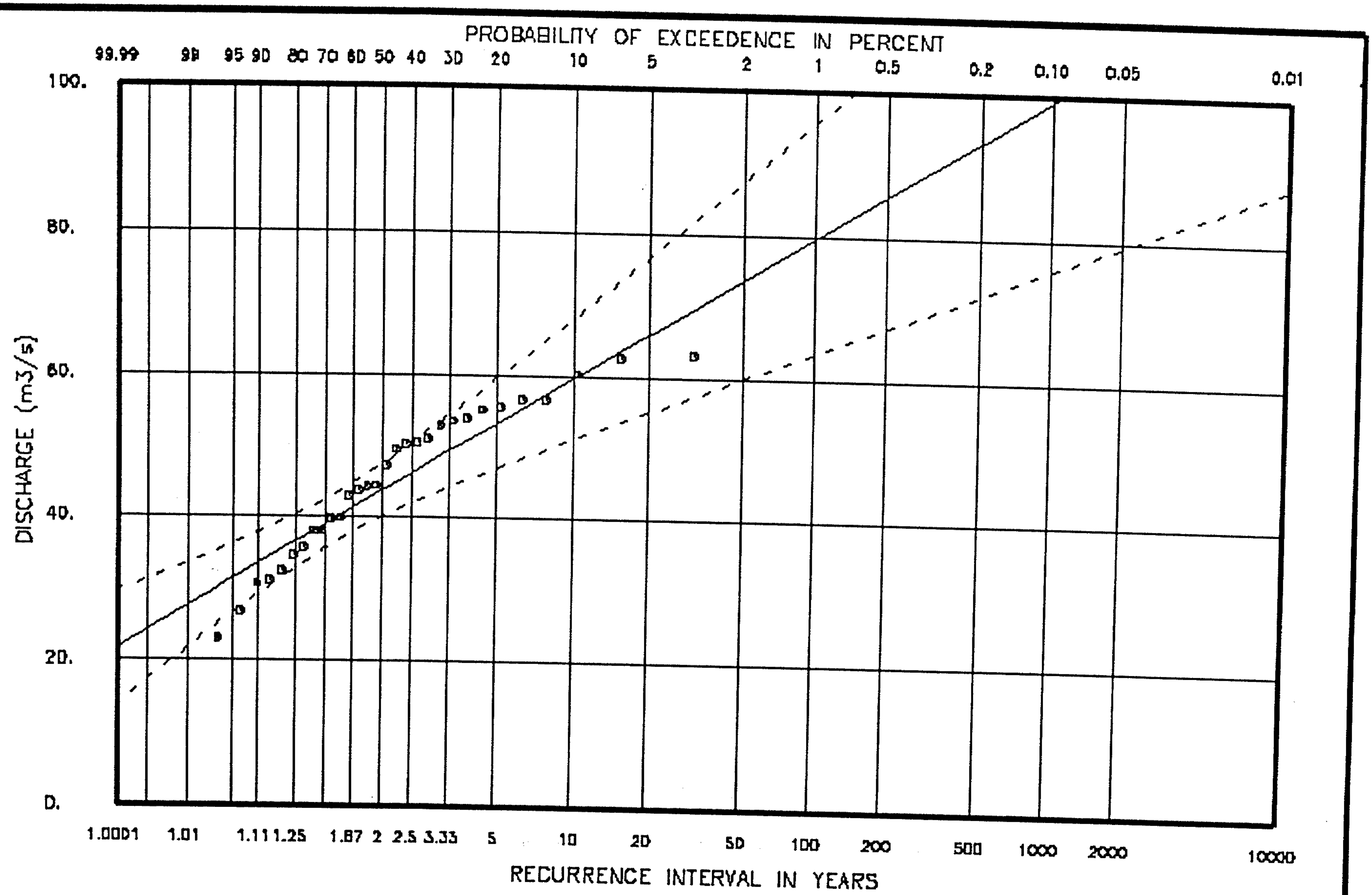


STA. 08NN015 – WEST KETTLE RIVER NEAR MCCULLOCH

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

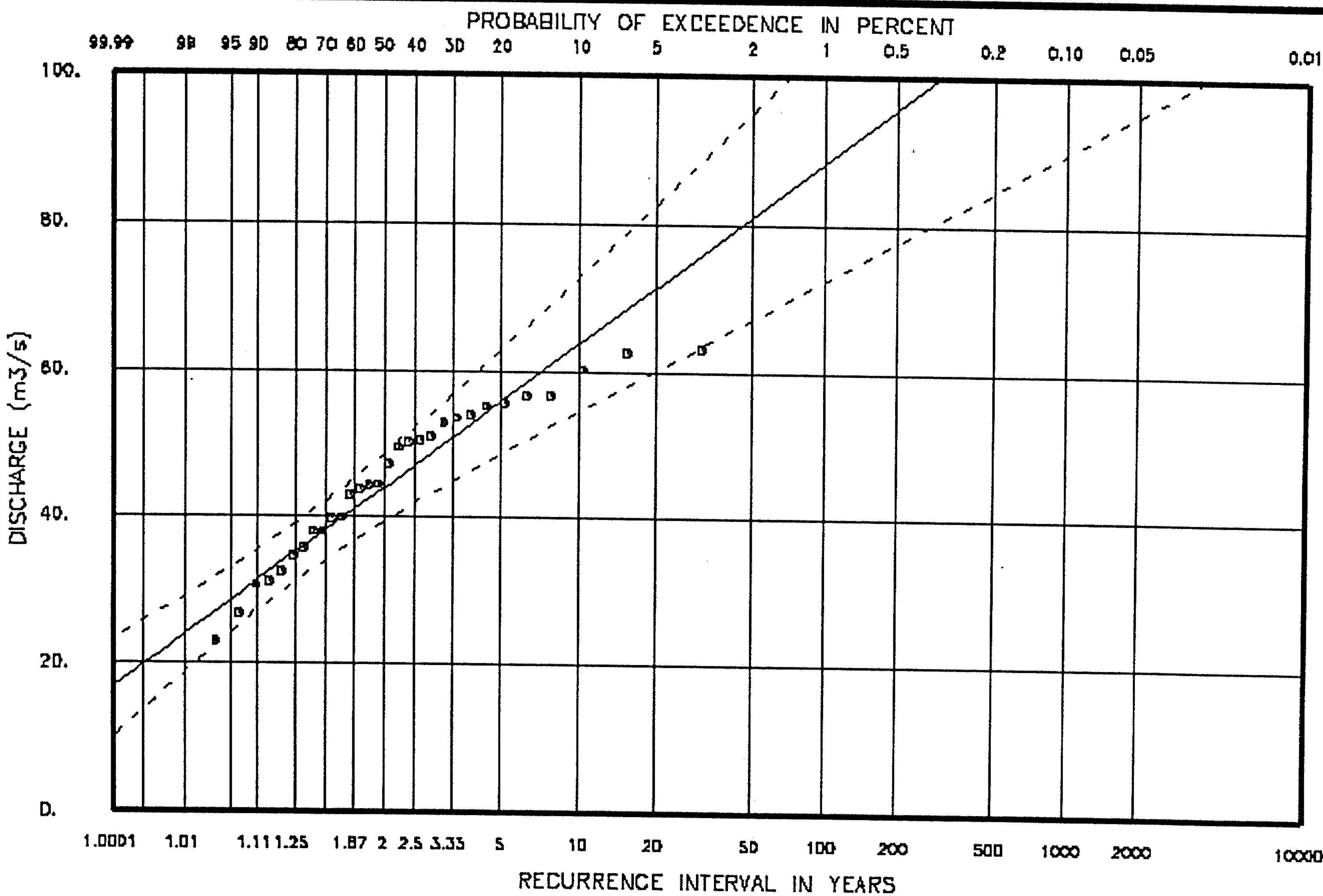


STA. 08NN015 – WEST KETTLE RIVER NEAR MCCULLOCH

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN015 – WEST KETTLE RIVER NEAR MCCULLOCH

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A8 -
West Kettle River Near McCulloch - Daily

STA. 08NN015 - WEST KETTLE RIVER NEAR MCCULLOCH

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
65	28.	48.	1	.033	30.000
66	22.	48.	2	.067	15.000
67	37.	48.	3	.100	10.000
68	35.	47.	4	.133	7.500
69	28.	45.	5	.167	6.000
70	27.	45.	6	.200	5.000
71	44.	44.	7	.233	4.286
72	48.	44.	8	.267	3.750
73	31.	43.	9	.300	3.333
75	45.	41.	10	.333	3.000
76	48.	40.	11	.367	2.727
77	28.	39.	12	.400	2.500
78	35.	38.	13	.433	2.308
79	31.	38.	14	.467	2.143
80	47.	37.	15	.500	2.000
81	39.	37.	16	.533	1.875
82	34.	35.	17	.567	1.765
83	45.	35.	18	.600	1.667
84	37.	34.	19	.633	1.579
85	48.	31.	20	.667	1.500
86	44.	31.	21	.700	1.429
87	43.	30.	22	.733	1.364
88	40.	29.	23	.767	1.304
89	29.	28.	24	.800	1.250
90	38.	28.	25	.833	1.200
91	38.	28.	26	.867	1.154
92	22.	27.	27	.900	1.111
93	41.	22.	28	.933	1.071
94	30.	22.	29	.967	1.034

STATISTICS OF DATA SERIES

SAMPLE SIZE = 29

MEAN =	36.5517	MIN. =	21.5000	MAX. =	48.1000
S.D. =	7.8297	C.S. =	-.1991	C.K. =	2.2122

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 29

MEAN =	3.5748	MIN. =	3.0681	MAX. =	3.8733
S.D. =	.2273	C.S. =	-.5678	C.K. =	2.7111

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = -.779

BETA = 100.920

GAMMA = 115.208

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	25.522	14.897	4.272	518.790
1.050	28.729	23.038	17.347	277.867
1.250	33.716	30.052	26.388	178.921
2.000	40.036	36.811	33.586	157.454
5.000	46.499	43.203	39.907	160.949
10.000	50.137	46.404	42.672	182.249
20.000	53.466	48.975	44.483	219.321
50.000	57.617	51.789	45.961	284.567
100.000	60.608	53.620	46.632	341.217
200.000	63.489	55.265	47.041	401.556
500.000	67.146	57.218	47.289	484.798
1000.000	69.814	58.562	47.310	549.425
10000.000	78.177	62.425	46.673	769.149

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR PEARSON III

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

NO MOMENT SOLUTION FOR THREE PARAMETER LOGNORMAL

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MAXIMUM LIKELIHOOD

NO MAXIMUM LIKELIHOOD SOLUTION FOR THREE PARAMETER LOGNORMAL

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .164

U = 33.028

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	27.429	22.843	18.258	9.802
1.050	29.763	26.231	22.700	6.573
1.250	32.796	30.123	27.450	4.332
2.000	38.003	35.266	32.529	3.790
5.000	46.793	42.186	37.578	5.333
10.000	52.987	46.767	40.546	6.495
20.000	59.018	51.161	43.305	7.498
50.000	66.882	56.850	46.818	8.617
100.000	72.798	61.112	49.427	9.337
200.000	78.704	65.359	52.015	9.969
500.000	86.507	70.963	55.418	10.696
1000.000	92.410	75.197	57.984	11.177
10000.000	112.031	89.257	66.484	12.458

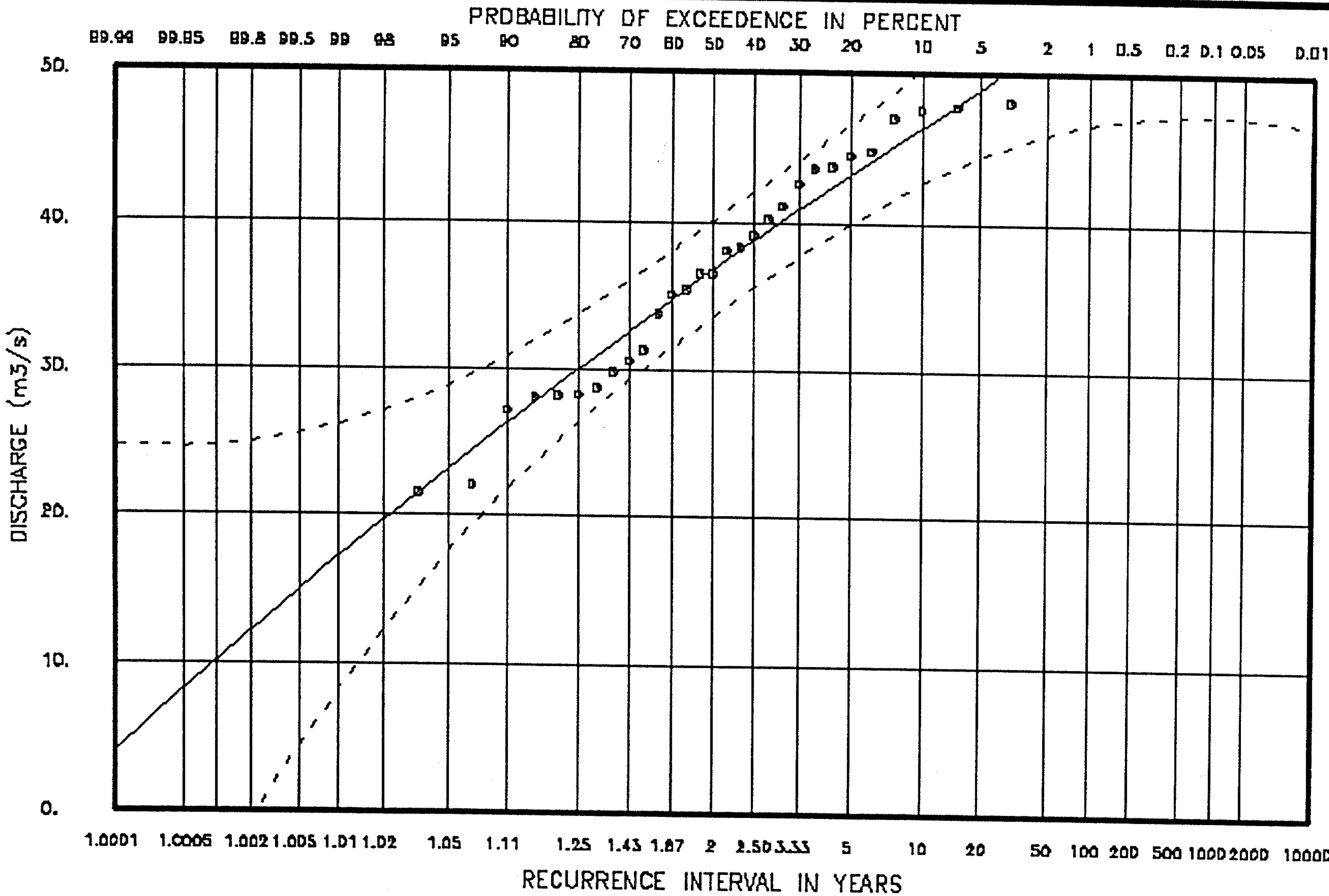
GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .135

U = 32.653

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	24.222	20.296	16.369	9.447
1.050	27.606	24.407	21.207	6.400
1.250	31.947	29.128	26.309	4.726
2.000	38.675	35.368	32.060	4.566
5.000	48.839	43.763	38.687	5.664

10.000	55.833	49.321	42.809	6.447
20.000	62.619	54.653	46.686	7.118
50.000	71.461	61.554	51.647	7.859
100.000	78.111	66.725	55.340	8.332
200.000	84.750	71.878	59.006	8.744
500.000	93.521	78.676	63.831	9.213
1000.000	100.157	83.814	67.470	9.521
10000.000	122.216	100.872	79.528	10.332

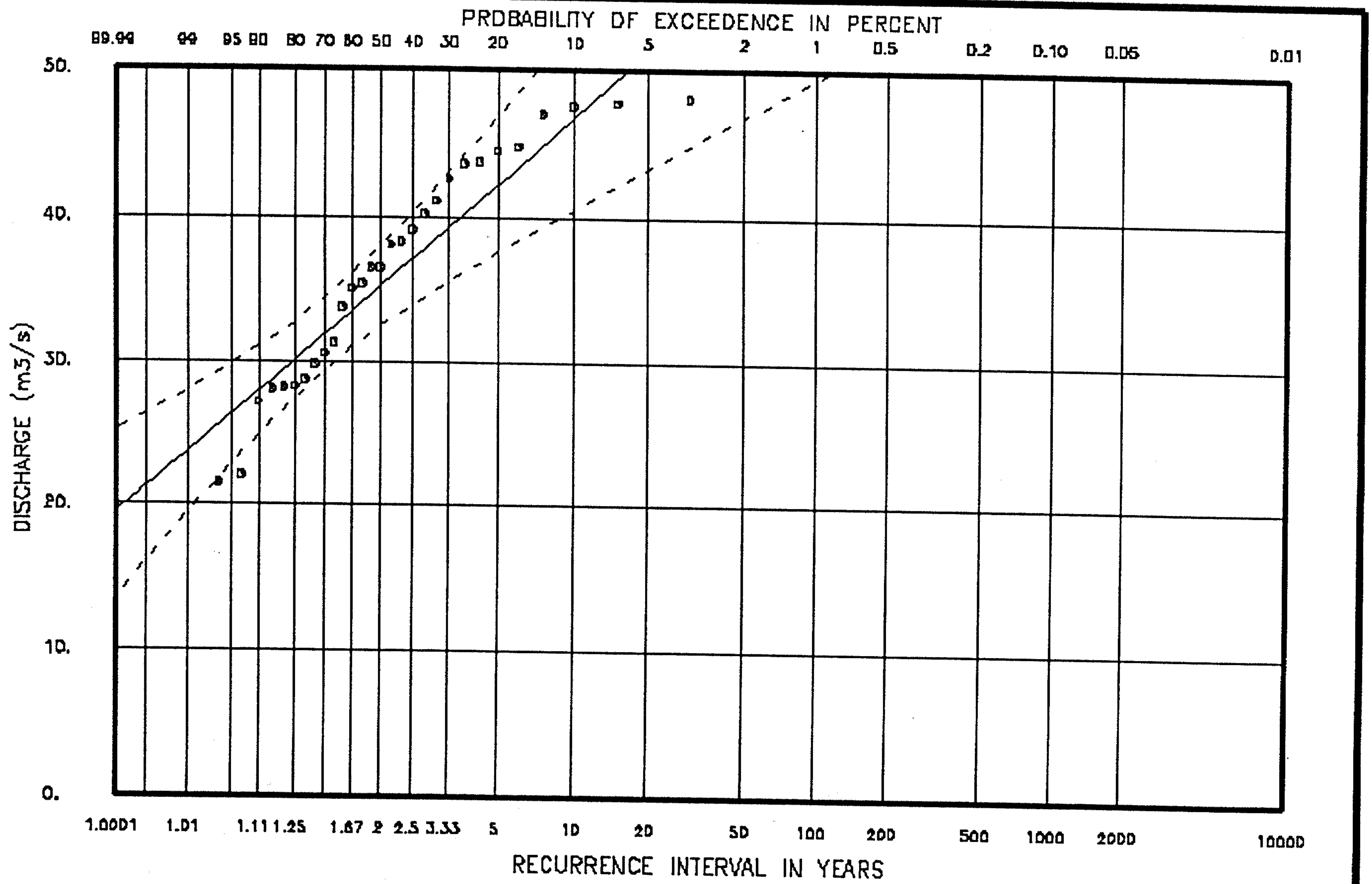


STA. 08NN015 – WEST KETTLE RIVER NEAR MCCULLOCH

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES

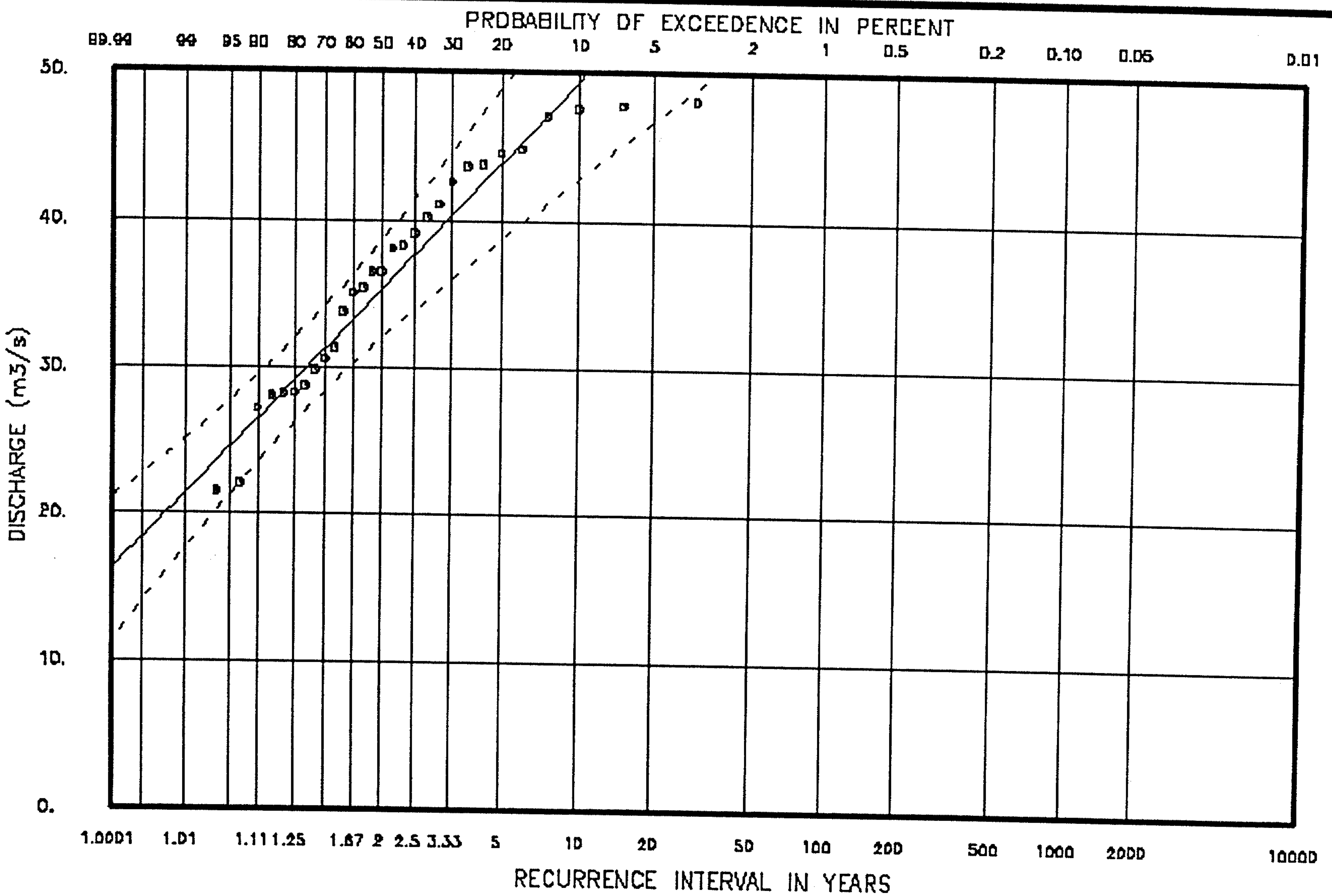


STA. 08NN015 – WEST KETTLE RIVER NEAR MCCULLOCH

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



STA. 08NN015 – WEST KETTLE RIVER NEAR MCCULLOCH

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX A9 -
Boundary Creek at Greenwood - Daily

STA. 08NN001 - BOUNDARY CREEK AT GREENWOOD

YEAR	DATA	ORDERED	RANK	PROBABILITY	RETURN PERIOD
14	16.	46.	1	.042	24.000
15	17.	44.	2	.083	12.000
16	16.	40.	3	.125	8.000
17	19.	32.	4	.167	6.000
18	13.	31.	5	.208	4.800
60	18.	31.	6	.250	4.000
62	17.	27.	7	.292	3.429
63	21.	27.	8	.333	3.000
64	24.	24.	9	.375	2.667
65	15.	21.	10	.417	2.400
66	11.	21.	11	.458	2.182
67	27.	19.	12	.500	2.000
68	18.	18.	13	.542	1.846
69	44.	18.	14	.583	1.714
71	46.	18.	15	.625	1.600
72	27.	17.	16	.667	1.500
73	17.	17.	17	.708	1.412
74	40.	17.	18	.750	1.333
75	31.	16.	19	.792	1.263
76	32.	16.	20	.833	1.200
77	18.	15.	21	.875	1.143
78	31.	13.	22	.917	1.091
79	21.	11.	23	.958	1.043

STATISTICS OF DATA SERIES

SAMPLE SIZE = 23

MEAN =	23.4000	MIN. =	11.2000	MAX. =	46.4000
S.D. =	9.8483	C.S. =	1.1096	C.K. =	3.5114

STATISTICS OF NATURAL LOGARITHMS OF DATA SERIES

SAMPLE SIZE = 23

MEAN =	3.0773	MIN. =	2.4159	MAX. =	3.8373
S.D. =	.3879	C.S. =	.4954	C.K. =	2.6716

PEARSON TYPE III DISTRIBUTION BY MOMENTS

ALPHA = 5.464

BETA = 3.249

GAMMA = 5.649

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	20.397	7.725	-4.947	611.010
1.050	16.428	10.687	4.947	276.786
1.250	18.458	15.089	11.721	162.410
2.000	26.673	21.640	16.607	242.682
5.000	37.097	30.682	24.268	309.284
10.000	45.183	36.540	27.898	416.699
20.000	54.227	42.014	29.801	588.865
50.000	67.188	48.906	30.623	881.505
100.000	77.497	53.952	30.406	1135.288
200.000	88.131	58.900	29.668	1409.418
500.000	102.599	65.335	28.070	1796.752
1000.000	113.816	70.145	26.473	2105.652
10000.000	152.521	85.910	19.299	3211.712

PEARSON TYPE III DISTRIBUTION BY MAXIMUM LIKELIHOOD

ALPHA = 7.751

BETA = 1.642

GAMMA = 10.670

MEAN = 23.400

S.D. = 9.933

C.S. = 1.561

RETURN PERIOD	UPPER CONFIDENCE	FLOOD ESTIMATE	LOWER CONFIDENCE	STANDARD ERROR

	LIMIT		LIMIT	PERCENT
1.005	12.972	10.898	8.824	100.000
1.050	13.848	12.245	10.642	77.299
1.250	17.690	15.293	12.897	115.561
2.000	24.623	20.987	17.351	175.316
5.000	36.748	30.092	23.436	320.942
10.000	45.750	36.484	27.218	446.776
20.000	54.738	42.711	30.684	579.889
50.000	66.672	50.831	34.990	763.784
100.000	75.769	56.942	38.115	907.743
200.000	84.938	63.051	41.163	1055.326
500.000	97.183	71.145	45.107	1255.452
1000.000	106.545	77.294	48.043	1410.363
10000.000	138.277	97.944	57.612	1944.679

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MOMENTS

A = -4.345

M = 3.264

S = .344

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	38.303	6.413	1.074	86.170
1.050	18.315	10.370	5.872	27.425
1.250	19.116	15.222	12.122	10.981
2.000	27.230	21.802	17.456	10.719
5.000	37.640	30.593	24.866	9.994
10.000	45.820	36.315	28.782	11.209
20.000	56.024	41.739	31.096	14.193
50.000	72.890	48.711	32.553	19.433
100.000	88.274	53.934	32.953	23.755
200.000	106.094	59.164	32.993	28.159
500.000	133.776	66.133	32.693	33.968
1000.000	158.192	71.473	32.293	38.307
10000.000	265.257	89.804	30.404	52.221

THREE PARAMETER LOG NORMAL DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = 8.188

M = 2.529

S = .645

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	13.206	10.562	8.447	10.771
1.050	14.574	12.457	10.648	7.567
1.250	18.094	15.470	13.227	7.553

2.000	24.764	20.724	17.344	8.586
5.000	37.674	29.768	23.521	11.357
10.000	49.828	36.862	27.269	14.533
20.000	64.727	44.444	30.517	18.127
50.000	89.357	55.397	34.344	23.052
100.000	112.306	64.480	37.021	26.754
200.000	139.534	74.315	39.579	30.376
500.000	183.063	88.562	42.844	35.011
1000.000	222.504	100.349	45.258	38.394
10000.000	403.752	146.471	53.136	48.890

GUMBEL TYPE I DISTRIBUTION BY MOMENTS

A = .130

U = 18.968

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	12.716	6.157	-.401	51.359
1.050	15.470	10.419	5.368	23.373
1.250	19.137	15.314	11.491	12.036
2.000	25.698	21.783	17.868	8.666
5.000	37.076	30.486	23.896	10.422
10.000	45.146	36.249	27.351	11.835
20.000	53.013	41.776	30.539	12.969
50.000	63.280	48.931	34.582	14.139
100.000	71.007	54.293	37.579	14.843
200.000	78.721	59.635	40.548	15.432
500.000	88.916	66.682	44.449	16.076
1000.000	96.628	72.009	47.389	16.485
10000.000	122.267	89.694	57.121	17.510

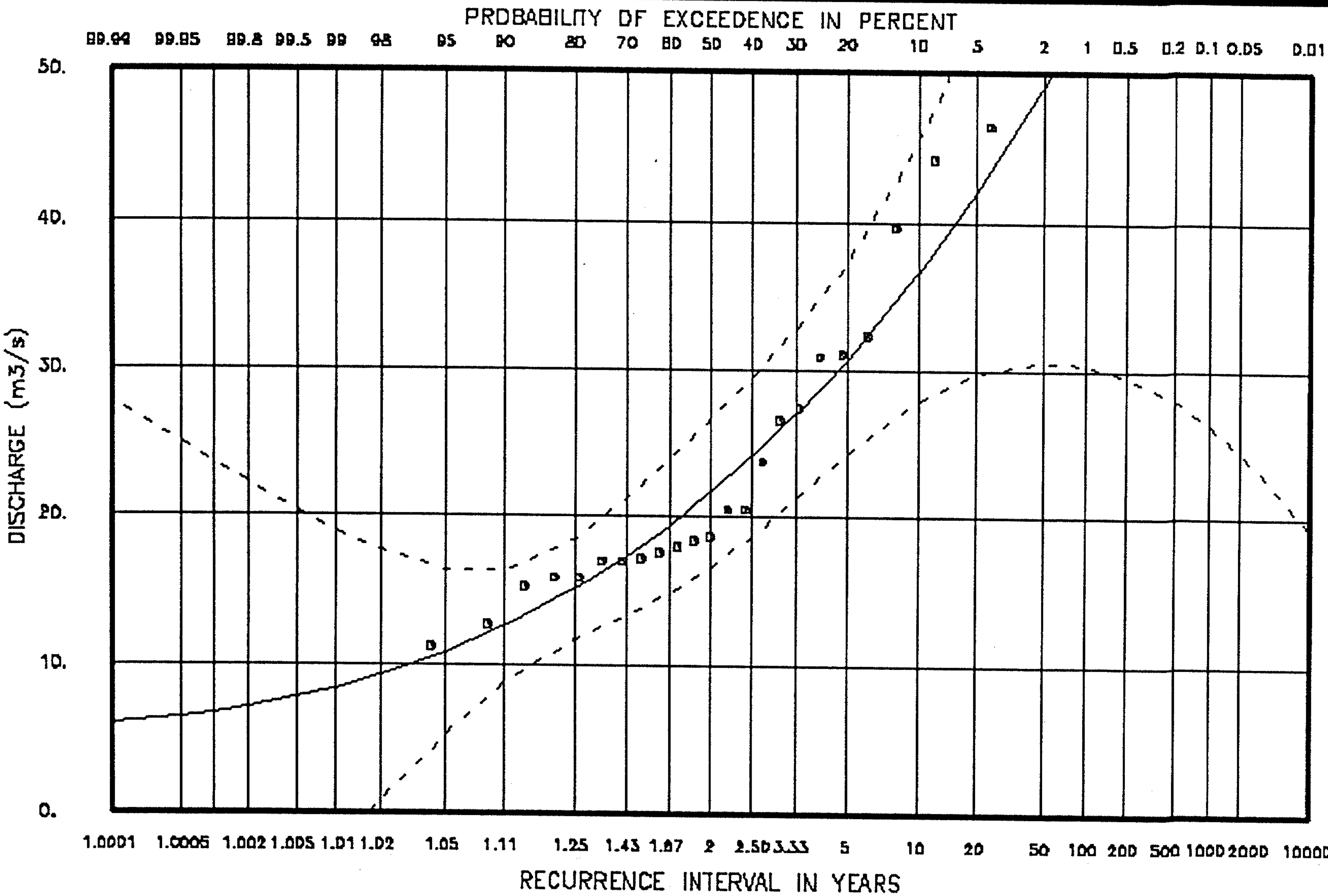
GUMBEL TYPE I DISTRIBUTION BY MAXIMUM LIKELIHOOD

A = .149

U = 19.156

RETURN PERIOD	UPPER CONFIDENCE LIMIT	FLOOD ESTIMATE	LOWER CONFIDENCE LIMIT	STANDARD ERROR PERCENT
1.005	12.020	7.983	3.946	24.384
1.050	14.989	11.700	8.411	13.556
1.250	18.868	15.969	13.070	8.752
2.000	25.012	21.611	18.210	7.588
5.000	34.421	29.202	23.982	8.618

10.000	40.923	34.228	27.532	9.432
20.000	47.240	39.048	30.857	10.114
50.000	55.475	45.289	35.102	10.845
100.000	61.672	49.965	38.258	11.297
200.000	67.858	54.624	41.389	11.682
500.000	76.034	60.770	45.507	12.110
1000.000	82.220	65.416	48.612	12.386
10000.000	102.786	80.840	58.894	13.089

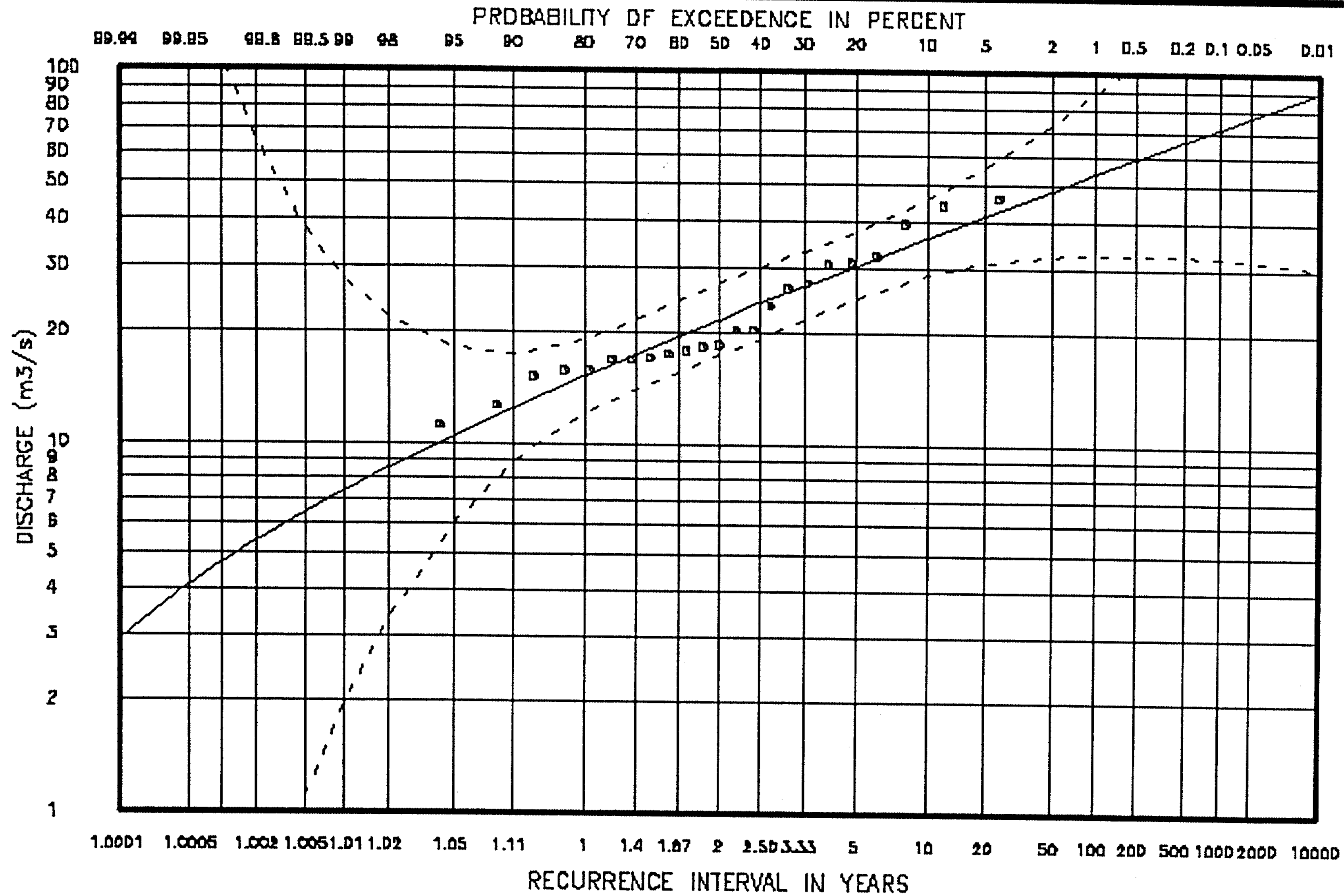


STA. 08NN001 — BOUNDARY CREEK AT GREENWOOD

PEARSON TYPE III DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

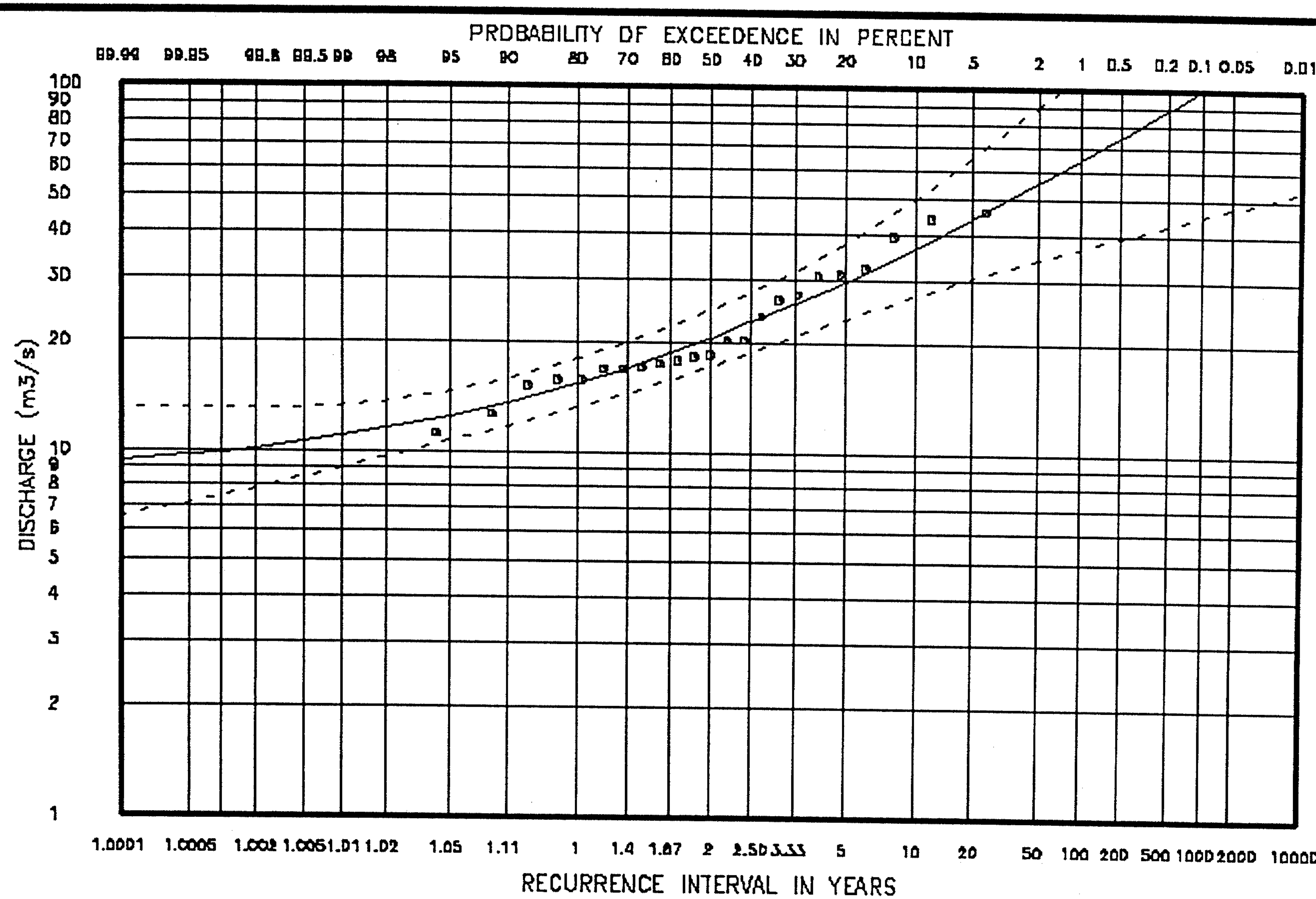
ACRES



STA. 08NN001 – BOUNDARY CREEK AT GREENWOOD

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

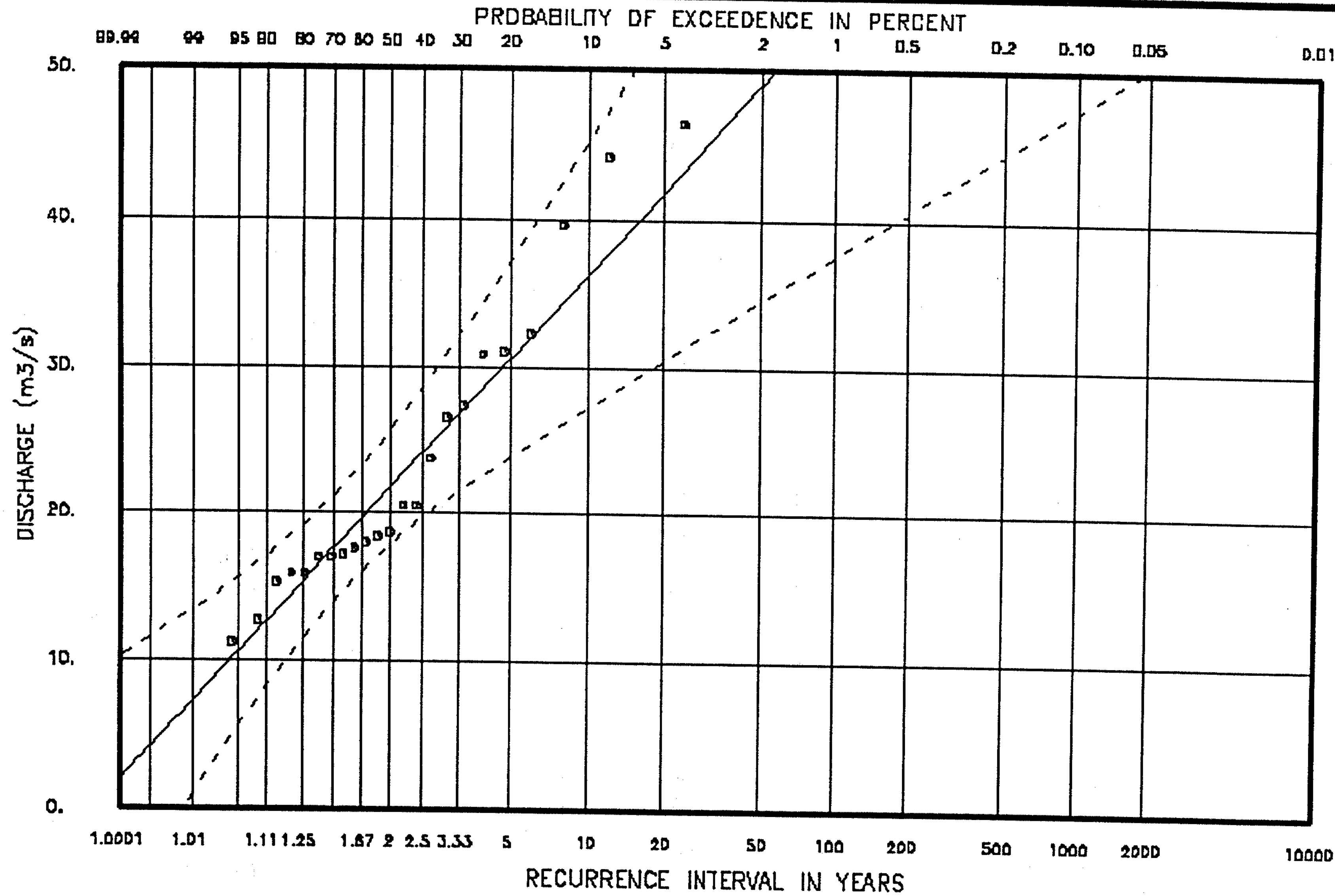


STA. 08NN001 — BOUNDARY CREEK AT GREENWOOD

THREE PARAMETER LOGNORMAL DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

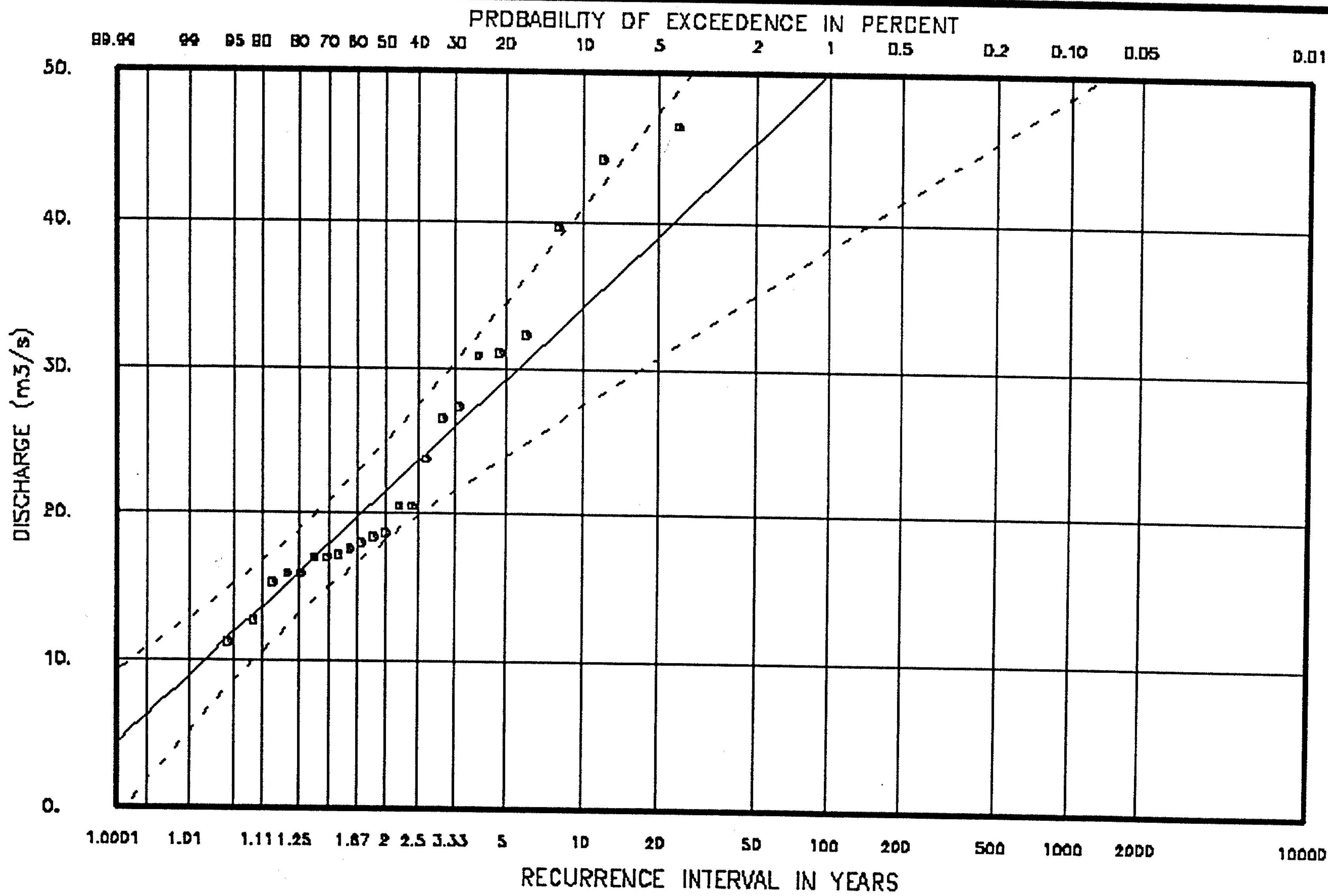


STA. 08NN001 – BOUNDARY CREEK AT GREENWOOD

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MOMENTS

ACRES



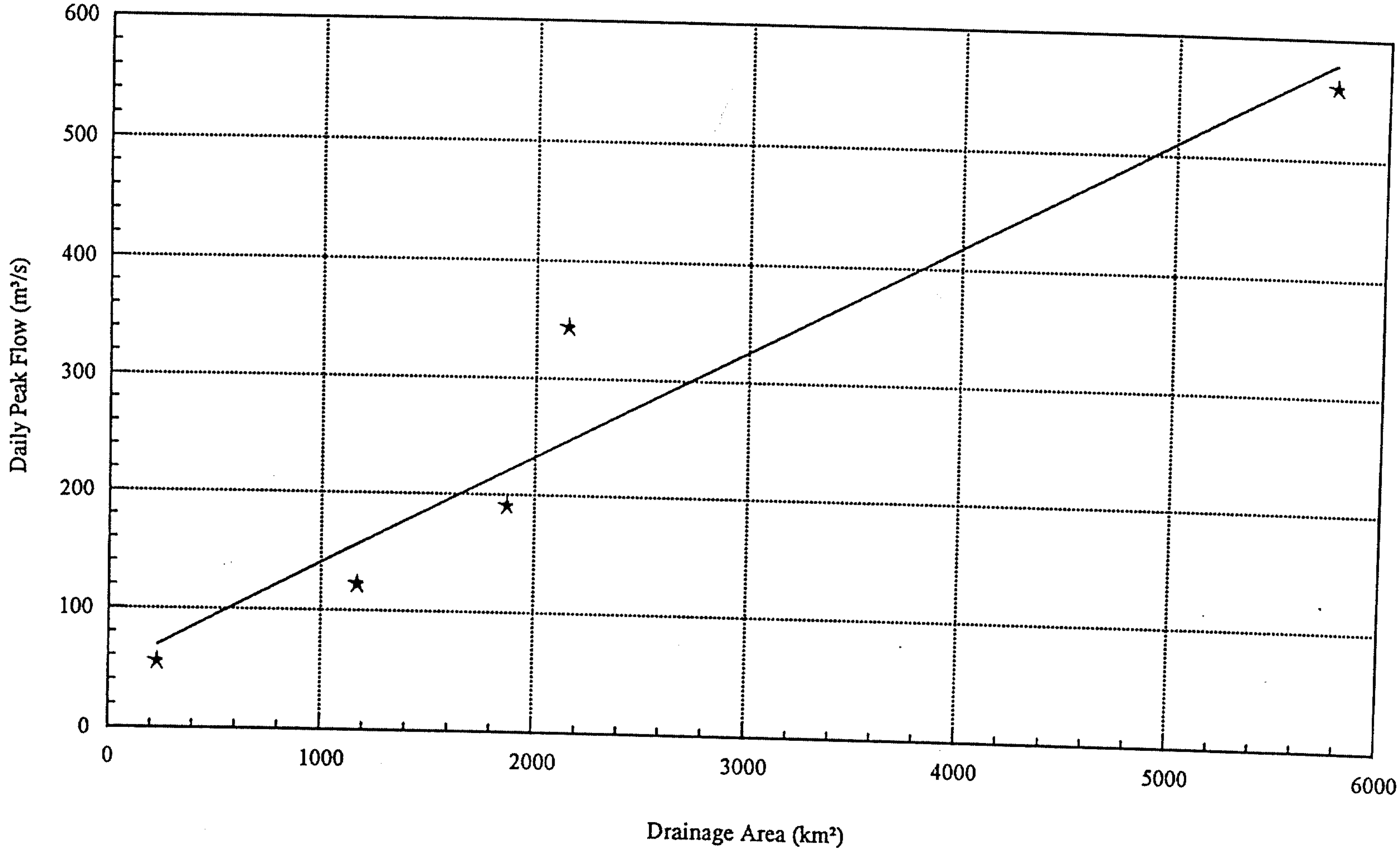
STA. 08NN001 — BOUNDARY CREEK AT GREENWOOD

GUMBEL TYPE I DISTRIBUTION

PARAMETERS ESTIMATED BY MAXIMUM LIKELIHOOD

ACRES

APPENDIX B - Frequency Relationships

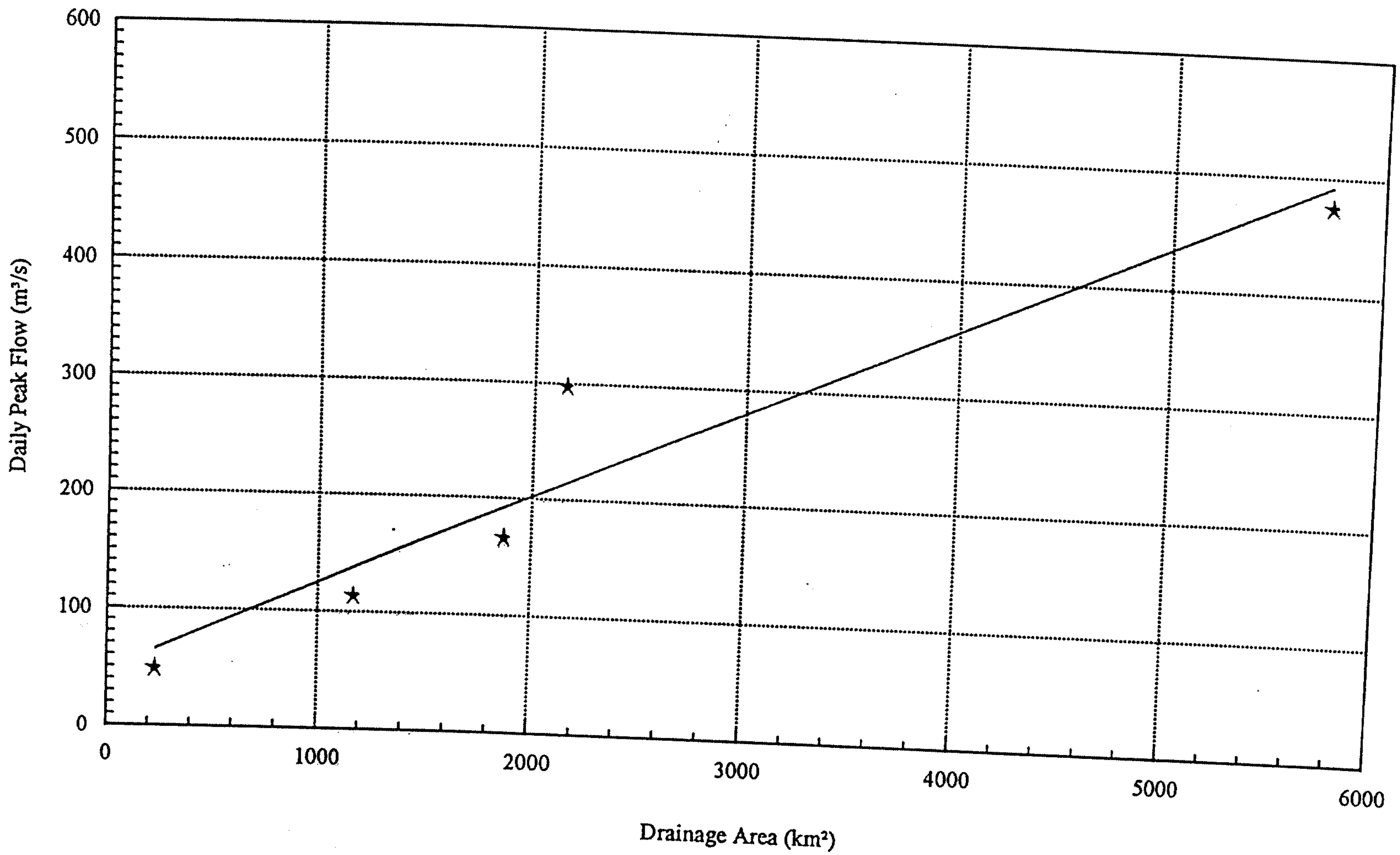


Kettle River Flood Study
200 Year Daily Peak Discharge vs. Drainage Area

ACRES

T1	A	B	C	D
1	Input	Output	y0	Residual
2	230	69.091	55.265	-13.826
3	1170	156.014	122.022	-33.9923
4	1870	220.745	190.449	-30.2955
5	2150	246.637	343.734	97.0974
6	5750	579.535	560.551	-18.9836

T2	A	B
1	Parameter	Value
2	a	47.8225
3	b	0.0924717

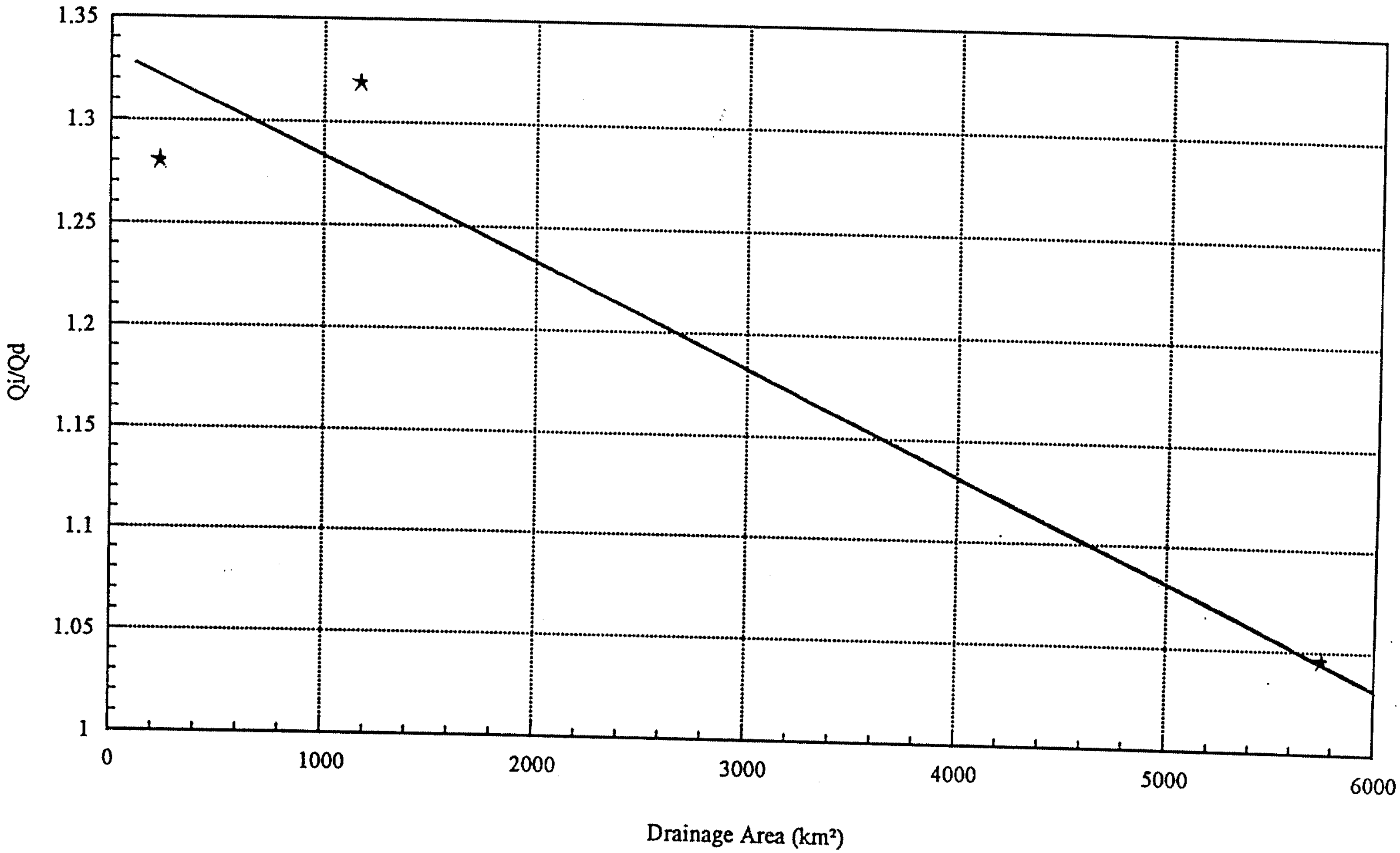


Kettle River Flood Study
20 Year Daily Peak Discharge vs. Drainage Area

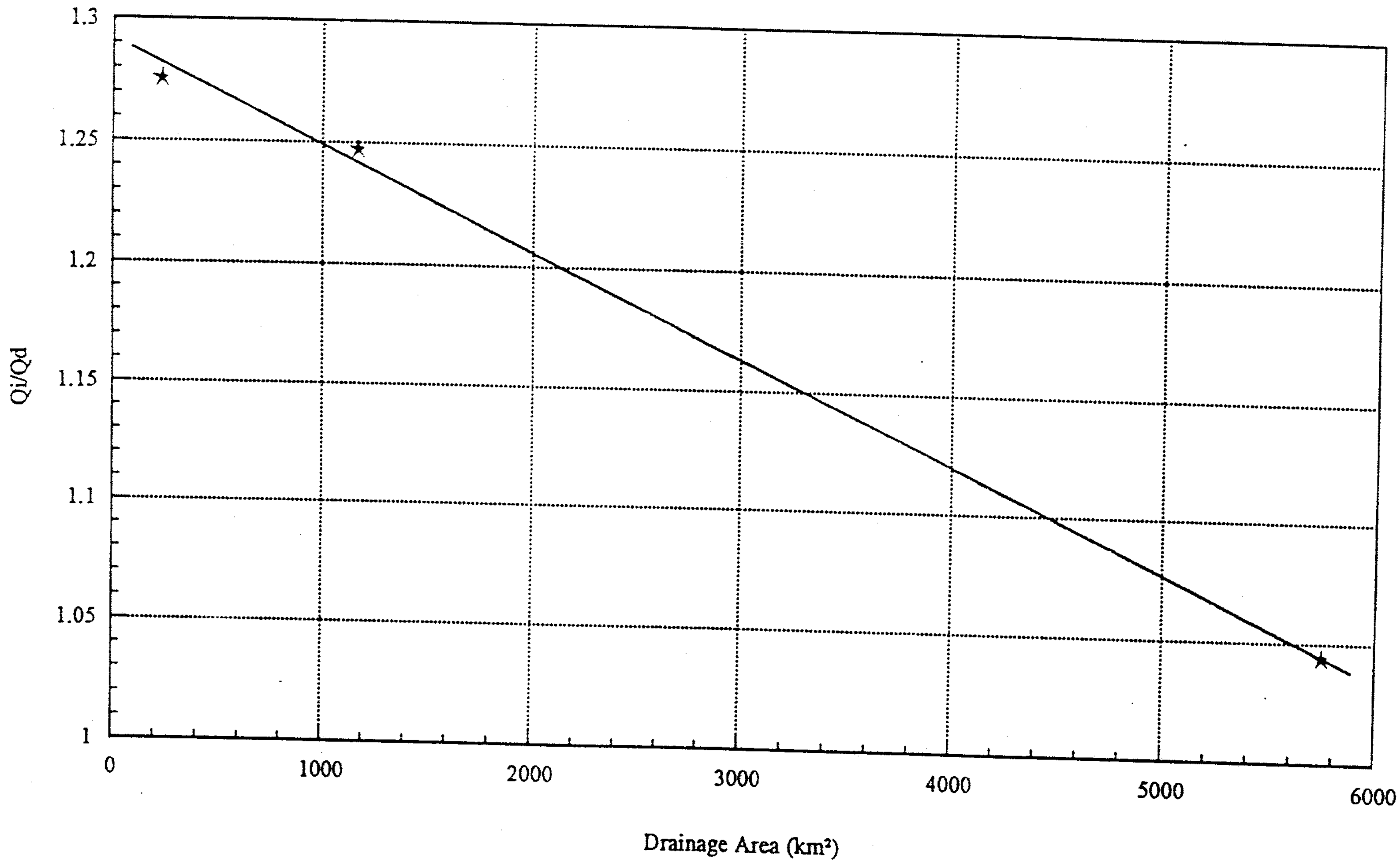
ACRES

T1	A	B	C	D
1	Input	Output	y0	Residual
2	230	65.065	48.975	-16.09
3	1170	137.848	113.654	-24.1938
4	1870	192.048	165.728	-26.3198
5	2150	213.728	297.546	83.8182
6	5750	492.471	475.256	-17.2145

T2	A	B
1	Parameter	Value
2	a	47.2564
3	b	0.0774285



Kettle River Flood Study
Qi/Qd vs. Drainage Area for T=200



Kettle River Flood Study
Qi/Qd vs. Drainage Area for T=20

ACRES