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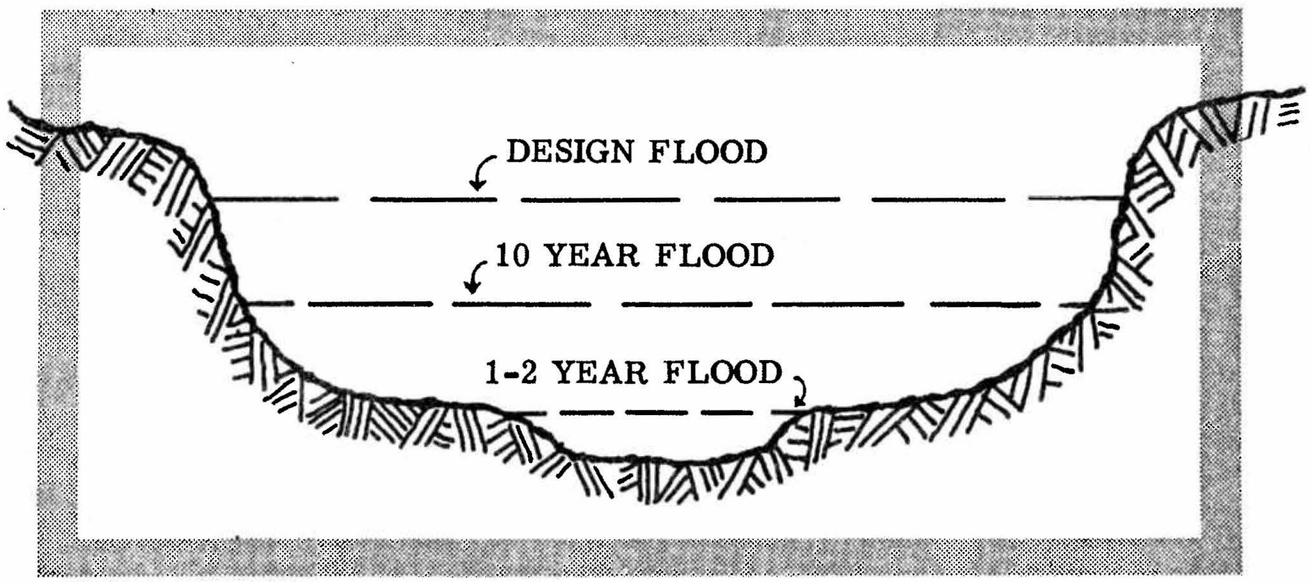
THE HYDROLOGIC DECADE

INTERIM REPORT ON

NATURAL STREAMS CROSS SECTION STUDY



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"NOT FOR PUBLICATION"

U.S. DEPARTMENT OF COMMERCE
Bureau of Public Roads

NATURAL STREAMS CROSS SECTION STUDY

by

Frank K. Stovicek

July 1965

FOREWORD

In the time when water resources engineering is getting more recognition from top government officials and scientific organizations, reflected by declaration of the

Hydrologic Decade,

Mr. William D. Potter, Hydrologist of the Bureau of Public Roads, initiated this study which is a contribution to the newest developments in international hydrology.

The author would like to express thanks to Mr. Potter for assigning of this large-scale project covering the eastern part of the United States as well as for enlightening and constructive comments on earlier drafts of this study.

The writer is also thankful to William P. Somers, Chief, Hydraulic Section of Surface Water Branch, USGS, for his help in selection of sites and for setting up an example of excellent cooperation between two federal agencies.

All concerned USGS District Engineers deserve commendation for cooperation and interest seen from many suggestions and offers of more information if needed.

A high degree of appreciation belongs to co-workers on this study to Mr. DeHaven, Technical Assistant, for long and patient processing of all basic data and Miss Stehman, Secretary, for her effort and willingness to retype many times the drafts and for typing of the final report.

Author

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ABSTRACT

Introduction. This hydrologic study is based on Potter's hypothesis that a stream writes its own life history in the shape of its channel and adjacent flood plain. As a background to this hypothesis were studies of flood occurrences, showing definitely that maximum annual peaks plotted on extremal probability paper define two frequency curves representing different populations.

The appearance of the transition period between the two curves, which was found to be in the range of five to ten years' frequency, generated the idea that somewhere in nature the streams would have expressed this difference of populations and transition during the formation of the stream bed.

This hypothesis was substantiated by other hydrologists who were looking simultaneously and independently into problems of hydrology in recent years.

Statement of Problem. The present procedures developed for estimating peak rates of runoff from small ungaged watersheds are still not satisfactory to many scientists as well as designers. The reason for these new studies in hydrology is to develop better methods which will enable engineers working in water resources development to make reliable estimates of the magnitude and frequency of flood flows.

Project Objectives. The objective of this project is twofold: first, to justify Potter's use of upper and lower frequency curve which represent two different populations of peak rates of runoff; and second, to verify findings of the pilot cross-section study that a relation exists between the magnitude of the ten-year peak rate of runoff and some characteristics of the stream cross section.

Scope of Work. The project will cover the eastern and middle parts of the United States. In this paper are the results of the first phase covering that portion of the country between the Atlantic Coast and 97th meridian.

Method of Study. The method of study is purely empirical and has no precedent in present hydrologic literature.

Results. The results obtained from ninety-five cross sections in the area of study verified that relationship between stream cross section and magnitude of peak rates of runoff exists and the estimate of the flood of the average recurrence interval of ten years is possible to make within a few days.

Field Use. The method of estimating Q_{10U} for use of the highway engineer is described. The designer must select and measure two or three stream cross sections and stream profile typical for the reach and make a proper selection of Manning's n for computation of discharge.

Limitations. The relationships established by this study are only applicable for streams that are generally free from any restrictions imposed on the natural development of their channel and flood plain.

Conclusions and Recommendations. The first phase of the study has shown very promising results. The reliability of the findings will increase with the number of watersheds included in the whole study.

With the ten-year frequency of stream flood established, there will be a possibility of further use of these data in connection with studies of floods of higher frequencies. The study which will show the relationship between the estimated ten years' frequency and fifty years' frequency is in development.

It is recommended that the second phase of this study be initiated and approved for the fiscal year 1966.

INTRODUCTION

The effort of scientists and engineers working in hydrology and hydraulics to find methods to estimate the magnitude or frequency of flood flows goes back into the last century.

Present Methods

The procedures now being used by state highway departments for estimating flood runoff fall into three general classes.

The first class originated during the latter part of the 19th century, and included formulas still being used by many state highway departments. Procedures falling in this class lump the effect of the many variables that affect runoff into one all-embracing coefficient "C". This coefficient is used in some unsubstantiated, empirical formula to obtain a peak rate of runoff of unknown frequency, which is then used as the basis for the hydraulic design of highway drainage structures.

The second class bases procedures on statistical sampling of selected variables on a regional basis. Frequency studies are made of the stream flow records for a selected sample of gaged streams within the region. One of two analytical methods is then applied to the data obtained from the frequency studies to derive a procedure for estimating peak rates of runoff from ungaged watersheds.

1. The first of these attempts to account for the variations in the magnitude of peak rates of some selected frequency by the introduction of two or more meteorologic or physiographic variables in a regression analysis.

2. The second method subdivides the region into varying numbers of hydrographic areas within which meteorologic and physiographic characteristics are similar. Correlation graphs of watershed areas and mean annual peak rates of runoff are then derived for each hydrographic area. Estimates of peak for other desired frequencies are obtained from composite

dimensionless graphs derived from the frequency curves of the sample watersheds.

Although the above procedures are statistically sound, the development presents some major difficulties described as follows:

a. To be reliable, a frequency study should be based on not less than 20-30 years of continuous stream flow records. For large sections of the country stream flow records for such minimum periods do not exist. Even when adequate records are available, a 20-30-year period is a very minute sample of the period comprising the entire life history of a stream and inferences on the magnitude and distribution of peak rates based on such small samples can be considerably in error.

b. Practically no data are now available on stream flow from small watersheds of 25 square miles or less in area. Many state highway departments now have contracts with the USGS that provide for the installation of stream gages for these small watersheds and for the analysis of the data when a sufficient record has been accumulated. However, as pointed out above, it will require approximately 20 years to acquire such a period of record.

The third class of procedures is based on an attempt to inventory precipitation that falls on a watershed in order to synthesize the record of the resulting stream flow. To accomplish this requires accurate knowledge of the mechanics that governs nearly every phase of the hydrologic cycle. Lack of such knowledge has forced researchers in this field to make many unproven assumptions in developing their procedures.

Although many procedures have been developed, none have been field tested to determine if they would produce accurate estimates of stream flow for watersheds other than those used in the derivation of the procedure. To determine estimates of peak rates of runoff for an ungaged watershed, it would be necessary to make frequency studies of synthesized peaks derived from a long-term precipitation record for the watershed. Unfortunately, such long-term precipitation records rarely are available.

New Developments

In recent years several hydrologists tried to find answers to the problem of estimating flood magnitudes and frequencies, in relating these events with stream valley development, more specifically, with stream cross sections and profiles.

POTTER[1], studying frequency curves of streams with natural flow, observed they exhibit a trend that might be defined by two straight lines designated as lower and upper frequency curves and suggested they are the result of sampling from two different populations of peak rates of runoff (Fig. 1, page 23).

Analysis of hundreds of stream runoff data confirmed Potter's conclusion that a frequency study is best expressed by two straight line curves--what he popularly called Dog-leg--and supported his assumption that these curves are the result of sampling from two different populations of peak rates of runoff.

The basic requirement for selection of stations in the analysis was that they are on streams with natural flow without any regulation and with natural stream bed not modified by man-made structures such as levees.

Potter assumed that peak rates of runoff in the lower part of the curve--Q_L--from zero to five years of frequency are functions of different variables than the peak rates in the upper part--Q_U--from ten to fifty years of frequency or more.

This observation could be expressed by the following equations:

$$Q_L = Q_{RI<5} = f_1(A) + f_1(P) + f(Inf.) + f(Perc.) + f(S.m.) + $$
$$+ f(W.h.c.) + f(L.u.) + \dots f(O.v.)$$

1 Designates reference on page 17.

That means that Q_L or Q with the recurrence interval smaller than five years is a function of small area, certain precipitation, infiltration, soil moisture, water holding capacity, land use, and other variables.

The Q_U can be expressed by relation:

$$Q_U = Q_{RI \geq 10} = f_2(A) + f_2(P) + f(L) + f(S) + f(D.d.) +$$

$$+ f(St.) + \ldots f(O.f.)$$

That means that Q_U or Q with recurrence interval equal or greater than ten years is a function of another area (larger), different precipitation (large storms), length of stream, slope, drainage density, storage, and other factors.

The above-mentioned idea of two frequency curves and the assumption of two different populations of peak rates of runoff, lead to the following line of reasoning.

If the assumption of two families of curves is true, then the work done on a stream channel by the two populations of peak rates of runoff should present discernible differences in the characteristics of the stream bed.

Since the stream bed is shaped by various stream flows, then a relationship must exist between various characteristics of the stream bed and the magnitude and frequency of the stream flow.

These subsequent ideas were the background to Potter's hypothesis that a stream writes its life history in the shape of its channel and adjacent flood plain. If this hypothesis is correct, then the stream flow defined by the stage or elevation of the water surface for peak rates of runoff of different average frequencies should correspond with some definable characteristics of the stream cross section. This should be particularly true for peak rates having an average recurrence interval of one in ten years (Q_{10}) as this recurrence interval defines the boundary between two different populations of peak rates of runoff.

In order to test this hypothesis, a pilot study of five selected watersheds in North Carolina was made (unpublished, 1963). The necessary basic data for each watershed and the cross sections at the gages with pertinent rating tables were received from USGS District Engineer in Raleigh, North Carolina.

The objective was to determine if some relationship exists between characteristics of the stream cross section and magnitude of the peak rate of runoff having an average recurrence interval of one in ten years.

Frequency studies were made for the maximum annual peaks for each of the five selected watersheds using Potter's upper and lower frequency curves.

After numerous attempts to find corresponding or related factors, a plot of cross-section area versus gage height on semi-logarithmic paper showed a consistency in flattening in certain sections of the curve where a point of tangency could be determined.

Readings of gage heights at the points of tangency were made and the corresponding Q's were determined from the stage discharge relations and compared with those from the split frequency curves. The points were always in the vicinity of Q_{10U} and this led to the belief that some relation between the cross section and floods with an average recurrence interval of ten years existed.

The pilot study produced very promising results and was an impetus for this project.

Potter's hypothesis was substantiated by other hydrologists who were looking simultaneously and independently into similar or related hydrologic problems. Excerpts from references related to the concept of this study are on page 18-22.

On the following pages is described the first phase of the project covering that portion of the country between the Atlantic Coastline and approximately the 95th meridian.

STATEMENT OF THE PROBLEM

Every highway bridge or drainage structure is designed for some estimated peak rate of stream flow.

The primary and most difficult problem for the highway engineer is to find out from available information which peak rate of runoff should be used as a design discharge. The problem becomes much more difficult when information for design are not available, which is especially true on small ungaged watersheds.

The designer has to determine the magnitude and frequency of such discharge as well as the probability of its exceedence a short time after construction, including the risk of possible damages to property and life.

Considered from an economic standpoint, if the discharge or flood estimate is too high, the first cost of structure will be too high. On the other hand, if the estimate is too low, the cost of maintenance and possible early replacement of the structure will be excessive.

Somewhere between these extremes lies a most economical design.

From a safety standpoint an underestimate that would create a frequent flooding of a high speed highway and adjacent property would result in many accidents, property damage, or the loss of lives and property including the possible loss of the whole structure.

Thus, the design data for the most economical structure must be modified by the risk factor which provides for safety of lives and property.

The secondary problem for a designer, however of equal importance, is to find a short, simple and reliable method for estimating flood discharges which would eliminate the loss of time due to long investigation procedures connected with the search for design data. The method should also eliminate use of personnel from related sciences as geology, soil sciences, geomorphology and etc. These specialists are rarely available during the design phase of highways.

In summary, it is very important that simple procedures be developed that will enable the highway engineer to make reliable estimates of the magnitude and frequency of flood flows for small gaged or ungaged watersheds within the shortest possible time.

THE PROJECT OBJECTIVES

Two prior Potter's studies indicated a new breakthrough in a basic research concept in hydrology which, if verified, would have a great significance for future development in this scientific field.

The first one, "Upper and Lower Frequency Curves for Peak Rates of Runoff," has shown that when maximum annual peak rates of runoff are plotted on extremal probability paper, they define two frequency curves representing different populations.

The second one, the pilot cross-section study, has shown that relationship exists between characteristics of the stream cross section and the magnitude of the peak rates of runoff having an average recurrence interval of one in ten years.

The objective of this project is twofold: first, to justify Potter's use of upper and lower frequency curve which represent two different populations of peak rates of runoff; and second, to verify findings of the pilot cross-section study that a relation exists between the magnitude of the ten-year peak rate of runoff and some characteristics of the stream cross section.

SCOPE OF WORK

The Work Schedule

The project has been divided into two phases. The first phase described in this interim report covers that portion of the country between the Atlantic Coastline and approximately the 95th meridian. The second phase will include that portion of the country between the 95th and the 105th meridian. It is planned to complete this phase by the end of fiscal year 1966, at which time a final report will be published covering both phases of the project.

If this project proves to be successful, it is planned to initiate a second one that would cover the balance of the country from 105th meridian to the Pacific Coastline.

Selection of Stations

This study includes 95 recording gaging stations selected in the eastern United States. The data, i.e., rating curves and cross sections, were obtained from USGS district offices through the central office of USGS, Surface Water Branch, Hydraulic Section. Location of stations is shown on Fig. 2, page 24.

The basic requirement for selection of stations was that they are on natural streams with channels not modified by man-made structures. The fundamental idea was that any significant change of the streams' natural conditions would have effect on their hydrologic equilibrium and, hence, on collected frequency data, cross sections and rating curves.

Only a few deviations from the above criteria were made. Few streams with negligible low flow regulation were included because in some areas it was impossible to find virgin flows. Also some bridge cross sections or sections close to bridges were added where the natural conditions of river bed under the bridge remained unchanged. These were included in order to obtain better sample distribution.

Other criteria included the condition that maximum drainage area should be approximately 400 square miles and the length of record should be a minimum of twenty years.

For the practical purposes data of stations from previously published Potter's studies were updated and used. Also selection of some stations was made from USGS list of selected gaging stations in the United States (1961) made by C. R. Gamble (report prepared for SCS, Department of Agriculture).

Preparation of Essential Material

For each selected gaging station having rating curve or table and cross section drawing it was necessary to develop and plot the split frequency curve on extremal probability paper. The rating curves and the cross-section area-stage curves were plotted on semi-logarithmic paper. In both cases the gage heights were shown on the linear scale.

All above described preparatory work, the selection of stations, request to USGS for pertinent data, evaluation of received material, and finally the development of data desired for the study was done continuously during the past year.

THE METHOD OF STUDY

This study is entirely empirical and the reliability of conclusions reached in this first phase will increase with the number of watersheds included in the sample used in the whole study.

The aim is to determine the boundaries of the area of applicability which could be done only by processing several hundreds of stream cross sections.

The study is based on the hypothesis that a stream writes its own life history in the shape of its channel and adjacent flood plain.

If this hypothesis is true, then the stage or elevation of the water surface for peak rates of runoff of different average frequencies should correspond with some definable characteristics of the stream cross section.

This should be particularly true for peak rates having an average recurrence interval of once in ten years (Q_{10}) as this recurrence interval defines the boundary between different populations of peak rates of runoff. Q_{10} values at the point of crossing with the upper frequency curve were read and designated as Q_{10U} as shown on split frequency curve taken from the study (Fig. 3, page 25).

The procedure followed is one of selective sampling of gaged streams that have long periods of record and which drain watersheds of limited area.

For each sample watershed tabulations were made of the accumulated stream cross-section area starting at the channel bottom and proceeding upward for each selected increment of stage until the cross section included an appreciable amount of cross-section area flow. A sample cross section taken from the study is shown on Fig. 4, page 26.

When the accumulated cross-section area is plotted on the logarithmic scale of semi-logarithmic graph paper against corresponding values of stage plotted on the linear scale, the plotted points define a curve with various rates of curvature until a stage is reached beyond which the curve approaches a straight line. At this stage, a point of tangency can be determined (Fig. 5, page 27). The peak rate of runoff corresponding to this stage is obtained from the rating curve of the stations (Fig. 6, page 28) and tabulated as the estimated ten-year peak - $\hat{Q}_{10U}$. The difference between the estimate and the value of Q_{10U} obtained from the split frequency curve of the measured maximum annual peaks is tabulated as error and is expressed as a percent of the estimated value (Table 1, Col. 8, page 30).

In order to observe the distribution of positive and negative signs, also actual differences, values of Q_{10U} and $\hat{Q}_{10U}$ were tabulated and are shown in Table 1, Col. 7. A brief check of the tabulation indicates that the sample provides unbiased estimates of $\hat{Q}_{10U}$.

The above described method was used for all 95 stations included in this interim report.

RESULTS

The results of this interim report meet both objectives as outlined in the project prospectus.

The study strengthens the hypothesis of the two families of peak rates of runoff and illustrates that the transition between these two families of peaks can be identified by the study of the characteristics of the stream cross section. The study shows that this transition occurs for peaks having an average recurrence interval of once in ten years.

The results also show that the method does not require long-time stream records as the estimated water level for a flood with ten years' recurrence interval is given by the cross-section characteristics of the natural stream.

Besides the objectives as set forth in the prospectus, the study supports the findings of others as pointed out in the recommendations and in excerpts from references.

The stations in the sample are arranged in alphabetical order of states and numbered 1 to 95. The basic and resulting data of the study are shown in Table 1, page 30.

Column 1 indicates the number of station in the study, column 2 shows the states where gages are located, and column 3 refers to the number of station as published in USGS Water Supply Papers (1960 compilation).

In column 4 are the drainage areas of stations and column 5 shows the Q_{10U} as determined from the split frequency curve.

Column 6 showing the $\hat{Q}_{10U}$ is divided into two parts. In subcolumn "a" are gage height readings from cross-section area curves at the point of tangency, and in subcolumn "b" are discharges corresponding to these gage heights as read from the rating curves.

Column 7 lists the differences of $\hat{Q}_{10U} - Q_{10U}$ (column 6b - column 5) in 1000 cfs. These differences with signs plus or minus are the errors in $\hat{Q}_{10U}$ which are expressed in column 8 in percent of $\hat{Q}_{10U}$.

We can observe in the table well-distributed positive and negative signs which are indicative of an unbiased sample. There are 56 positive and 38 negative signs of estimated error; one value is $\pm$ 0.

For better illustration of the reliability of results, a curve was drawn which shows the distribution of error for $\hat{Q}_{10U}$. The curve shows that for 68% of the sample the maximum error is $\pm$ 11%, and that for 95% of the sample the maximum error is $\pm$ 23%. Since the maximum error for 95% of the sample is approximately twice of the maximum error for 68% of the sample, the error distribution may be assumed as normal.

The tabulation of data for the error distribution curve is shown in Table 2, page 33, and the curve, Fig. 7, page 29.

In order to show the balance among drainage areas as far as size is concerned, another table, Drainage Area Distribution, has been added (Table 3, page 34).

The results of this study should be of very high value to the design highway engineer as this method of estimating is as reliable as any other present day method, but does not require long-time stream records and time-consuming preparation of frequency curves, as the necessary data are given by the cross-section characteristics of the natural stream.

THE FIELD USE

The estimating of floods with different recurrence intervals on ungaged streams is a very difficult and laborious work. The method offered in this study for determination of Q_{10U} is meant as practical help to highway engineers facing this problem.

As a first step, the designer should select two or three stream cross sections typical for the reach in the vicinity of the proposed highway crossing. The distance between sections depends on the channel condition. The basic requirement is that the channel slope is fairly uniform, i.e., the mean velocity in the reach remains constant. When such conditions exist, the distance between cross sections should be about 1,000 feet.

Measuring of cross sections and profile of the reach by survey crews should be precise in order to get the true shape of stream bed geometry. Plotting of the cross sections and elevation area curves should be accurate if the point of tangency is to be clearly identified. The points of tangency on all elevation area curves, plotted on the profile of the reach, designate the water level of a flood with an average ten-year recurrence interval.

The practical criterion for correctness of water surface plotting is that the profile of the average ten-year flood stage should plot approximately parallel to the longitudinal profile of the water surface at some given discharge through the reach, for example, bankfull flow.

Knowing the cross section area A under the ten-year flood level and using Chezy's formula for $V = C\sqrt{RS}$, the Q_{10U} is computed from equation $Q = AV$. In the formula for V, hydraulic radius R and water surface slope S are known. The only unknown is coefficient C depending mainly on the roughness of the stream bed and on hydraulic radius.

Most commonly used formula for determination of C is Manning's $C = \frac{1.486}{n} R^{1/6}$ where proper selection of n is the only requirement imposed on the engineers' judgments.

The detailed procedures for computation of the discharge in a stream reach are given in USGS Water Supply Paper 888, page 81, in the section dealing with measuring of discharges by slope-are method.

LIMITATIONS

The relationships established by this study are only applicable for streams that are free from any restrictions imposed on the natural development of their channel and flood plain. Such restrictions may be physiographic as when the stream channel is bounded by steep rocky slopes, or man-made as when the stream flow is significantly constricted by a bridge or regulated by a reservoir.

Undoubtedly, there will be other restrictions which can be only found by additional sampling.

CONCLUSIONS AND RECOMMENDATIONS

The first phase of the project has shown promising results. The study substantiated Potter's hypothesis that the stream writes its own life history in the shape of its channel and adjacent flood plain.

Using the split frequency curves in the study, the relationship between characteristics of the stream cross section and magnitude and frequency of peak rates of runoff has been found. The reliability of results reached in this first phase will increase with the number of watersheds included in the whole project.

It is believed that the study though purely empirical will be a significant contribution to the new concept in the stream hydrology investigated by several scientists in recent years. It might provide a basis for other hydrologic or related studies.

It would be highly desirable if highway engineers would further field check the procedures described in this report on natural streams in the area covered by this phase of the study.

It is recommended that the second phase of the study be initiated and approved for the fiscal year 1966.

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EXCERPTS FROM REFERENCES

In recent years during the development of Potter's hypothesis several hydrologists were looking independently into similar or related hydrologic problems. For convenience of the reader, the author selected from references a few ideas related to the concept of this study.

WOLMANN and LEOPOLD [2] during the study of flood plain formations observed that the frequency of overbank flow is remarkably uniform in many rivers in diverse climatic and physiographic regions.

Frequency data from eastern and western United States and the examples from India showed that in most cases the bankfull flow is attained or exceeded every year or every other year, i.e., recurrence interval of bankfull flow was 1-2 years.

LEOPOLD [3] writing about rivers, their forms, and systems pointed out that the first and most important aspect of the river is that it is self-formed and self-maintained. The flowing water carves the groove in which it flows. The water fashions the depth, the cross section, the area configuration, and the longitudinal profile.

Existing river channels had a history in many respects analogous to the history of a species in the biological world.

CARLSTON [4] dealing with transmissibility of terrane stated: "It has been assumed by hydrologists and geomorphologists that certain relations must exist between runoff characteristics and topographic or geomorphic characteristics of stream basins.

Much effort has been devoted to statistical correlation of these relations without a clear understanding of how runoff is related to the geomorphic and geologic character of the basins."

KILPATRICT and BARNES [5] found that bankfull depth was defined by the average elevation of the widest bench which could be traced along a considerable reach of stream channel.

The consistency of this relation for the 34 study sites in the Piedmont area demonstrated that the elevation and slope of valley benches were significantly related to the frequency of flood discharge.

Thus, the authors confirmed the findings of Wolmann and Leopold. What they probably did not realize was that the small benches, Nos. 2 and 3, indicated another relation to the frequency of flood discharge.

Using Potter's split frequency curves and procedures described in this paper, the authors would be able to establish the frequency of flood discharge for some benches Nos. 2 and 3.

ROSSOMAKHIN [6] in his paper dealt with the changes in the characteristics of the transverse profiles of the valley along the lengths of the Irtysh River and with the problems of defining the relative elevation zones of the valley and their inter-relationship with the water stage regime sediment and most recent tectonic movements.

He analyzed the shape of the cross sections of the valley and the methods of constructing the graphical relationship of flooded areas to water levels.

For the identification of relative elevation zones by means of dividing planes in cross sections, the author introduced the graph of the relationship:

$$B = \psi(H) \tag{1}$$

where B is the width of innudation and H is elevation of water surface.

To obtain the innudation areas of flood plain by floods of any design frequency, another curve, $F = \varphi(H)$, was drawn showing the relationship between the water levels at some reference section and the corresponding areas of flooding.

The innudation area of flood plains are function of three variables:

The water level	-	H
The width of flooding	-	B
And the length of the investigated segment of the valley	-	L

In the plan, for certain water level H, the innudation area of the flood plain is expressed by the formula:

$$F = BL \tag{2}$$

When the assumption is made that in a given segment of a river the length L is a constant, then the flooded area is basically the function of water level H and the width of flooding B or:

$$F = \phi (H, B) \tag{3}$$

However, the width B is a function of water level H expressed previously by relationship (1) and hence:

$$F = \varphi (H) \tag{4}$$

In the case of a small river segment, where L = 1, i.e., cross section, the equation (2) shows that F = B and then it is necessary to investigate the function $B = \psi (H)$.

This expression means, that the relation between the variables has to be found in the study of stream cross section.

The graphical analysis of the function $B = \psi (H)$ have shown a curve with two inflection points which are determined by the morphological characteristics of river valleys with developed flood plains. The first inflection point corresponds to the lower boundary of zone III. The second corresponds to the upper one. The Russian observation of inflection points, i.e., transition in the curve and cross section, and Potter's tangents, are both explained by change in morphological characteristics of river valleys.

It would be interesting to know in the Russian study the relation between frequency of floods and water levels at the inflection points. The points might be approximate locations of boundaries for 3 to 10-year flood frequencies, as indicated by description of zone III.

POPOV [7] in his study discussed hydromorphological principles of the theory of channel and their use in hydrotechnical planning.

This paper confirms Potter's station selections in pointing out that regulating of river flow is inevitably leading to a change in the course of the deformations of river channels and flood plains, their re-forming not only along river reaches but also in the tributary system of the rivers.

KAZMANN [8] discussing problems of stream regimen proposed a concept of "hydrologic equilibrium" and "hydrologic non-equilibrium" to differentiate the methodology of "classical" hydrology from that of the "new" or "modern" hydrology.

These "new" problems are caused by the "non-goodness" of observed hydrologic data, that has resulted as a "side effect" of current programs in water resources development.

The "old" or "classical" problems of hydrology are based on the proposition that the observational data in hydrology are statistically similar in the character to data pertaining to other natural phenomena.

According to his classification, this study of "virgin" or natural streams is made in the field of "classical hydrology."

TRESTMAN [9] in his study of hydrometeorological services discussed the problems of hydrometry with special emphasis laid on the relation between stream discharge variation and change of stream bed geometry.

The purpose of the study was to increase the quality of hydrometric work in connection with computation of stream runoff.

The author stated that every cross section of a river has its specific water regime which calls for close study. The analysis of stream cross-section area curve is presented on page 48 of the reference book.

STOVICEK, author of this interim report, added another idea for observation of physiographic changes in the cross sections.

The plots of elevation area curves have shown in most cases two different types of curves. One type was a continuous curve with a section of maximum curvature, the other type was a curve with two inflection points.

If Potter's flattening of curves or minimum curvature (tangents) indicates change in the natural valley shape and it was observed as one extreme, then the maximum curvature or inflection points located below the tangent on these curves could be observed as another extreme.

It was found that the cross sections without clearly defined flood plains define a curve which on semi-logarithmic paper is a continuous one, and the point of maximum curvature indicates a change in geometry of the cross section and lies on elevation indicating bankfull stage (1-2-year frequency).

In the cross sections with clearly defined flood plains the curve shows two inflection points of which the lower one, if located in the cross section, shows the elevation of transition from bankfull flow to overbank flow, i.e., 1-2-year frequency.

A brief check of this observation has been made on several stations included in this study and the results were positive. The observation, if verified, would help to determine Wolmann and Leopold's bankfull flow theory. These preliminary trials suggest that the check should be made on all cross sections included in the final report of the cross-section study, and the results tabulated and analyzed.

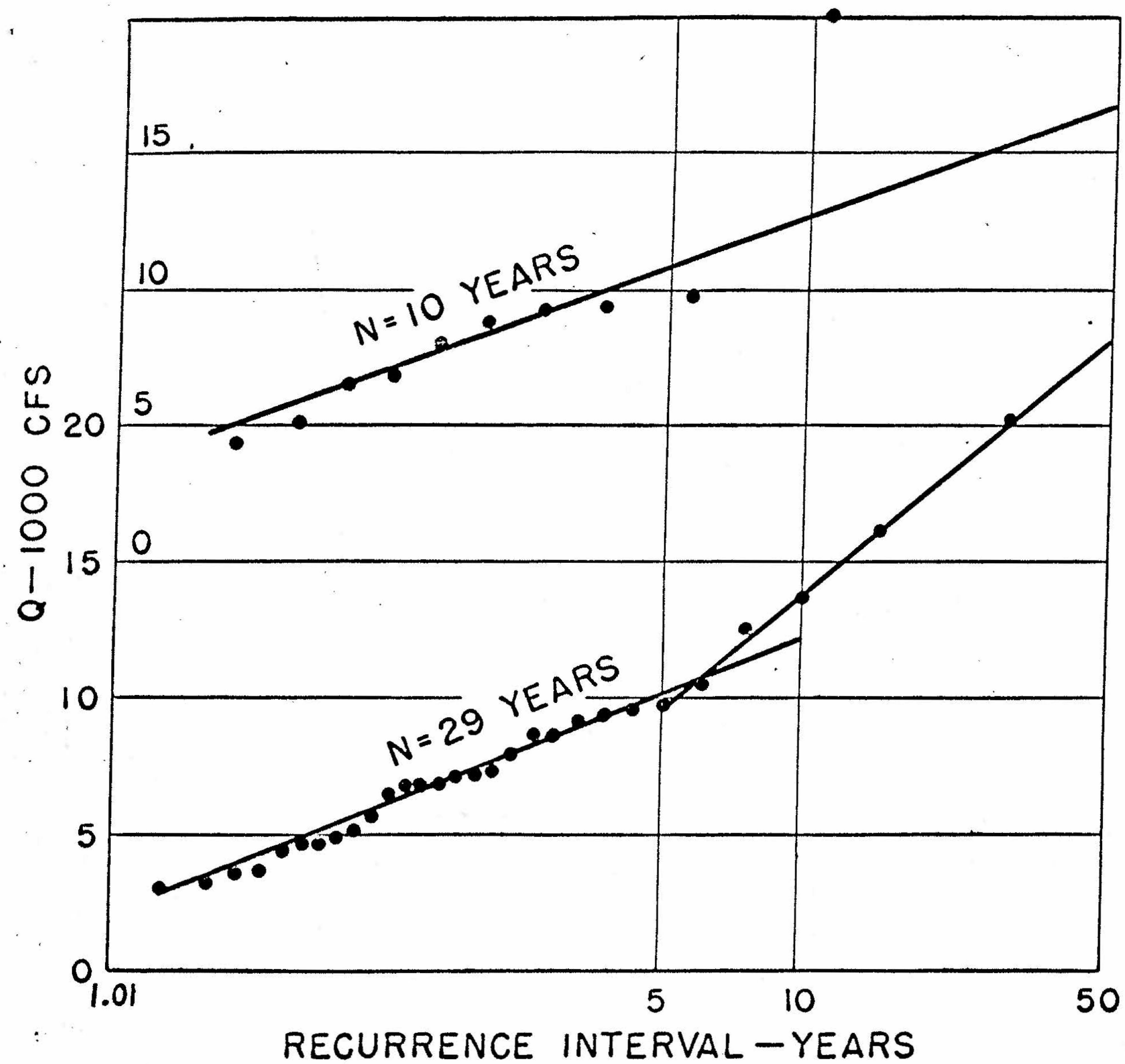

Figure 2. Frequency curves -- Flat R. at Bahama, N. C.

Figure 1. Split Frequency Curve--Potter, TAGU, 1958

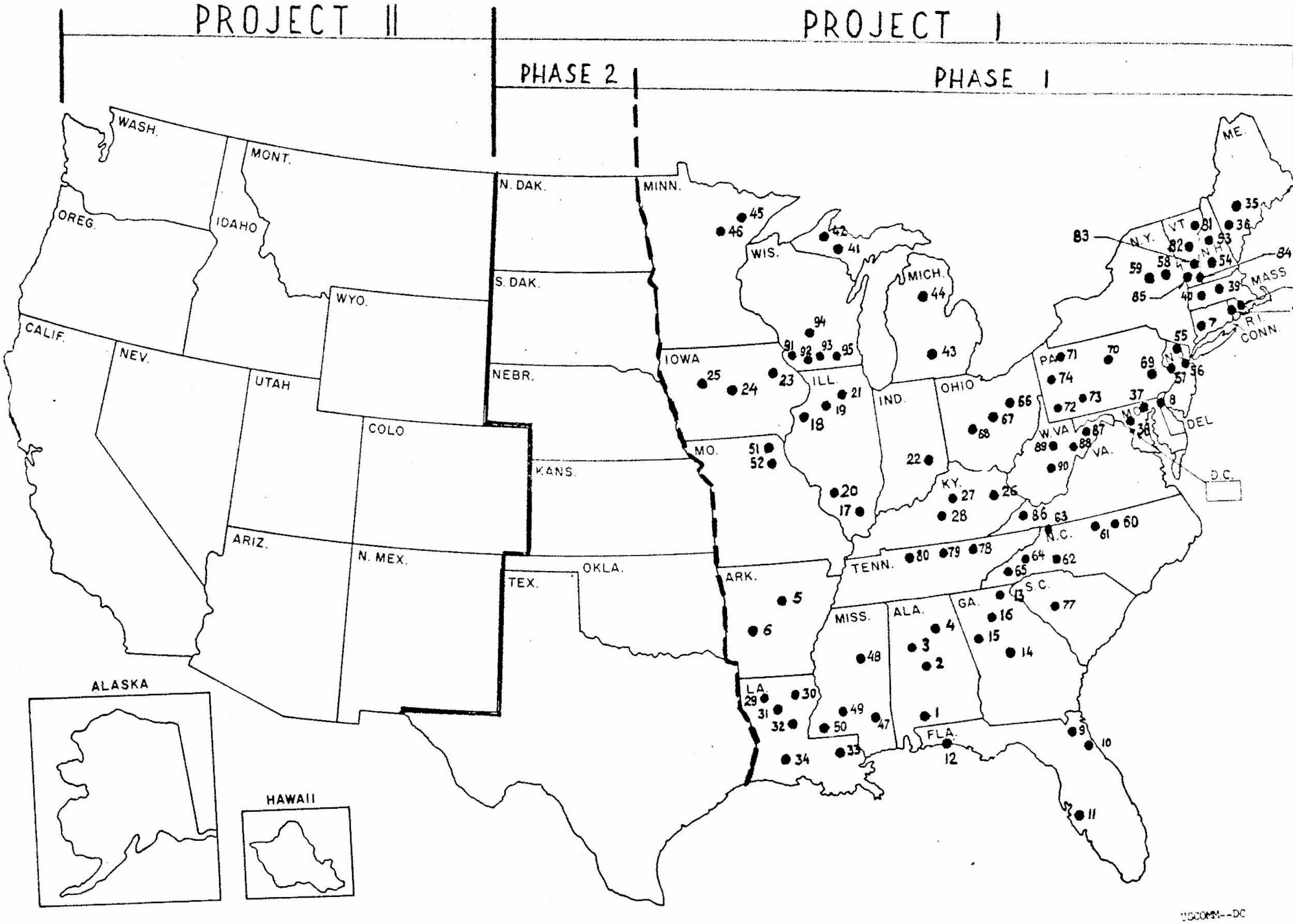

Figure 2. Location Plan of Stations in Study

F.K.S.

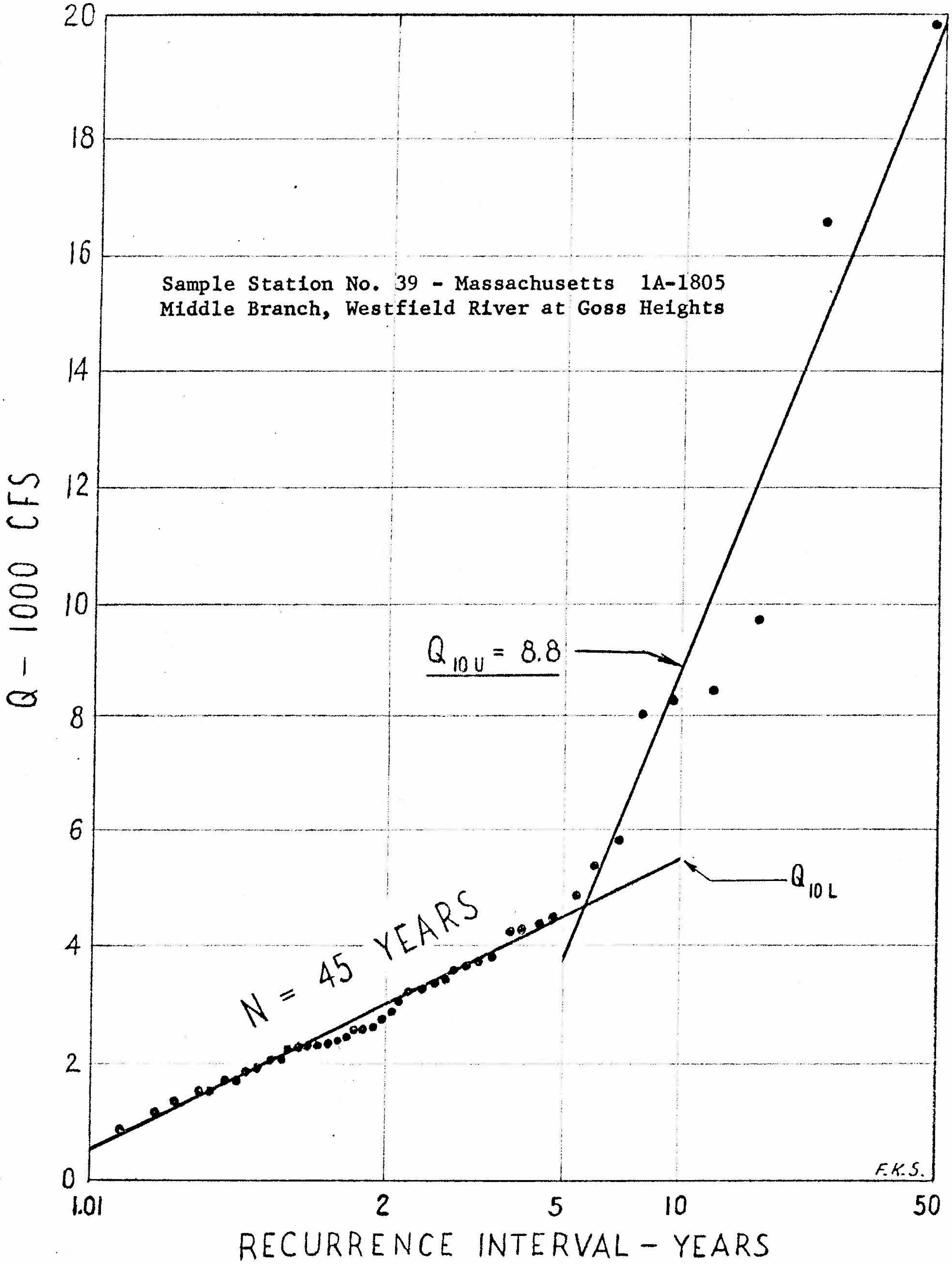

Figure 3. Typical Split Frequency Curve From the Study

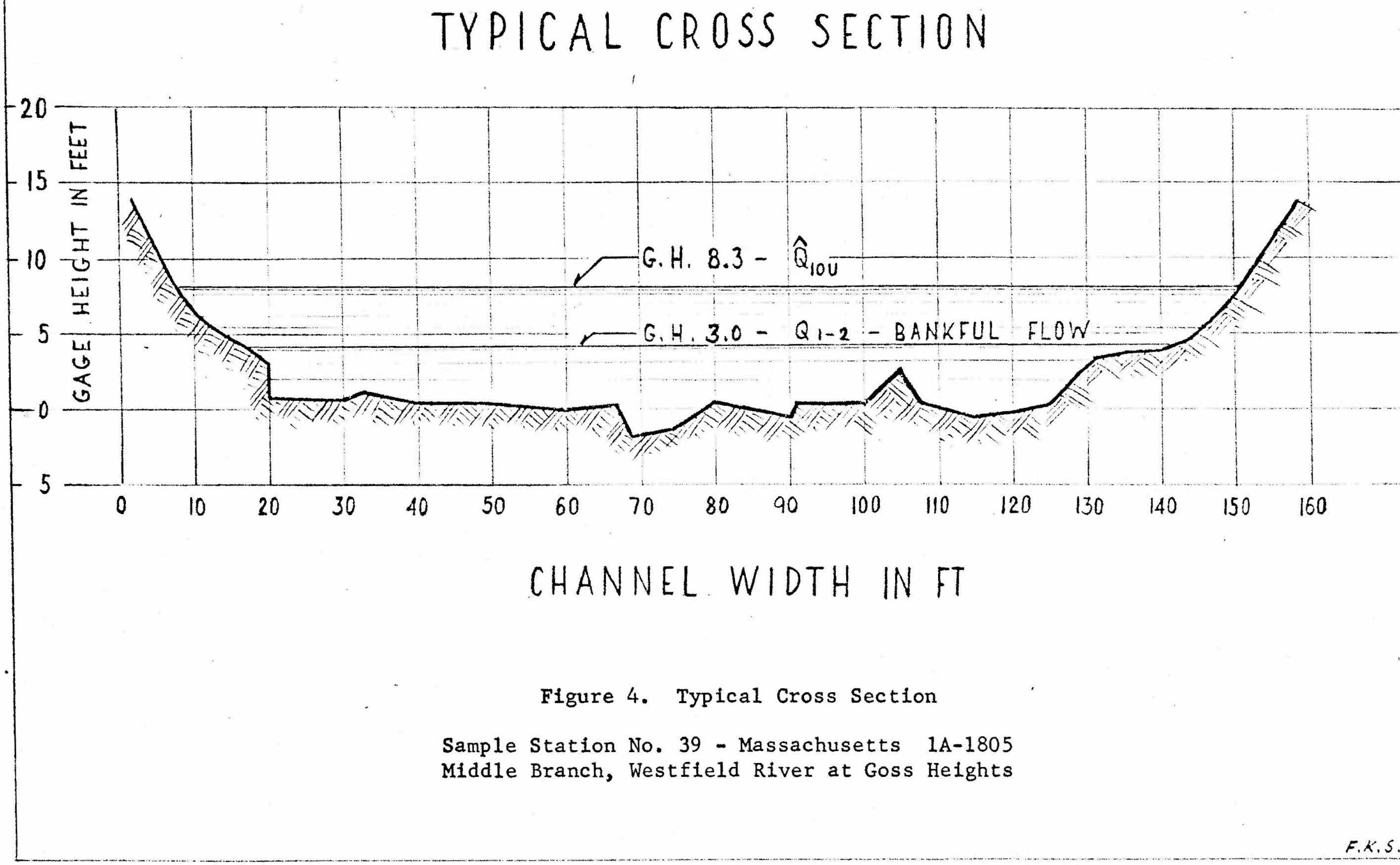

Figure 4. Typical Cross Section

Sample Station No. 39 - Massachusetts 1A-1805
Middle Branch, Westfield River at Goss Heights

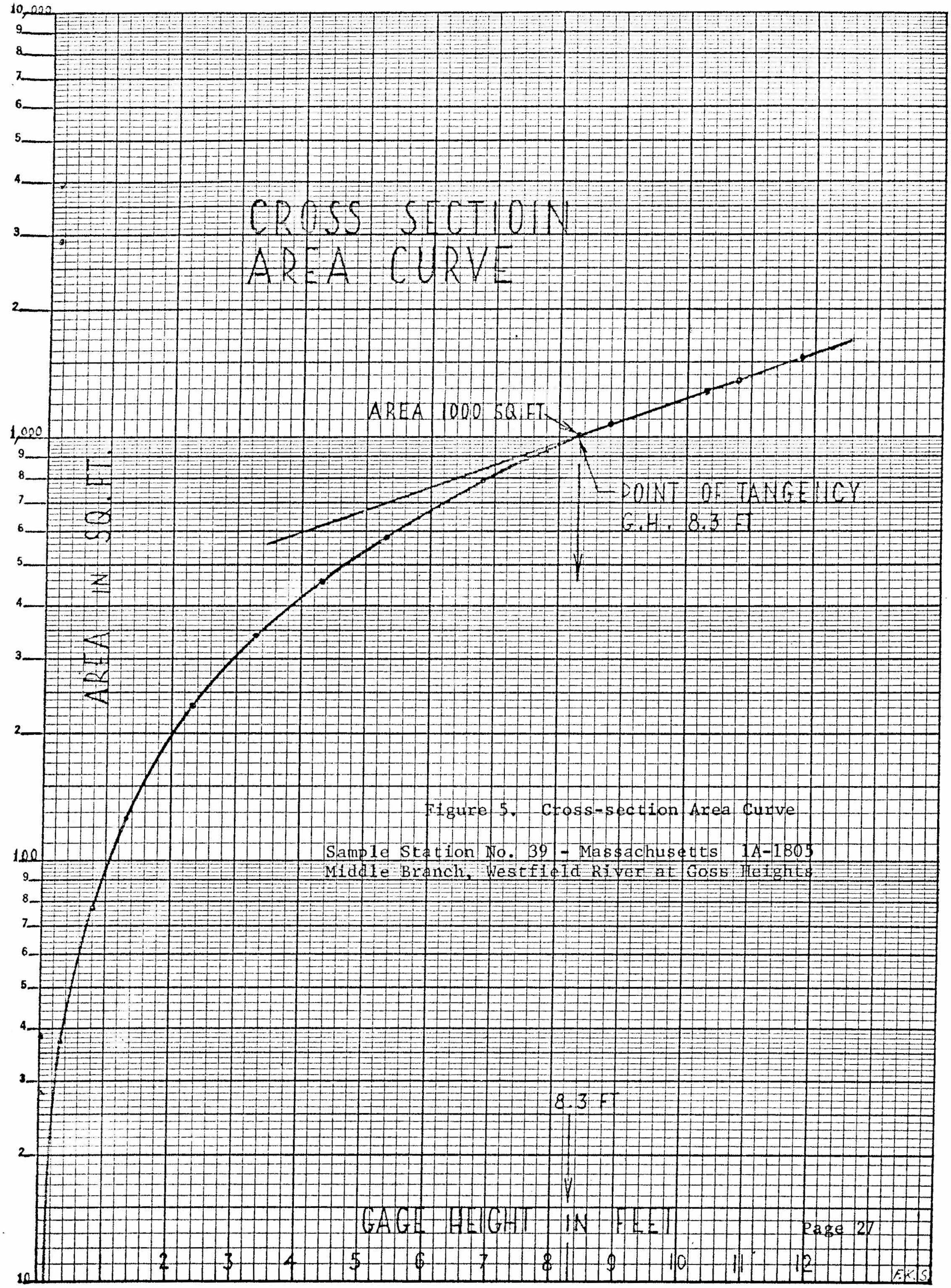

Figure 5. Cross-section Area Curve

Sample Station No. 39 - Massachusetts 1A-1805
Middle Branch, Westfield River at Goss Heights

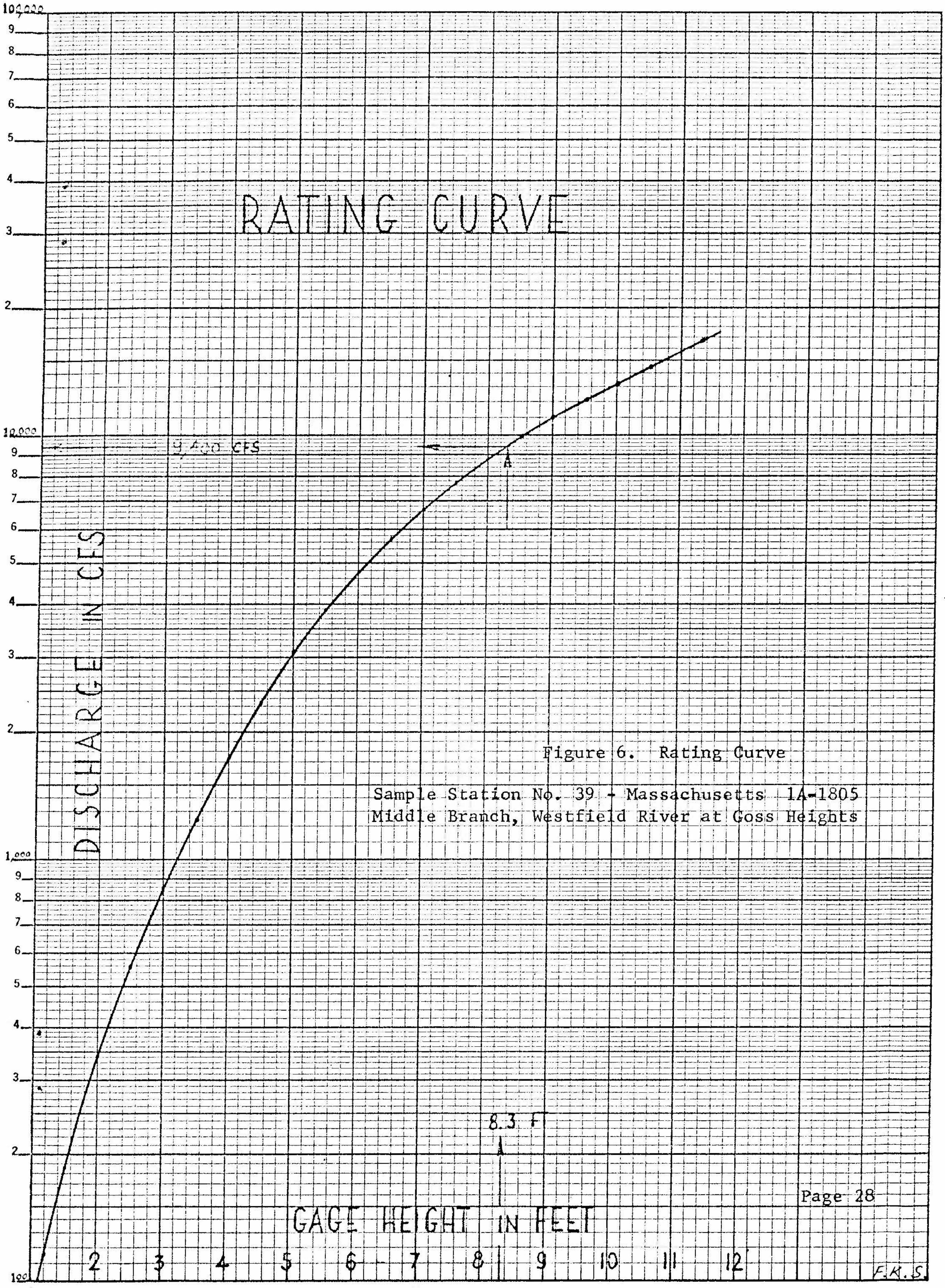

Figure 6. Rating Curve

Sample Station No. 39 - Massachusetts 1A-1805
Middle Branch, Westfield River at Goss Heights

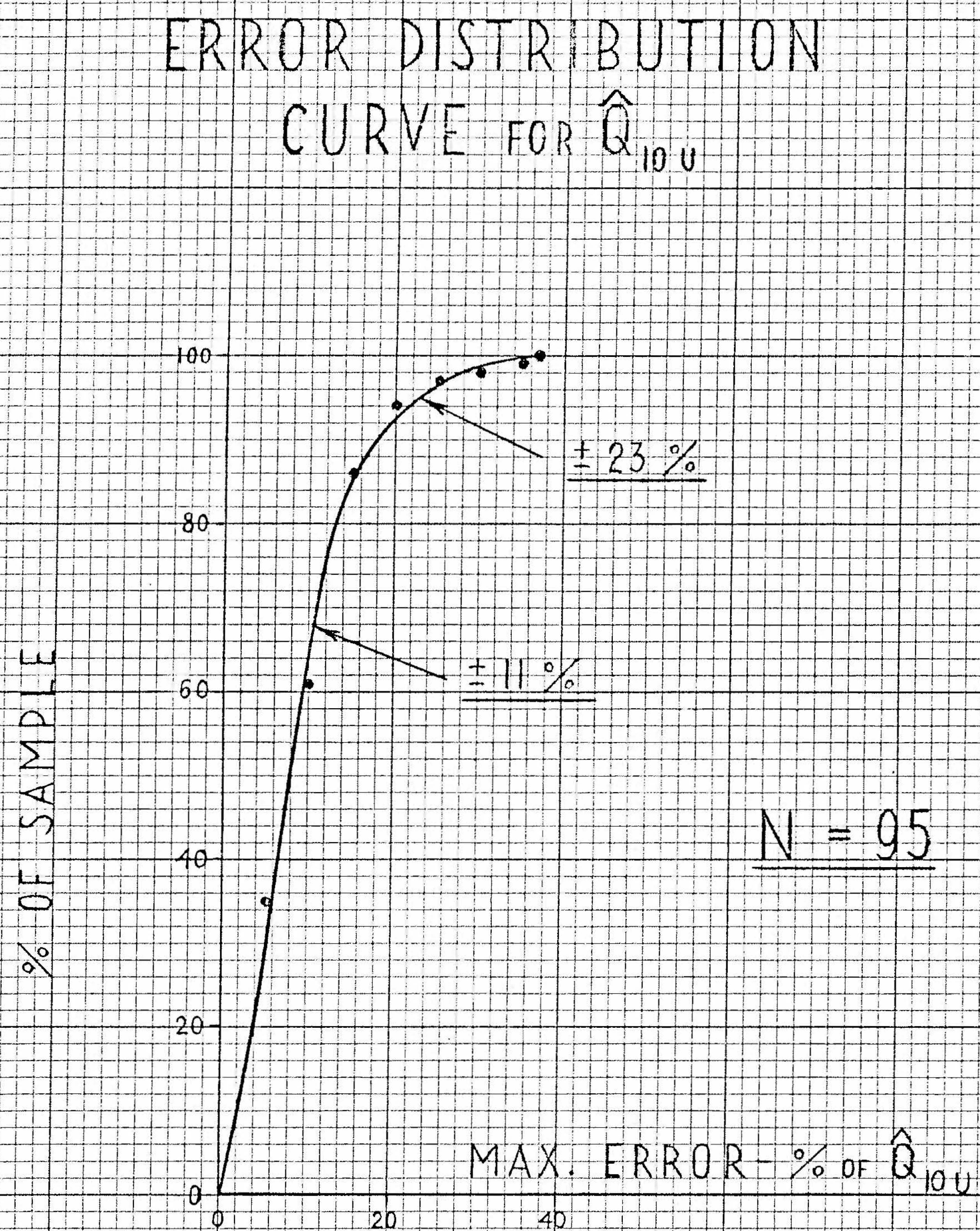

Figure 7. Error Distribution Curve for $\hat{Q}_{10U}$

TABLE 1. BASIC AND RESULTING DATA

Basic Data					Resulting Data			
1	2	3	4	5	6		7	8
Study No.	State	USGS Station No. (1960 Comp.)	Drainage Area Sq. Mi.	Q_{10U} Freq. Curve 1000 cfs	$\hat{Q}_{10U}$ a P.O.T. G.H. Ft.	$\hat{Q}_{10U}$ b 1000 cfs	Diff. 1000 cfs	Error % of Est.
1	Ala	2B-3745	170	13.5	14.5	14.0	+ 0.5	4
2		2B-4225	208	18.5	27.0	23.8	+ 5.3	22
3		2B-4530	188	7.8	11.0	7.6	- 0.2	3
4		2B-4550	309	30.5	16.0	33.2	+ 2.7	8
5	Ark	7 -0755	316	49.5	27.0	54.0	+ 4.5	8
6		7 -2630	211	40.1	18.5	47.0	+ 6.9	15
7	Conn	1A-2000	204	10.0	12.0	11.5	+ 1.5	13
8	Del	1B-4790	87.8	6.0	17.0	7.2	+ 1.2	17
9	Fla	2B-2455	134	10.8	24.0	11.0	+ 0.2	2
10		2B-2470	23.3	1.08	8.0	0.94	- 0.14	15
11		2B-3000	90	7.1	26.0	9.8	+ 2.7	28
12		2B-3705	237	13.5	14.5	15.2	+ 1.7	11
13	Ga	2A-1770	207	16.5	11.0	20.4	+ 3.9	19
14		2B-2135	182	8.1	21.0	8.0	- 0.1	1
15		2B-3370	246	7.3	16.0	7.1	- 0.2	3
16		2B-3890	103	4.7	16.0	5.0	+ 0.3	6
17	Ill	3A-6120	243	8.4	16.0	7.4	- 1.0	13
18		5 -4670	171	3.9	28.0	4.6	+ 0.7	15
19		5 -5565	186	8.4	14.0	8.6	+ 0.2	2
20		5 -5570	83	5.6	12.5	6.6	+ 1.0	15
21		5 -5575	101	5.0	16.0	4.3	- 0.7	16
22	Ind	3A-2770	248	27.5	18.0	32.5	+ 5.0	15
23	Iowa	5 -4145	130	17.6	20.0	16.6	- 1.0	6
24		5 -4700	315	6.45	11.0	6.0	- 0.45	8
25		5 -4800	257	6.4	13.0	6.6	+ 0.2	3
26	Ky	3A-2485	140	10.0	24.0	11.8	+ 1.8	15
27		3A-2955	196	13.6	20.0	14.7	+ 1.1	7
28		3A-2990	239	24.8	22.0	24.1	- 0.7	3
29	La	7 -3520	154	10.8	11.8	9.6	- 1.2	13
30		7 -3705	271	17.0	16.0	19.8	+ 2.8	14
31		7 -3725	92	10.5	20.5	11.5	+ 1.0	9
32		7 -3730	51	14.5	16.0	16.0	+ 1.5	9

TABLE 3. DRAINAGE AREA DISTRIBUTION

Drainage Area	No. of Watersheds	% Of Sample
< 100	21	22
100-200	40	42
200-300	23	24
300-400	10	11
> 400	1	1
Total	95	100