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THE DESCRIPTION AND CLASSIFICATION OF HYDROLOGIC CHARACTERISTICS FOR MILITARY PURPOSES

by

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July 1964

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CORPS OF ENGINEERS

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Department of Civil Engineering

Vanderbilt University

Nashville, Tennessee

July 1, 1964

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U. S. Army Waterways Experiment Station
Corps of Engineers
Vicksburg, Mississippi

Attention: Mr. Warren E. Grabau, Chief
Area Evaluation Section

Gentlemen:

In accordance with the terms of U. S. Army Contract Number DA-22-079-eng-360, dated 28 June 1963, it is a pleasure to submit this report entitled: "The Description and Classification of Hydrologic Characteristics for Military Purposes".

We will be most pleased to discuss any aspects of this investigation with you at your request and convenience.

Respectfully submitted,

PETER A. KRENKEL, Ph.D.
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for:

Area Evaluation Section, Embankment and Foundation Branch,
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I. INTRODUCTION

The purpose of this study was to develop a descriptive system for the analysis of water bodies as related to their effects on the mobility of personnel and vehicles engage in military activities. Toward this end, the following objectives were established:

1) The collection of data to indicate typical cross-section shape of rivers and streams throughout Tennessee.

2) The development of an accurate, universally applicable descriptive system for the analysis and classification of these data.

3) The establishment through literature survey of those factors in the environment which bare a causative relationship to bank slope at the land, water, and air interface.

FACTORS WHICH AFFECT MOBILITY:

This study is limited to the investigation of those factors which are uniquely associated with a water body. For this reason, steep slopes high above the water level and dense vegetation on the bank will be considered macrogeometrical and vegetational factors not related with the water body. This then, focuses the investigations on conditions within the stream (predominantly maximum velocity), and on conditions at points of entry and points of exit, that is, at the interface between the water surface and the bank, plus several feet above and below this interface.

The ability of amphibious vehicles to successfully enter and leave the water body is greatly influenced by bank slope (tangent of the angle between the bank and a horizontal datum at the surface of the water body), and by the rate of change of bank slope within the immediate area of the point of entry which would be a measure of the radius of curvature of the bank.

GENERAL FACTS ABOUT THE REGION SAMPLED

The state of Tennessee has an area of 42,022 square miles which is divided into three major drainage basins, the Tennessee River basin, the Cumberland River basin, and a portion of the Mississippi River basin. The state is also divided into several distinct provinces or physiographical areas:

The Blue Ridge formed by the Unaka Mountains along the eastern border
The Valley-Ridge Province parallel to the west of the Blue Ridge
The Cumberland Plateau parallel to the west of the Valley-Ridge Province
The Highland Rim which parallels the Cumberland Plateau and surrounds Central Basin
The Coastal Plain which covers the western section of the state
The Central Basin located in the mid section of the state.

The Tennessee River rises in the Unaka Mountains and flows south-ward through the Valley-Ridge Province into Alabama. It then re-enters the state in the western section of the Highland Rim at the Tennessee, Alabama, and Mississippi River border, and flows north through the Highland Rim into Kentucky.

The Cumberland River has its headwaters in Kentucky and enters the state at approximately the middle of the northern boundary. It then follows a curved path through the Central Basin, finally cutting into the Western Highland Rim. The Cumberland River flows east of the Tennessee River along a parallel path and enters Kentucky at a point very close to the Tennessee River. The Western Coastal Plain drains directly into the Mississippi River.

Tennessee is located in the mild, humid climate of the southern portion of the temperate zone. The mean annual rainfall is 50 inches or more, and the heaviest periods of rainfall occur during the late winter and early spring months. The annual snowfall is light, and ground cover usually only for short periods of time.

The wet weather of Tennessee is generally caused by the moist air coming up the Mississippi River Valley from the Gulf of Mexico and weather fronts from the Northwest. These two fronts meet and move west to east across the state. The Unaka Mountains act as a barrier to this weather, thus causing the orographic effect on the East Tennessee area. The Cumberland Plateau also offers a small orographic effect which gives rise to several rivers on the Highland Rim which flow through the Central Basin. Occasionally, a few hurricane centered storms from the Atlantic cross the Unaka Mountains and add to the headwaters of the rivers starting in this area. This is illustrated by the mean annual rainfall in the different areas of the state, 45-55 inches over the western and most of middle Tennessee, 50 to 60 inches along the eastern Highland Rim, and 55 to 80 inches in the Unaka Mountains on the Tennessee-North Carolina Boundary[1].

II. FIELD DATA COLLECTION PROGRAM

The field investigation consisted of two general areas of endeavor, one being to obtain an indication of the general variation to be expected within a given stream with regard to its cross-sectional shape and maximum velocity, and the other involving a relatively complete description of a small stream segment in order to allow more detailed investigation.

General Stream Survey: In most cases, the samples were selected near bridges or where easy access by road was possible and were located on U.S.G.S. quadrangle maps. Where possible, locations were chosen adjacent to USGS Gaging Stations in order to facilitate the collection and analysis of hydrologic data.

These surveys were located such that a wide variation in stream condition was obtained and were limited only by available time and funds. The two extreme conditions are demonstrated by the variations encountered between the South Fork of the Forked Deer River and the Little Pigeon River. The South Fork of the Forked Deer River is located in the western part of the state,and the bed material consists of sand, clay, loam, and loess, as described in a subsequent section. This survey consisted of seventeen cross-sections distributed over approximately one hundred miles of the river. The Little Pigeon River is located in the mountainous eastern portion of the state, and covers approximately eighteen miles and contains thirty-five cross-sections.

Detailed Survey of Short Stream Segment: The detailed investigation of the shorter river segments were always located adjacent to a USGS gaging station. In these investigations, horizontal and vertical controls were maintained; the horizontal distances and the direction between cross-sections being obtained by stadia measurements utilizing a transit. Vertical controls were maintained with reference to an arbitrary datum with a standard dumpy level, and bench marks were established. Three such studies were made and all were located in middle Tennessee.

The description of cross-sectional shape was made by use of a hand level, a level rod, and a 100 foot metal tape. At sections where no vertical control was available, a point was arbitrarily designated to have an elevation of one hundred feet, and all other elevations were located with reference to this station. At sections where vertical control points had been established, the elevation was taken from these points. In two cases, the control points where the tops of line stakes, and in the Harpeth River study at the Bellview Gage, permanent bench marks were established by driving railroad spikes into trees. In most instances where the stream flow was tranquil, the stream surface was assumed to be horizontal from bank to bank; and served as a datum for points taken within the stream, for it is probable that less error is involved in this procedure than in using a hand level.

A small boat was used in the Duck River study because the stream could not be waded, and a 3/4 inch diameter rope was secured across the stream by tying it to trees. This proved to be time consuming in that the drag on the rope by the water tended to pull the boat downstream quite rapidly and made it necessary to paddle upstream roughly 3/4 of the stream width and then to paddle rapidly across. Using this method, it was still necessary to make as many as four attempts before the rope could be successfully tied. It obviously would have been quite helpful to have had a small out-board motor to facilitate the measurements.

In situations where the stream could be successfully waded, a three-man team proved adequate for data gathering. This included a rod man, a hand level man, and a recorder. When the boat was used, at least four men were required in order to secure the rope.

Except for steep slopes where break chaining was required, horizontal distances were referenced from one point; that is, the recorder who served as back chainman, did not move ahead until one hundred feet had been traversed. The hand level was rested on a five foot Jacob's staff so that the location of turning points could be used as points in the cross-section. This procedure apparently added to survey efficiency.

Velocity measurements were obtained utilizing a Gurney Price Current Meter; however, this phase of the data collection program was hindered because the velocity meter was not received until late July. No standard method for obtaining velocity data was followed, as in some cases, velocities were recorded at uniform intervals across the stream, and in others, measurements were taken only in that part of the stream which appeared to contain the maximum velocity.

III. VELOCITY MEASUREMENTS FROM USGS DATA

Discharge measurement notes taken by field teams of the USGS were obtained from the Chattanooga office of the USGS for several of the gages visited in the field during the summer, and data were selected at each gage to show the variation that might be expected in the spectrum from extreme low to extreme high water conditions.[2]

Using data for the highest available stage obtained, the cross-section was plotted for each site. Next, each set of notes was examined to determine the maximum velocity recorded at any point within the cross-section. A plot was then made for each location of stage vs. maximum recorded velocity as shown on figure 1. The patterns obtained ranged from a nearly straight line fit (the Duck River above Hurricane Mills, Tennessee; figure 1a), to a curve whose slope changes by roughly 90° and could be fitted by two straight line segments at right angles to each other (Harpeth River at Bellview, Tennessee; figure 1b). The Harpeth River near Kingston Springs (figure 1c) appears to reach a maximum velocity at 15 feet mean gage height and then the maximum velocity tends to decrease with an increase in stage.

One is tempted at this point to speculate on the cause of the eratic variation in this relationship indicated by these data. Such factors as: the location of sampling points relative to bridge piers, the change in hydraulic characteristics with season because of vegetation growth, or the periodic erosion of the channel may influence this relationship.

In general, these data indicate that the unexpected variations of the stage-maximum velocity relationship is an area of fruitful future investigation. The nature of the parameters involved point toward data collection programs similar to the detailed survey of short stream segments mentioned above, because such an investigation would surely require detailed knowledge of channel shape.

IV. GENERAL DESCRIPTIONS OF FIELD SAMPLES

The cross-section data may be grouped regionally into three general classes: The mountainous area of the extreme eastern part of Tennessee, the central basin of Middle Tennessee, and the flood plains of the Mississippi and Tennessee Rivers as shown on figure 2.

The samples in the mountainous region were taken on the Little River, the West Prong of the Little Pigeon River in the Great Smoky Mountain National Park, and on Rock Creek at Lookout Mountain in Chattanooga. Figure 3 demonstrates that the stream profile sections on the Little River and the upper sections on the Little Pigeon are quite steep. These sections form narrow valleys between steep mountain slopes, and the channel is filled with large boulders, gravel, and sand ranging in size from 10 to 20 feet across to the small, rounded sands. As a general rule, most sections contain rocks 5 to 10 feet across and flat gravel roughly the size of a half dollar. The rock in the channel consists of slate, coarse-grained sandstone, quartz, conglomerates, and other partly crystalline rocks.

The large energy head provided by the steep channel slope is dissipated in violent turbulence as water flows around the boulders, and occasionally pools occur at the base of every steep section or in a bend. The mountains along the channel have a slope of 30° to 60° and are covered with thick vegetation which at this elevation consists of large trees and mountain laurel. The area generally consists of rock covered with a layer of sandy-humus soil, and there are frequent outcrops of rock.

The stream segment from Gatlinburg to Pigeon Forge, Tennessee, represents a transition zone between the very steep channel slope and a lower reach which has a wide flood plane. The rocks in this transition section are smaller than in the previous section. In and below Pigeon Forge, Tennessee, the river is contained within a well-established flood plain. At this point, the character of the stream changes, and appears similar to the streams visited in the middle basin.

Samples in the central basin were located on three rivers: The Stones River near Una, Tennessee; the Duck River at Columbia, Tennessee; and the Harpeth River from the mouth of the Little Harpeth River to Petway Bridge, north-northeast of White Bluff, Tennessee.

The samples taken on the Stones River are contained within a four-mile reach below the USGS gaging station near Donelson, Tennessee. The lowest sections taken are at the Couchville Pike bridge and the drainage area at the Donelson gage is 834 square miles.

The maximum recorded discharge was 73,000 c.f.s. at a stage of 59.6 feet in March of 1902, and the lowest discharge recorded was 10 c.f.s. on September 21,22, and 24, 1940. The average discharge recorded for 22 years of record is 1377 c.f.s., which represents a stage of 14.9 feet. The gage is located 18 miles upstream from the mouth, and backwater from the Cumberland River affects the rating during periods of high stages.[3]

The data obtained contains typical sections for straight river sections and bends, and several cross-sections show the bluffs which occur quite typically along the Stones River. The channel is composed of flat bedrock covered with gravel and large flat rock, approximately 5 to 6 inches across by 1 to 3 inches thick.

In a section of river around a sharp bend, the insides banks were much more gradually sloped to the waters' edge. The outside section ranged from flat cultivated fields at the top of the banks to steep bluffs rising from steep banks. The cultivated area was much lower (that is in reference to the water elevation) than it had been in the other section upstream at the gaging station. The bluffs were also located much farther back from the waters' edge than they were in the other locations, and the flat cultivated area was located above the bend and rapidly rose to form the bluffs along the hill.

The banks on the outside of the curve were very steep, and generally they were soil with outcrops of rock. The bluffs were 20 to 30 yards from the waters' edge and continued on downstream from the last cross-section and were about 50 feet high. The bank on the inside of this curve had a very gradual slope to within 20 or 30 yards of the waters' edge and increased down to the waters' edge. This latter slope was much less than the slope of the opposite bank, and both banks were covered with trees and low-growing vegetation.

The inside section of the bend was a large gravel bar which covered about half the channel width. The bar is above the waters' surface during most of the year and is used as a gravel pit for local users. The remainder of the channel, where the flow is confined in the bend, was bed rock with a mud section located on the downstream end of the gravel bar, and the channel on either side of the bend was similar to the other sections of the river investigated.

The section of the Duck River investigated started at the gaging station at Columbia, Tennessee, and ran downstream into a residential farming area. A traverse line was run and cross-sections were taken at typical sections along its length.

The area is generally very sandy soil with thick vegetation covering the banks, and the bluff is limestone with thick beds of shale. The channel has occasional gravel bars along the shores, but the water was too deep to obtain river bed conditions. At the end of the section studied, an unusual ridge, cut parallel to the river, was formed by a creek flowing parallel to the main channel.

The drainage area at the gaging station is 1208 square miles, and the largest known flow occurred on February 14, 1948, which was a discharge of 61,100 c.f.s.at a stage of 51.75 feet. The minimum flow occurred on October 22, 1922, when no flow occurred, and the average discharge for a period of 44 years is 1921 c.f.s. Available records cover the period from 1904 to 1908 and from 1920 to 1960.[3]

The Harpeth River data covers most of the river starting on the Little Harpeth and continues downstream for most of its length. Several traverse lines were run at different locations, and most of the information obtained was along a traverse starting at the gaging station at Bellview, Tennessee.

The river at this location cuts through a large flat area, and the shape of the section is shown in Figure 6. The banks consist of clayey soil and are covered with moderately spaced trees and grasses. The channel is generally filled with small gravel with a section of bedrock on the downstream end of the bend in the channel.

Three streams were investigated in the flood plain areas of Tennessee: Chattannoga and Rock Creeks at Chattanooga, Tennessee; and the South Fork of the Forked Deer River in the Mississippi River Valley of West Tennessee.

Both Chattanooga and Rock Creeks flow through the Tennessee River flood plain. Rock Creek, which is a tributary of Chattanooga Creek, flows through the flood plain after passing through a transition zone at the base of Lookout Mountains.

The banks of the creeks are generally gradually sloped with a few locations where they become more steeply sloped to vertical. They are composed of silty-clay with some sections covered with rock and occasionally roam. The channel is predominantly silt with areas of gravel and inorganic matter, and the sections containing gravel are located near the upper reaches.

Rock Creek flows into Chattanooga Creek near the midpoint of its length, and Chattanooga Creek flows into the Tennessee River at Chattanooga, Tennessee. The lower end of the Chattanooga Creek is filled with the backwaters of the Tennessee River.

The information on the South Fork of the Forked Deer River consists of cross-sections made from Huggins Creek in the headwaters near Finger, Tennessee, to the Forked Deer River at its mouth in the Obion River at the Mississippi River. The majority of the river was straightened by the building of a new channel in 1917.

In the headwaters, the banks slope very gently to the waters' edge with a very flat, shallow stream. The area is flat and covered with thick vegetation consisting of trees, cane breaks, and vines. The channel is filled with gravel and sand, and the banks are sandy clay.

The majority of the river from the headwaters to the mouth flows through very flat terrain, and the river has almost vertical walls. The tops of the banks are predominantly natural levees covered with trees which are mainly willows. The areas which are not swampy are planted in cotton, and the soil conditions range from sandy clay near the headwaters to loess near the end to silts along the Mississippi Valley. The vegetation along the river is mostly willow trees with some cane and vines, and it is not generally very thick.

The U.S.G.S. gage at Jackson represents a drainage area of 574 square miles, and has a maximum recorded discharge of 43,600 c.f.s. at a stage of 24 feet on January 21, 1935. The minimum discharge is 67 c.f.s. on October 9, 1941, and the average flow for 31 years of record (1929 to 1960) is 732 c.f.s.[3]

Figure 4 contains typical cross-sections from the sites visited, and Table 1 contains brief descriptions of these locations.

V. DISCUSSION OF DESCRIPTIVE SYSTEM

A. Introduction: The intent of this phase in the development of a descriptive system for water bodies has of necessity been oriented toward fitting as much data as possible into an accurate, compact scheme which allows efficient retrieval of data and highly intuitive graphical representation. The water bodies considered are streams of moderate size which flow without significant artificial control; however, this bias might require later adjustment if it is to be applied in certain locations.

B. Method of Procedure: Given the above limitations as to the scope of the investigation, it was decided that the desired system might be most easily perfected by the application of all proposed techniques of data classification and arrangement to a single well-defined stream segment. The purpose of this procedure was to eliminate the duplication of methods which yield little or no usable information. There exists in the method, however, the potential danger of discarding a significant system useful in comparison of different stream segments.

Although we do not attempt to establish causal relations between parameters of primary interest and conditions in the environment which control these parameters, it is quite logical to anticipate that a well organized descriptive system with adequate data available may itself point to such causal relationships.

C. Factors to be Considered: As mentioned previously, maximum velocity and conditions at the land-water interface (i.e.,slope and rate of change of slope) will be considered as primary parameters.

Conditions at the interface within a given stream segment can be grouped into two general types of variation. First, at a given instant in time, there will be variation in slope and rate of change of slope along the length of the stream segment. Second, there will be variation with time in these conditions as the varying flow causes a change in water level.

Previously, emphasis has been placed on describing conditions of slope as defined by the angle between the bank and a horizontal datum which intersects the bank at the water surface.

Considering the rate of change of slope, it is apparent that this definition is of little value and should be changed. This is obvious because as the bank approaches the vertical, the previously defined slope would approach infinity, and the rate of change of slope might be misleadingly large with only a few degrees change in bank angle. For this reason, it is suggested that slope be defined as the angle between the bank and a horizontal datum at the water surface.

A further clarification is desirable with respect to the definition of the rate of change of slope. If the change in slope were measured with reference to some horizontal or vertical increment, where the measurement is made over some measurable region, then not only radius of curvature of the existing curve, but also the slope of the bank in that region would be considered. This may be illustrated by examining the curve of constant radius or the arc of a circle as shown in figure 5. Let the radius equal 10 and let $\Delta X = 1$. Then, if $\Delta\theta / \Delta X$

is measured at both the horizontal and vertical axis, it is observed that $\Delta\theta/\Delta X$ is not constant. For this reason, the rate of change of slope should be defined in terms of the change of slope within a given change of arc length, $d\theta/ds$. It should be noted that where cross-sections are described mathematically rather than graphically, this problem will not exist.

D. Description of Sample Location: It was felt that the ideal stream-segment for this study should be one that is well defined by detailed field data, and, in addition, contain a gaging station. The stream-segment chosen was at the Bellview gage on the Harpeth River which has had a continuously recording gage station since October 4, 1933.

The area of the drainage basin at this gage is 408 square miles as measured on 7-1/2 minute topographic maps, scale 1:24,000, and the maximum stage recorded since 1902 is 24.34 feet representing a discharge of 40,000 c.f.s. The point of zero flow occurs at 0.63 feet and the average discharge for 39 years of record is 556 c.f.s. which represents a stage of approximately 2.7 feet.[3]

The channel is composed of solid rock overlain with gravel and is straight for 500 feet upstream from the gage and about 1,000 feet downstream. Both banks are cleared agricultural land, fringed with trees; the left bank overflows at about a 10.5 foot stage and the right bank at about 15.0 foot stage.

The low-water control is a solid rock shoal 80 feet downstream from the gage, and directly under the bridge, and is practically free of aquatic growth, but in the fall collects garbage and other debris dumped from the bridge during low water. Control for higher stages is the channel, possibly affected by the bend 1,000 feet downstream, and for extremely high stages by the road fill.[4]

The segment chosen for investigation is roughly 1/2 mile long as shown on figure 6, and contains a pronounced bend. The Harpeth is joined by the Little Harpeth River (drainage area 46.7 square miles) within 0.05 miles above our uppermost measured cross section and the gaging station is roughly 0.1 mile from the upper end of the traverse.

An azimuth-stadia traverse was run on the northern bank of the river, which is the outside bank of the curve, and vertical controls were then established with a line of permanent bench marks which were railroad spikes driving into trees. These bench marks were referenced to an arbitrary datum which later tied in with the gage elevation by reference to the staff gage secured to the gage house. Twenty-three cross-sections were taken within the 1/2 mile reach. These cross-sections were located so as to define the low-water channel shape; however, this bias was not very strong, and probably would not destroy any requirements for randomness. As previously mentioned, these cross-sections were referenced to control in plain view and in the vertical and, therefore, the resulting data may be used to reproduce a three dimensional model of the segment.

E. Analysis and Development of Stage Frequency Relationship: A pertinent question to be answered prior to river crossing is concerned with the depth of the water and the quantity of flow. With interest centered on points of entry and exit, it is intuititively observed that the bank slope at the land-water interface and the degree of curvature will be varied with variation in water depth. It is, therefore, important to describe as accurately as possible the probability of encountering a given stage at the time when crossing is to occur.

Initial attempts of expression included plotting a daily discharge hydrograph for three years of record.[5] This method appeared to be quite cumbersome and did not lend itself to quantitative methods of analysis. However, it did emphasize the already apparent fact that a usable descriptive system must in some way account for seasonal variations in stage occurrence patterns.

The first attempt to account for seasonal variation in stage consisted of dividing the year into four three-month periods. These divisions were made on the basis of data in the U.S.G.S. Water Supply Paters with the water year beginning in October. Discharge data were converted to stage data using a rating curve.[6] These data were then tabulated so as to yield 4 cumulative frequency curves for stage occurrence; and visual comparison of these curves indicated an obvious variation in stage occurrence patterns with season. The question then arose as to the validity of these arbitrary boundaries for seasonal classes and to secure a more rational seasonal grouping of data, an analysis was run in which the year was divided into 24 half-month periods and a stage cummulation frequency study was made for each period. Originally, this division was seen as a means by which the data could be regrouped into more logical seasonal divisions; however, the resulting family of curves showed only a gradual change from one half-month period to the next, and no logical divisions could be made by visual comparison. In further attempts to regroup these data, a study was undertaken to graphically define the function by some mathematical model. The procedure usedwas to replot the data on various types of graph paper seeking a trend indicating linearization of the data.

Plots of the data on arithmetic-probability paper were non-linear tending to form a rather smooth arch with the exception of local irregularities. This indicated a striking lack of normality of the stage data. In certain of the half-month periods from December to April, there is an indication of a discontinuity of the function from stage sixteen feet upward, as the curve assumed a noticeably flatter slope. It should be noted that this range of stages represents a condition of over-bank flooding and that the discontinuity usually includes only one or two percent of the data. Also, since this represents only four to eight data points, it is possible that analysis of longer periods of record would clarify the relationship.

The use of log-probability paper also proved non-linear, and, therefore, only two seasonal periods were examined, thus negating the use of log transformation to obtain a normal population.

The use of the Gumbel extremal probability function was attempted against both the stage and the log of the stage. Logarithmic transformation in this case yielded a gentle "S" shaped curve which approached linearity. The similarity in the shape of the stage data to the Poisson distribution indicated that root transformation might be beneficial. Therefore, using the January 1-15 data group, various functions were plotted on normal probability paper. Stages taken to the 2/3, 1/2, 1/3, 1/4, and 1/10 powers were plotted and the 1/10 power yielded a curve approaching linearity. A similar attempt which has been made of the August 1/15 data group indicated no such tendency to become linear, even though the method was carried to its extreme with the use of the function, $(\text{stage})^{1/100}$.

The most promising attempt to secure a normally distributed function of stage thus far encountered involved the function f(x) = ln(x), where x indicates the stage. The function f(x) = ln(x), when plotted on log-probability paper, can be fitted quite well with a straight line. This amounts to a log of a log transformation of the raw data. In some cases, the apparent discontinuity noted in the arithmetic-probability curves is still noticeable as shown on figure 7. There are also some indications of discontinuity above a stage of 10 feet which indicates over bank flow for the low southern bank. Despite this possibility, the mathematical modeling has been excellent for the data tested thus far, and merits further investigation to test its validity.

An additional attempt at defining the stage function relation, which does not involve the creation of a normally distributed function, is the use of log-log plots of stage vs. cumulative frequency as shown on figure 8. A least-squares line of best fit was found for the expression log y =a log x + log b, where y = stage and x = frequency, and a regression analysis was performed to obtain the goodness of fit. The values obtained for the correlation coefficients, r,listed in Table 2 were quite high, indicating a good fit; however, an indication of discontinuity in the upper end of this relationship is apparent. This equation would be a possible method of defining the pattern of seasonal fluctuation of stage through the analysis of the constants a and b, which are defined by the individual stage-cummulative frequency relationships as shown on figure 9. These constants not only define seasonal fluctuations, but also may lead to a method for comparison of these fluctuations among streams which exhibit this logarithmic distribution of the stage cumulative frequency relationship.

The shape of the original curves indicated that some reciprocal function of these factors might yield a linear relationship. Using the January 1-15 data, plots of cumulative frequency vs. cumulative frequency/stage and stage vs. cumulative frequency/stage were attempted without apparent success. Logarithmic plots of stage vs. stage/cumulative frequency and stage vs. cumulative frequency/stage were analyzed for least squares line of best fit as shown on figure 10. Comparison of the a and b constants indicated that these were redundant forms of the same relationship. Further comparisons with the values for a and b in the expression for log stage vs. log stage/cumulative frequency indicates that these functions are also related because the absolute values of b are identical, and the a values differ by a constant. These reciprocal relationships will generally approach linearity more closely than will the log (stage) = a log (cumulative frequency) + log b form.

Another method selected for the arrangement of these data designated as the seasonal fluctuation of stage diagram is shown in figure 11. The abscissa indicates seasonal period and the ordinate indicates stage and the diagram consists of a family of curves, each representing a uniform probability that the indicated value of stage will be equaled or exceeded within the given seasonal period. This system has two attractive qualities. First, it is the most easily interpreted representation of these data developed thus far, and second, the shape of the curves indicates that it might be accurately described by a few terms of the Fourier series, and thereby be useful in the desired quantitative description.

The seasonal fluctuation of the stage diagram indicates an irregular oscillation of the uppermost curves of the family. This oscillation tends to emphasize the fact that the upper ends of the stage-cumulative frequency curves may not in fact be accurate indications of the population from which they originate. It should also be mentioned that these data were obtained by a rather circuitous procedure. That is, stage records were converted to average daily discharges which were reconverted into stage. Although the process has probably yielded a relatively accurate picture of what actually exists, it is not ideal and will probably introduce a slight error. For example, in a period of rapid fluctuation of flow, the average discharge for a given day may not correspond to the average stage for the same day.

<u>Summary and Conclusions</u>: Attempts to define the stage-cumulative frequency function for the Bellview gage on the Harpeth River for half-month seasonal periods have yielded several promising relationships. First, the expression $f_{(x)} = \ln x$, appears to conform quite well to a log-normal distribution. Also, a log-log plot of stage vs. cumulative frequency gives a good linear fit as does a related expression of stage vs. stage/cumulative frequency on the same paper. The final method of arranging these data, named the seasonal fluctuation of stage diagram, probably can be fitted with a simple Fourier series.

The obvious anticipation of these attempts is to find an expression which can be made to fit the data from many locations and which would allow a quantitative means of comparing phenomena at various locations. The above expressions are very likely not universally applicable for such factors as overbank flow, artificial regulation of streams, and application to intermittent or ephemeral streams would very likely yield poor fits. Nevertheless, there could very well be a large segment of perennial streams which would have flow patterns conforming to these expressions.

For locations which do yield good fits, comparison of stage patterns might be made on the basis of statistical inference. It is impossible to speculate whether a parametric statistic might be used; however, a non-parametric statistic may still yield some valid basis of comparison.

F. Analysis & Development of Stage-Bank Slope Relationship: This analysis is also of the data taken at the Bellview gage on the Harpeth River which, as previously mentioned, consisted of 23 cross sections referenced to a common datum.

Three methods have been used to study this relationship: (1) an individual analysis of each bank segment for bank slope vs. elevation; (2) an attempt to describe each individual set of bank shape data by a mathematical curve using only a few measured values. (The data in this section were not drawn from the Bellview gage study); and (3) a composite analysis of slope variation vs. river stage at a point in time.

(1) Individual analysis of each bank segment for bank slope vs. elevation:

Using the previously stated definition of bank slope, the slope was calculated directly from the field notes. If ΔX is the horizontal distance between adjacent points and ΔY is the change in elevation between adjacent points, the slope for the segment is then equal to $\Delta Y/\Delta X$.

In this analysis, each set of cross-section data was divided at the lowest point in the channel into two bank segments. Each bank segment was then analyzed for bank slope vs. elevation and plotted as on figure 12. Presently, this method has not been expanded and its potential appears to be a more quantitative picture of slope variation than observation of the plotted cross section.

Several weaknesses of the system are apparent. First, it does not yield a composite picture of variation in slope conditions within a given stream segment at a given instant in time (i.e. at a given degree of channel filling), and, in addition, it does not yield a composite picture of how these conditions would change with a change in channel "filling". This method is also quite difficult to relate to any system of stage-frequency curves for the purpose of predicting a probable bank slope condition at the time when crossing is to be attempted.

(2) Mathematical Model of Bank Section:: For reconstructing the river channel cross sections with as little field data as possible, several different approaches have been investigated. Each method will be discussed briefly, and the development of the most promising method will be included.

A. Chebyshev Polynomial -- Owing to the nature of the Chebyshev polynomial, only those channel cross sections having flat and even shapes(i.e. shape of cosine or sine) will work. Therefore, this is not a universal method.

B. Trigonometric Series -- This method involves too much labor, especially when the channel cross section is very irregular.

C. High Degree of Polynomial with Bank Shape Factor Parameters -- This method yields good results for a wide range of shapes because the bank shape factors govern the shape of channel cross-section. It is the best method of the three, and the derivation and application are given below:

1. Derivation of Equation:

Any channel cross section may be divided into two parts, each half being represented by a general equation. The lowest point of the channel is chosen as the origin point as shown in figure 13. A reference line must be chosen so that the interface of the reference line and channel cross section will determine the boundary of the abscissa. The choice of reference line depends on individual purpose; therefore, the details will not be covered here. The abscissa and ordinate will be defined as x-axis and y-axis and the boundary of the abscissa will be normalized to be one unit for each half of the cross section. The general equation will be a fifth degree polynomial in terms of five bank shape factor parameters which will govern the shape of channel cross section. Of these parameters, L,M, and N, are normalized ordinates at x = 1/3,2/3, and 1,respectively, and Q and P are slopes at points x = 1/3 and x = 2/3, respectively.

The polynomial equation is

$$y = A + Bx + Cx^2 + Dx^3 + Ex^4 + Fx^5$$

and the boundary conditions are

$x = 0$	$x = 1/3$	$x = 2/3$	$x = 1$	$x = 1/3$	$x = 2/3$
$y = 0$	$y = L$	$y = M$	$y = N$	$\frac{dy}{dx} = Q$	$\frac{dy}{dx} = P$

Apply the boundary conditions to the polynomial equation y and solve for the polynomial coefficients B,C,D,E, and F by matrix inversion. The result is

$$\begin{bmatrix} B \\ C \\ D \\ E \\ F \end{bmatrix} = \begin{bmatrix} 1.3736 & -13.3321 & 22.3101 & -6.9321 & -3.8827 \\ -12.1764 & 153.9487 & -183.1429 & 50.0387 & 33.0290 \\ 38,4433 & -478.3290 & 518.9574 & -126.9471 & -98.3301 \\ -51.0993 & 568.8885 & -589.4596 & 135.1565 & 119.6724 \\ 24.4587 & -231.1762 & 231.3351 & -51.2891 & -50.4884 \end{bmatrix} \begin{bmatrix} N \\ L \\ M \\ Q \\ P \end{bmatrix} \quad \text{---(1)}$$

2. Application of the Equation:

Values of N,j,and k are field data stored in the file and values of L and M can easily be obtained as shown in figure 14. Values of Q and P based on values of N,L,and M will be calculated by following directions.

Because of the irregular shape of the channel cross section,several formulae for calculating values of Q and P are given below.

(a) Straight line O-A must be connected first and then values of g and h can be found.

(b) When

$L < g$, $M \lesssim h$ and both L and M are not approximately equal:

$$P = \frac{(N-M)}{(0.33)(2)} \qquad Q = \frac{(N-L)}{(0.67)(3)}$$

(c) When

$L < g$, $M \lesssim h$ and both L and M are almost equal:

$$P = \frac{M}{(0.33)(2)} \qquad Q = \frac{L}{(0.67)(3)}$$

(d) When

$L \doteqdot g$, $M < h$

P and Q calculated as (b)

(e) When $L > g$, $M > h$

$$P = \frac{2(N-M)}{(0.33)} \qquad Q = \frac{(N-L)}{(0.67)} \times \left(\frac{3}{2}\right)$$

(f) When

$L < g$, but close to g

$M > h$, but close to h

$$P = \frac{(2)(N-M)}{(0.33)} \qquad Q = \frac{L}{(0.67)}$$

(g) When

$L < g$, $M > h$

$$P = \frac{(N-M)}{(0.33)} \qquad Q = \frac{(N-L)}{(0.67)} \times (\frac{3}{2})$$

As soon as these parameters are found, values of B,C,D,E,and F can be evaluated from Equation 1 and for every value of x, a value of y can be found.

This method has been used to reconstruct several shapes of channel cross section.With the exception of case (g), the results are highly satisfactory. Several examples are given in figure 15.

The method has an advantage in that it only needs five field measurements for the entire cross section, and if the library programs are used, the IBM 7072 will automatically give the entire shape of the channel cross-section within a few seconds. An example of reconstructing the channel cross section from stored field data is given below.

<u>Example</u>:

Given: The width of a channel is 2x = 120'. Assume the deepest point, which also the origin point, is at the middle of channel width and its value is N = 30'. At point x = 20', 40' of each side, the corresponding values of j and k are 12' and 4.8',respectively, on the left-hand side and j = 25.8' and k = 18' on the right-hand side.

Problem: Reconstruct the channel cross section.

Solution: Step 1. Split channel into two parts, then

$$x = \frac{120'}{2} = 60'$$

Step 2. Normalize x and values of N,j,k

left side $x = \frac{60}{60} = 1.0$; $N = \frac{30}{60} = 0.5$; $j = \frac{12}{60} = 0.2$;

$$k = \frac{4.8}{60} = 0.08$$

right side $x = \frac{60}{60} = 1.0$; $N = \frac{30}{60} = 0.5$; $j = \frac{25.8}{60} = 0.43$;

$$k = \frac{18}{60} = 0.3.$$

Step 3. Calculation of values of L,M,g,h

left side $L = N-j = 0.5-0.2 = 0.3;$

$M = N-k = 0.5-0.08 = 0.42$

right side $L = N-j = 0.5-0.43 = 0.07$

$M = N-k = 0.5-0.3 = 0.2$

Step 4. Compare values of g,L and h,M and calculate values of Q and P for each side.

left side $Q = \frac{0.3}{0.67} = 0.448 \quad P = \frac{0.15}{0.33} = 0.455$

right side $Q = \frac{0.15}{0.67} = 0.224 \quad P = \frac{0.15}{0.33} = 0.455$

The bank shape factors for each side of the channel are

left side	right side
N = 0.5	N = 0.5
L = 0.3	L = 0.07
M = 0.42	M = 0.2
Q = 0.448	Q = 0.224
P = 0.455	P = 0.455

Step 5. Evaluation of polynomial coefficients B,C,D,E,and F.

Put the values of the bank shape factors of each side of the channel section in equation (1) and it will have the values of B, C, D, E, and F.

Step 6. Evaluation of ordinates.

$$y = Bx + cx^2 + Dx^3 + Ex^4 + Fx^5$$

in which for each value x will exist a value of y, respectively.

The original cross section and the reconstructed channel cross section are shown in figure 16.

3. Composite analysis of slope variation vs. river stage at a point in time: this method of data organization can best be understood by following the steps by which it was created. Given the analysis completed in method (1), the elevations were corrected from the arbitrary vertical datum to the gage height datum, and it was assumed that the slope on the stream surface could be represented by a constant value. The Harpeth River profiles from mile 0 to mile 107.2, which were obtained

from the Nashville office of the U.S.Corps of Engineers, show the profile of the river bed, low water profile, and high water profile.[7] From these plots, the slope on the stream was found for the Bellview gage area for high and low water conditions. It was decided that no significant error would be caused by assuming a constant slope of the stream surface of 0.0322 ft/100 ft. Two field checks were run to determine the accuracy of this value as shown on figure 17, and although the agreement is not perfect, it should have no significant effects on the resulting system. Using this value of slope and the distance between the cross-section and the gage, the location of the water level can be found at any cross-section given the gage reading at the gage station. This amounts to the creation of a sloping datum parallel to the hypothesized water surface.

Using this method, it is possible to tabulate the slope at the land-water interface at each of the 23 cross-sections for any given value of stage. These tabluations of slope were made from stage zero to stage 15 feet at half-foot increments, and, at each value of stage, values of slope were arranged in ascending order of magnitude and divided into 5 groups of equal size. Each group, therefore, represents 20% of the slope values for that value of stage, and the average of each of these five groups was then tabulated. The results can be seen on figure 18 where the lowest curve of the family represents the 20% slope value which was encountered for a given stage with the gentlest slope.

The result of this system is an overall picture of the relation between bank slope and channel filling, and the integrated system may be used in conjunction with a stage frequency curve, thus yielding a quantitative picture of the conditions of bank slope that will be encountered at a given seasonal period.

The disadvantage of this system should be noted, for it does not contain any measure of the rate of change of slope and it is not apparent how this might be added. There are also problems which relate to the fact that the identity of the individual cross-section has been lost. For example, an overall picture masks tendencies for bank segments in similar positions relative to a bend in the river or a river pool to form similar patterns of slope vs. degree of channel filling. This handicap might be overcome by subsequent analysis based on the location relative to these physical features.

C. Use of the above systems for prediction of difficulty of entrance and exit of a vehicle within a well defined stream-segment: This method, of necessity, must consider that the difficulty is a function of slope at the land-water interface. If it can be said that failure to successfully enter or exit a stream with a given vehicle is dependent on bank slope, then there exists some critical value of slope such that when the slope is greater than this value, the vehicle can not advance. Given this value of critical slope, figure 18 can be used to predict ability to cross the Harpeth River at the Bellview Gage. For example, if the critical slope were 1.2, then it is easily seen that entrance and exit will be no problem at 80% of the sites chosen regardless of degree of channel filling. If the critical slope were 0.5, crossing would be accomplished at only 40% of the sites chosen regardless of degree of channel filling.

To see how seasonal variations might be a factor, a hypothetical situation will be examined. Figure 19 shows both a composite analysis of slope variation with stage and on the seasonal fluctuation of stage diagram. Given these conditions, it is easily seen that the probability of a successful crossing in mid-March is 1-(.95-.15) or 0.2, while the probability of crossing in mid-August is 1.0-(0.1-0.01) or 0.91.

Another promising area of investigation is the combination of the mathematical model for bank shape proposed above, with some mathematical model of the stage-frequency relationship. An accurate representation of bank shape in equation form would yield an accurate, easily attained expression for slope and rate of change of slope by simple differentiation. Comparison of coefficients from various data might be a valid way to group or classify bank segment data in some meaningful way. This presently appears to hold the most promise for including the rate of change of slope in the proposed system.

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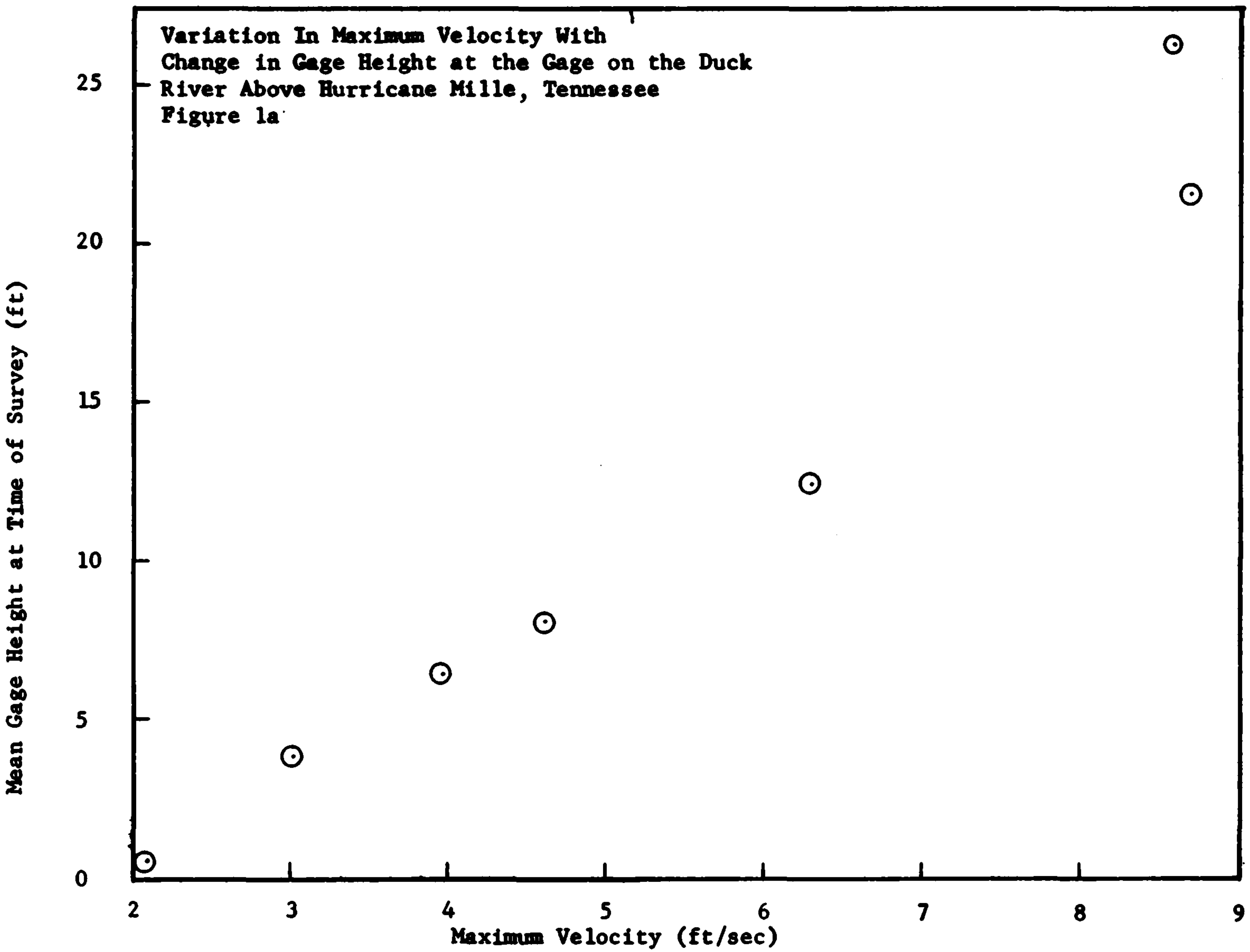
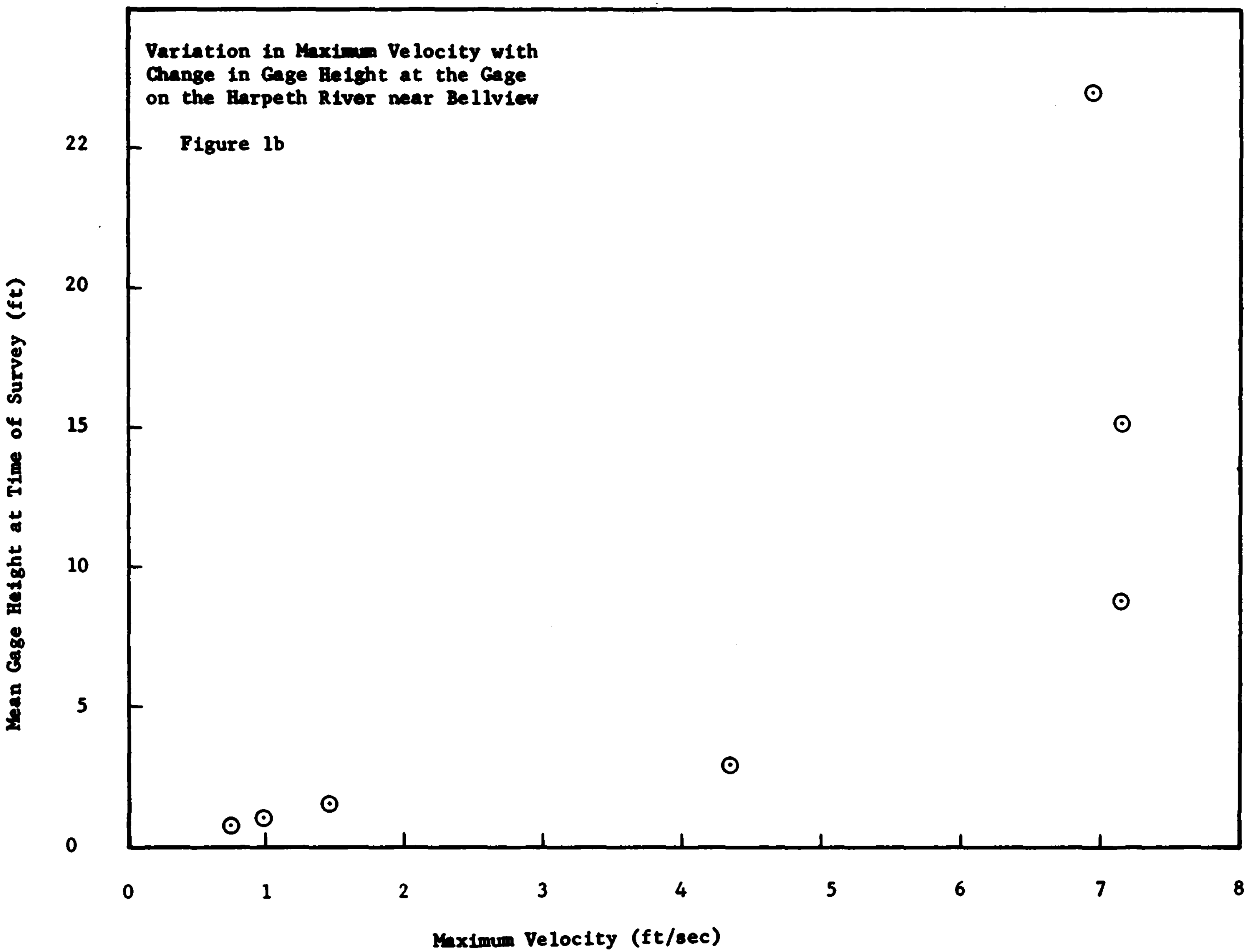
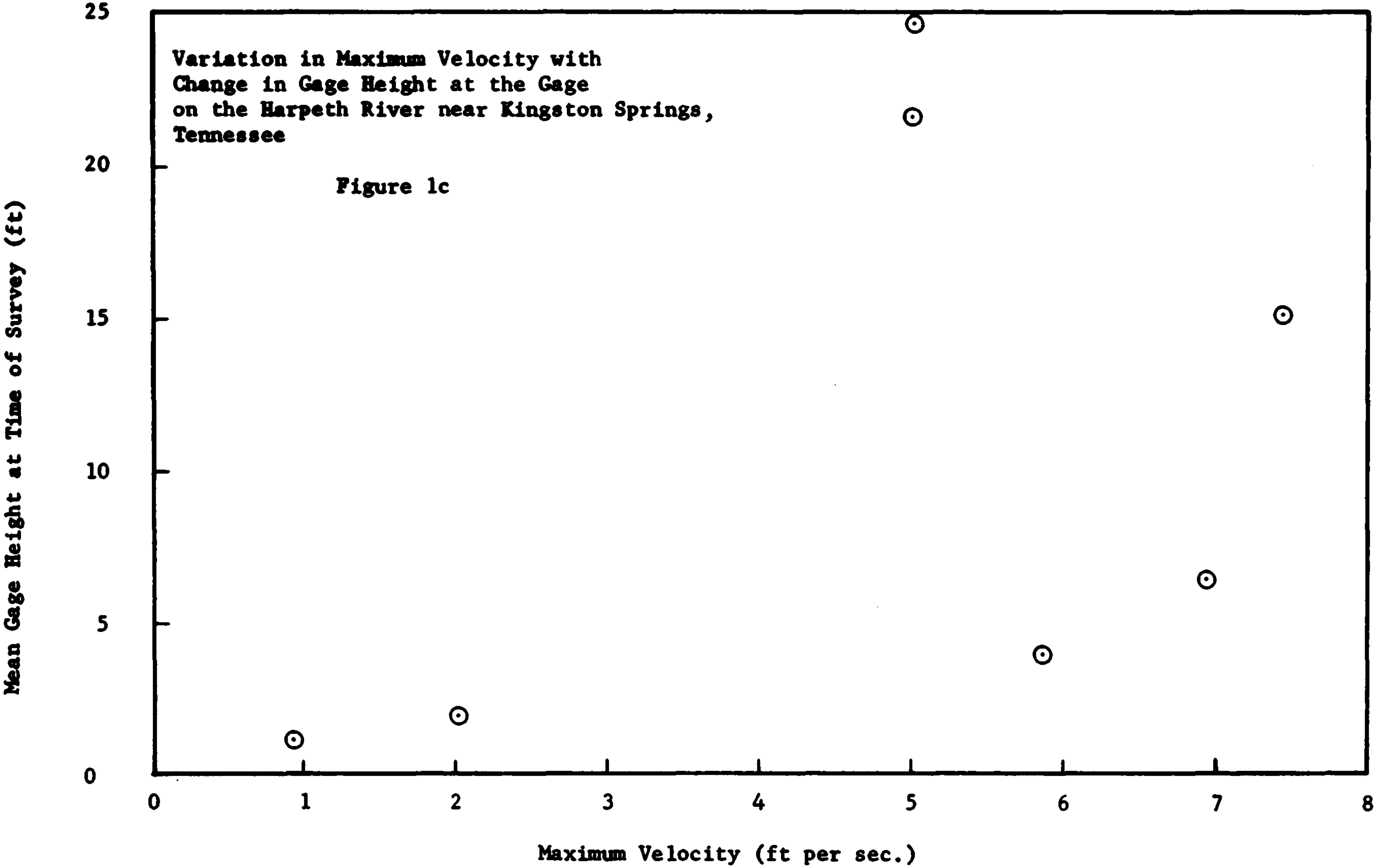

Variation In Maximum Velocity With
Change in Gage Height at the Gage on the Duck
River Above Hurricane Mille, Tennessee
Figure 1a
Mean Gage Height at Time of Survey (ft)
Maximum Velocity (ft/sec)
0
5
10
15
20
25
2
3
4
5
6
7
8
9



Variation in Maximum Velocity with Change in Gage Height at the Gage on the Harpeth River near Bellview

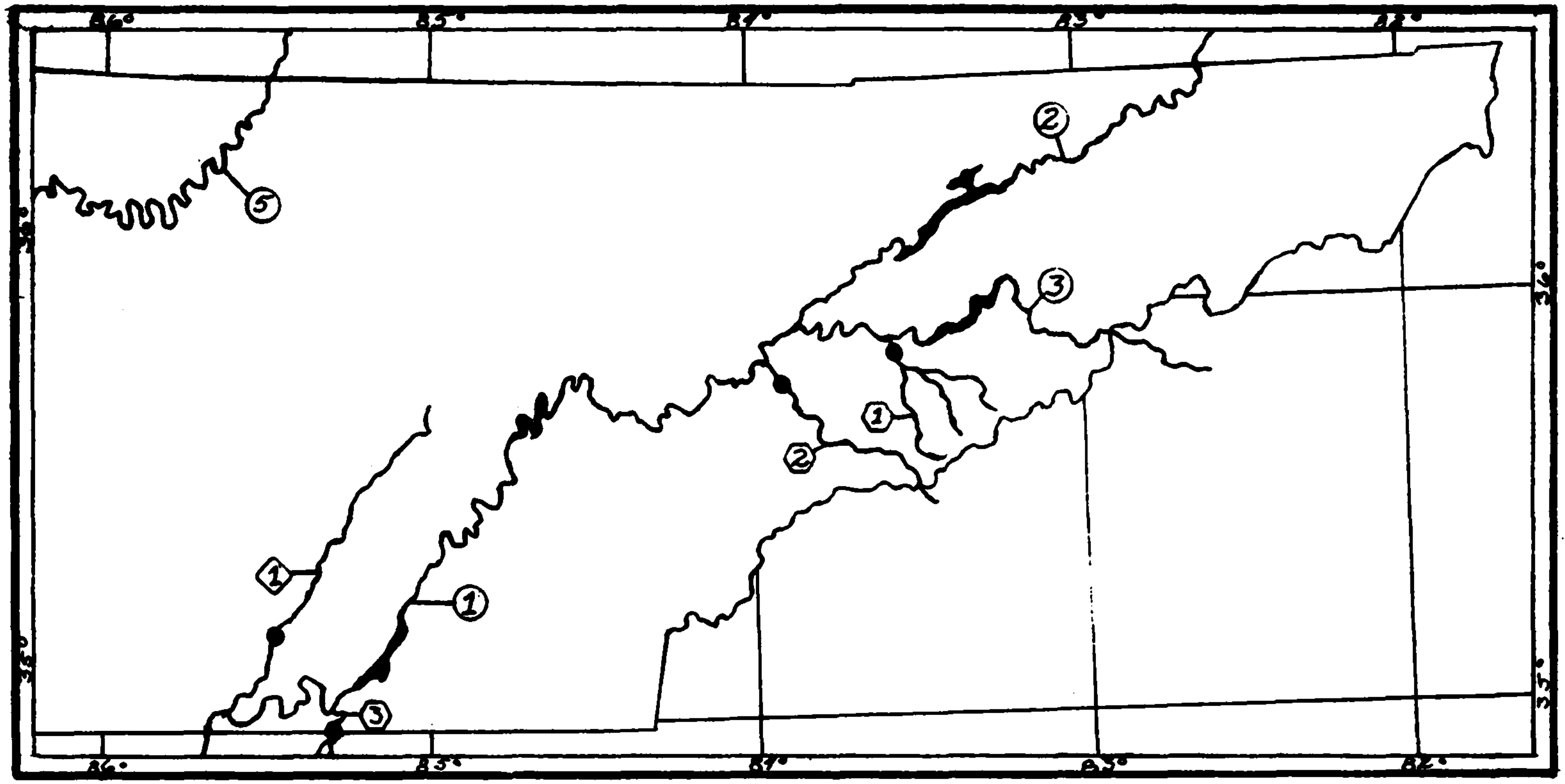
Figure 1b



Variation in Maximum Velocity with Change in Gage Height at the Gage on the Harpeth River near Kingston Springs, Tennessee

Figure 1c

EAST TENNESSEE



RIVERS & CREEKS

NO DATA

① TENNESSEE RIVER
② HOLSTON RIVER
③ FRENCH BROAD RIVER
⑤ CUMBERLAND RIVER

DATA OBTAINED DURING SUMMER

① WEST PRONG LITTLE PIGEON RIVER
② LITTLE RIVER
③ CHATTANOOGA & ROCK CREEKS

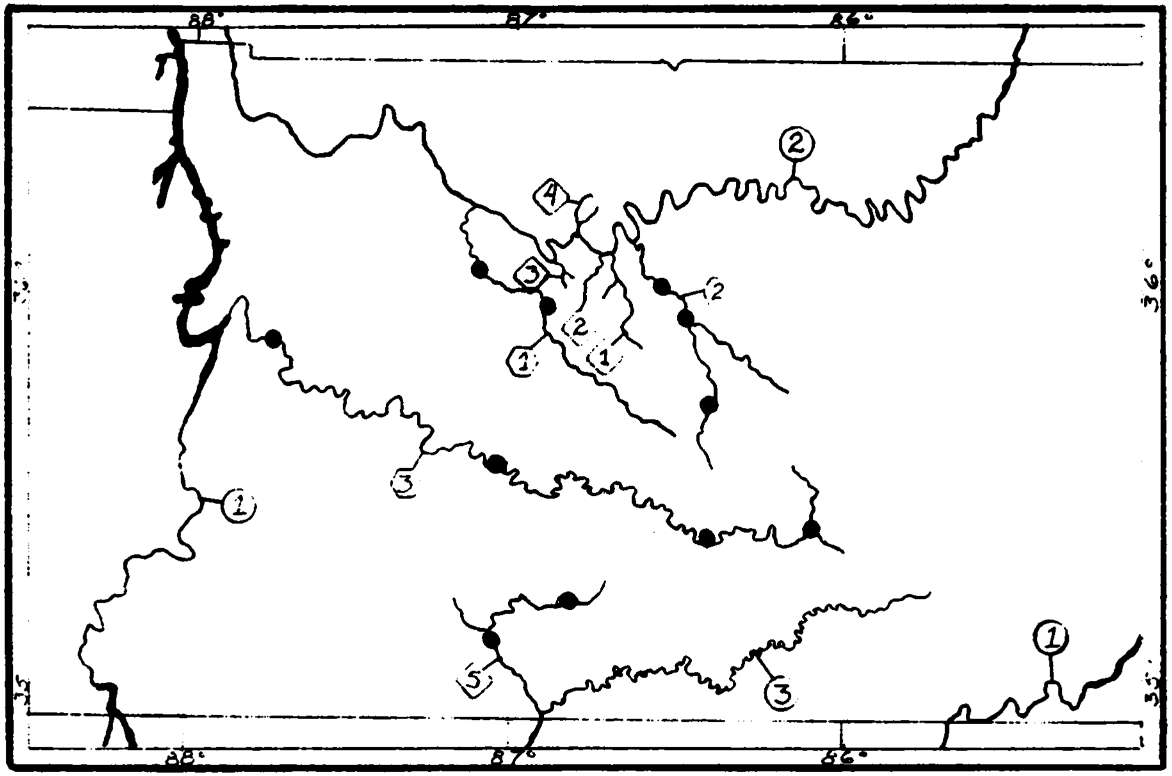
DATA OBTAINED FROM OUTSIDE SOURCE

◇1 SEQUATCHE RIVER

• GAGING STATION

Figure 2

MIDDLE TENNESSEE



RIVERS & CREEKS

NO DATA

① TENNESSEE RIVER
② CUMBERLAND RIVER
③ ELK RIVER

DATA OBTAINED DURING SUMMER

① HARPETH RIVER
② STONES RIVER
③ DUCK RIVER

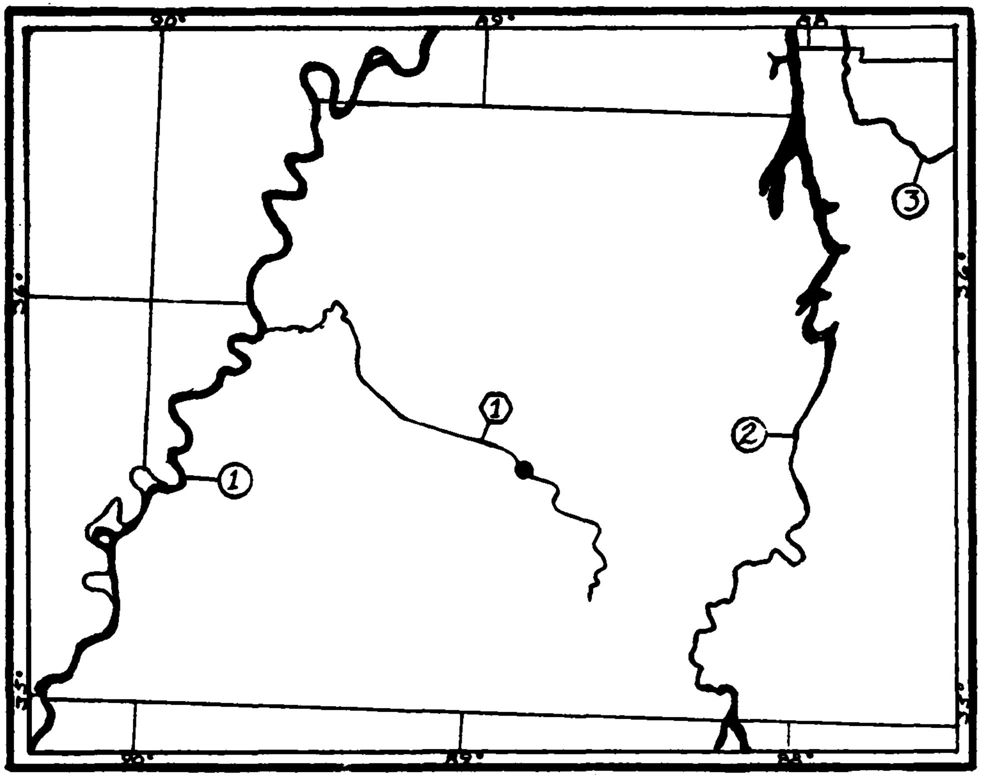
DATA OBTAINED FROM OUTSIDE SOURCE

① MILL & SEVENMILE CREEKS
② BROWN'S CREEK
③ RICHLAND & SUGARLAND CREEKS
④ WHITE'S CREEK
⑤ RICHLAND CREEK, GILES COUNTY

● GAGING STATION

Figure 2

WEST TENNESSEE



RIVERS

NO DATA

① MISSISSIPPI RIVER
② TENNESSEE RIVER
③ CUMBERLAND RIVER

DATA OBTAINED DURING SUMMER

① SOUT FORK FORKED DEER RIVER

● GAGING STATION

Figure 2

FIGURE 3

STREAM PROFILES

OF

RIVERS SAMPLED

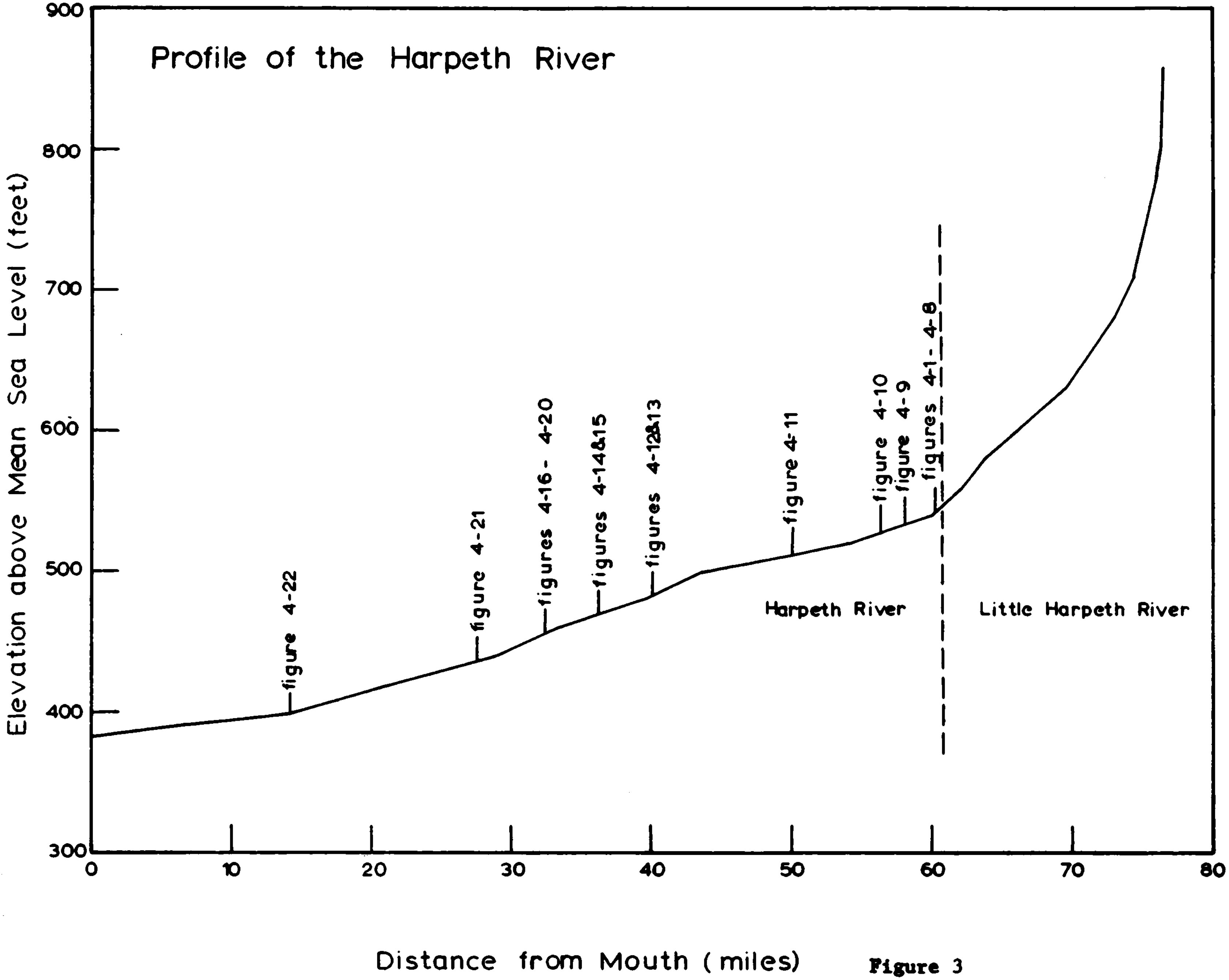
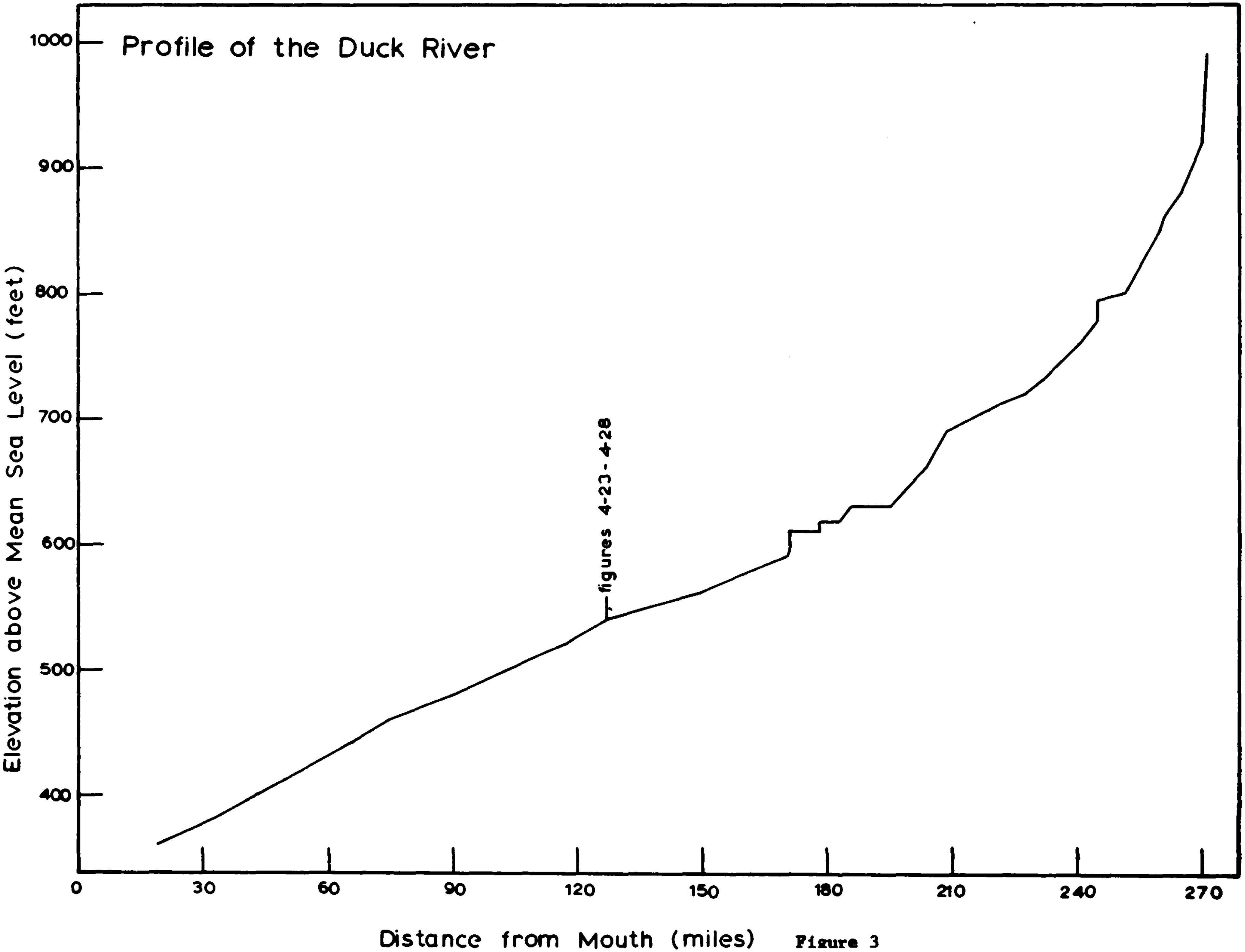

Profile of the Harpeth River
Elevation above Mean Sea Level (feet)
900
800
700
600
500
400
300
0
10
20
30
40
50
60
70
80
figure 4-22
figure 4-21
figures 4-16 - 4-20
figures 4-14&15
figures 4-12&13
figure 4-11
figure 4-10
figure 4-9
figures 4-1 - 4-8
Harpeth River
Little Harpeth River
Distance from Mouth (miles)

Figure 3


Profile of the Duck River
Elevation above Mean Sea Level (feet)
1000
900
800
700
600
500
400
figures 4-23 - 4-28
0
30
60
90
120
150
180
210
240
270
Distance from Mouth (miles)
Figure 3

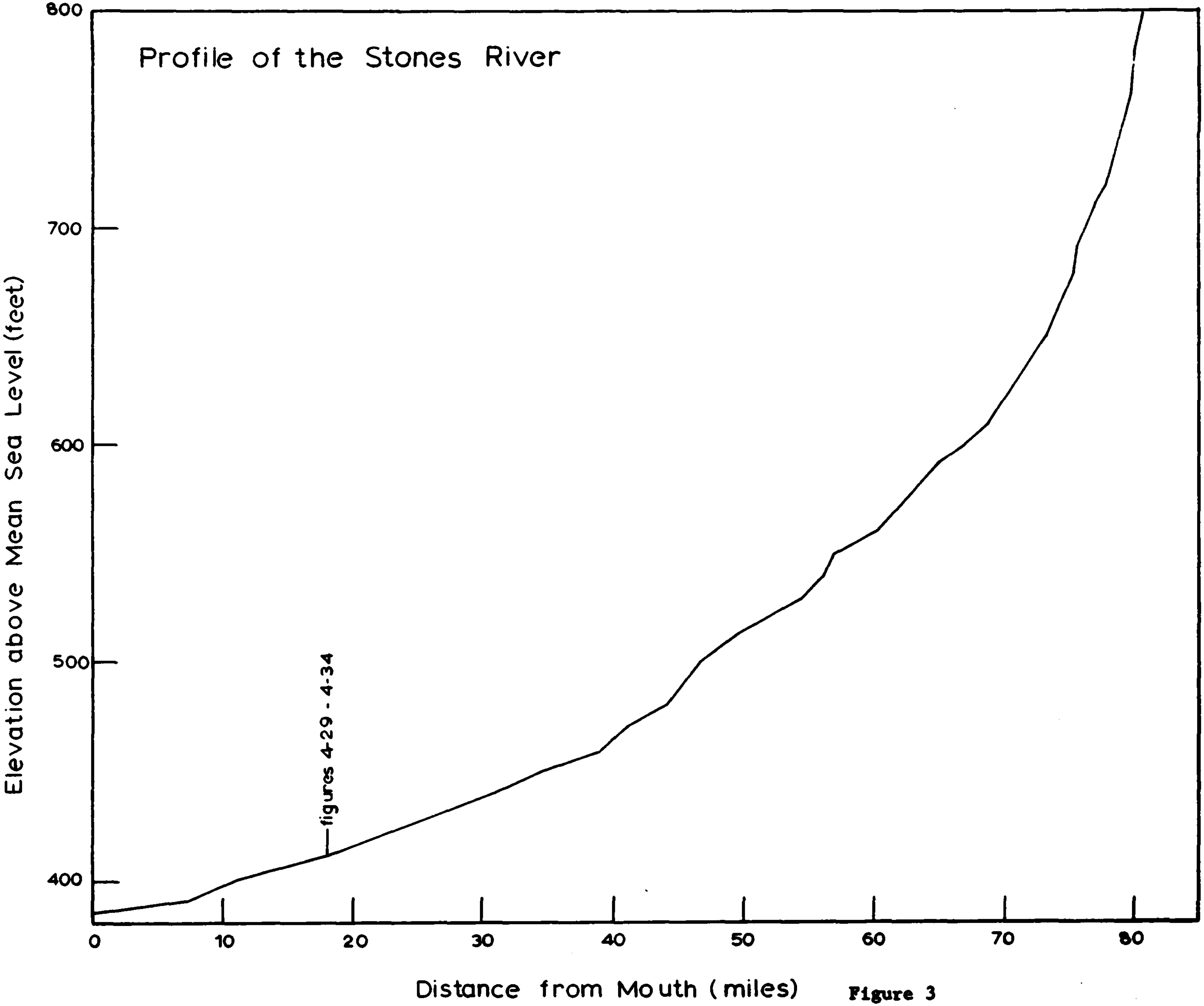
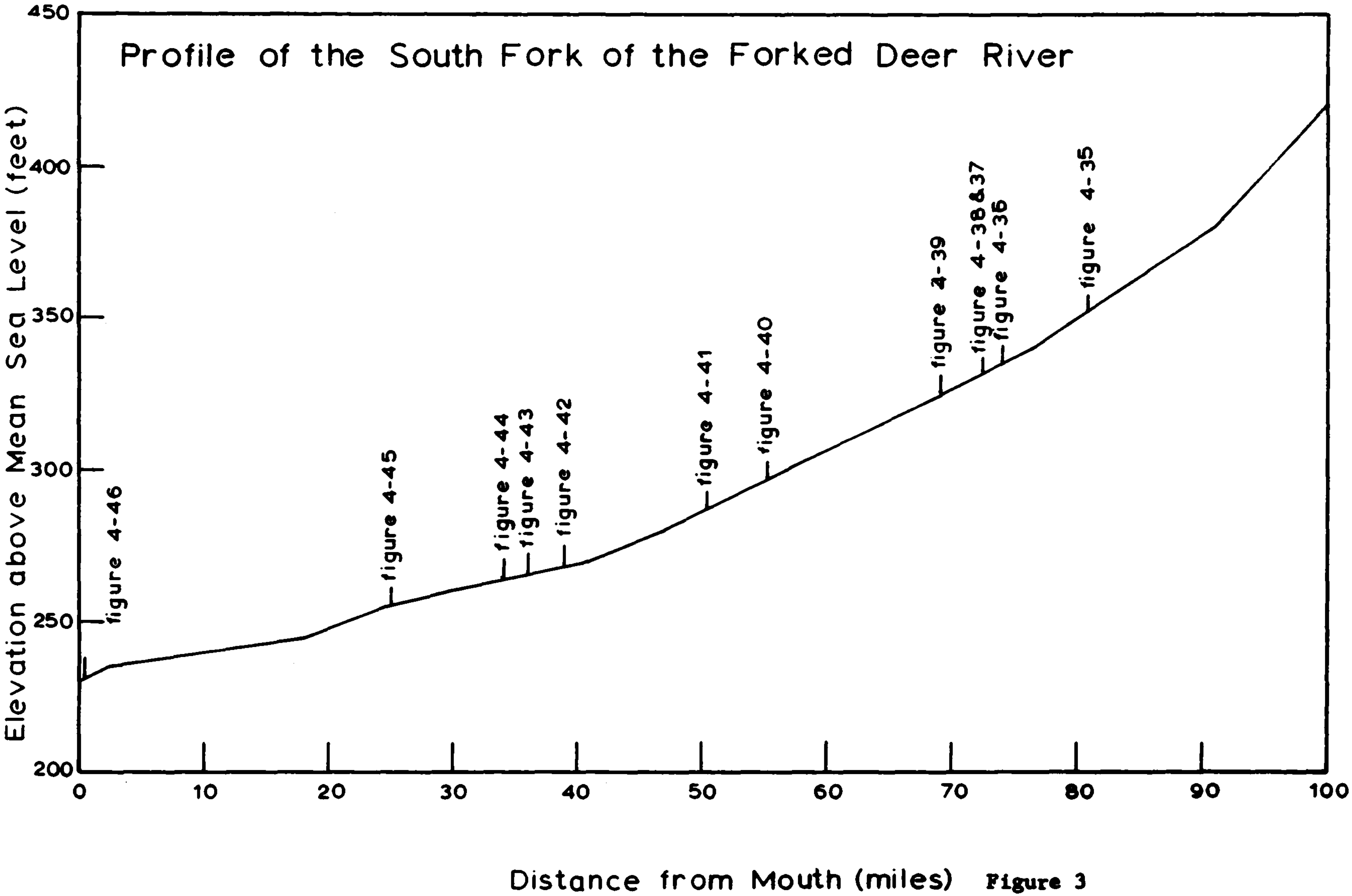

Profile of the Stones River
Elevation above Mean Sea Level (feet)
800
700
600
500
400
figures 4-29 - 4-34
0
10
20
30
40
50
60
70
80
Distance from Mouth (miles)

Figure 3


Profile of the South Fork of the Forked Deer River
Elevation above Mean Sea Level (feet)
450
400
350
300
250
200
0
10
20
30
40
50
60
70
80
90
100
figure 4-46
figure 4-45
figure 4-44
figure 4-43
figure 4-42
figure 4-41
figure 4-40
figure 4-39
figure 4-38&37
figure 4-36
figure 4-35
Distance from Mouth (miles)
Figure 3

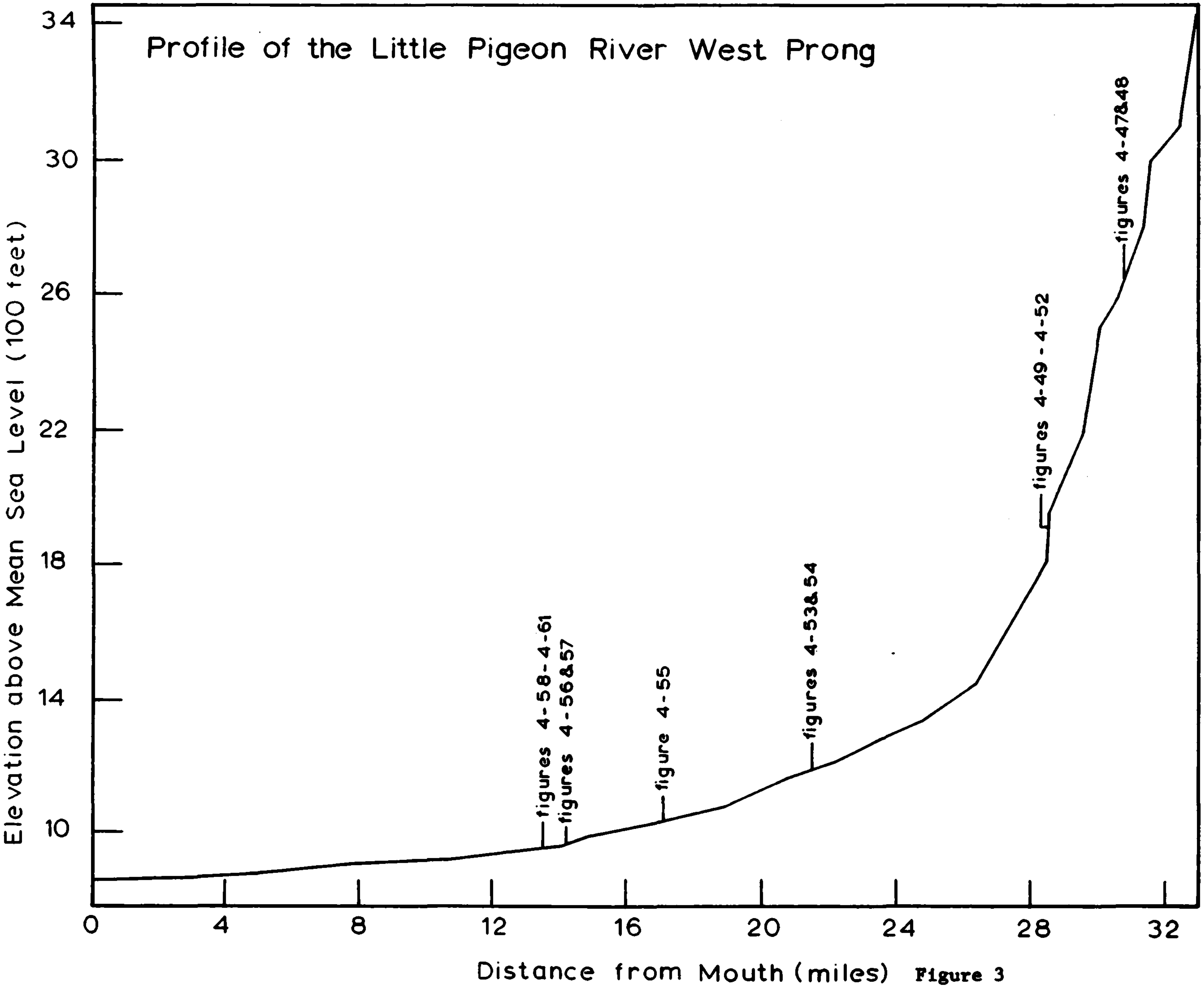

Profile of the Little Pigeon River West Prong
Elevation above Mean Sea Level (100 feet)
34
30
26
22
18
14
10
0
4
8
12
16
20
24
28
32
Distance from Mouth (miles)
figures 4-58 - 4-61
figures 4-56&57
figure 4-55
figures 4-53&54
figures 4-49 - 4-52
figures 4-47&48

Figure 3

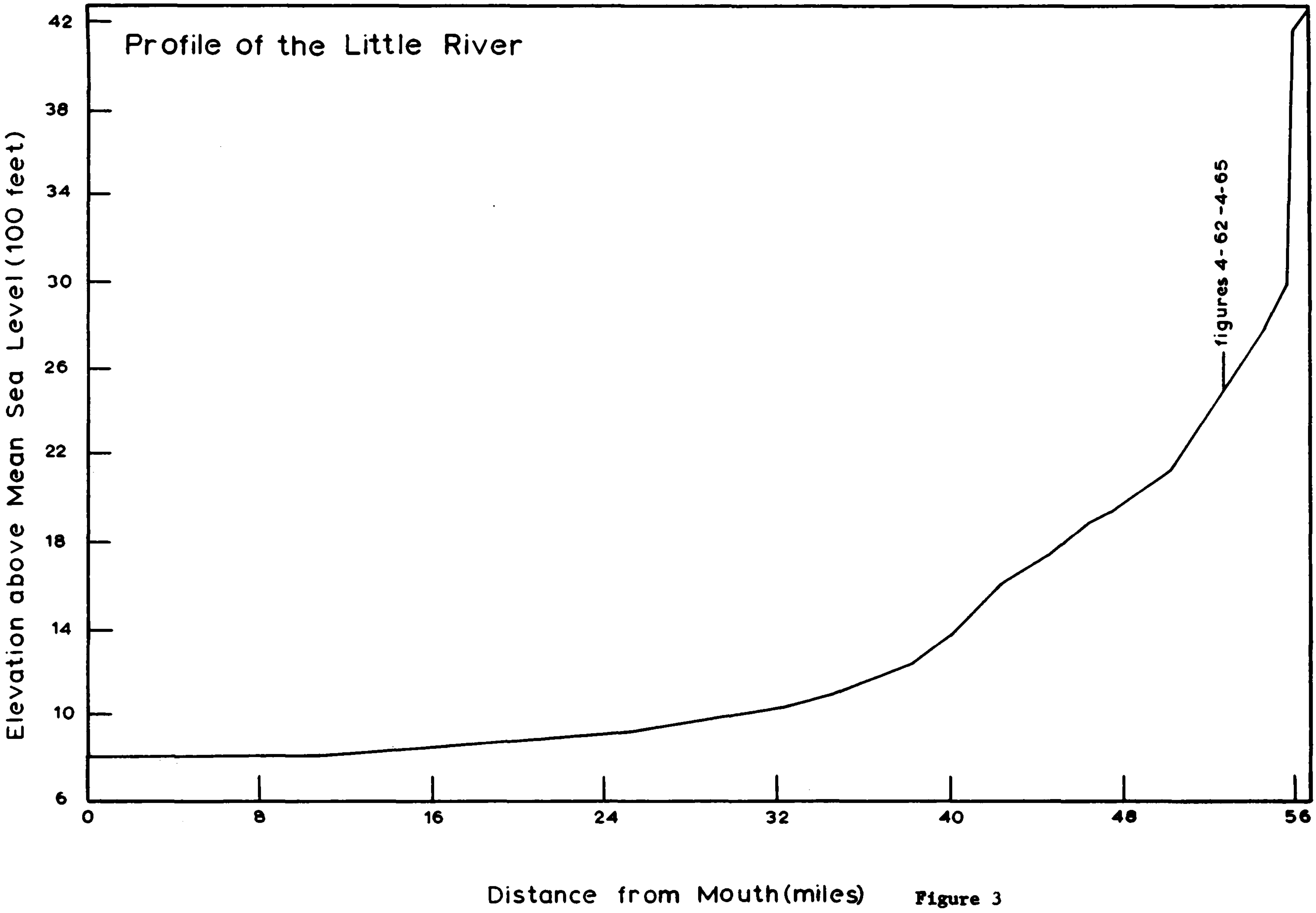

Profile of the Little River
Elevation above Mean Sea Level (100 feet)
42
38
34
30
26
22
18
14
10
6
0
8
16
24
32
40
48
56
figures 4-62-4-65
Distance from Mouth (miles)

Figure 3

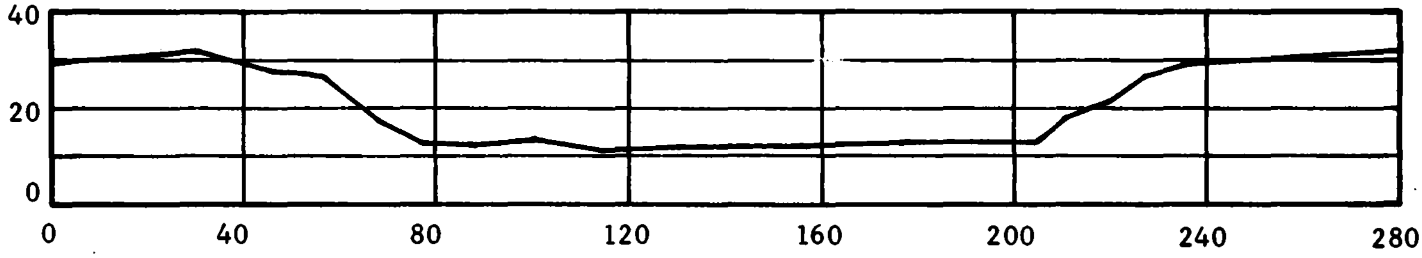
FIGURE 4

TYPICAL CROSS SECTIONS

OF

STREAMS SAMPLED

Figure 4-1



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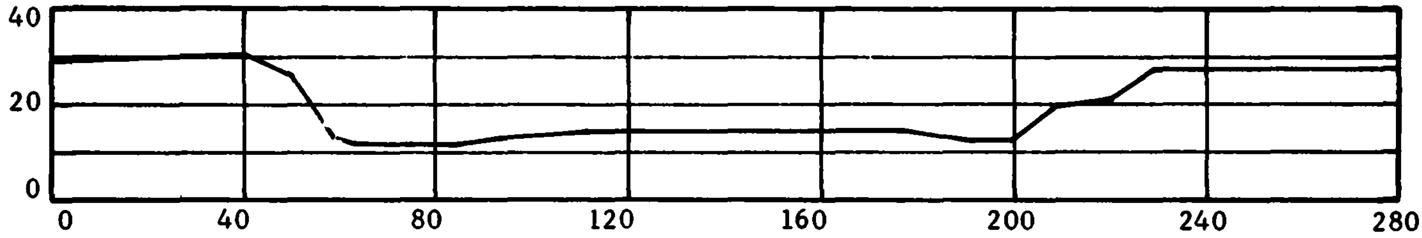

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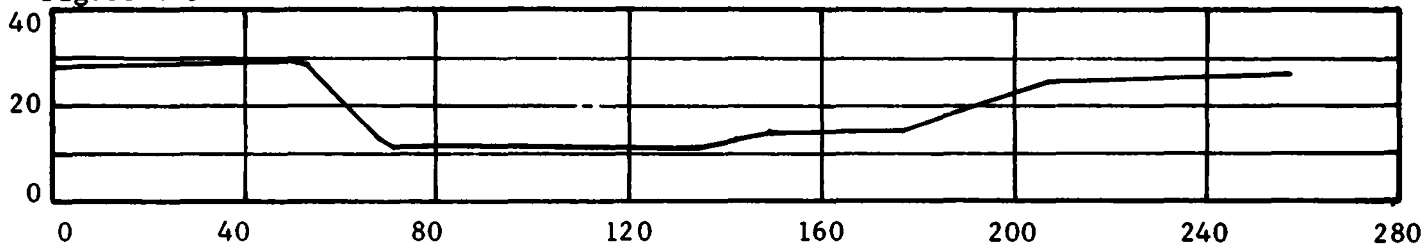

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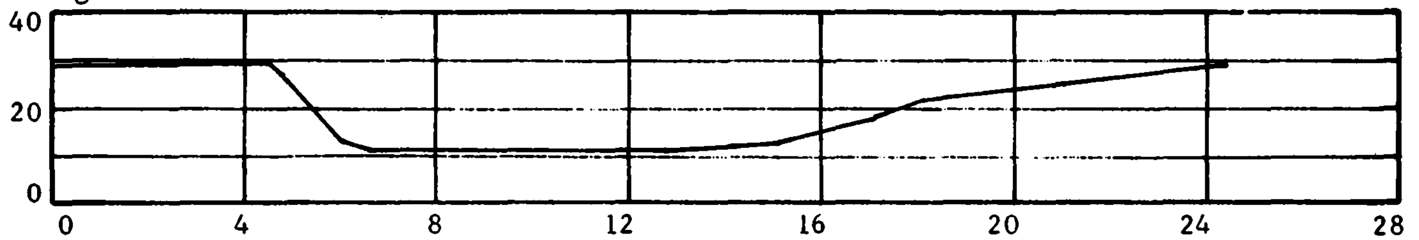

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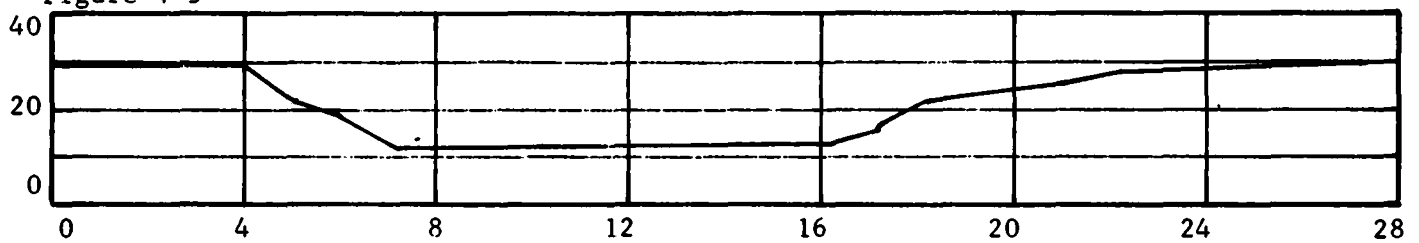

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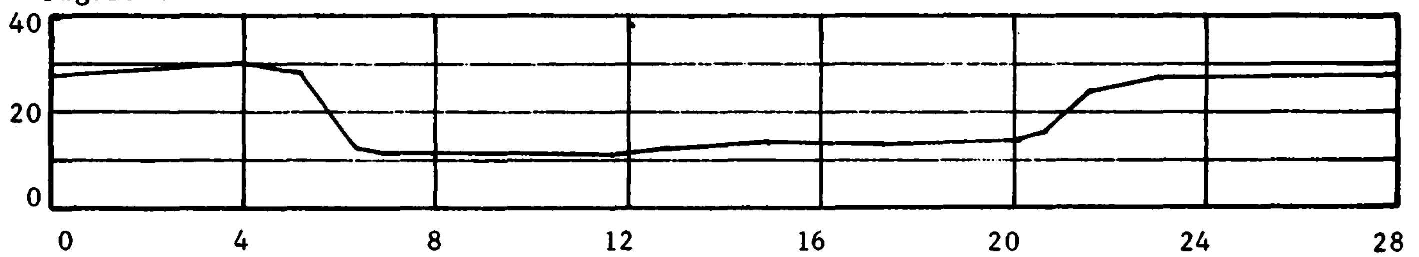

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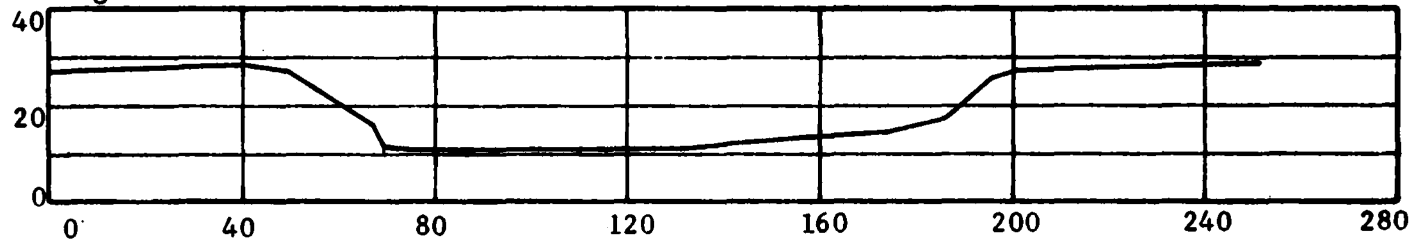

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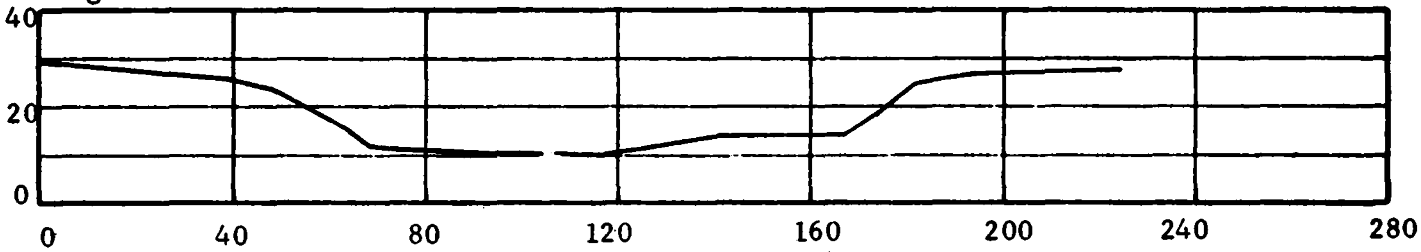

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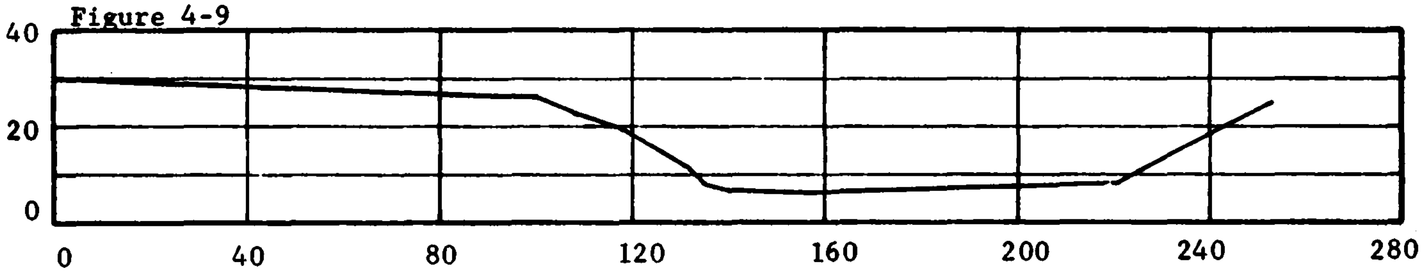

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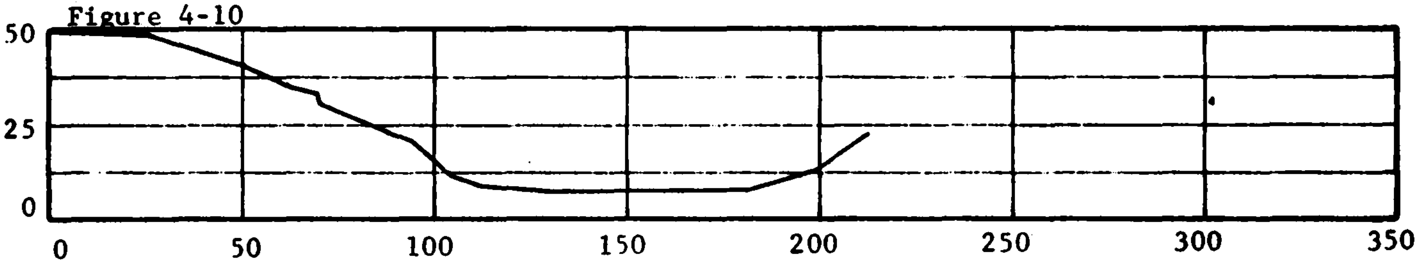

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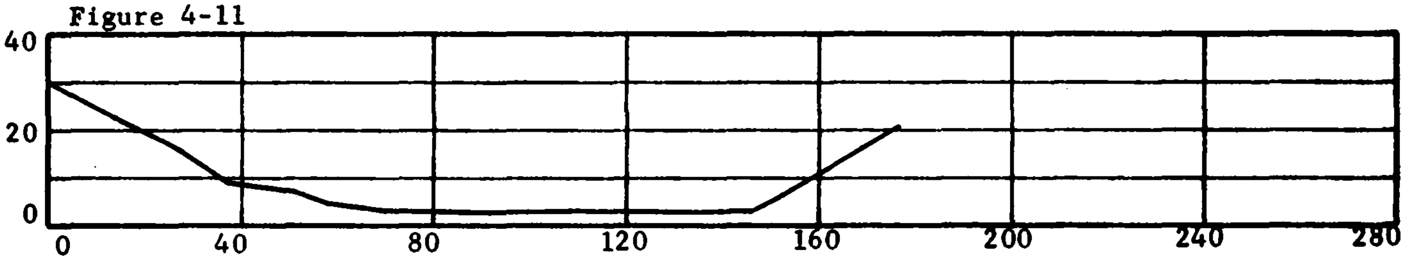
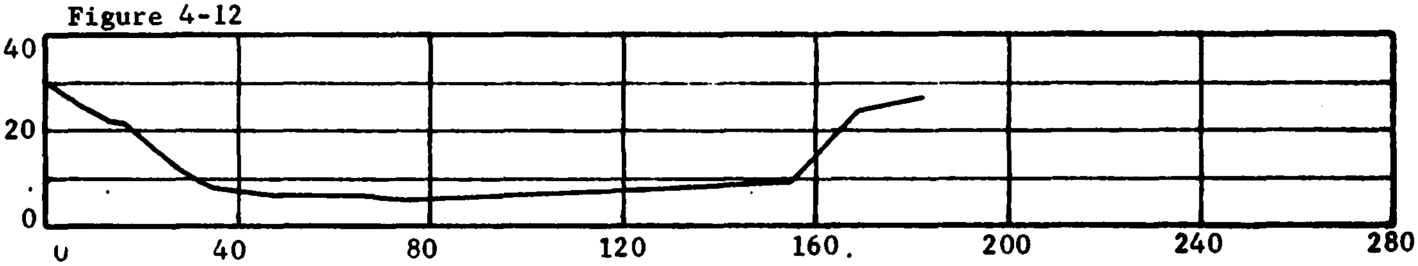


Figure 4-12



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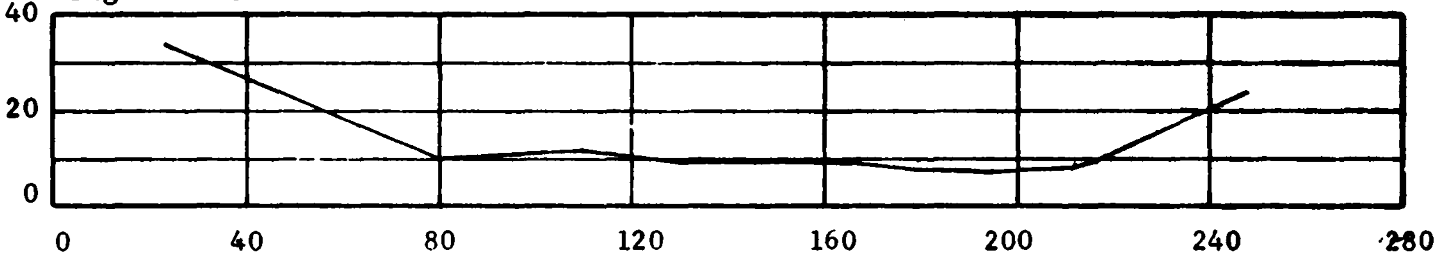

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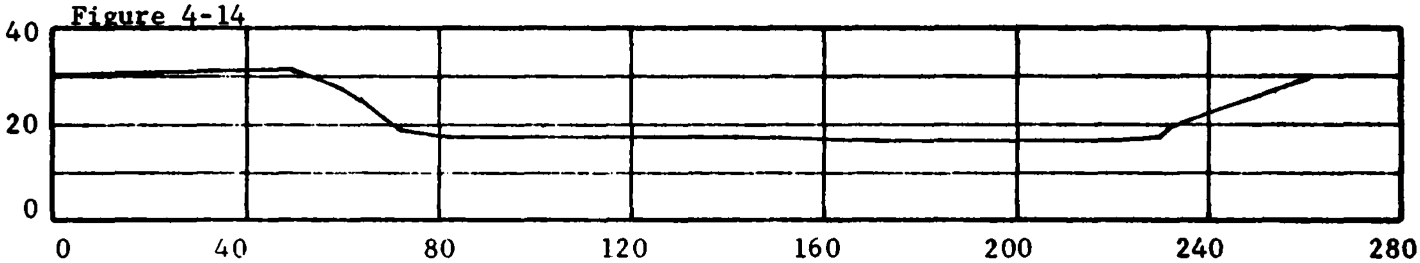

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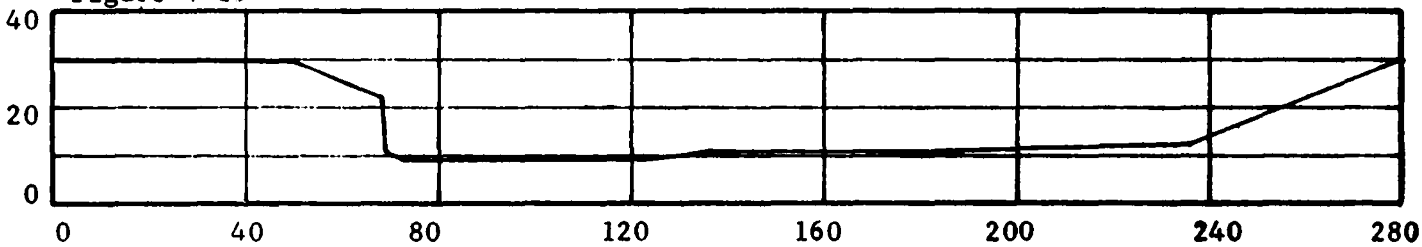

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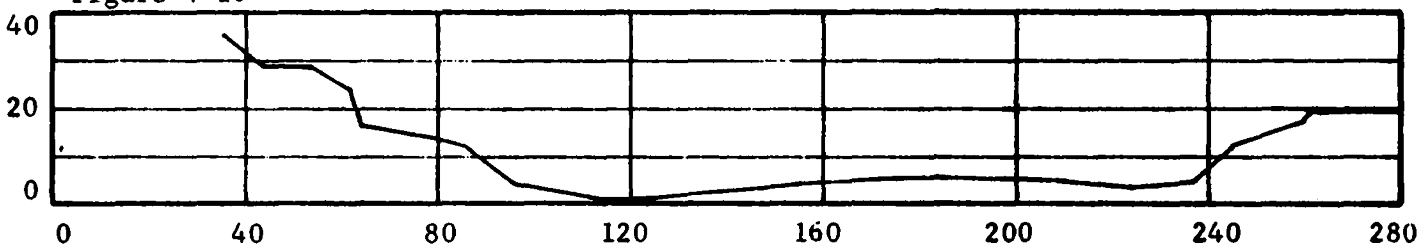


Figure 4-17

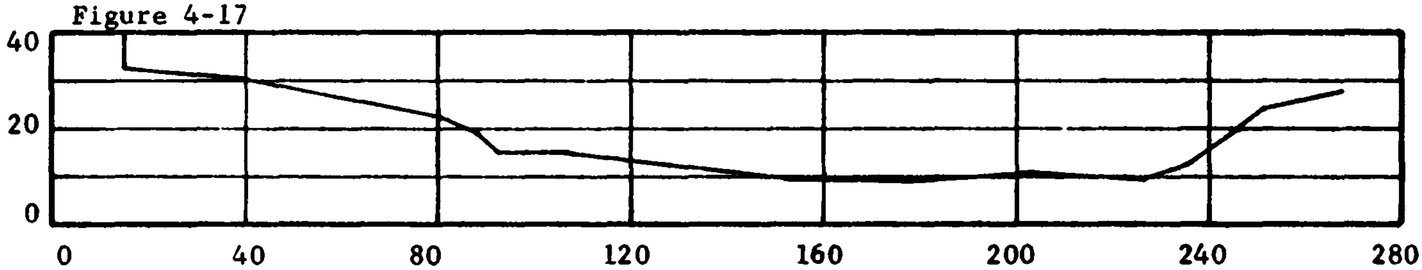
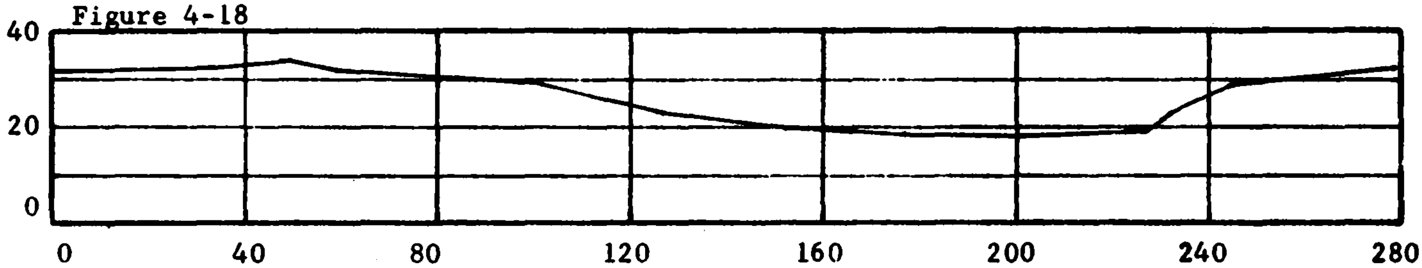


Figure 4-18



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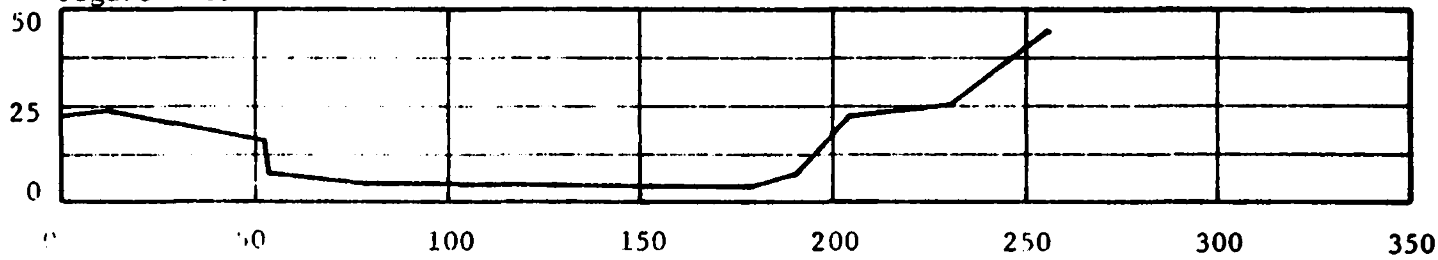

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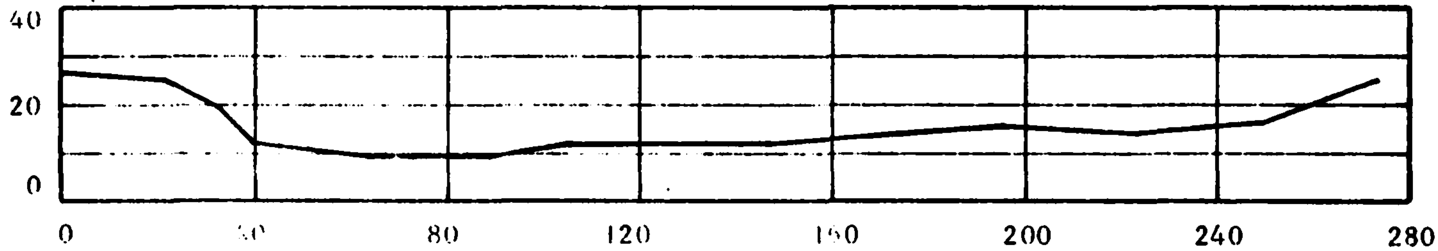

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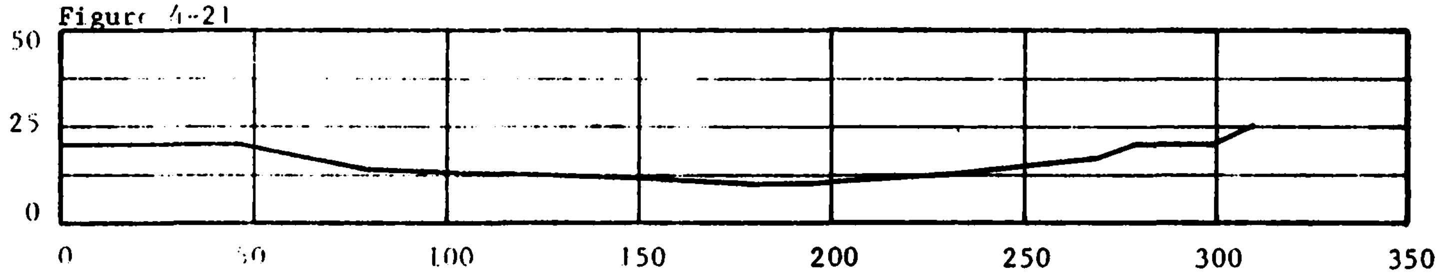

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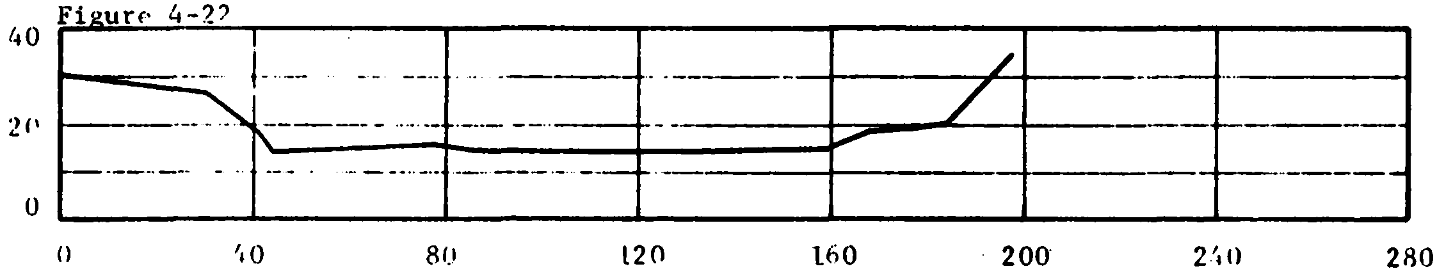

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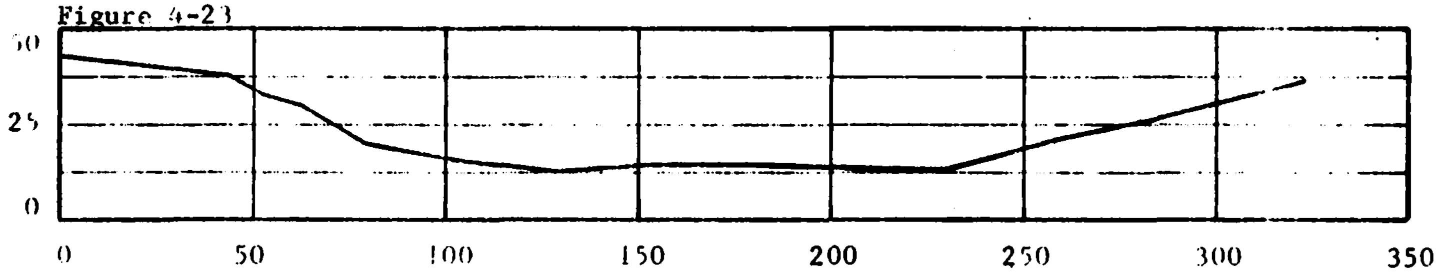

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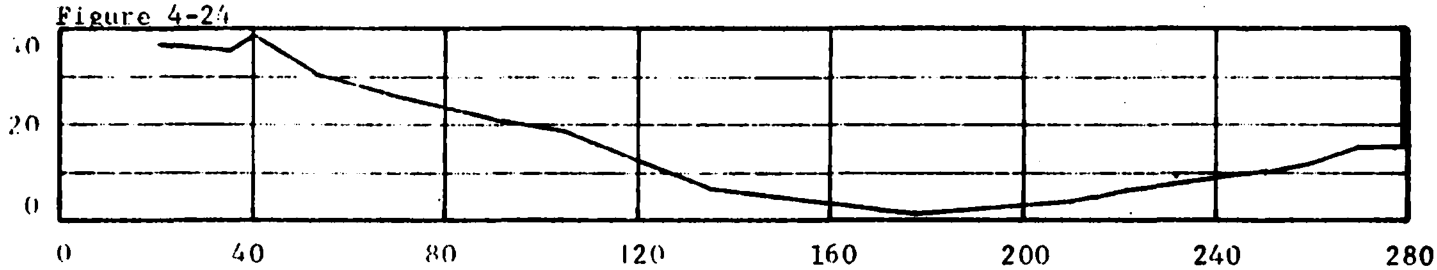

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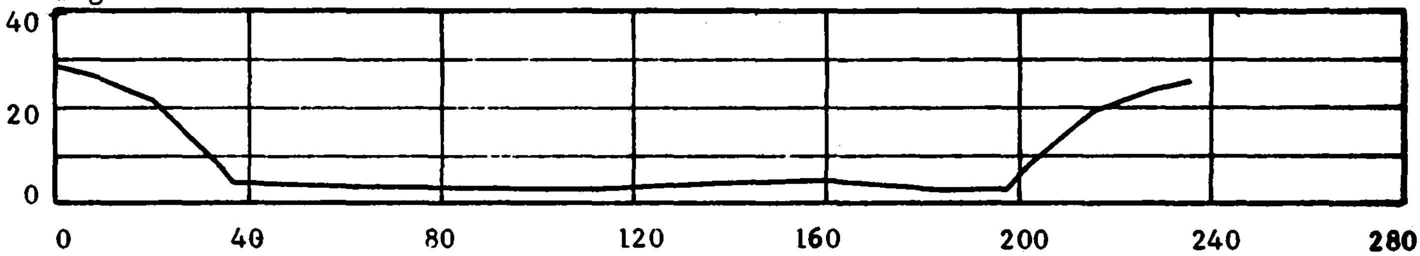

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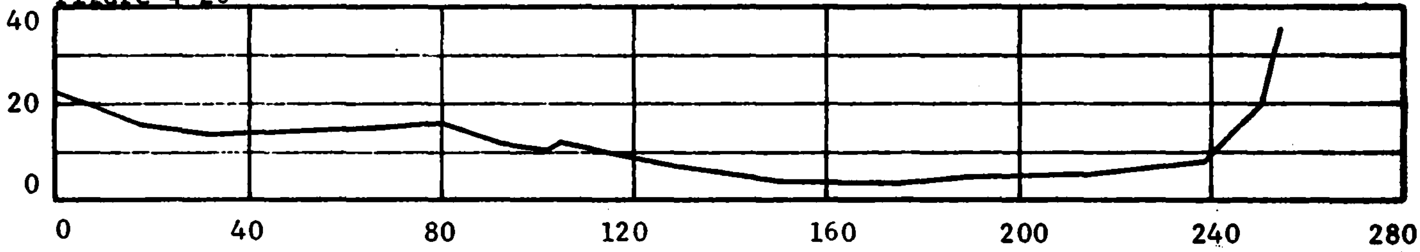

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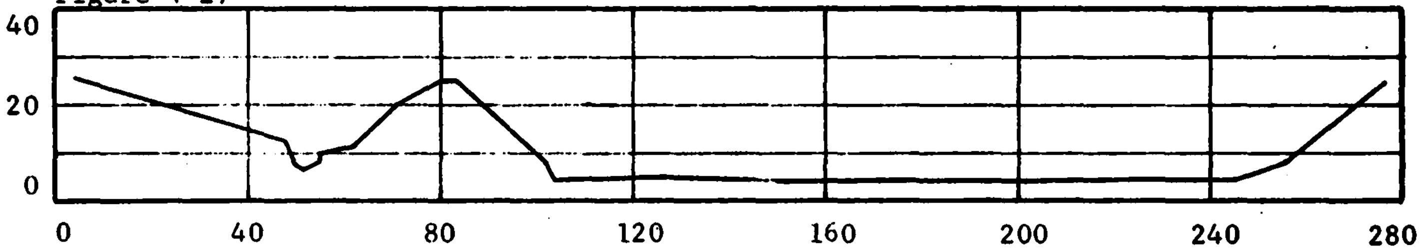

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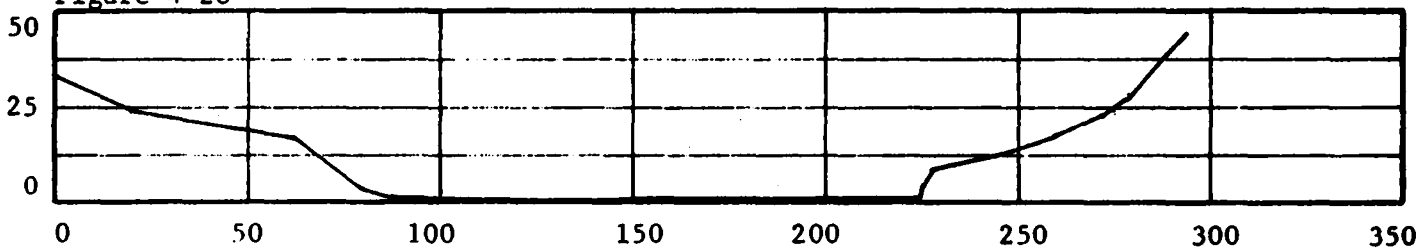

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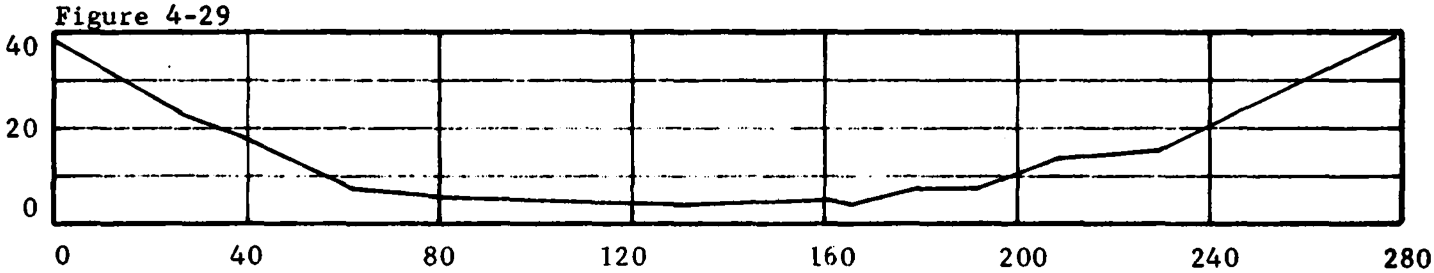

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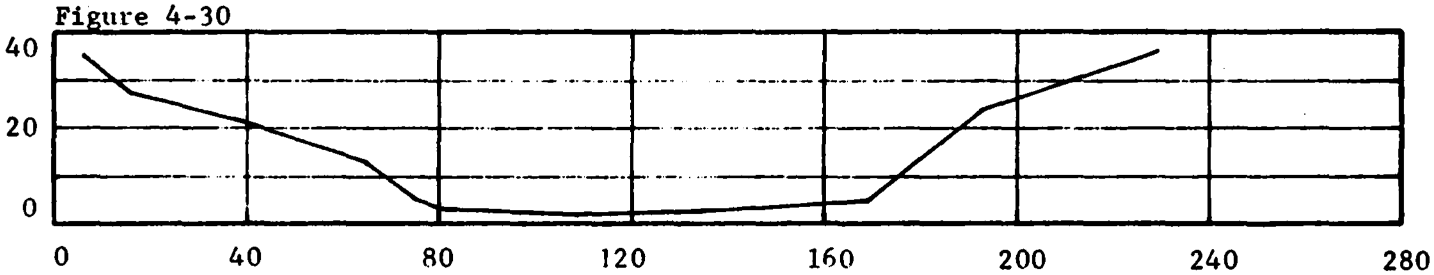

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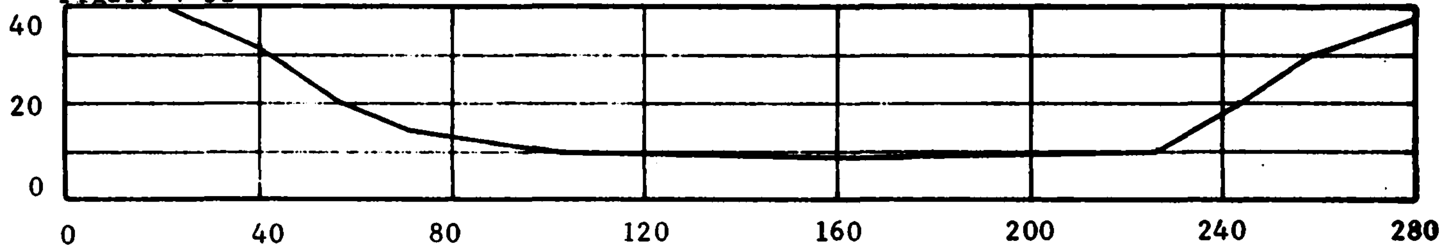

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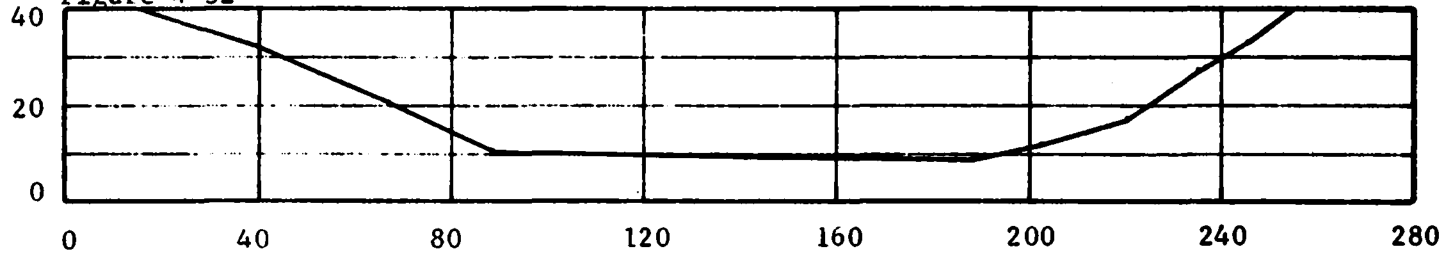

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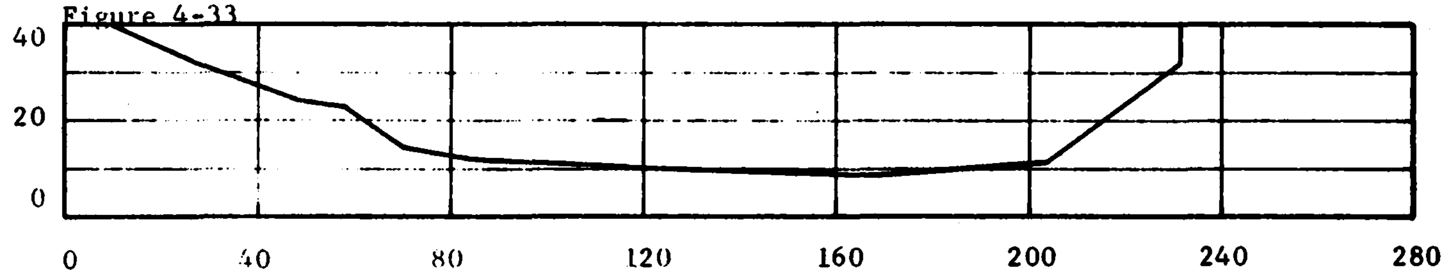

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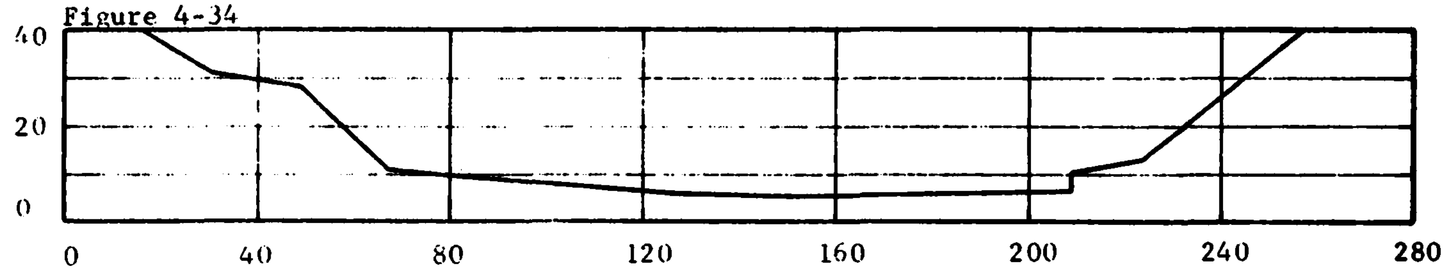

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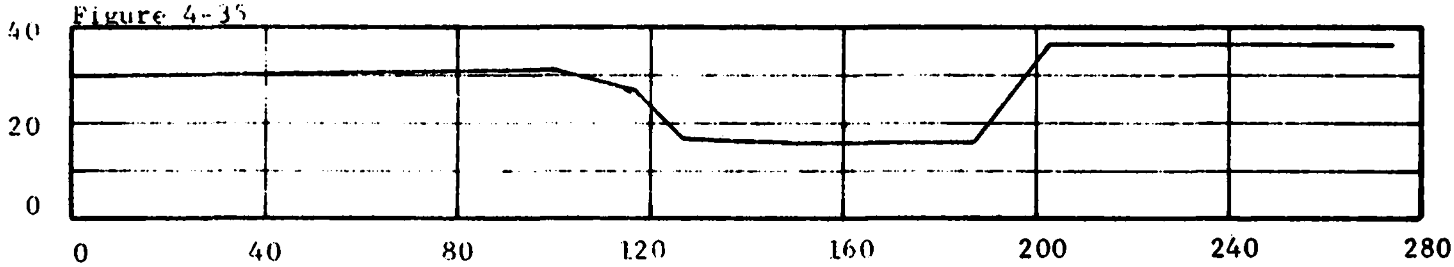

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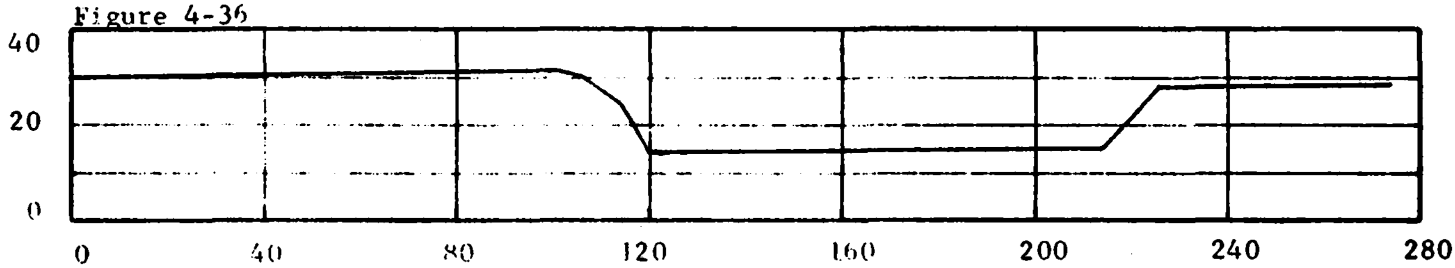

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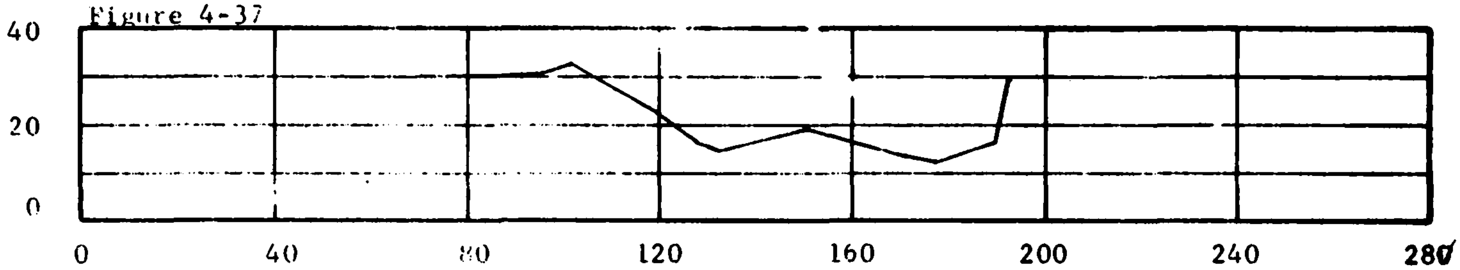

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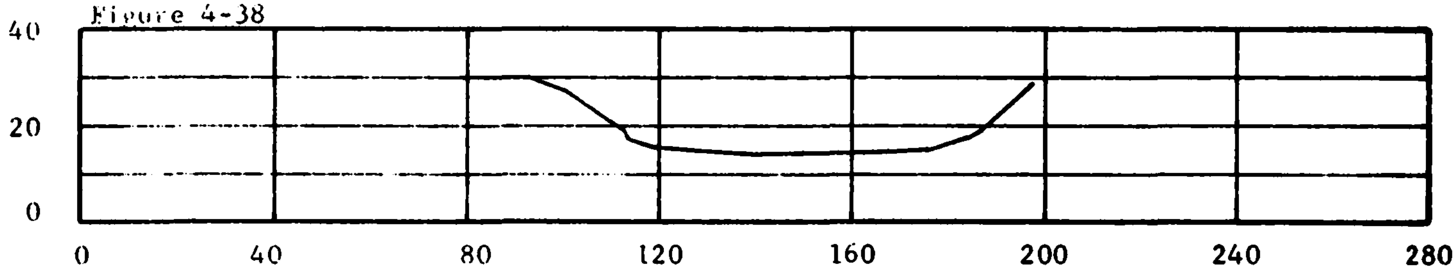

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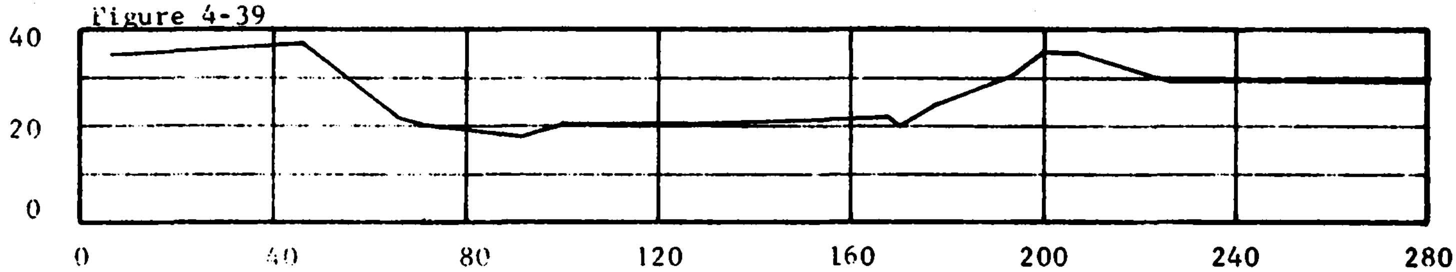

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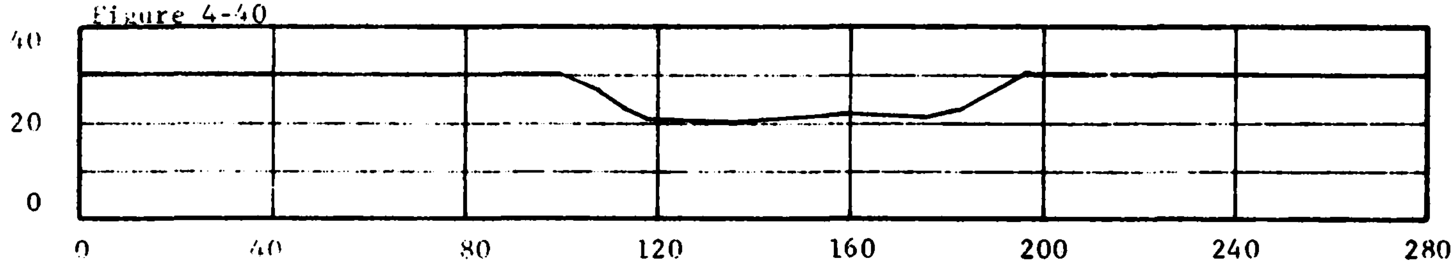

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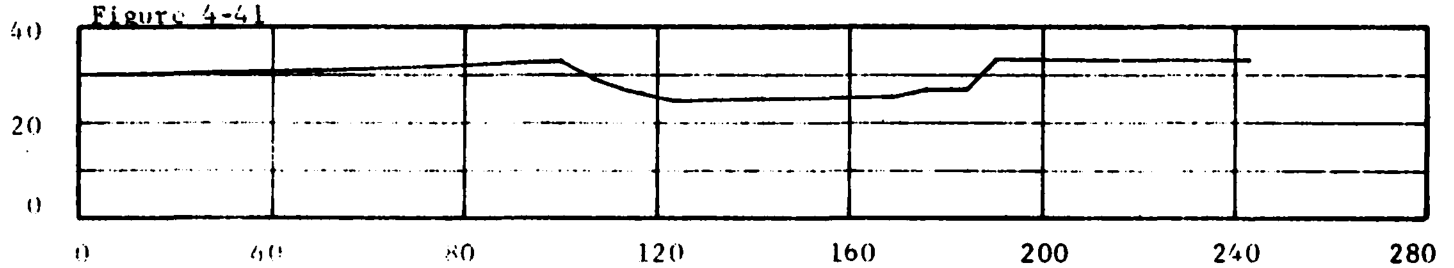

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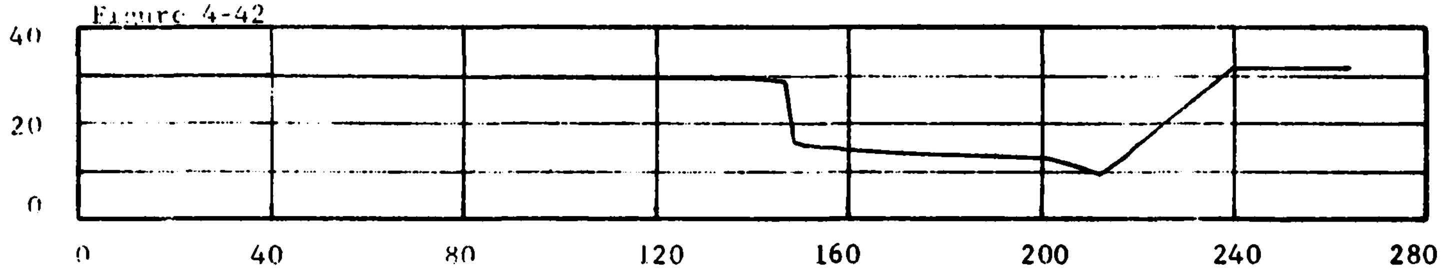

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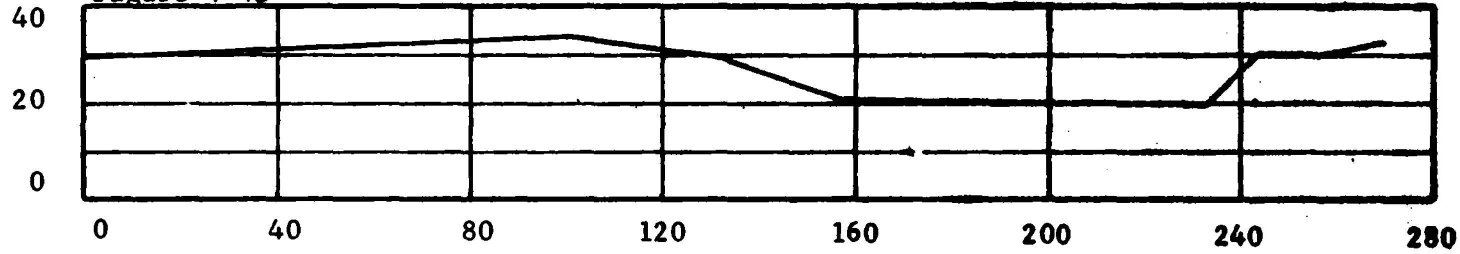

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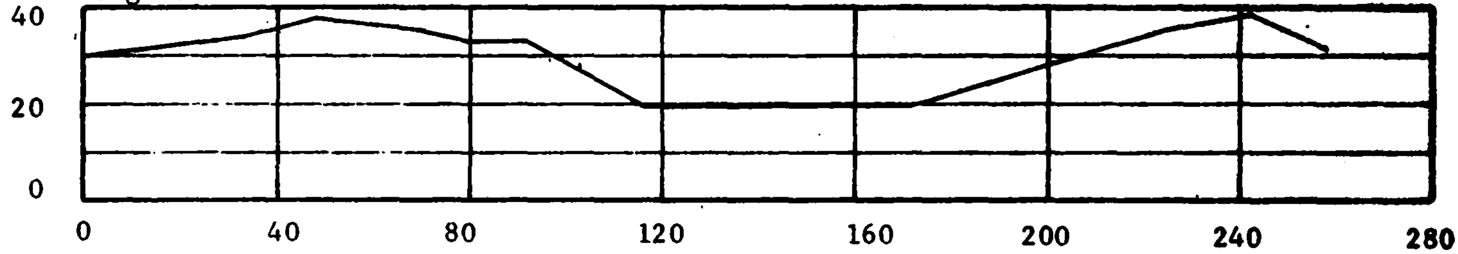

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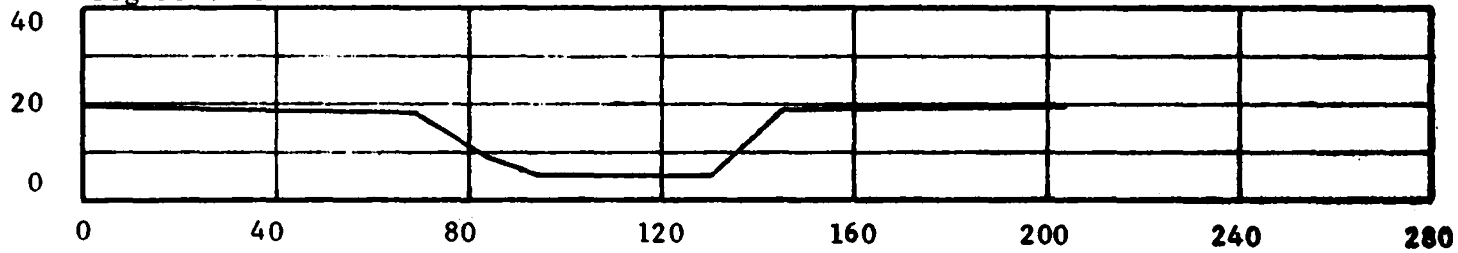

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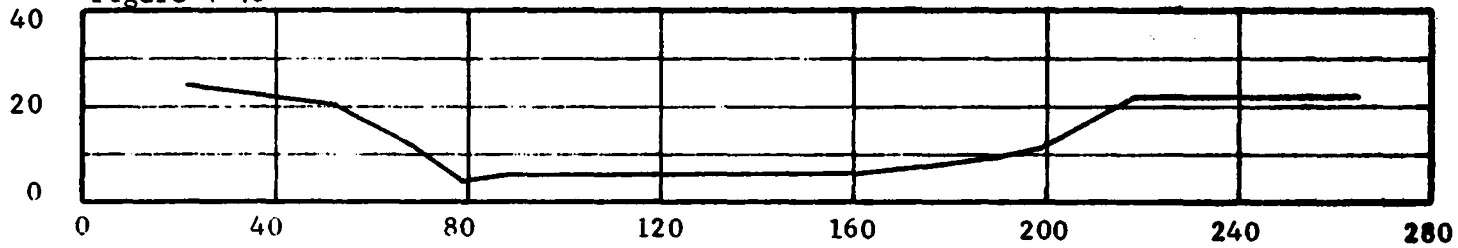

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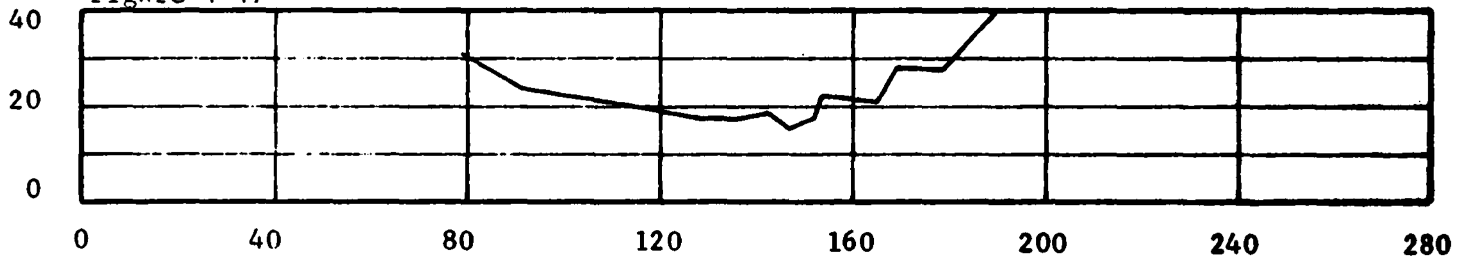

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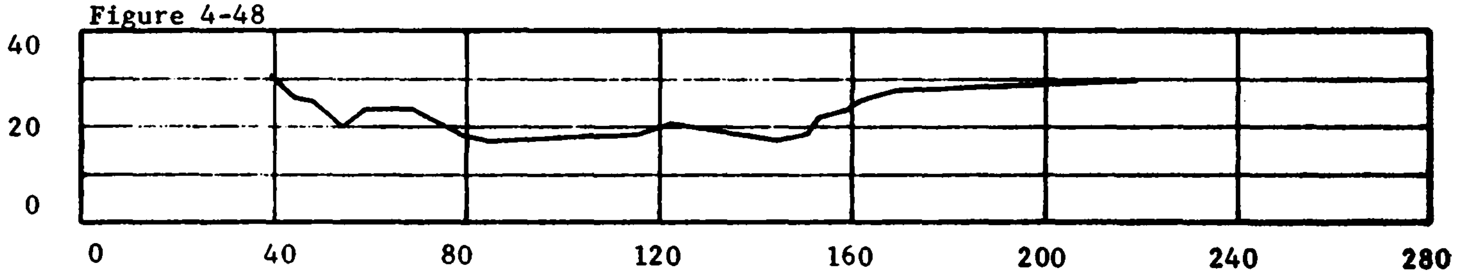

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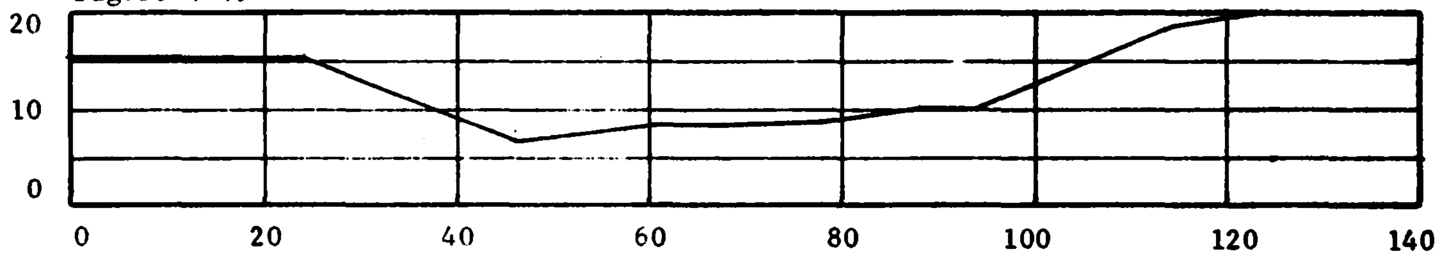

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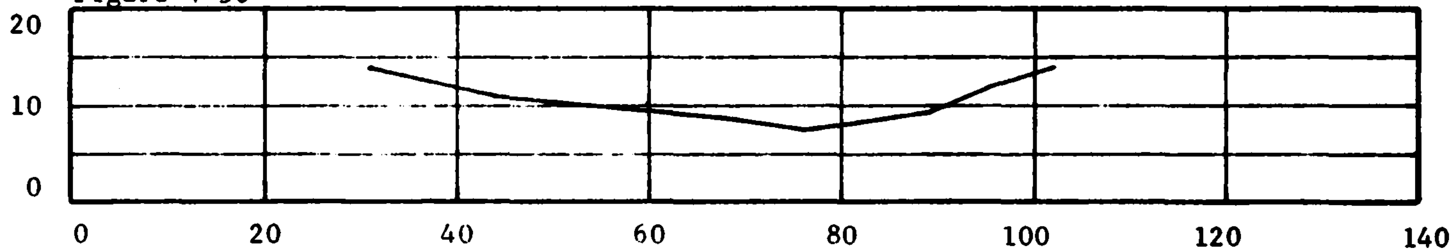

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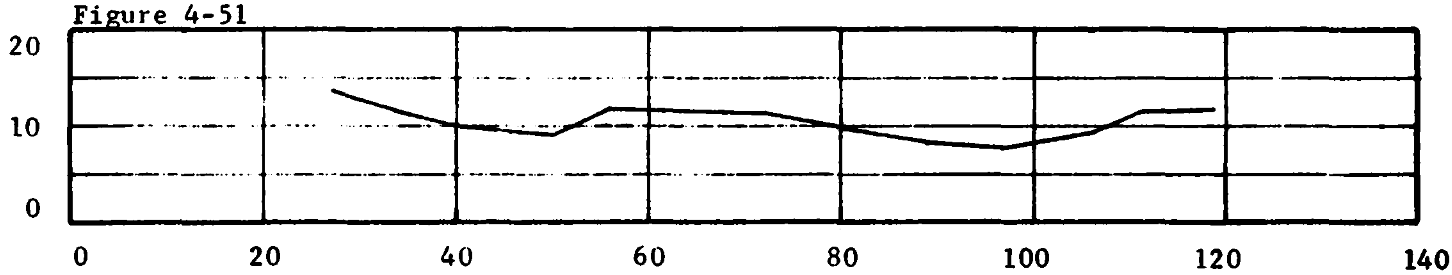

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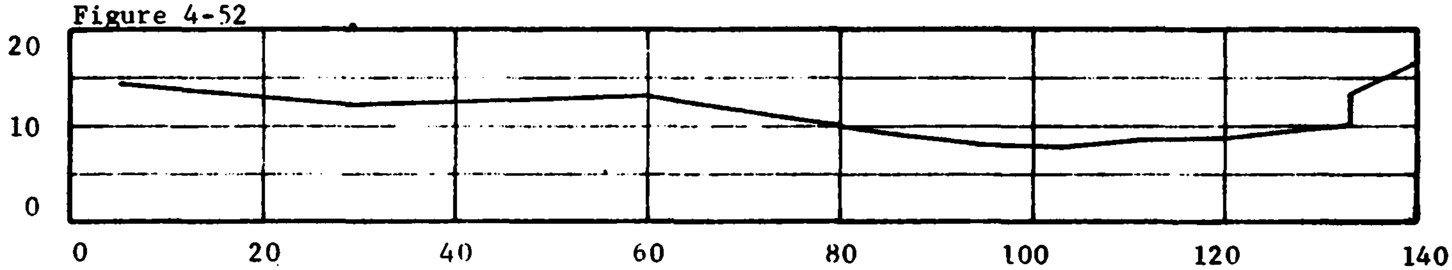

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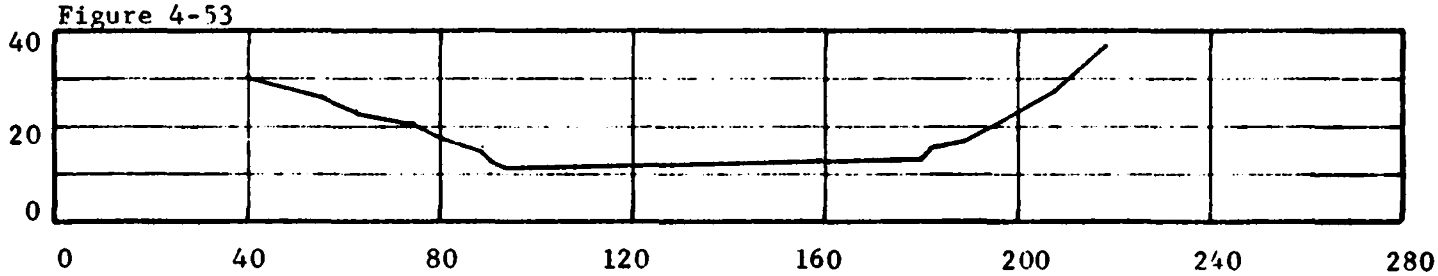

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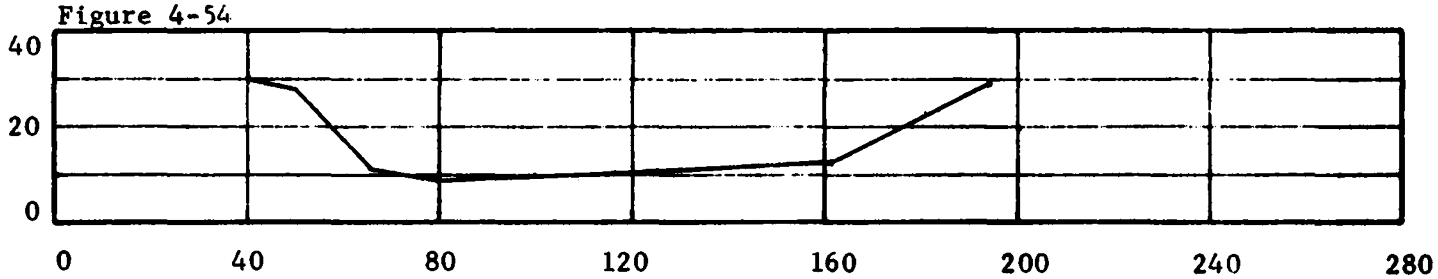
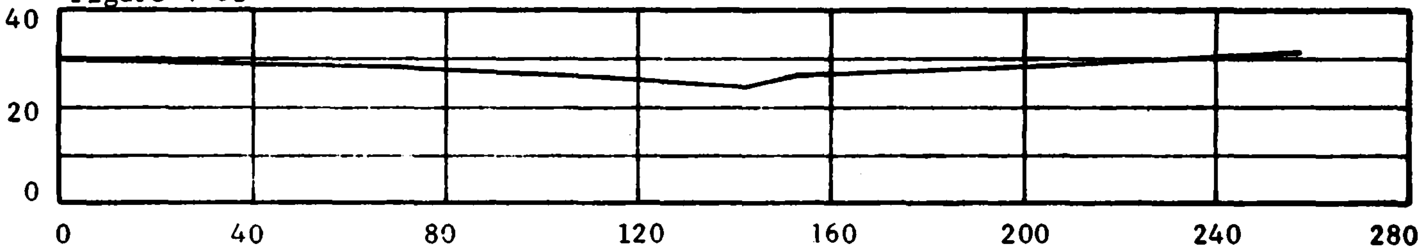


Figure 4-61



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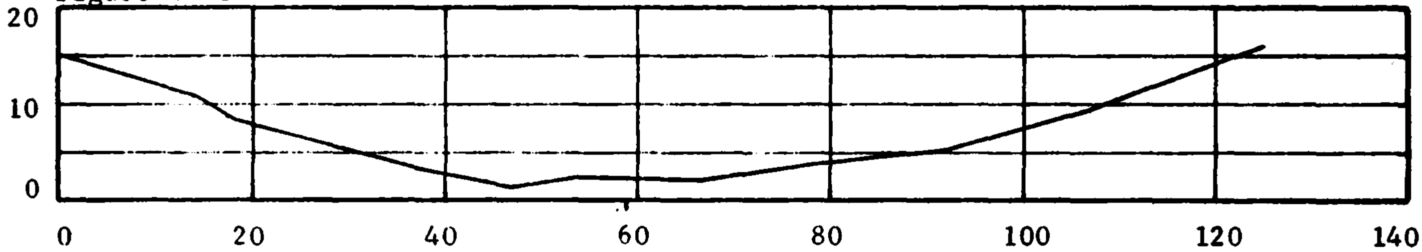

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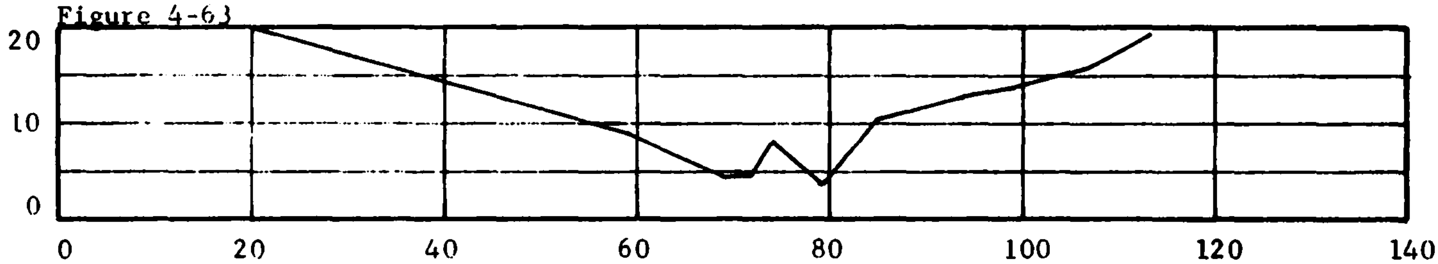

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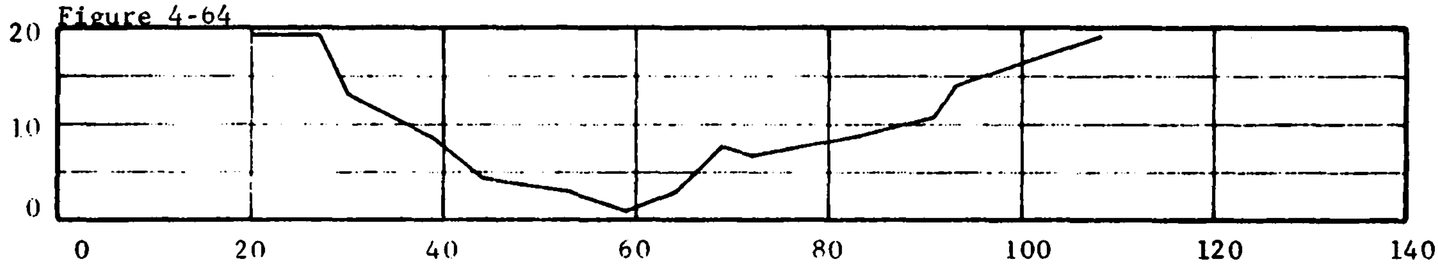

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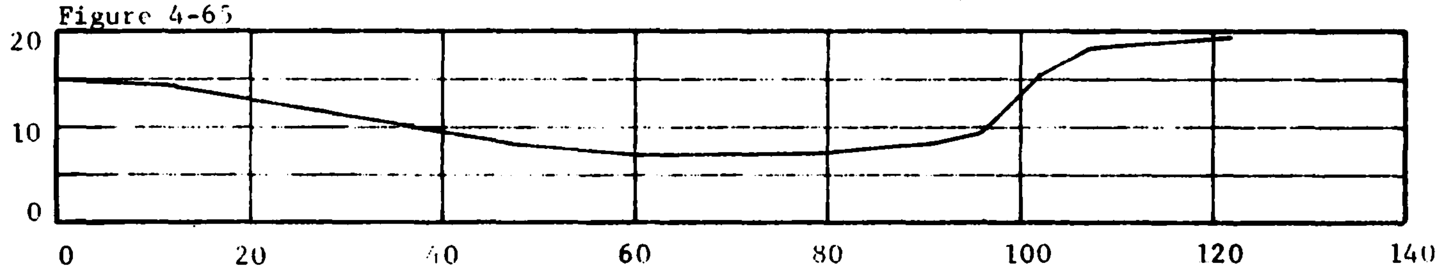

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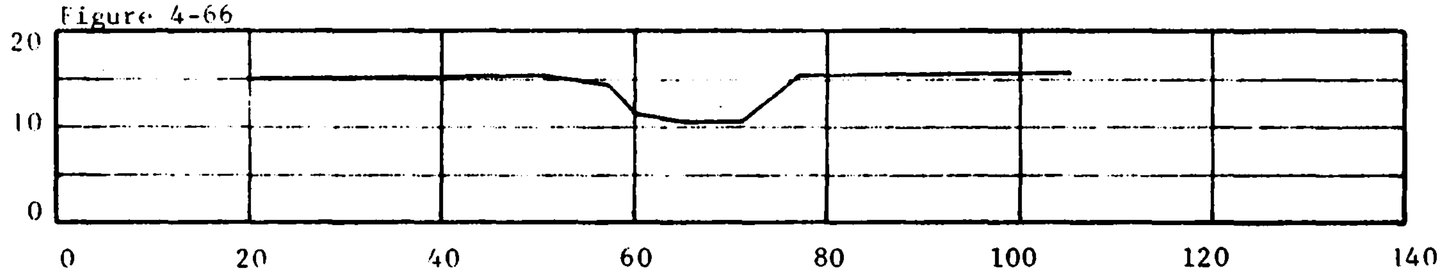

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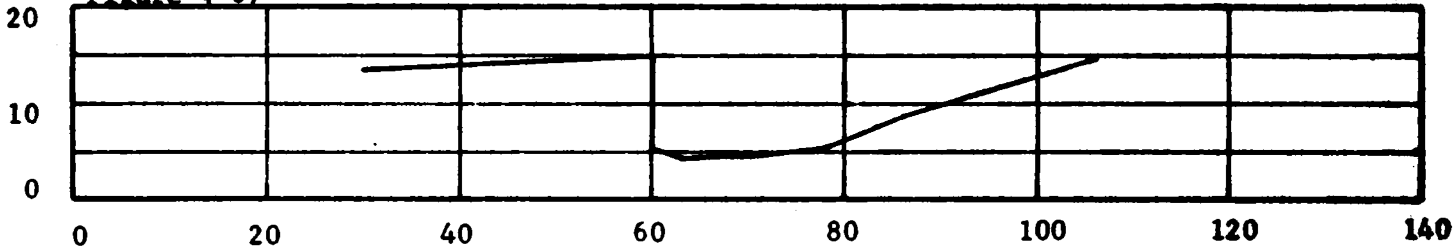

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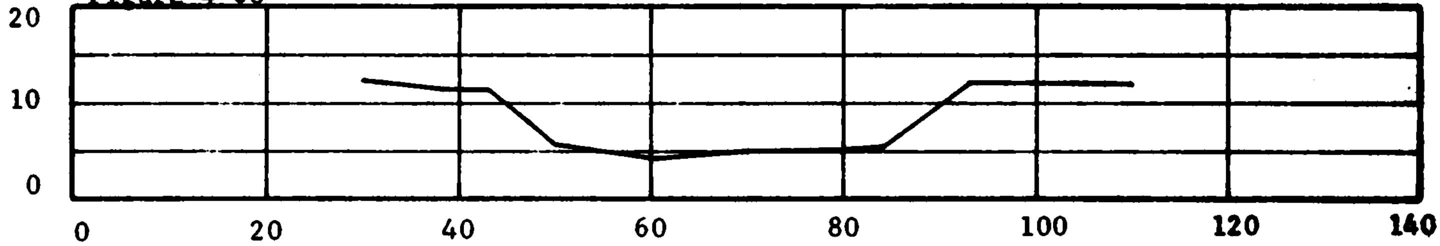

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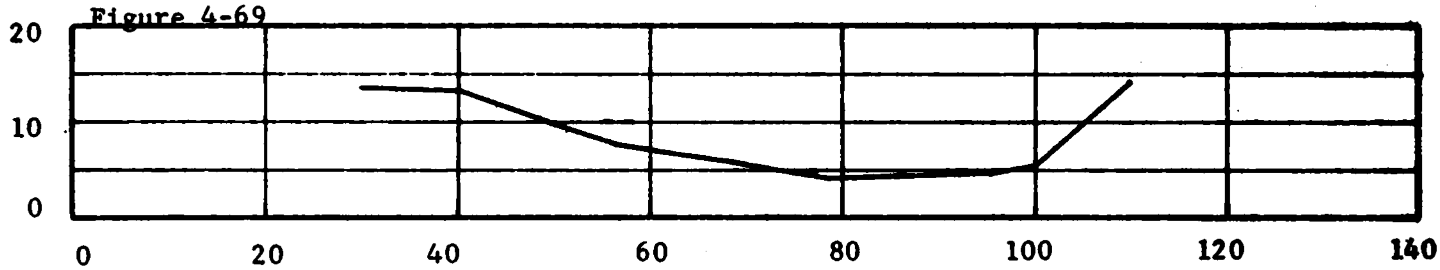

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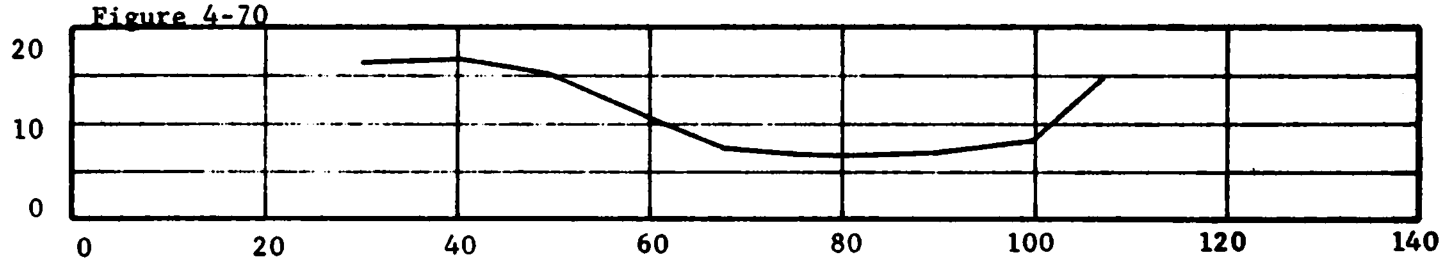

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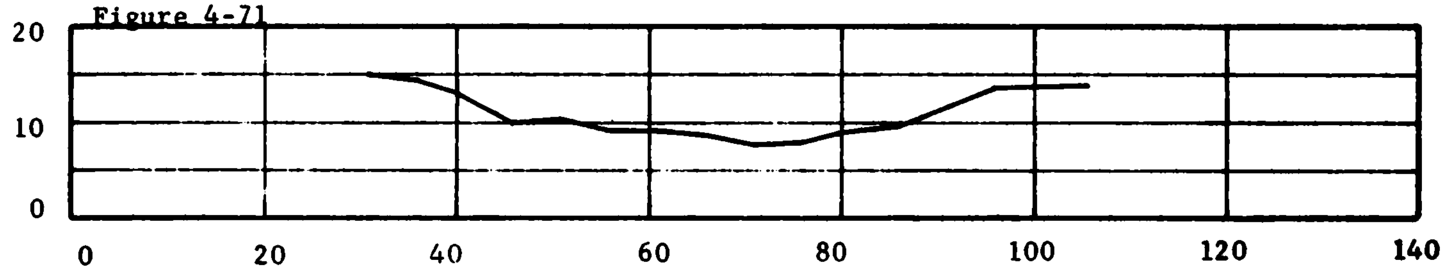

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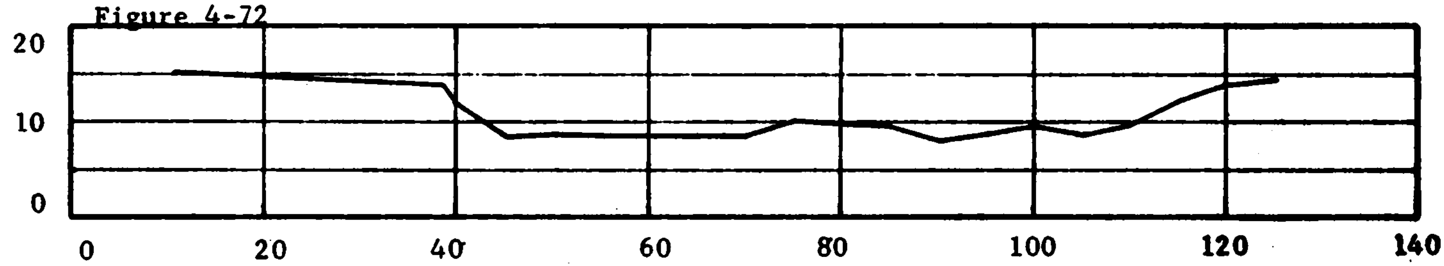
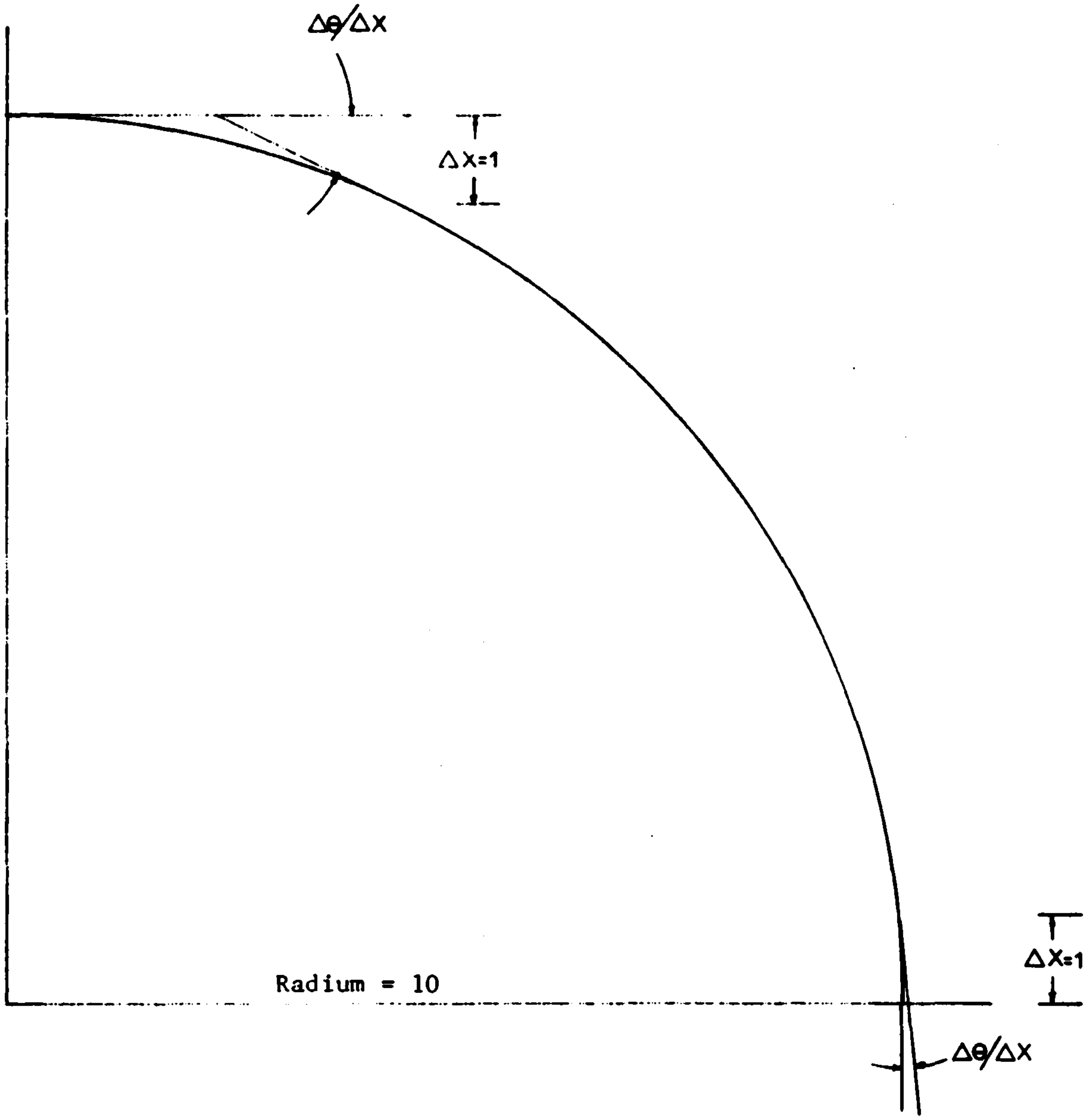


Figure 5. Demonstration of Effect of Slope on Measure of Rate of Change of Slope When Measured over a Finite Distance



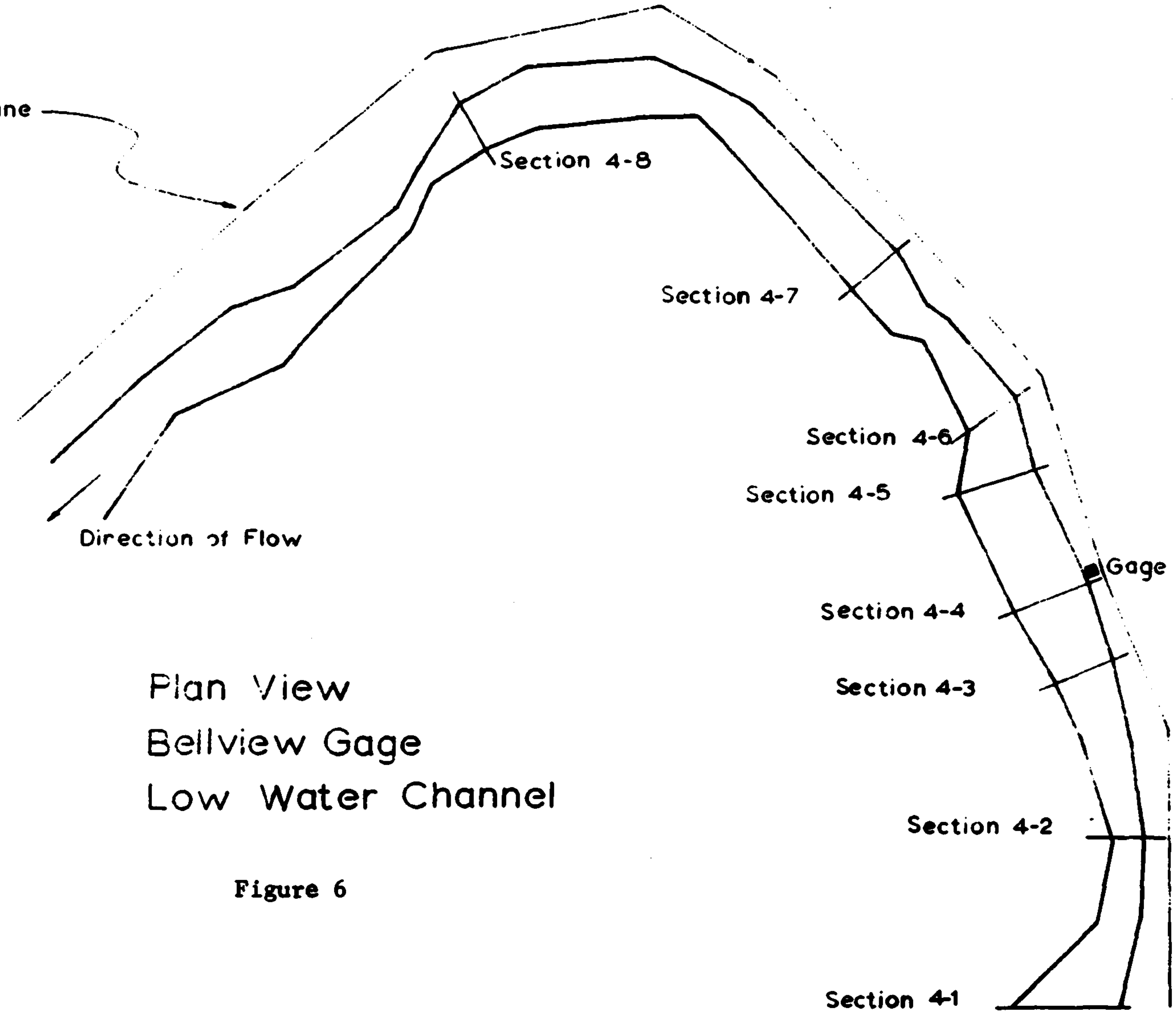
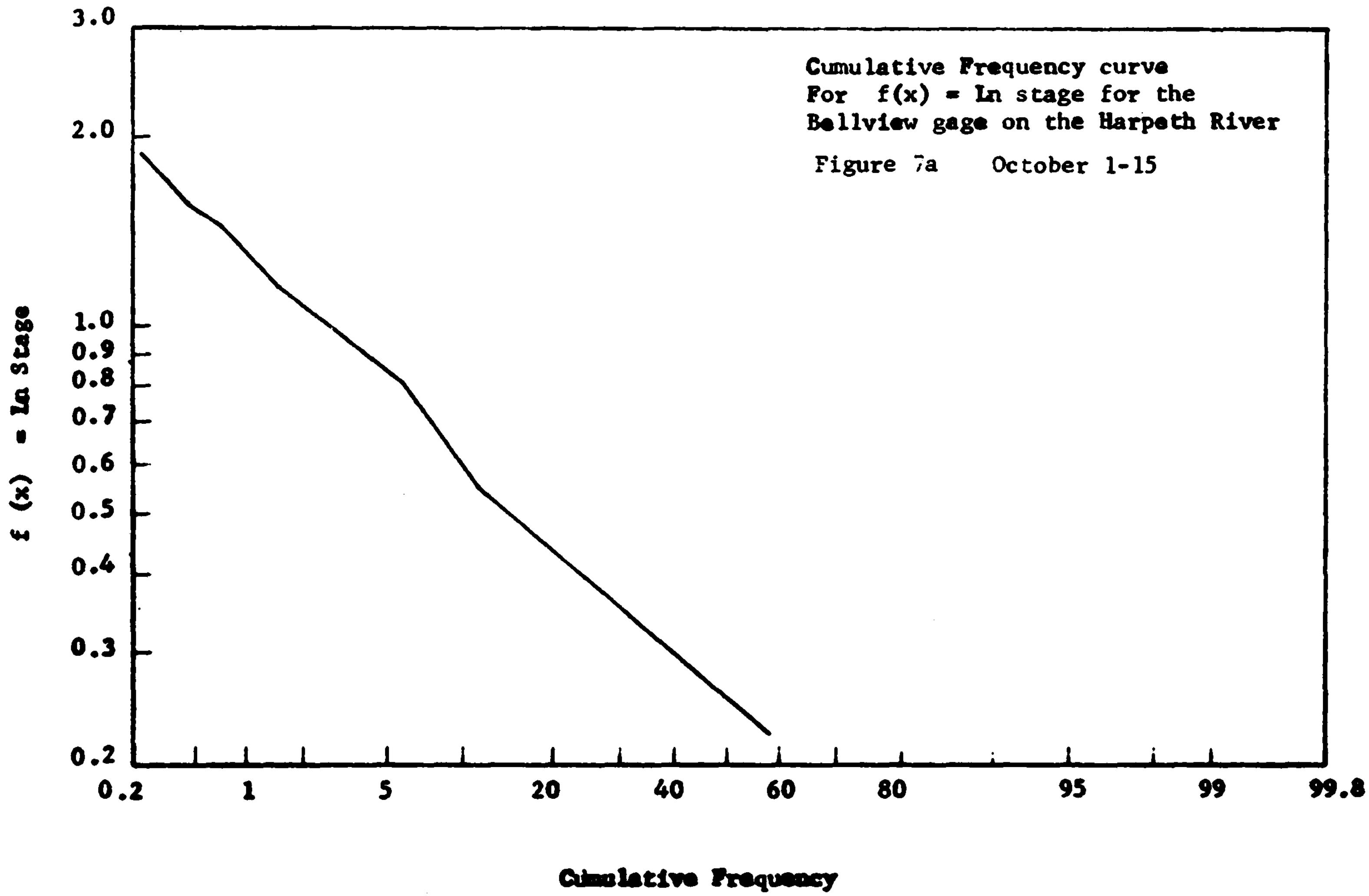
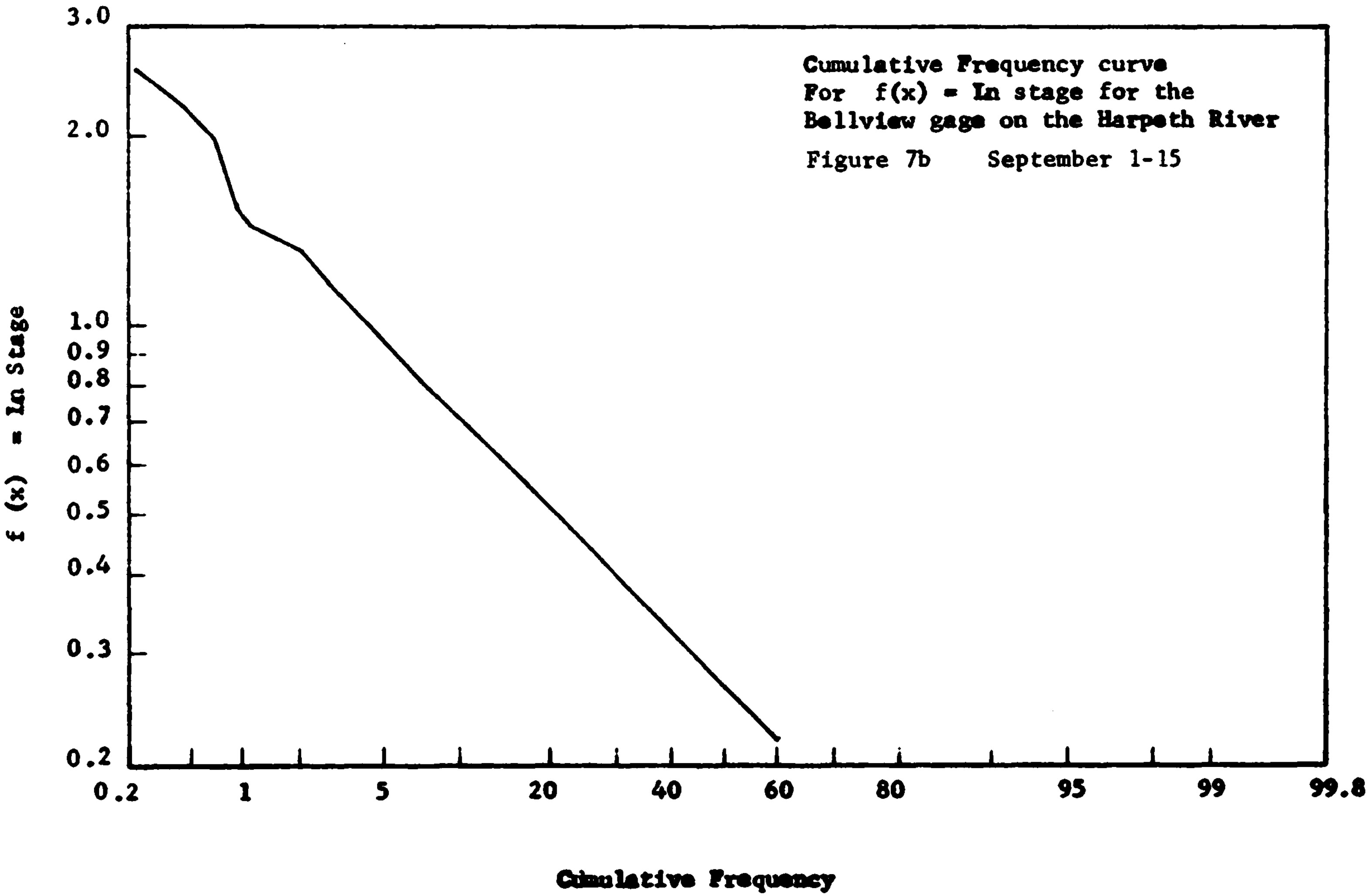
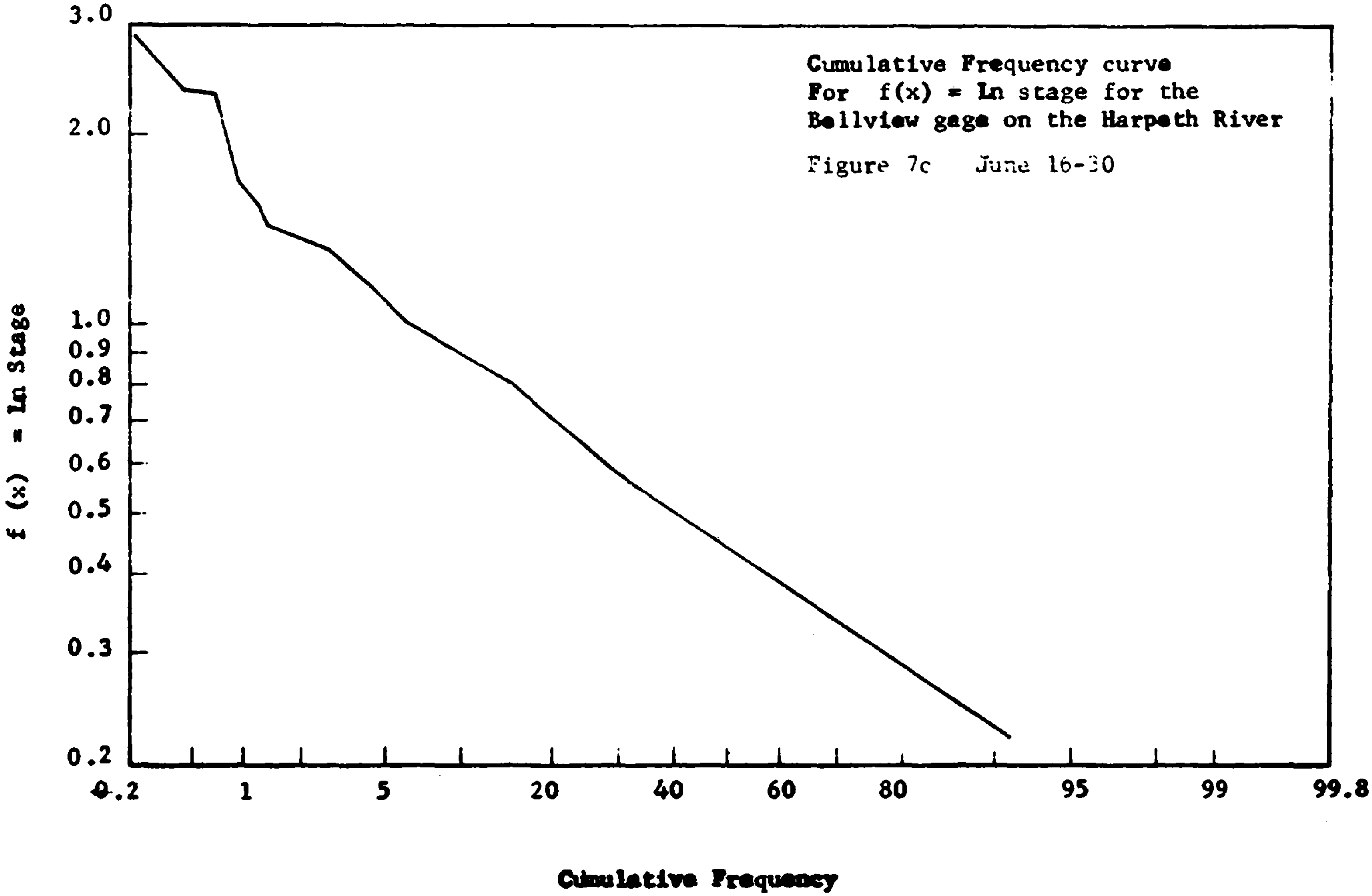

Azimuth Line
Section 4-8
Section 4-7
Section 4-6
Section 4-5
Gage
Section 4-4
Section 4-3
Section 4-2
Section 4-1
Direction of Flow
Plan View
Bellview Gage
Low Water Channel

Figure 6

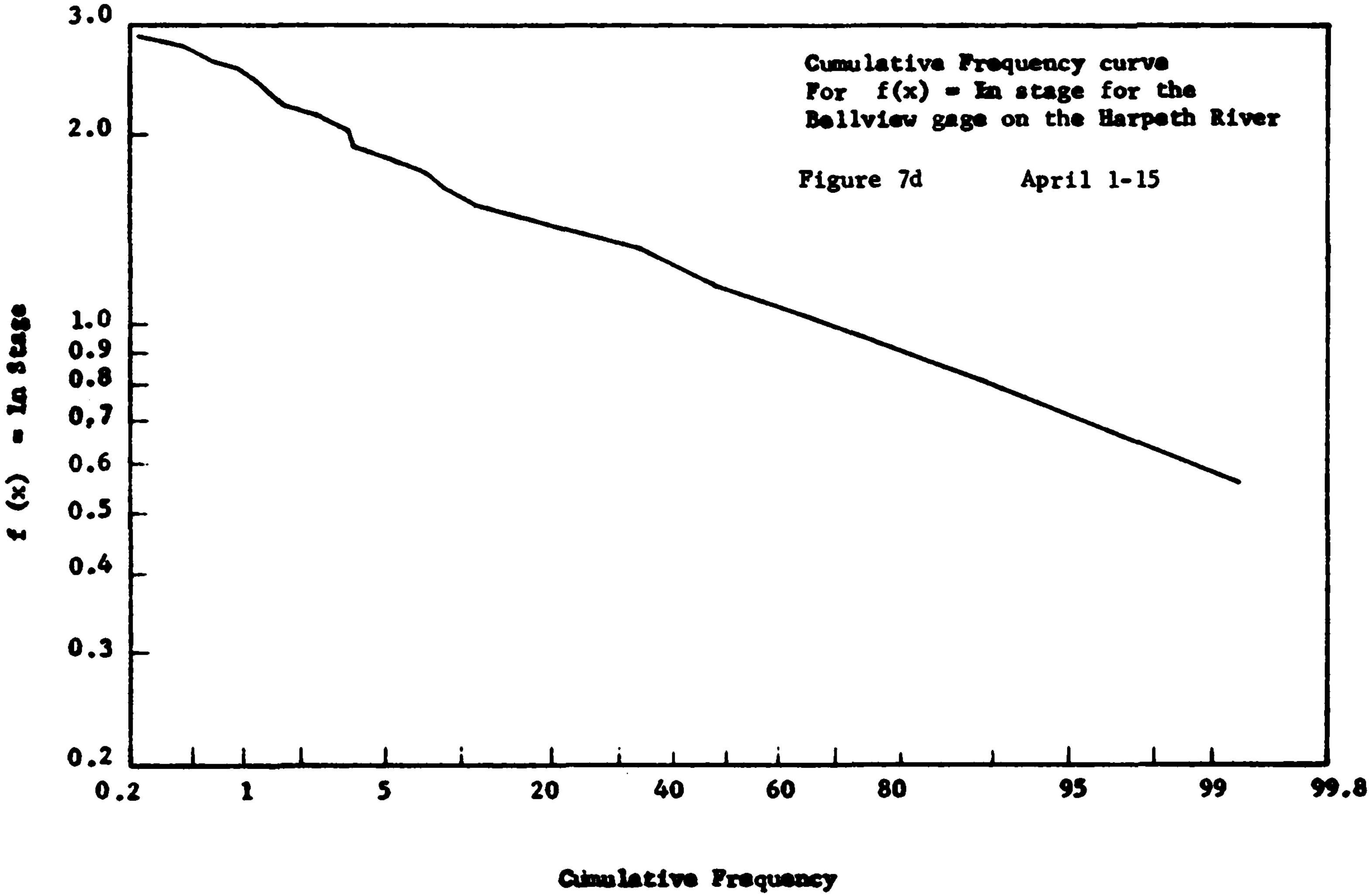

Cumulative Frequency curve
For f(x) = Ln stage for the
Bellview gage on the Harpeth River
Figure 7a October 1-15
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
f (x) = Ln Stage
0.2
1
5
20
40
60
80
95
99
99.8
Cumulative Frequency

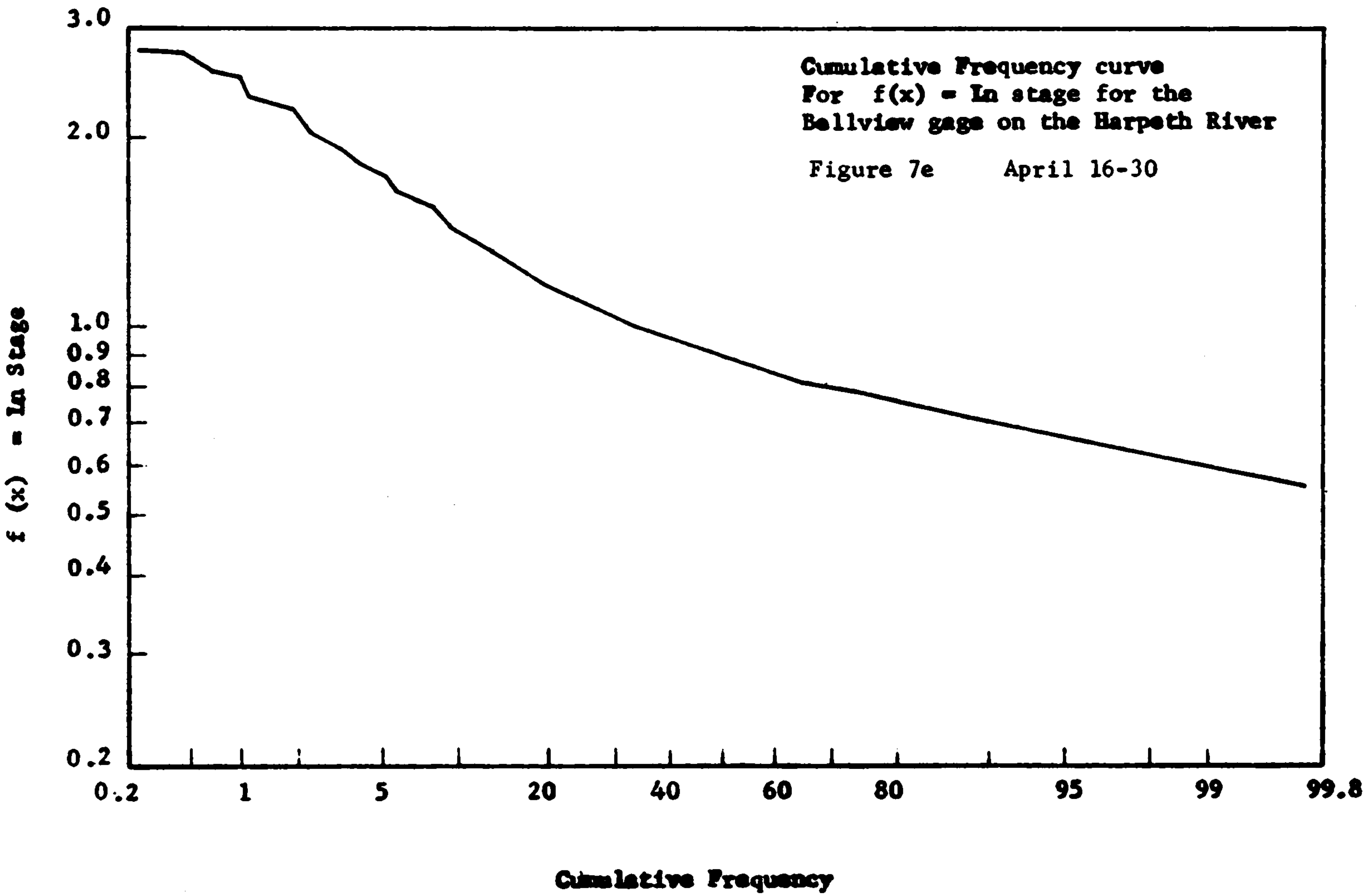

Cumulative Frequency curve
For f(x) = Ln stage for the
Bellview gage on the Harpeth River
Figure 7b September 1-15
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
f (x) = Ln Stage
0.2
1
5
20
40
60
80
95
99
99.8
Cumulative Frequency

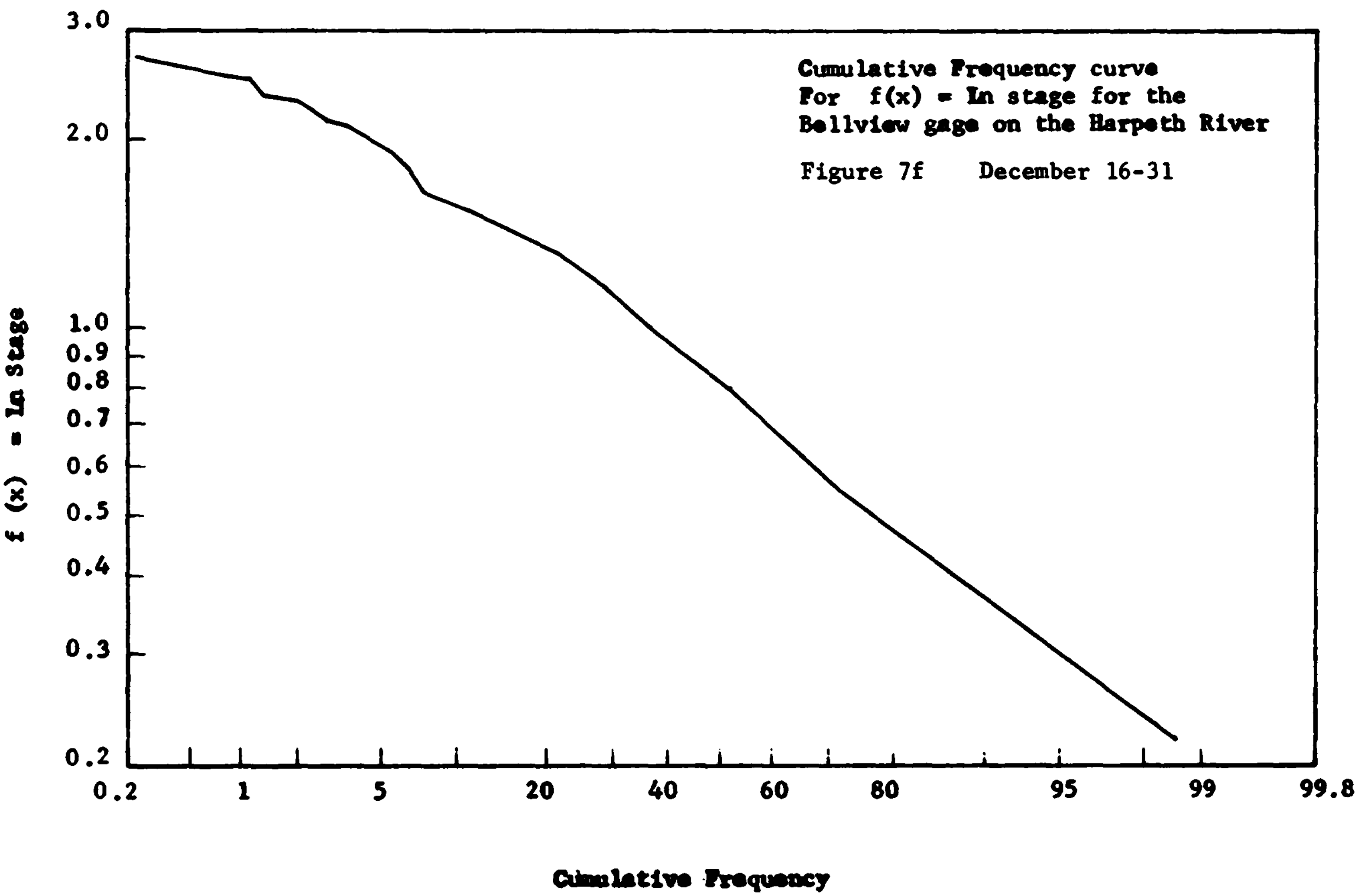


Cumulative Frequency curve
For f(x) = Ln stage for the
Bellview gage on the Harpeth River

Figure 7c June 16-30

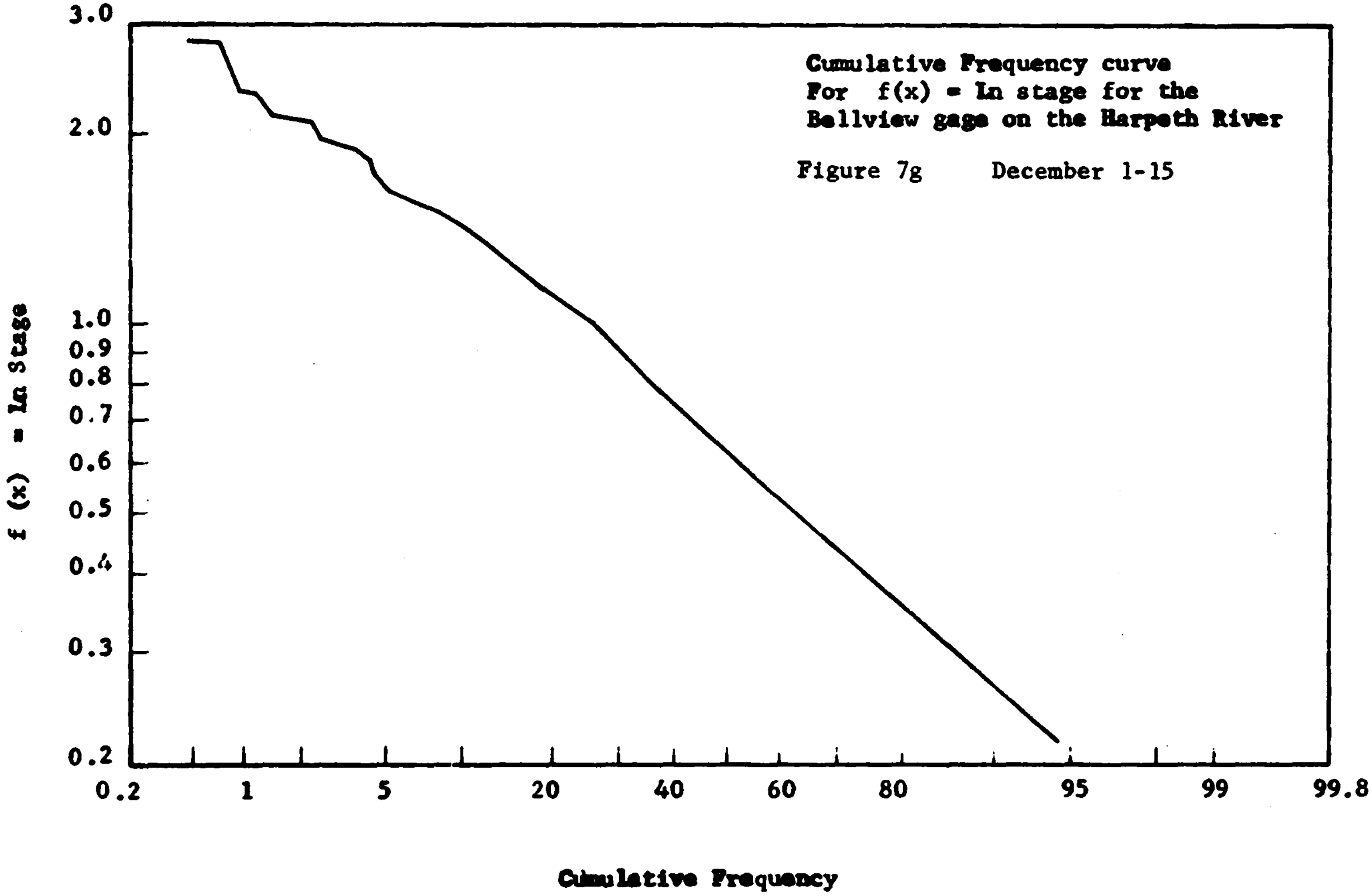

Cumulative Frequency curve
For f(x) = ln stage for the
Bellview gage on the Harpeth River
Figure 7d April 1-15
3.0
2.0
1.0
0.9
0.8
0,7
0.6
0.5
0.4
0.3
0.2
f (x) = ln Stage
0.2
1
5
20
40
60
80
95
99
99.8
Cumulative Frequency

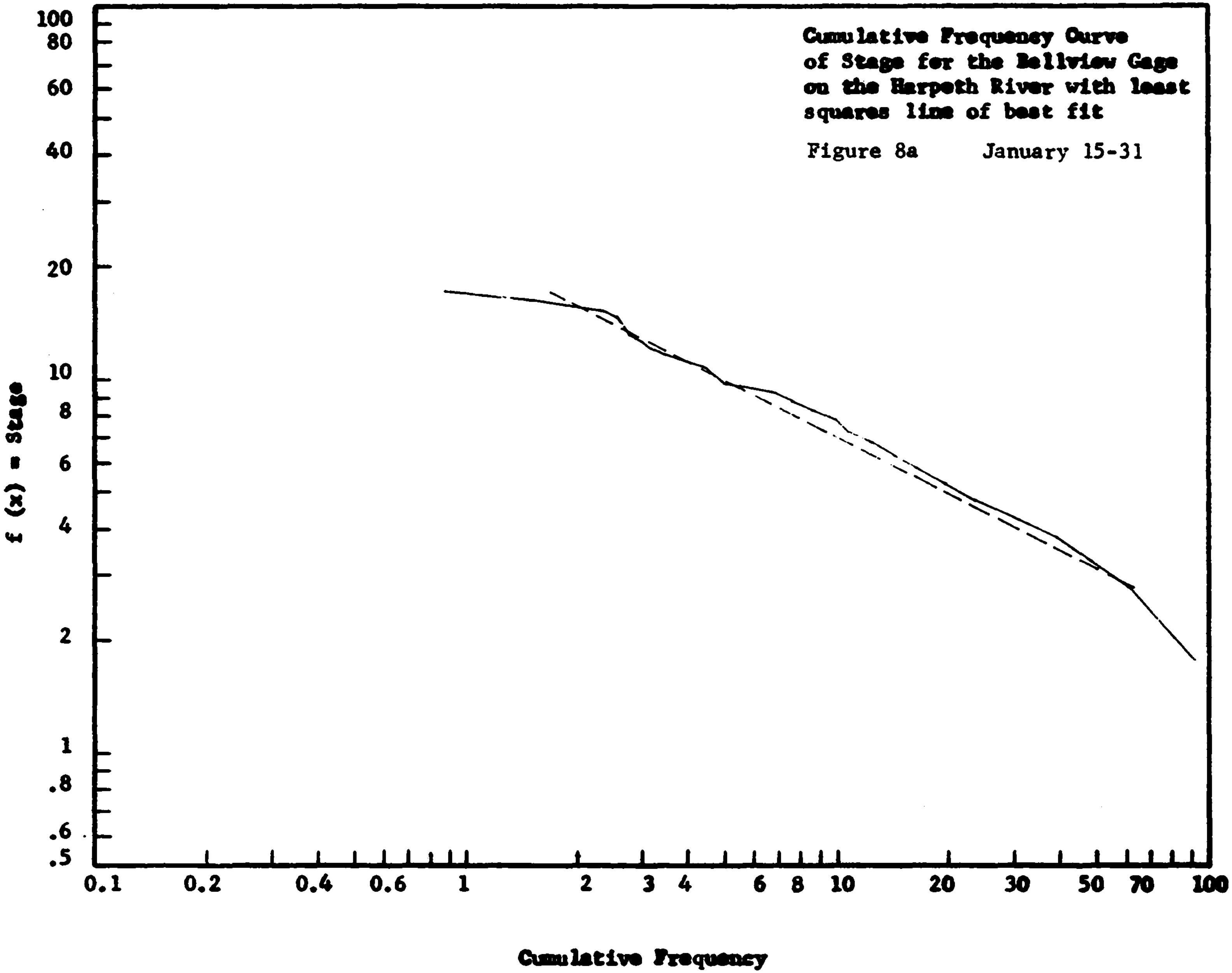

Cumulative Frequency curve
For f(x) = Ln stage for the
Bellview gage on the Harpeth River
Figure 7e April 16-30
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
f (x) = Ln Stage
0.2
1
5
20
40
60
80
95
99
99.8
Cumulative Frequency



Cumulative Frequency curve
For f(x) = Ln stage for the
Bellview gage on the Harpeth River

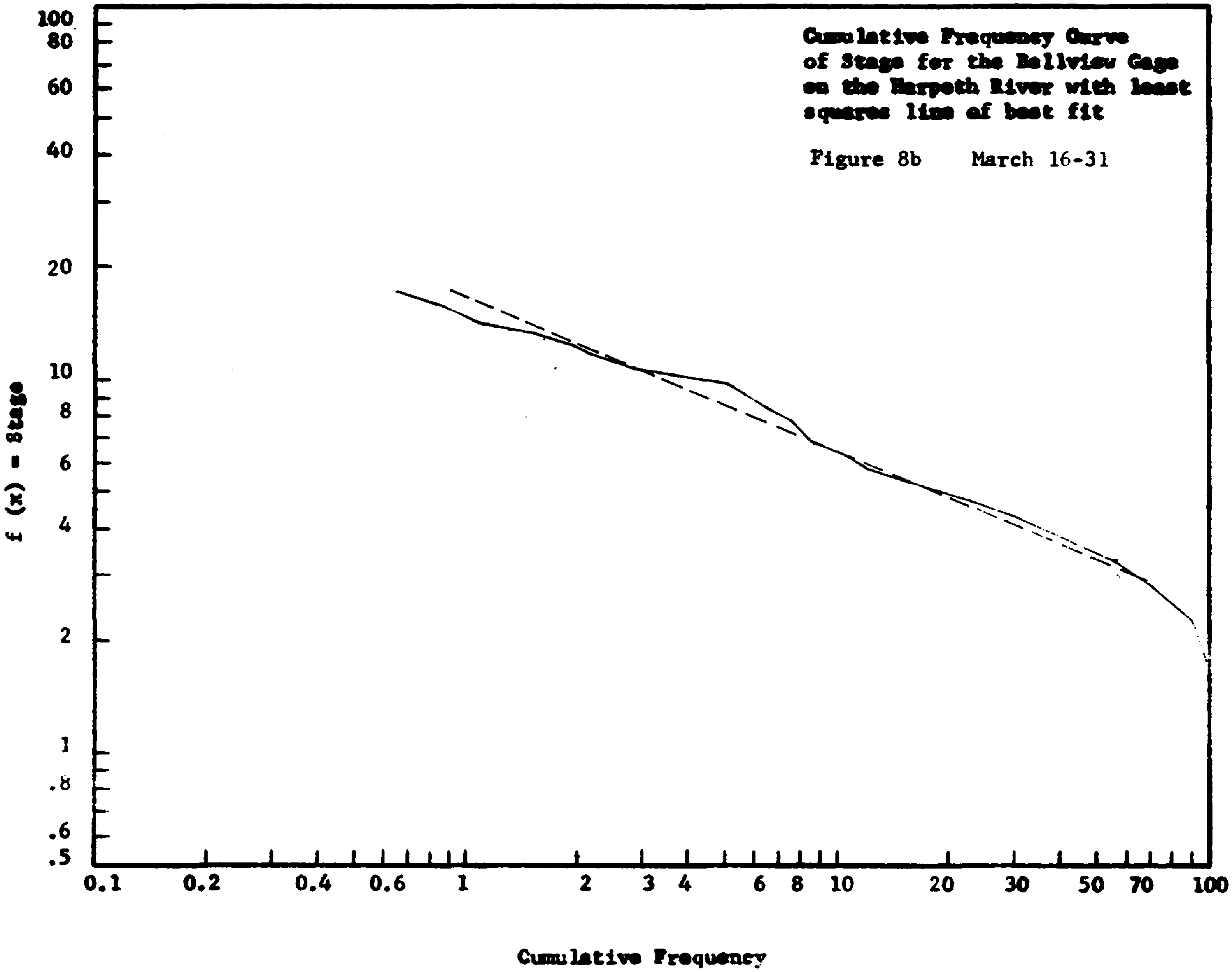
Figure 7f December 16-31


Cumulative Frequency curve
For f(x) = Ln stage for the
Bellview gage on the Harpeth River
Figure 7g December 1-15
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
f (x) = Ln Stage
0.2
1
5
20
40
60
80
95
99
99.8
Cumulative Frequency

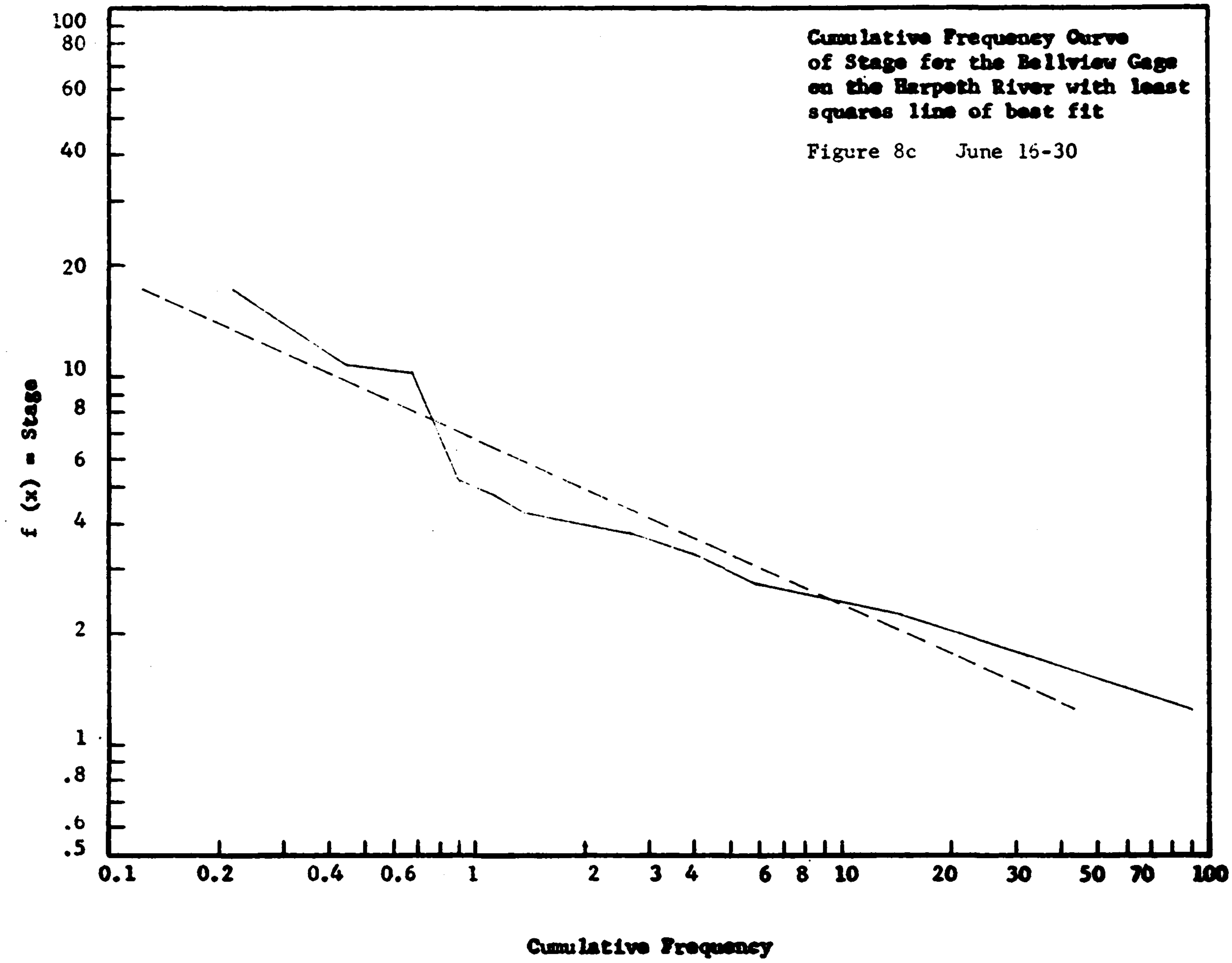


Cumulative Frequency Curve of Stage for the Bellview Gage on the Harpeth River with least squares line of best fit

Figure 8a January 15-31

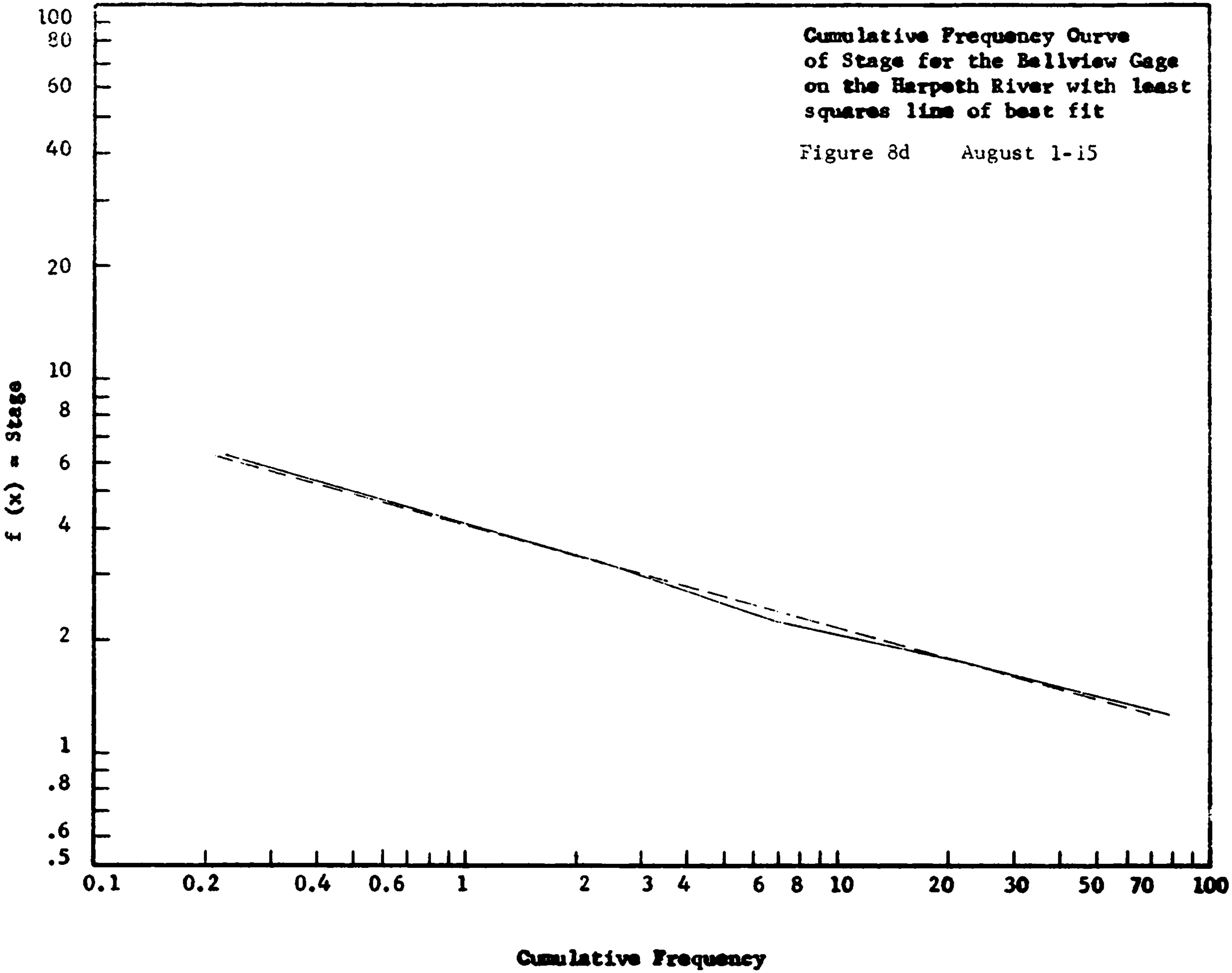


Cumulative Frequency Curve of Stage for the Bellview Gage on the Harpeth River with least squares line of best fit
Figure 8b March 16-31
f (x) = Stage
100
80
60
40
20
10
8
6
4
2
1
.8
.6
.5
0.1
0.2
0.4
0.6
1
2
3
4
6
8
10
20
30
50
70
100
Cumulative Frequency



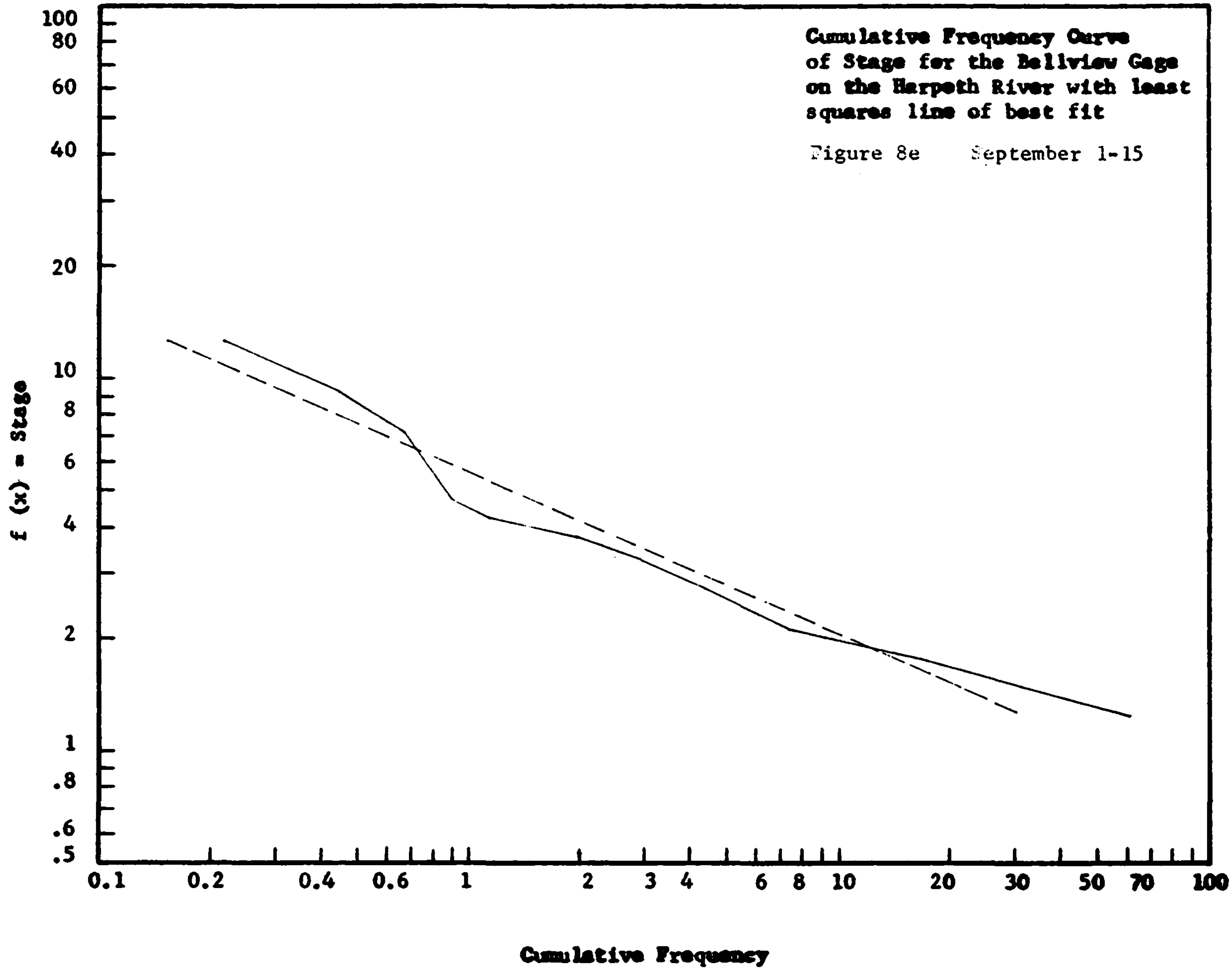
Cumulative Frequency Curve of Stage for the Bellview Gage on the Harpeth River with least squares line of best fit

Figure 8c June 16-30



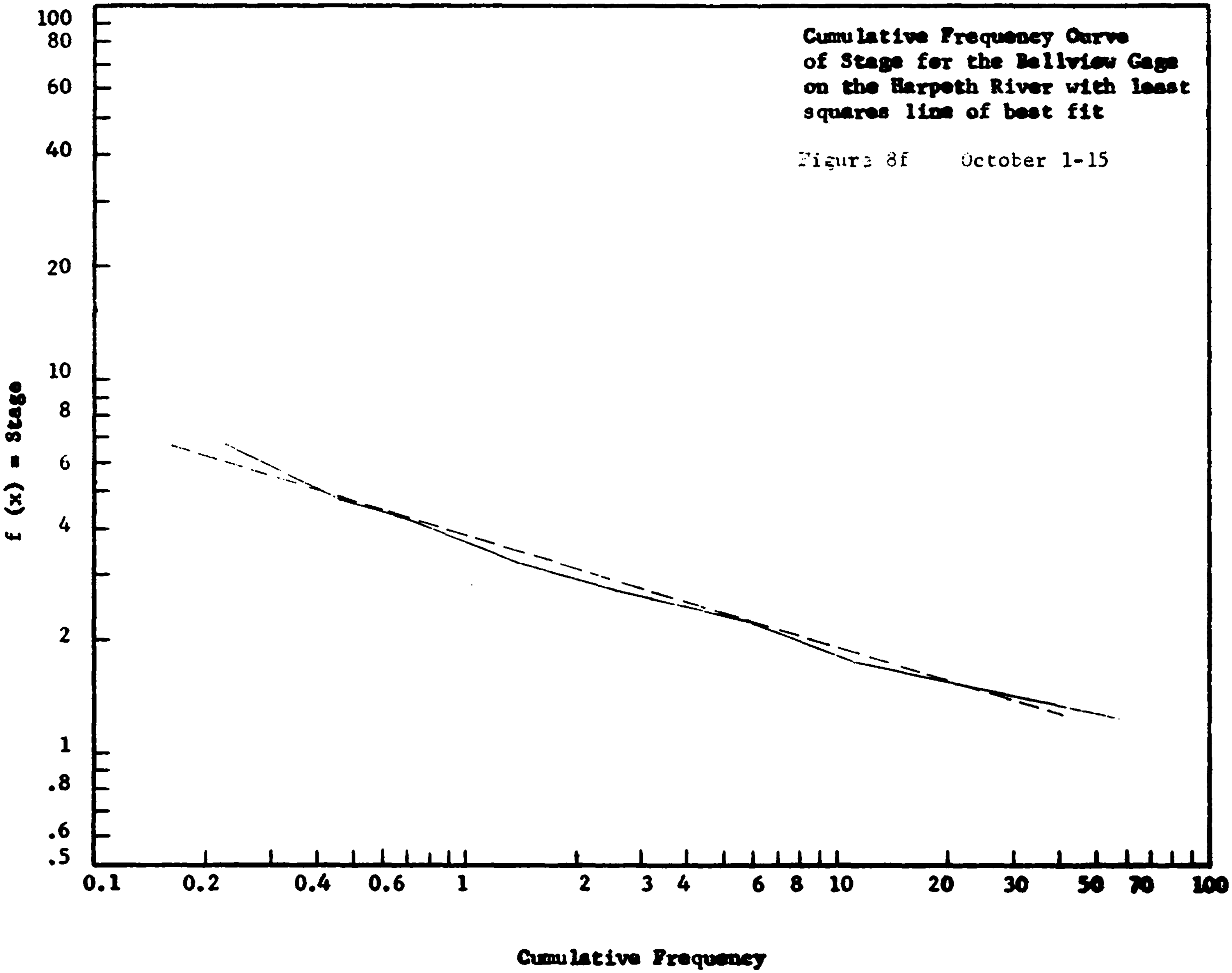
Cumulative Frequency Curve of Stage for the Bellview Gage on the Harpeth River with least squares line of best fit

Figure 8d August 1-15



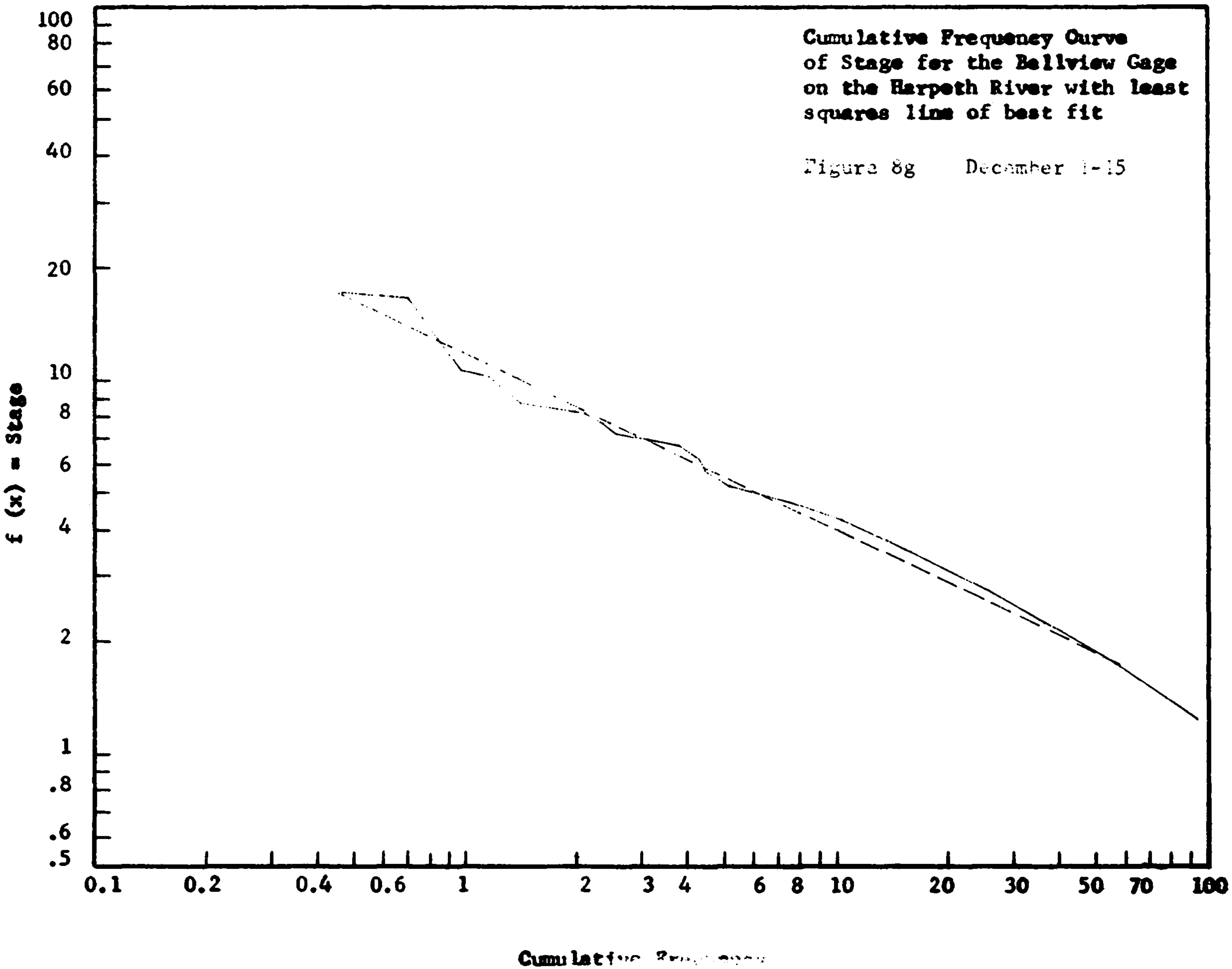
Cumulative Frequency Curve of Stage for the Belliview Gage on the Harpeth River with least squares line of best fit

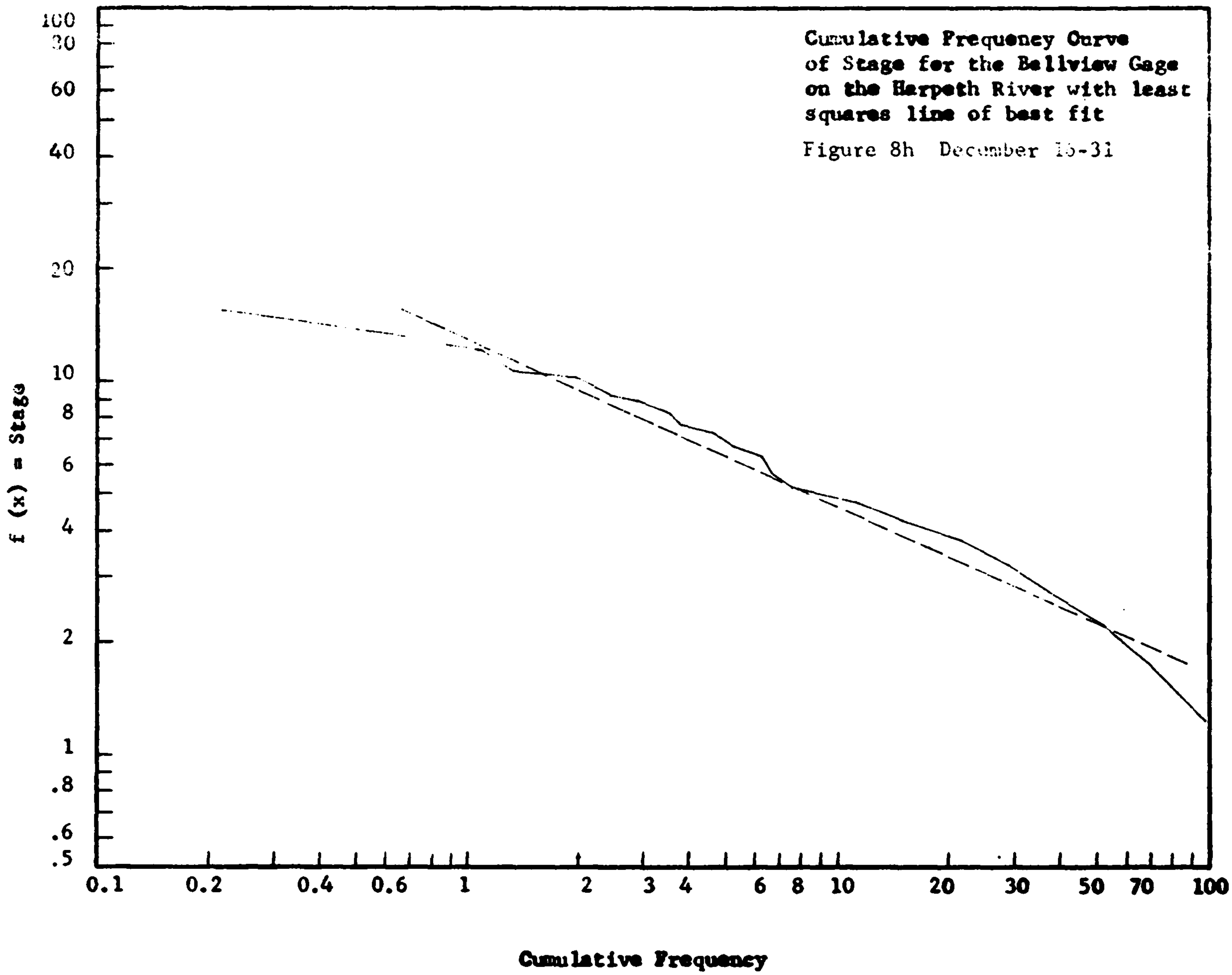
Figure 8e September 1-15

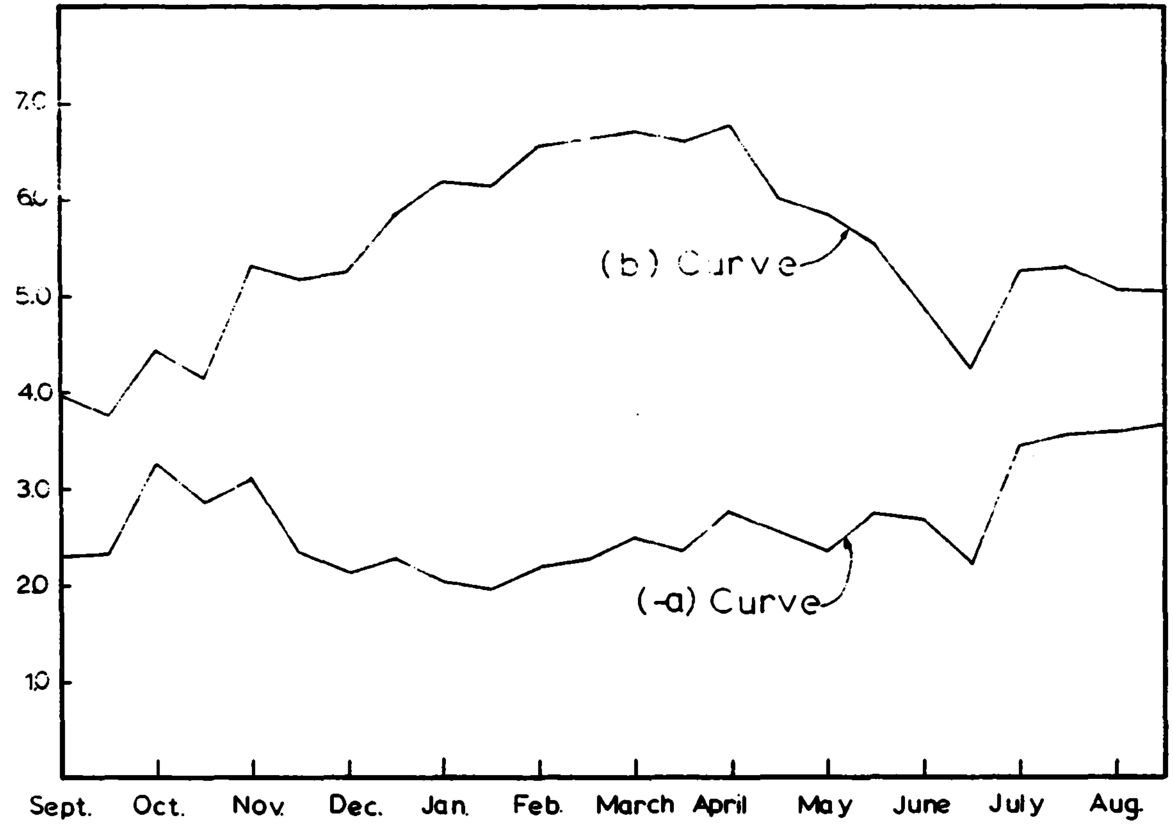


Cumulative Frequency Curve of Stage for the Bellview Gage on the Harpeth River with least squares line of best fit

Figure 8f October 1-15


Cumulative Frequency Curve
of Stage for the Bellview Gage
on the Harpeth River with least
squares line of best fit
Figure 8g December 1-15
f (x) = Stage
100
80
60
40
20
10
8
6
4
2
1
.8
.6
.5
0.1
0.2
0.4
0.6
1
2
3
4
6
8
10
20
30
50
70
100

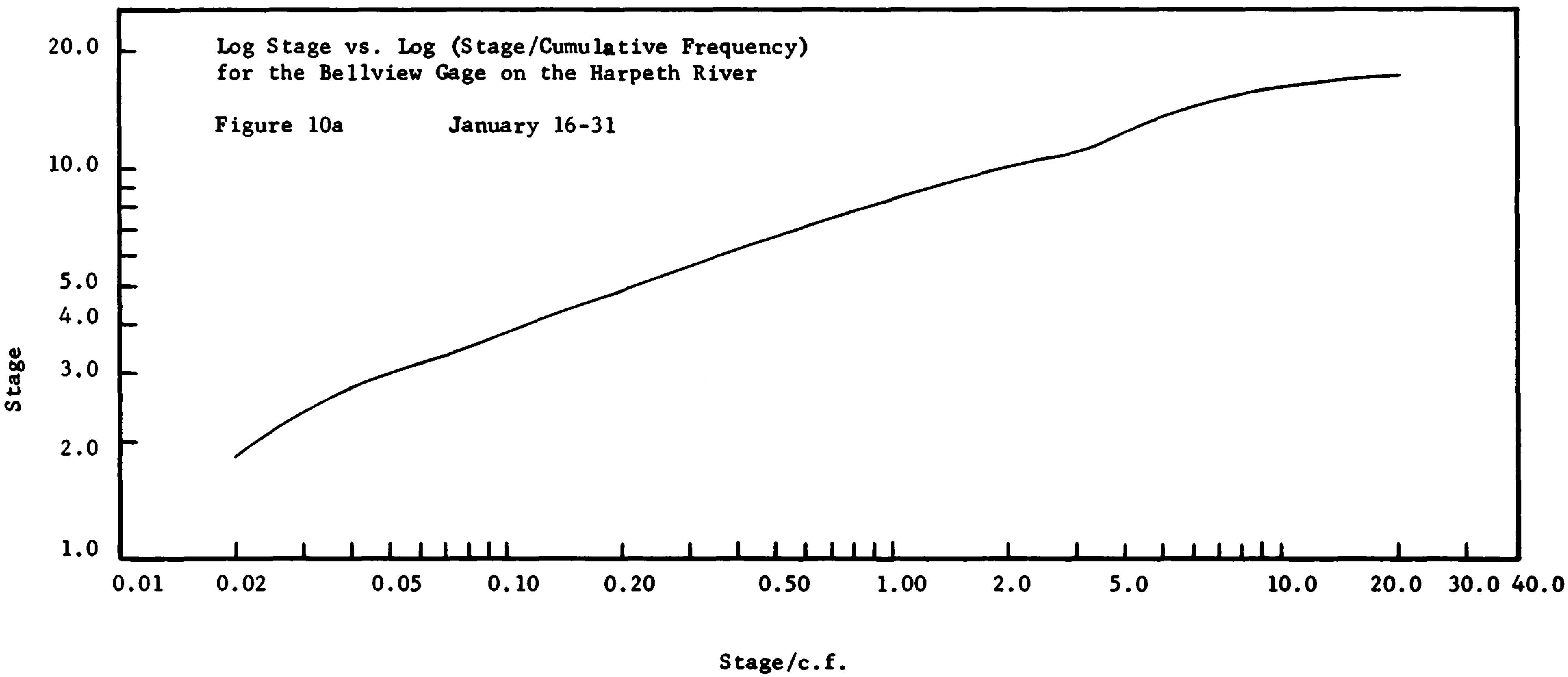

Cumulative Frequency Curve
of Stage for the Bellview Gage
on the Harpeth River with least
squares line of best fit
Figure 8h December 16-31
f (x) = Stage
100
80
60
40
20
10
8
6
4
2
1
.8
.6
.5
0.1
0.2
0.4
0.6
1
2
3
4
6
8
10
20
30
50
70
100
Cumulative Frequency

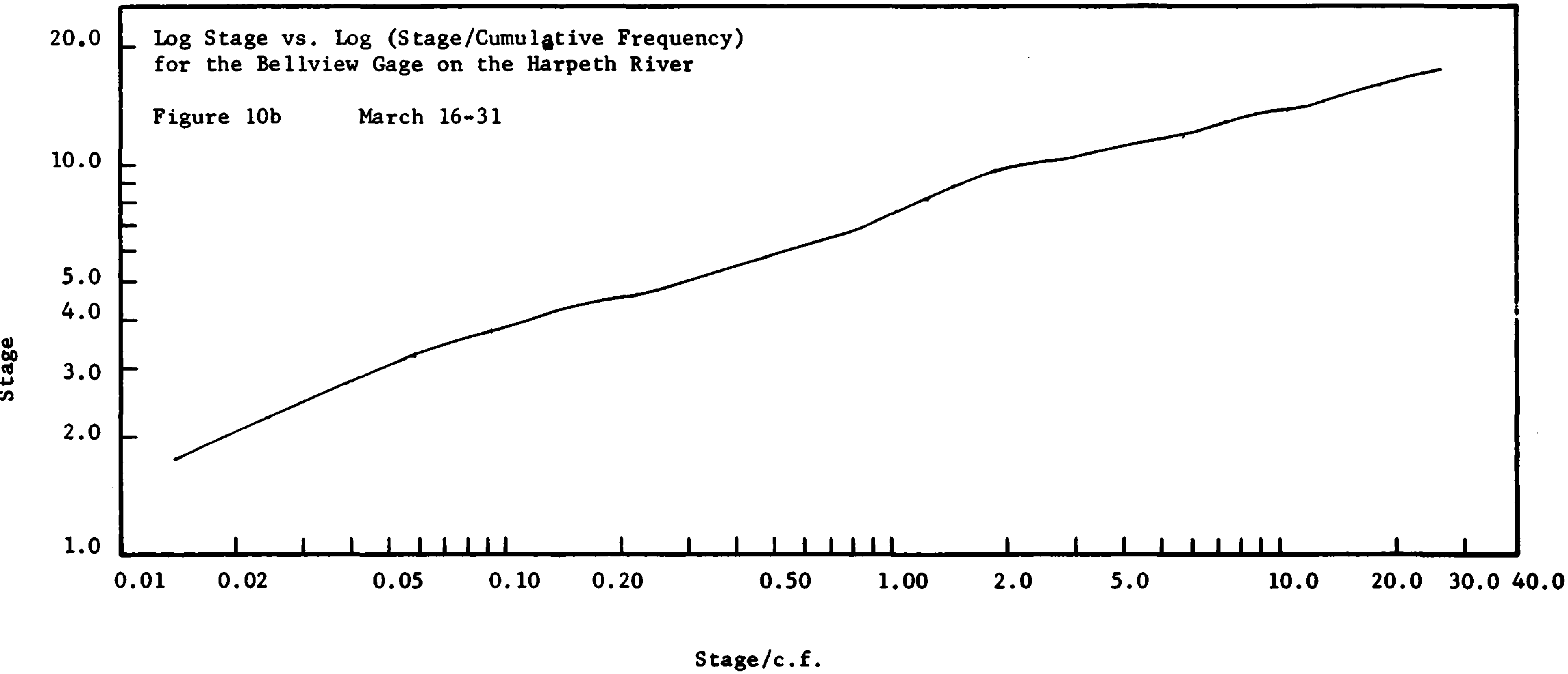


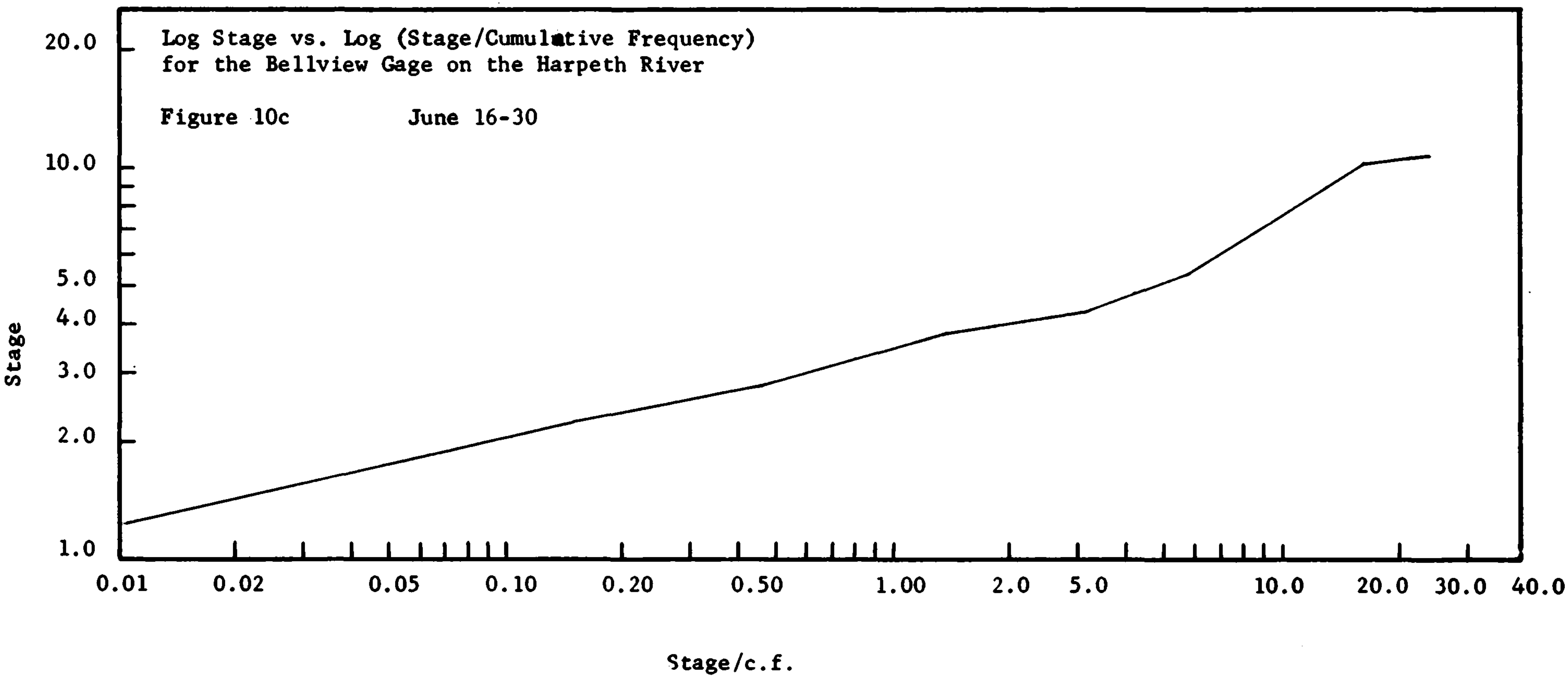
Seasonal Variation in the Coefficients (-a) and (b) for the Equation

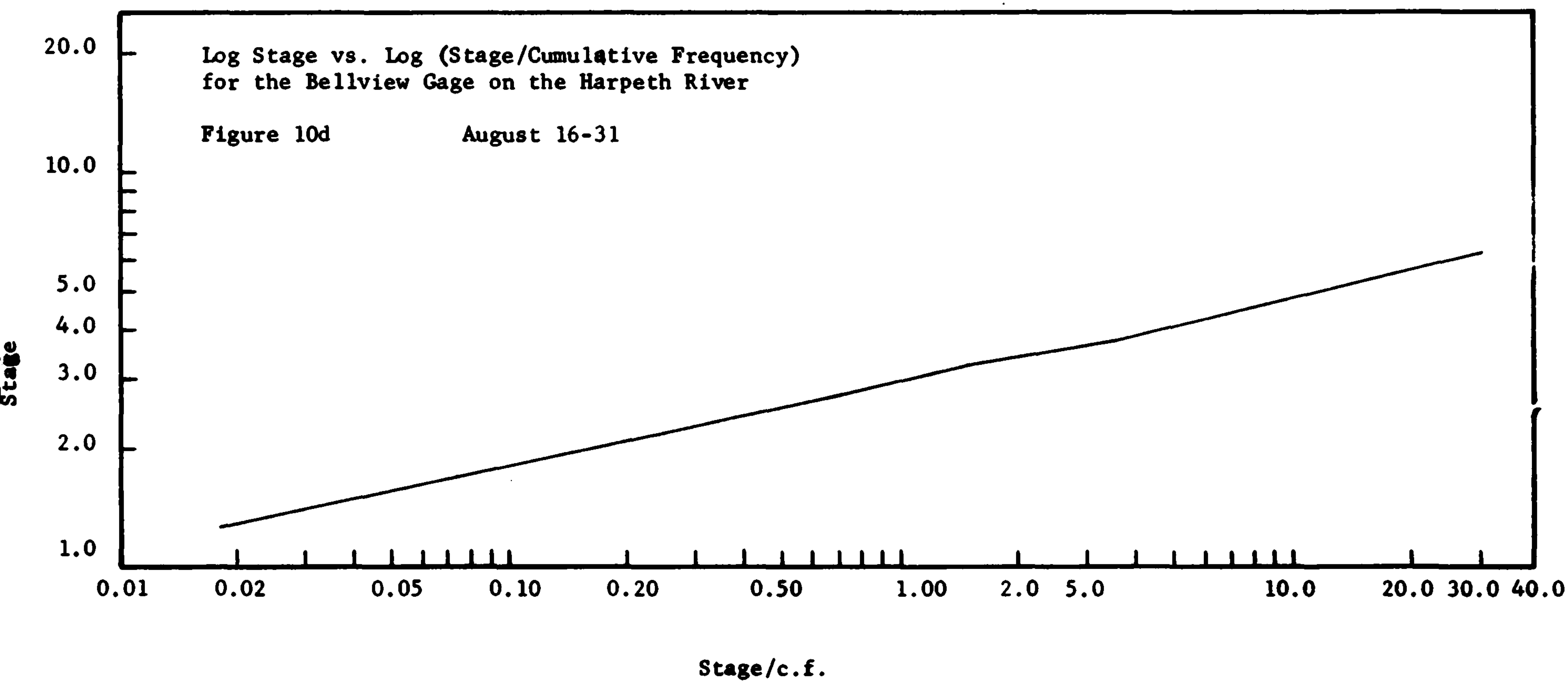
ln(stage) = ln(cumulative frequency)(a) + (b)

Figure 9

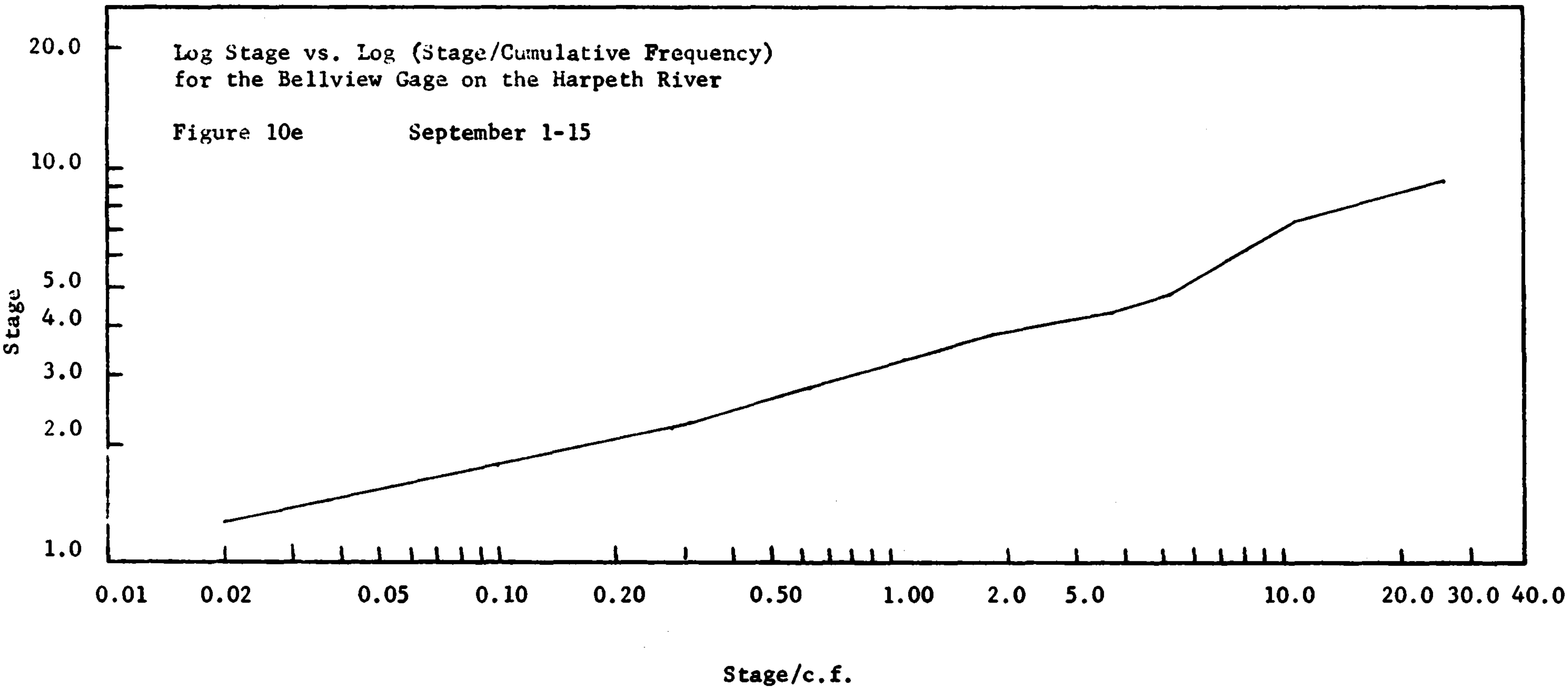

Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River
Figure 10a
January 16-31
Stage
20.0
10.0
5.0
4.0
3.0
2.0
1.0
0.01
0.02
0.05
0.10
0.20
0.50
1.00
2.0
5.0
10.0
20.0
30.0
40.0
Stage/c.f.


Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River
Figure 10b March 16-31
20.0
10.0
5.0
4.0
3.0
2.0
1.0
Stage
0.01
0.02
0.05
0.10
0.20
0.50
1.00
2.0
5.0
10.0
20.0
30.0
40.0
Stage/c.f.


Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River
Figure 10c
June 16-30
20.0
10.0
5.0
4.0
3.0
2.0
1.0
Stage
0.01
0.02
0.05
0.10
0.20
0.50
1.00
2.0
5.0
10.0
20.0
30.0
40.0
Stage/c.f.

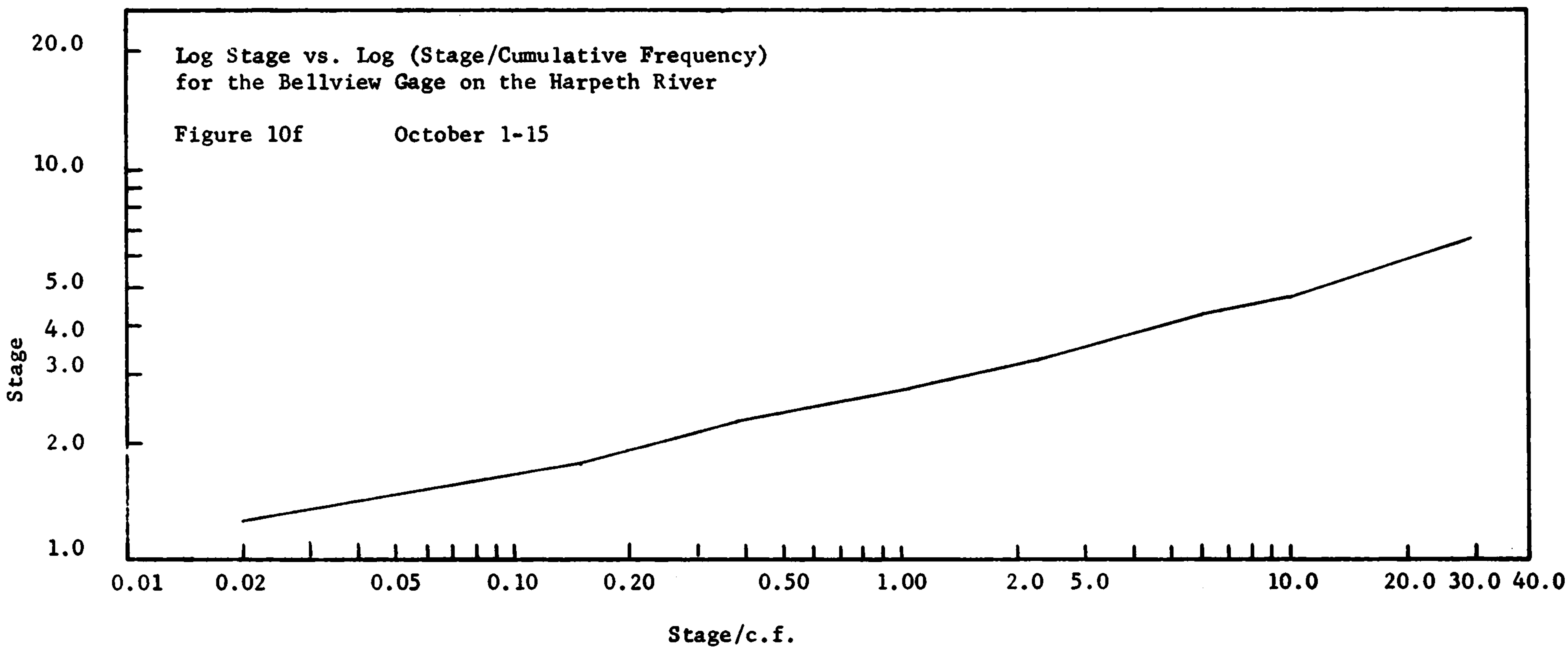


Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River
Figure 10d
August 16-31
20.0
10.0
5.0
4.0
3.0
2.0
1.0
Stage
0.01
0.02
0.05
0.10
0.20
0.50
1.00
2.0
5.0
10.0
20.0
30.0
40.0
Stage/c.f.



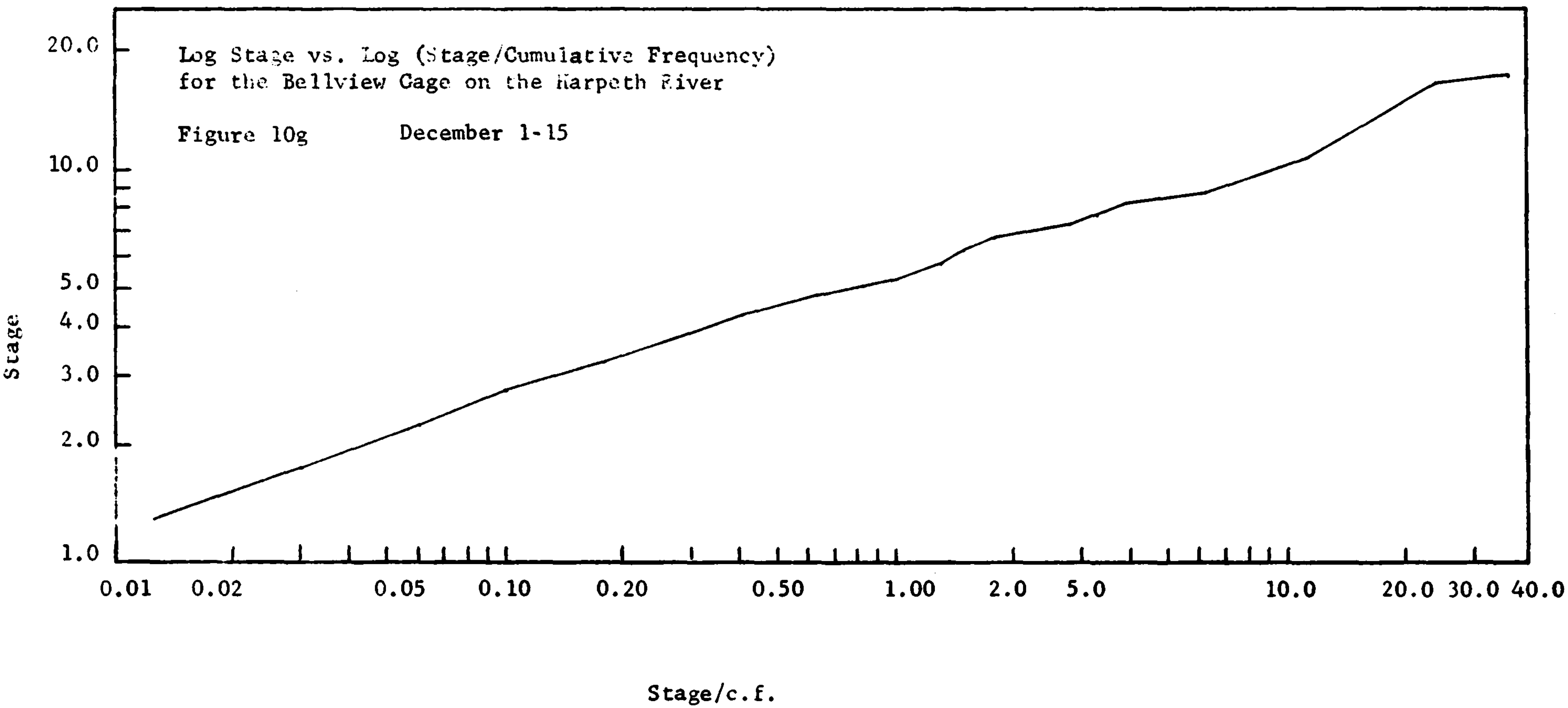
Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River

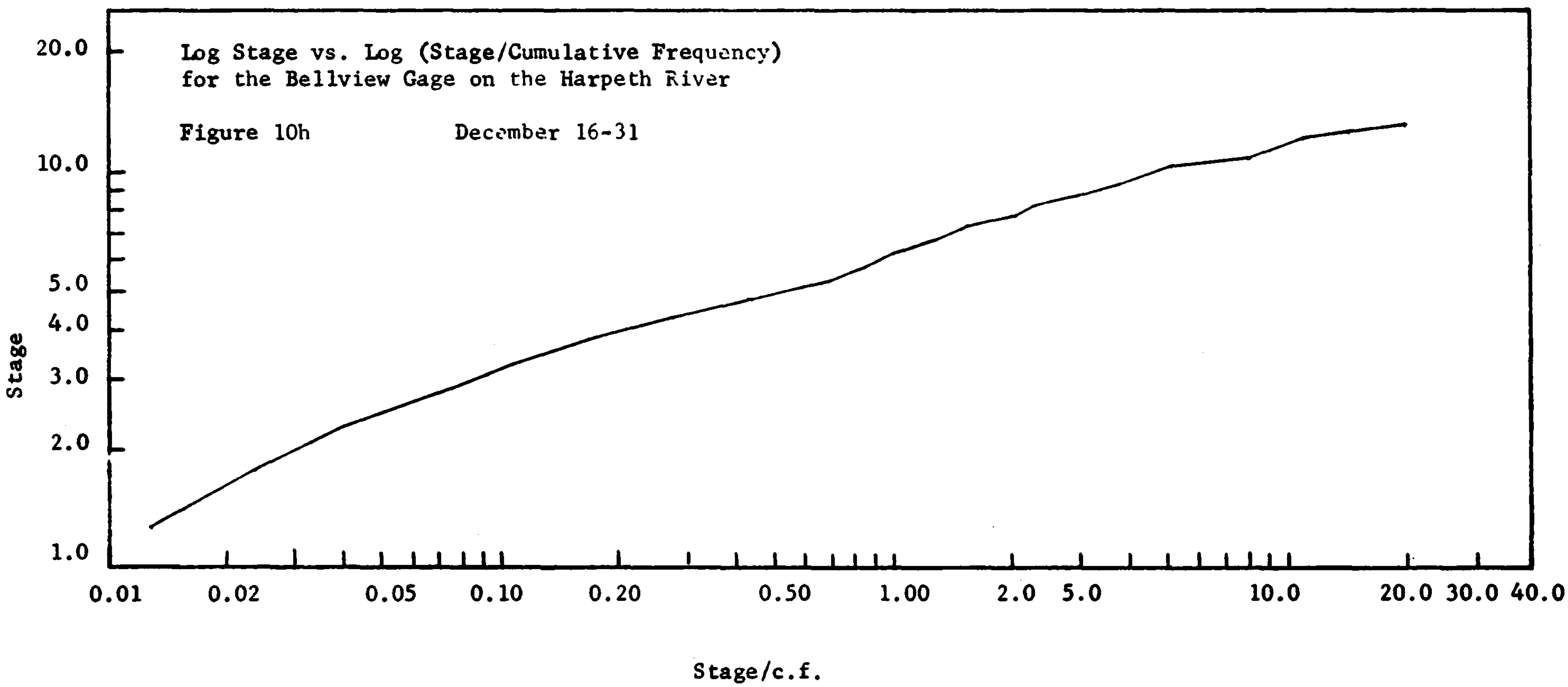
Figure 10e September 1-15

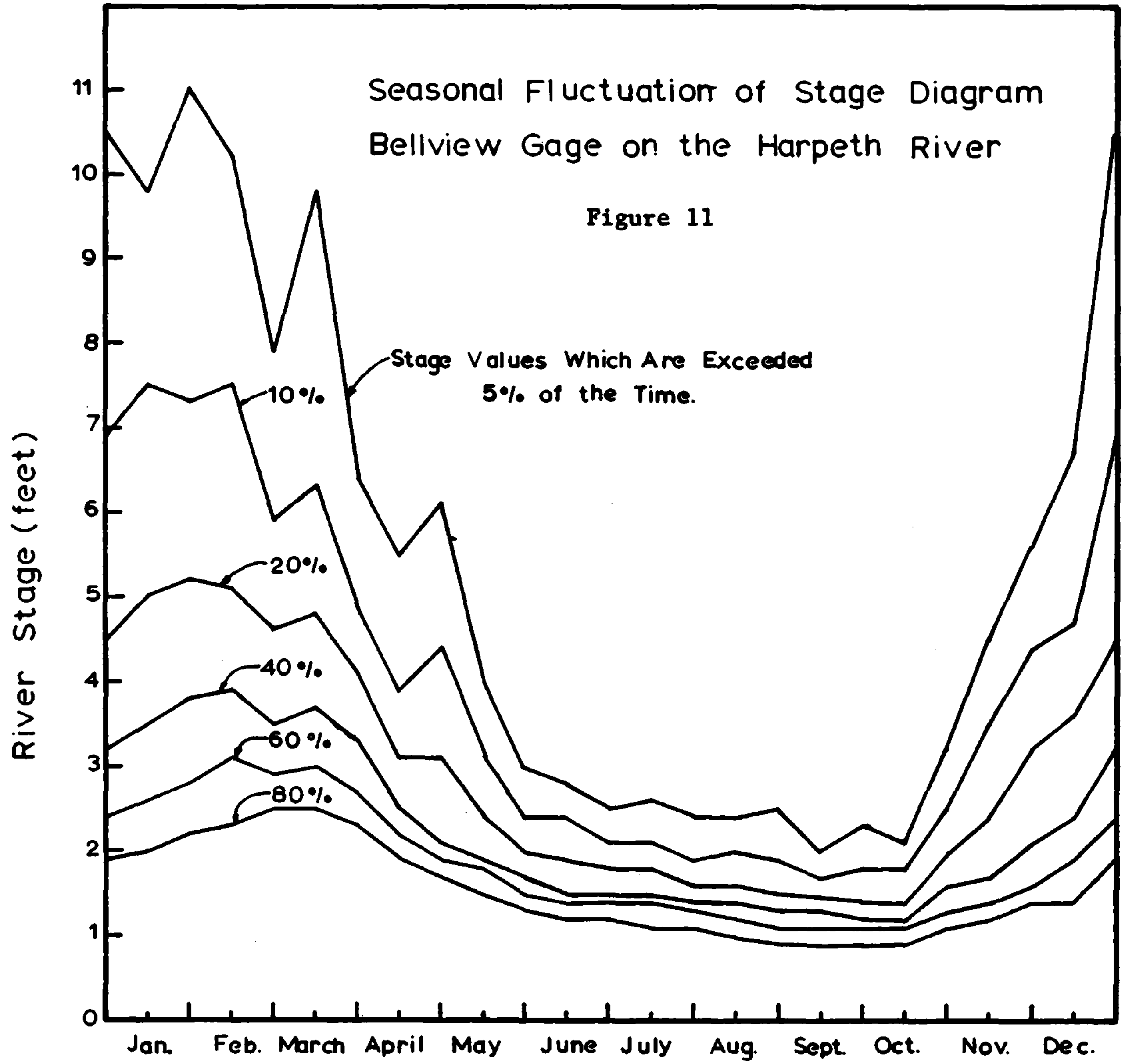


Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River

Figure 10f October 1-15

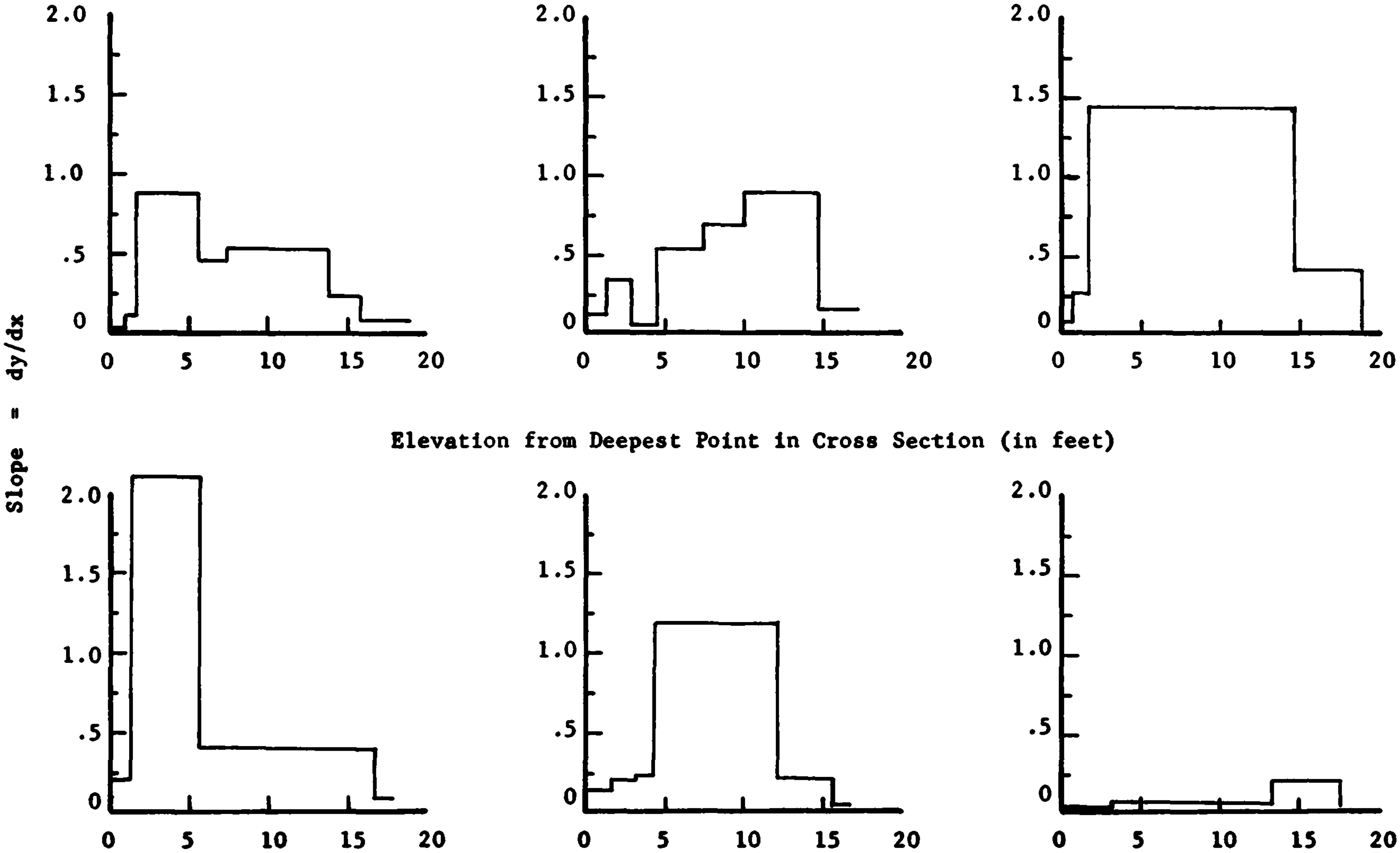

Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River
Figure 10g December 1-15
20.0
10.0
5.0
4.0
3.0
2.0
1.0
Stage
0.01 0.02 0.05 0.10 0.20 0.50 1.00 2.0 5.0 10.0 20.0 30.0 40.0
Stage/c.f.


Log Stage vs. Log (Stage/Cumulative Frequency)
for the Bellview Gage on the Harpeth River
Figure 10h
December 16-31
Stage
20.0
10.0
5.0
4.0
3.0
2.0
1.0
0.01
0.02
0.05
0.10
0.20
0.50
1.00
2.0
5.0
10.0
20.0
30.0
40.0
Stage/c.f.



Seasonal Fluctuation of Stage Diagram
Bellview Gage on the Harpeth River

Figure 11



Analysis of Stage vs. Bank Slope for Individual Bank Segments

Figure 12

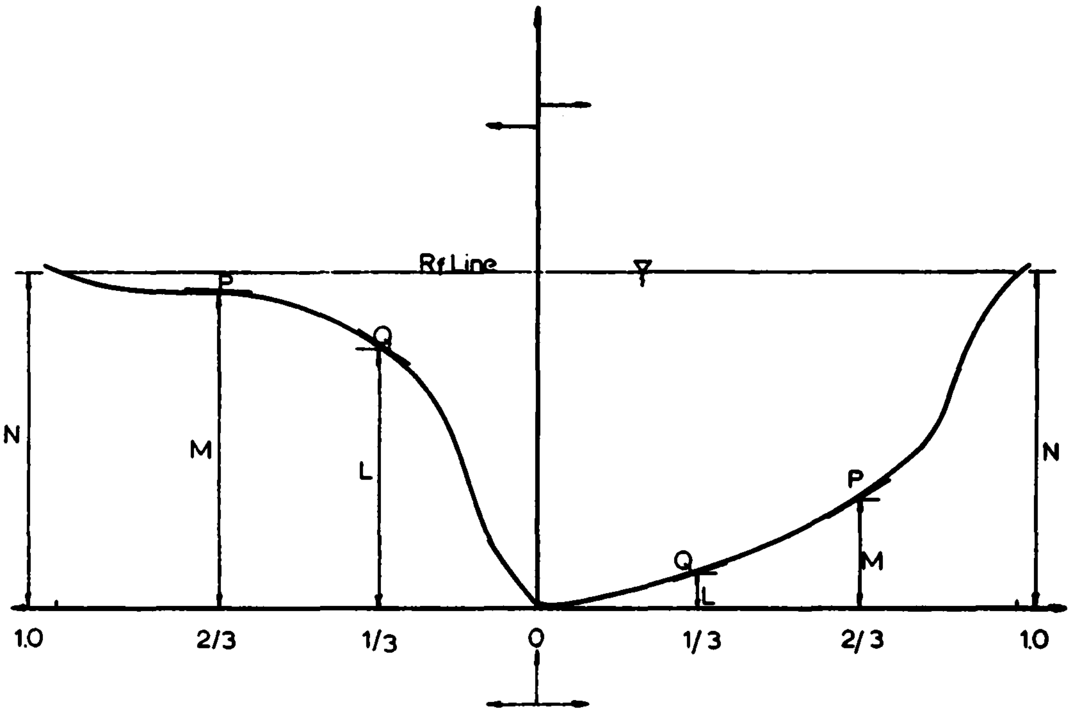
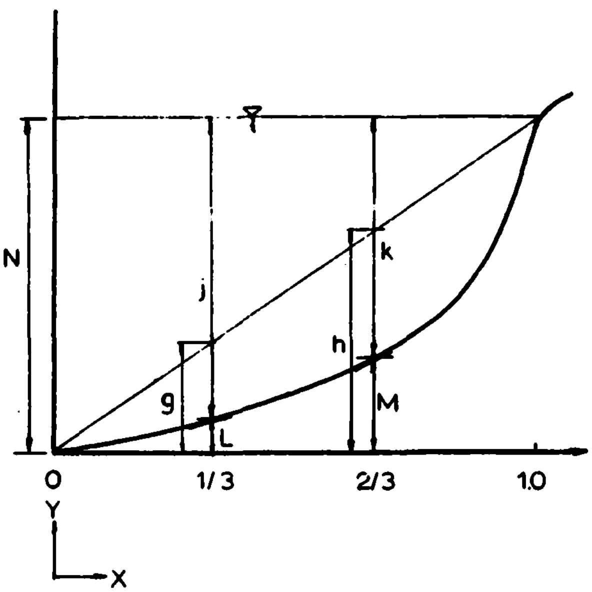


Illustration of Bank Shape Factor Parameters Figure 13



Definition of Terms Used in the Evaluation of P and Q
Figure 14

Figure 15

Comparison of actual bank shape with mathmatical reconstructions using the polynomial equation $y = A + B x + C x^2 + D x^3 + E x^4 + F x^5$ and Bank Shape Factor Parameters.

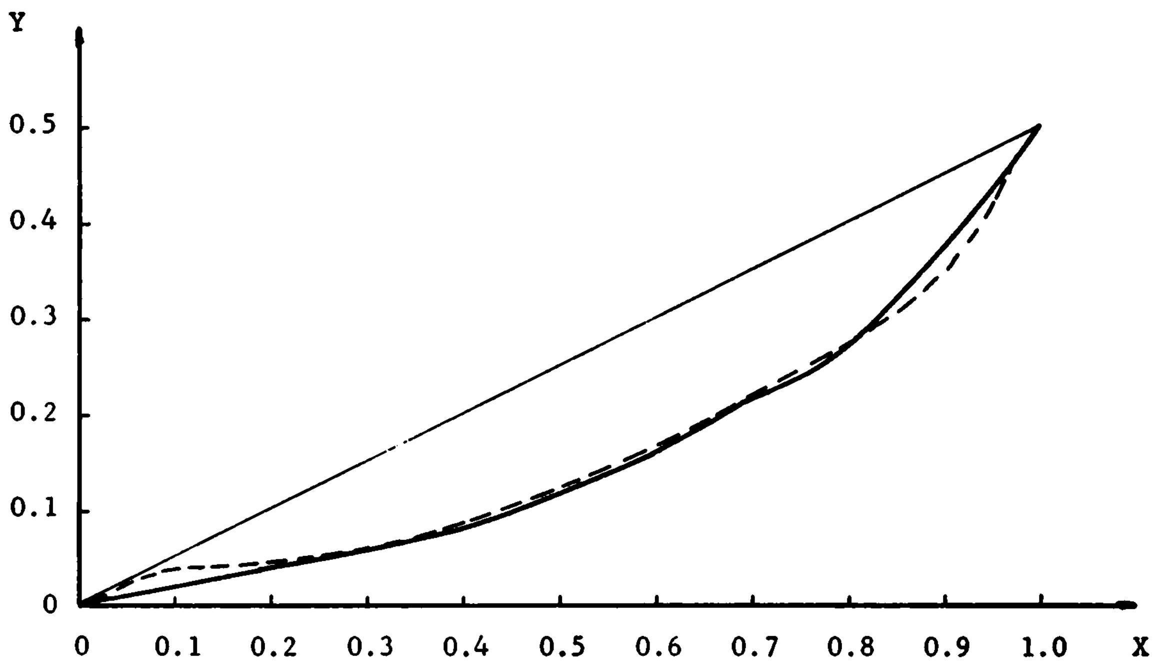


Figure 15a

N=0.5 M=0.2 L=0.07 Q=0.224 P=0.455

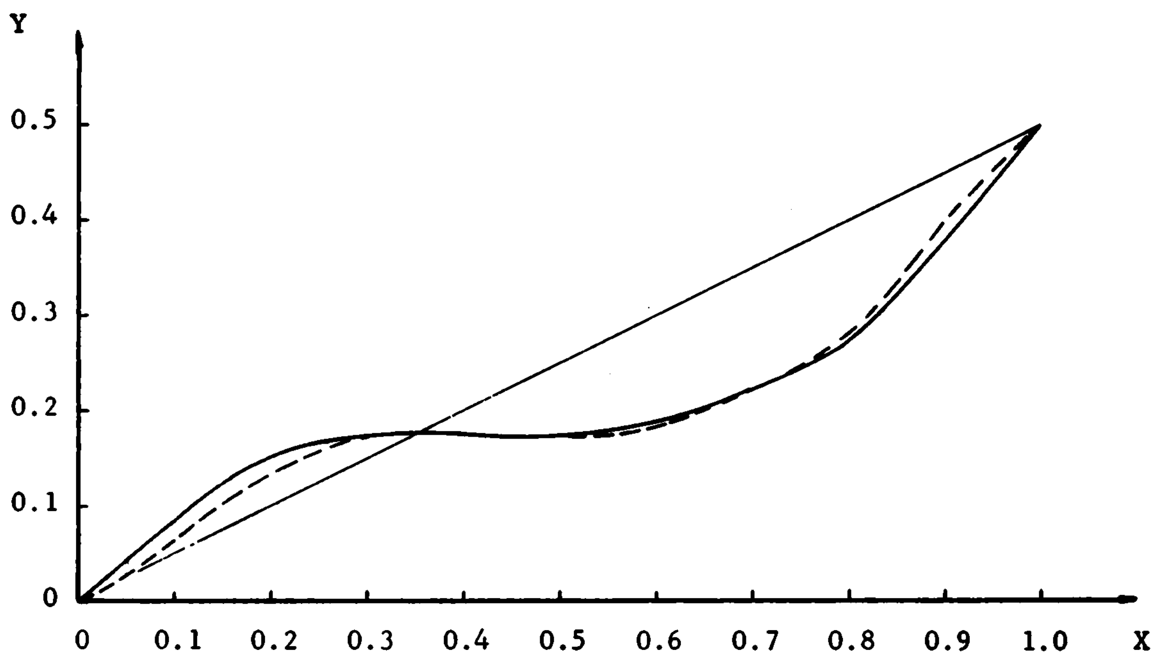


Figure 15b

N=0.5 M=0.2 L=0.175 Q=0.164 P=0.454

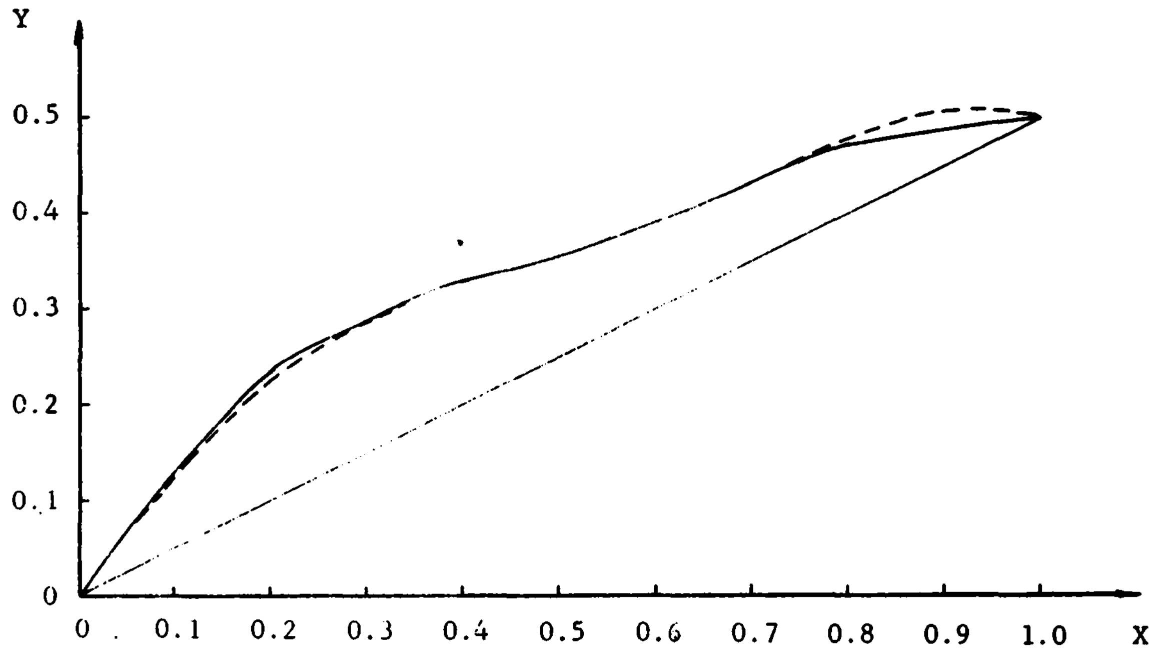


Figure 15c

N=0.5 L=0.3 M=0.42 Q=0.448 P=0.455

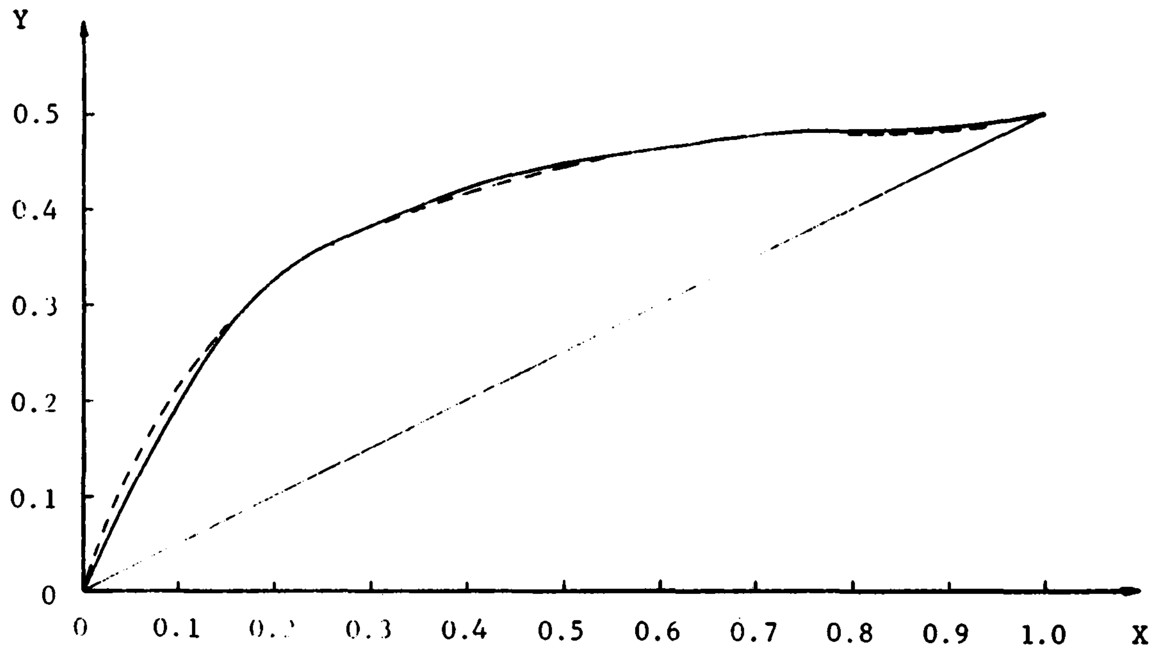


Figure 15d

N=0.5 L=0.39 M=0.47 Q=0.254 P=0.182

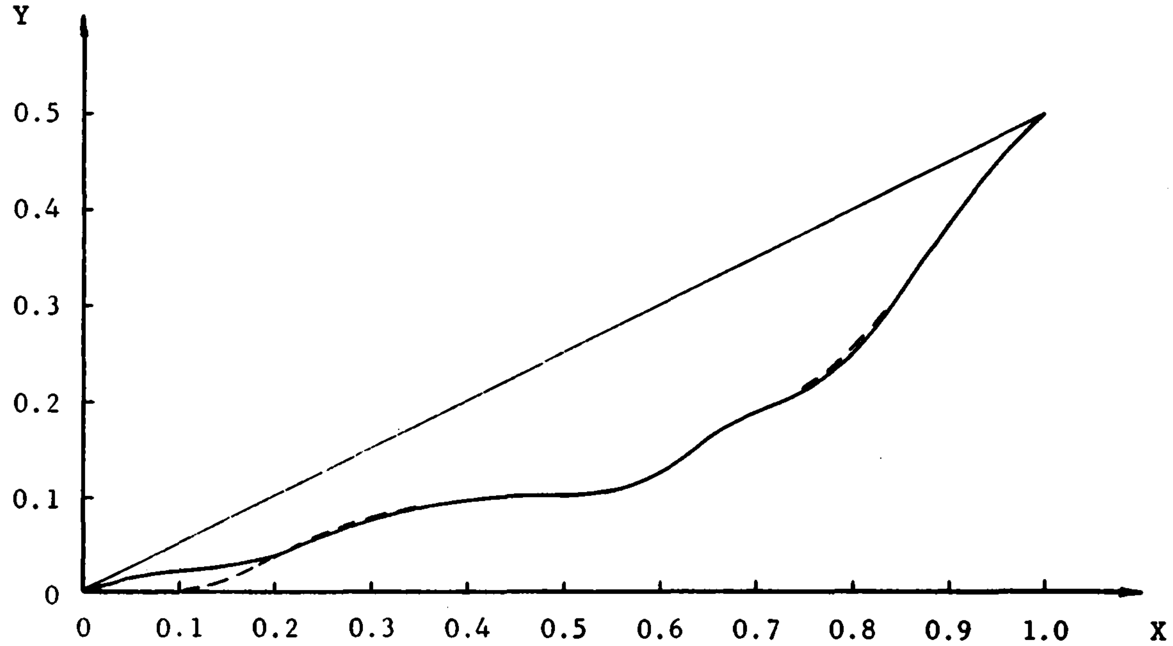


Figure 15e

N=0.5 L=0.07 M=0.14 Q=0.209 P=0.545

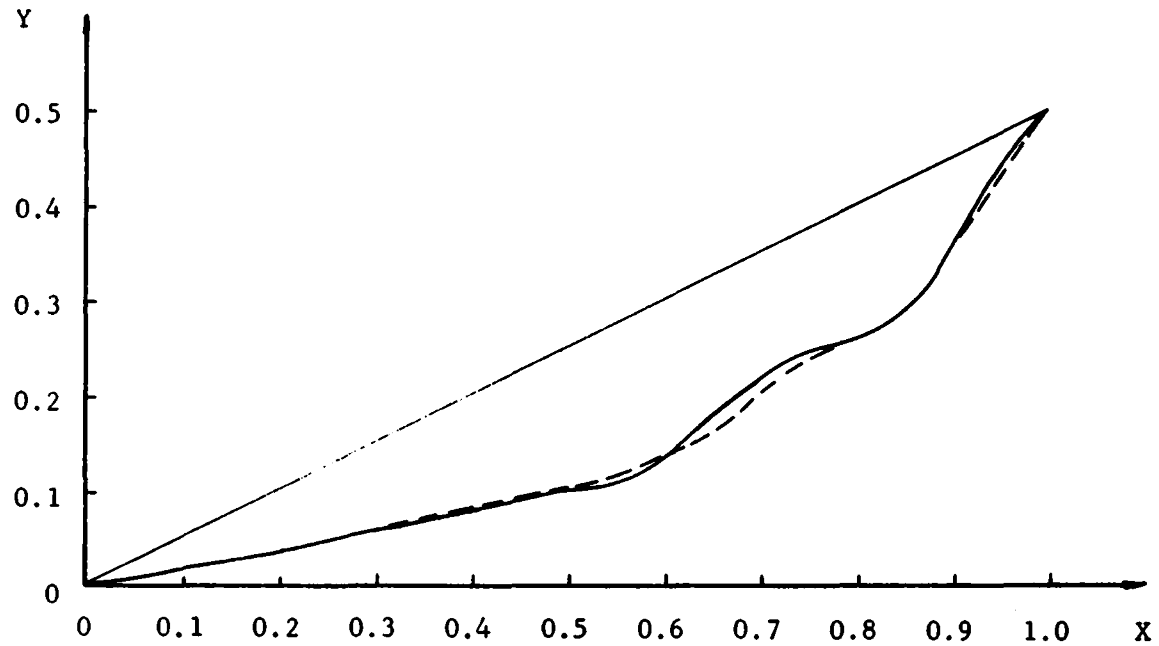


Figure 15f

N=0.5 L=0.06 M=0.17 Q=0.209 P=0.485

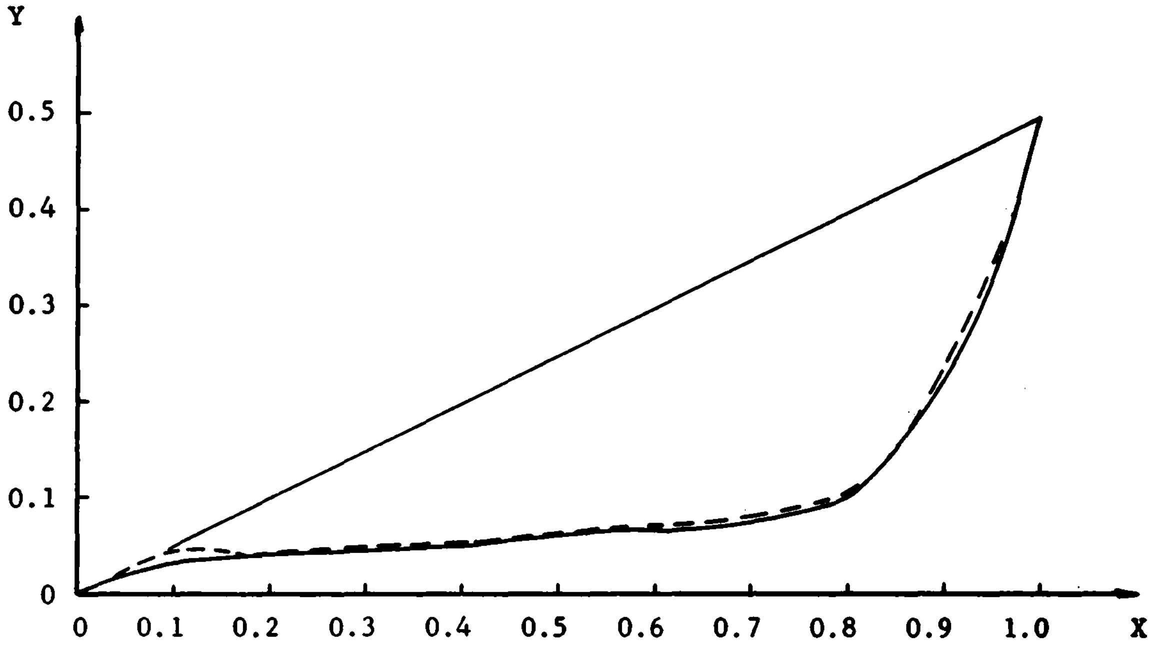


Figure 15g

N=0.5 L=0.04 M=0.07 P=0.106 Q=0.0164

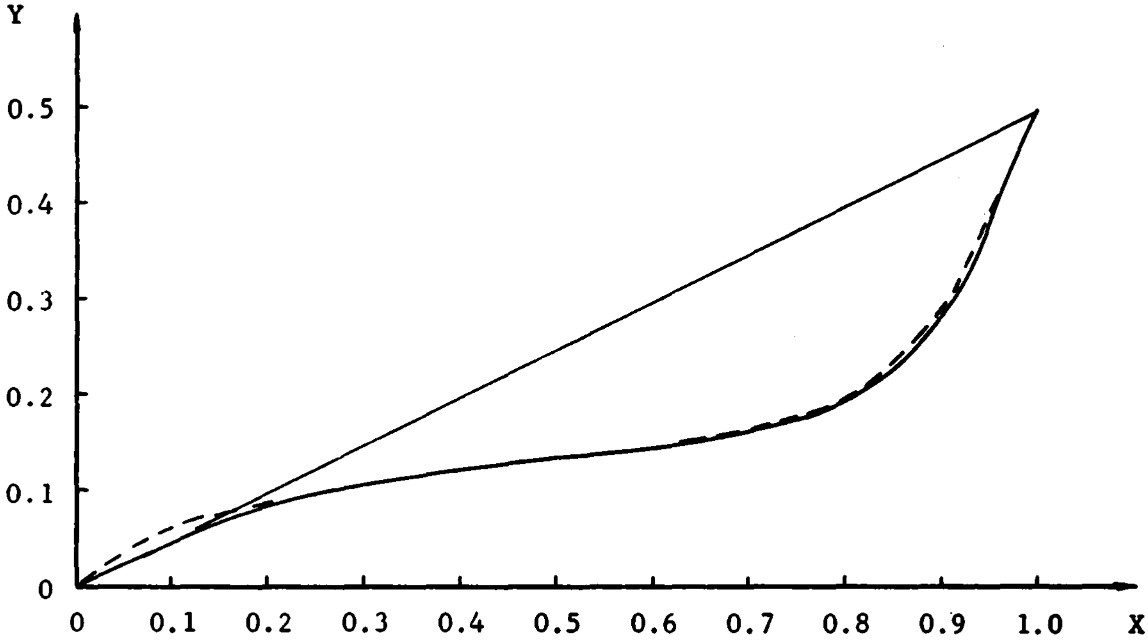


Figure 15h

N=0.5 L=0.11 M=0.15 Q=0.054 P=0.212

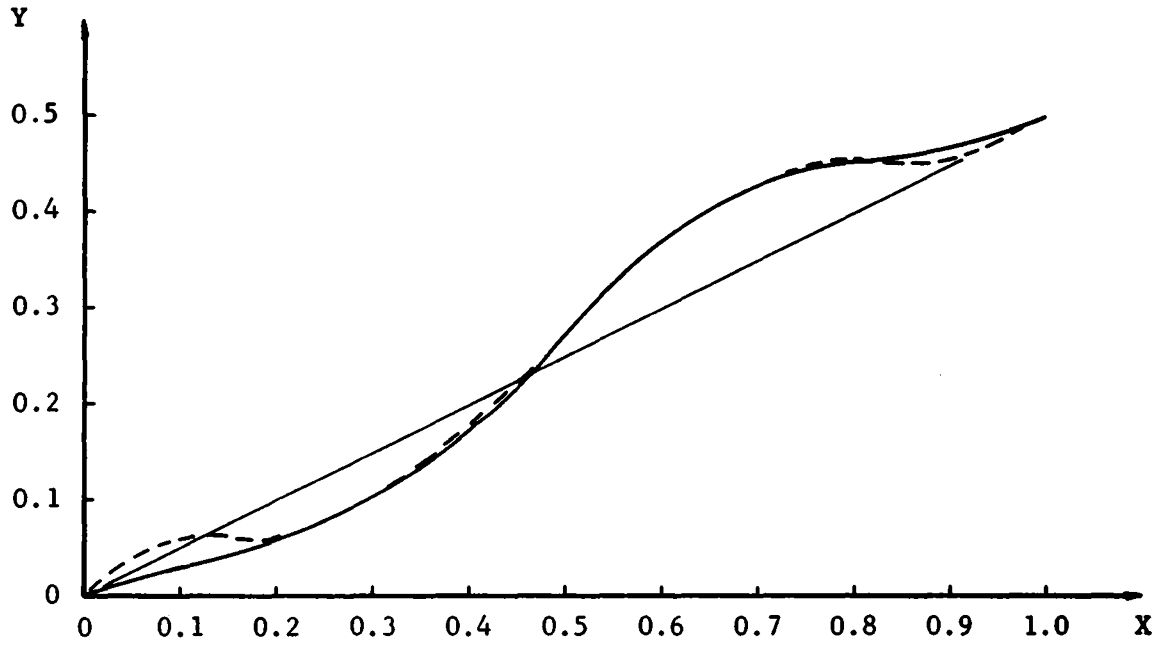


Figure 15i

N=0.5 L=0.12 M=0.4 Q=0.567 P=0.606

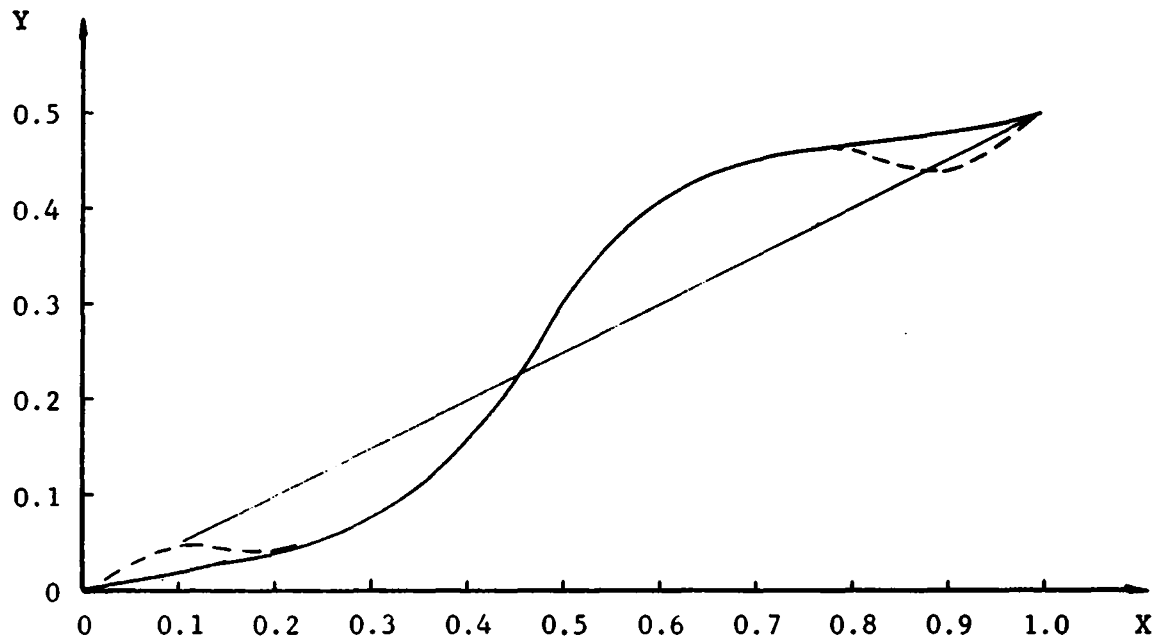


Figure 15j

N=0.5 L=0.09 M=0.43 Q=0.816 P=.212

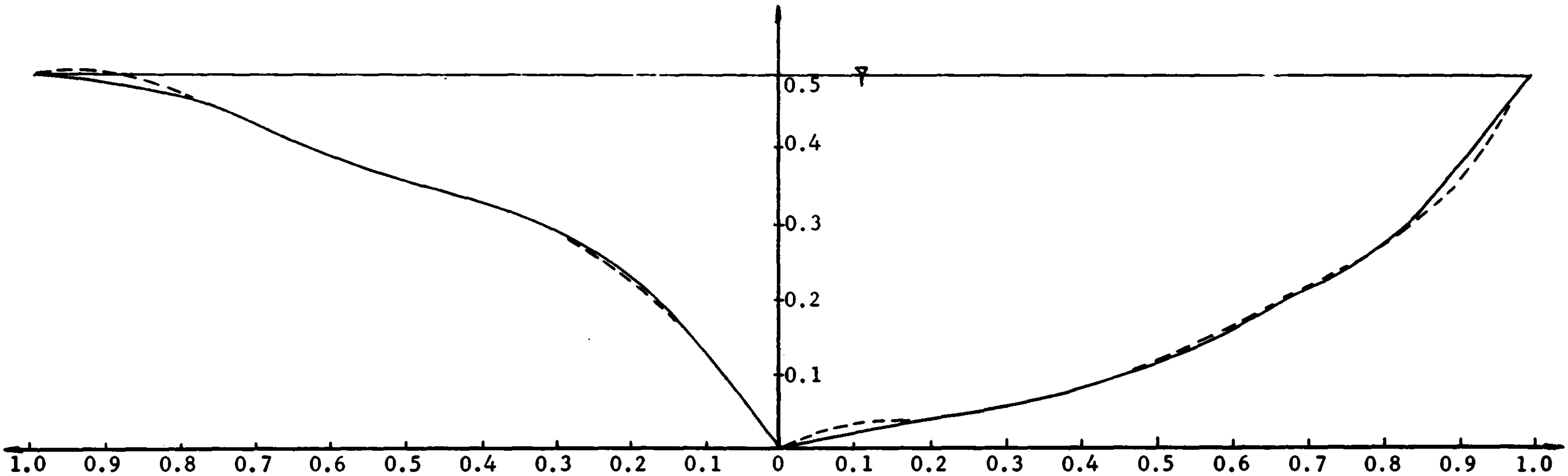


Figure 16. Reconstruction of a total cross-section with fifth order polynomial equation.

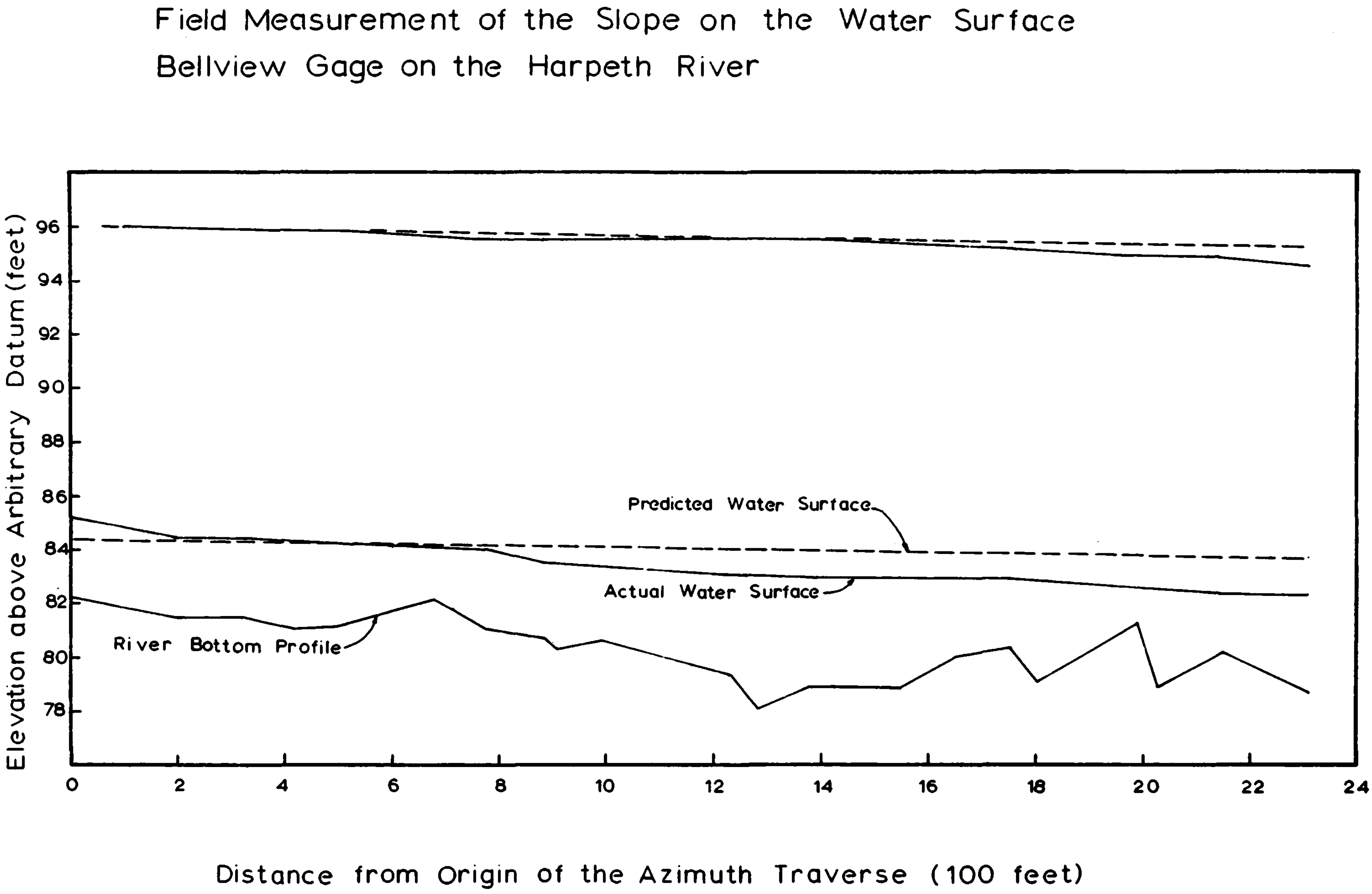
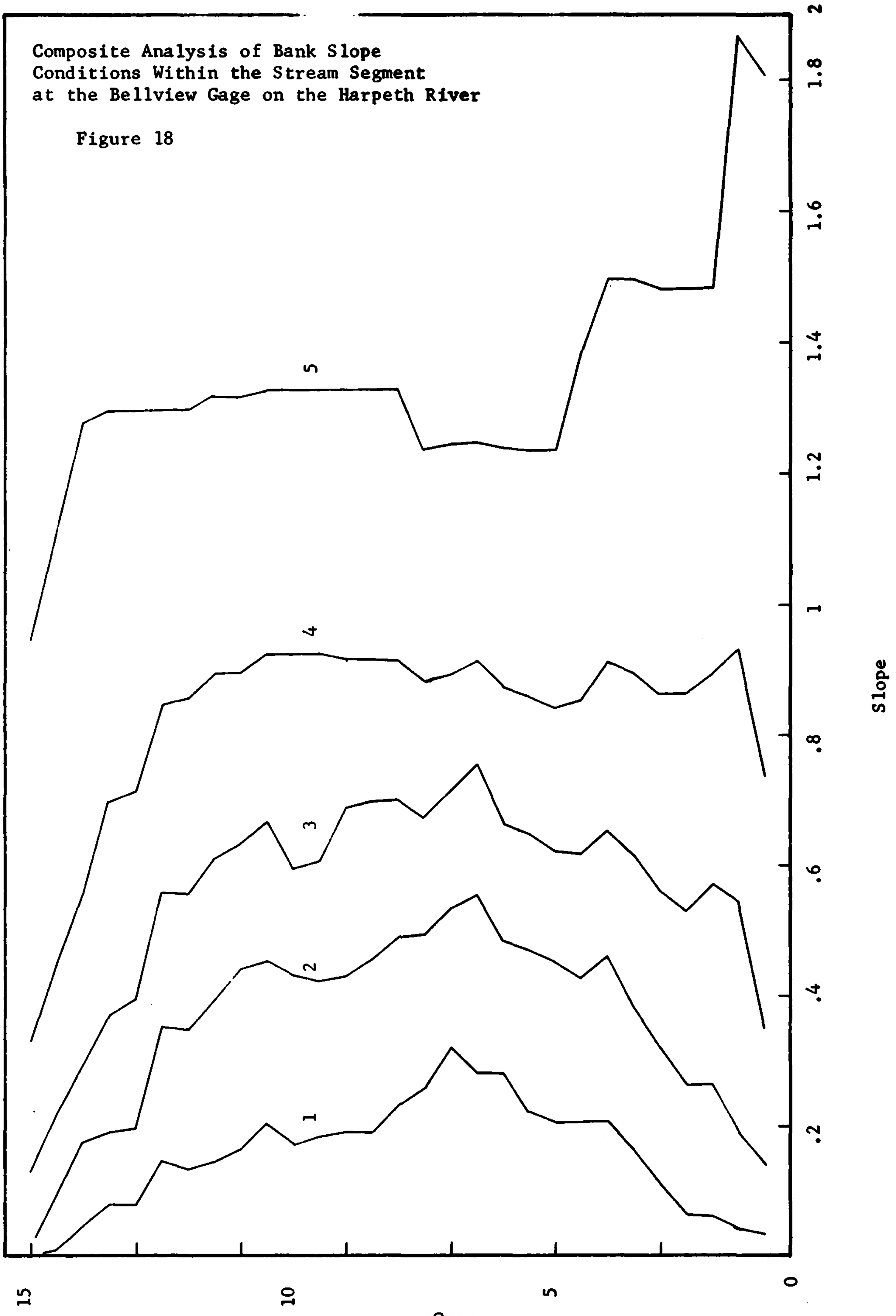

Field Measurement of the Slope on the Water Surface
Bellview Gage on the Harpeth River
Elevation above Arbitrary Datum (feet)
96
94
92
90
88
86
84
82
80
78
Predicted Water Surface
Actual Water Surface
River Bottom Profile
0
2
4
6
8
10
12
14
16
18
20
22
24
Distance from Origin of the Azimuth Traverse (100 feet)

Figure 17



Composite Analysis of Bank Slope
Conditions Within the Stream Segment
at the Bellview Gage on the Harpeth River

Figure 18

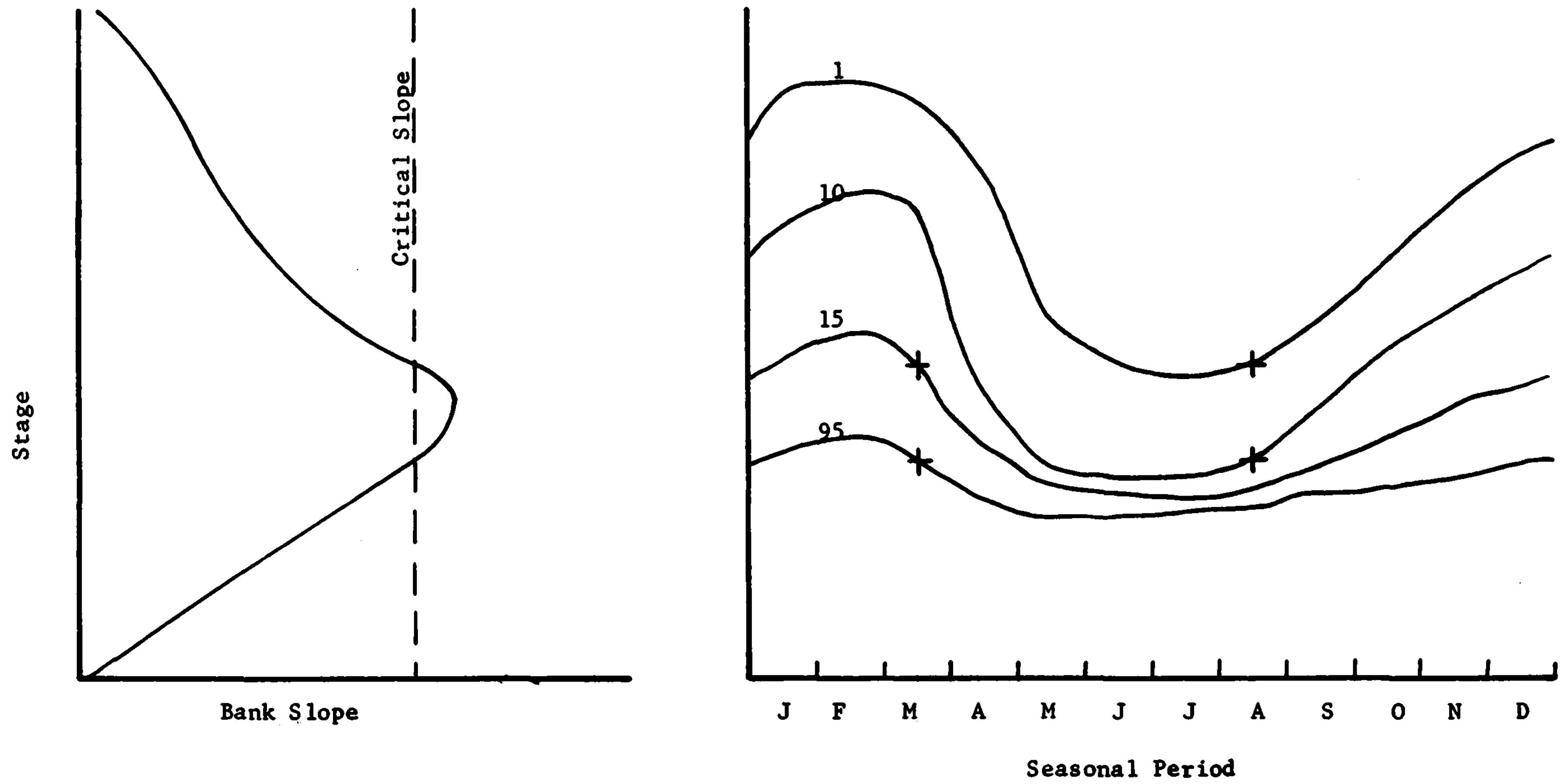


Figure 19

Illustration of Prediction Technique

TABLE I

LOCATION AND DESCRIPTION OF

CROSS SECTIONS

W.S.W. = Water Surface Width at Time of Sampling

D (Max)= Maximum Depth at the Time of Sampling

V (Max)= Maximum Velocity Measured at any Point in the Stream at the Time of Sampling

4-1 Location: 520 ft. upstream from gaging station at Bellview on the Harpeth River immediately downstream from the mouth of the Little Harpeth River

Quadrangle: Bellview W.S.W. = 116 ft. D (Max) = 1.5 ft.
Description: Soil Banks and Rock Bottom

4-2 Location: 320 ft. upstream from gaging station at Bellview on the Harpeth River

Quadrange: Bellview W.S.W. = 34 ft. D (Max) = 1.5 ft.
Description: Soil Banks and Rock Bottom

4-3 Location: 97 ft. upstream from gaging station at Bellview on the Harpeth River

Quadrangle: Bellview W.S.W. = 74 ft. D (Max) = 1.9 ft.
Description: Soil Banks and Rock Bottom

4-4 Location: At gaging station on Harpeth River at Bellview, Tennessee. Upstream side of bridge on Tennessee Highway 100

Quadrangle: Bellview W.S.W. = 90 ft. D (Max) = 1.8 ft.
Description: Soil Banks and Rock Bottom

4-5 Location: 142 ft. downstream from gaging station at Bellview on the Harpeth River, immediately downstream from bridge on Tennessee Highway 100

Quadrangle: Bellview W.S.W. = 90 ft. D (Max) = 0.4 ft.
Description: Soil Banks and Rock Bottom

4-6 Location: 255 ft. downstream from gaging station at Bellview on the Harpeth River

Quadrangle: Bellview W.S.W. = 64 ft. D (Max) = 1.3 ft.
Description: Soil Banks and Rock Bottom

4-7 Location: 465 ft. downstream from gaging station at Bellview on the Harpeth River

Quadrangle: Bellview W.S.W. = 70 ft. D (Max) = 1.2 ft.
Description: Soil Banks and Rock Bottom

4-8 Location: 1134 ft. downstream from gaging station at Bellview on the Harpeth River

Quadrangle: Bellview W.S.W. = 58 ft. D (Max) = 1.8 ft.
Description: Soil Banks and Rock Bottom

4-9 Location: 100 ft. below Old Harding Road Bridge, 0.4 miles S.W. of Bellview on the Harpeth River

Quadrangle: Bellview V (Max) = 0.965 f.p.s. W.S.W. = 94 ft. D (Max) = 5.2 ft.
Description: Soil Banks and Rock Bottom Covered with Some Gravel

4-10 Location: 100 ft. below the first bridge on Interstate 40 proceeding S.W. from Bellview Interchange on the Harpeth River

Quadrangle: Bellview V (Max) = 0.965 f.p.s. W.S.W. = 94 ft. D (Max) = 4.4 ft.
Description: Rock Bluff on Left Bank, Facing upstream

4-11 Location: Where Harpeth River parallels U.S. 70 Highway, 1.3 Miles West of Buffalo Junction

Quadrangle: White Bluff V (Max) = 0.941 f.p.s. W.S.W. = 101 ft. D (Max) = 3.5 ft

4-12 Location: 100 ft. above small bridge, 2.4 miles east of Kingston Springs, Tennessee on the Harpeth River

Quadrangle: White Bluff V (Max) = .91 f.p.s. W.S.W. = 123 ft. D (Max) = 3.9 ft.
Description: Two Rock Bluffs on One Bank

4-13 Location: 50 ft. above small bridge, 2.4 miles east of Kingston Springs, on the Harpeth River

Quadrangle: White Bluff V (Max) = 2.65 f.p.s. W.S.W. = 62 ft. D (Max) = 2.2 ft.
Description: Two Large Gravel Bars in Stream

4-14 Location: 100 ft. below Kingston Springs Road Bridge at Kingston Springs on the Harpeth River

Quadrangle: White Bluff V (Max) = 1.57 f.p.s. W.S.W. = 160 ft. D (Max) = 2.7 ft.

4-15 Location: 200 ft. below Kingston Springs Road Bridge at Kingston Springs on the Harpeth River

Quadrangle: White Bluff V (Max) = 4.615 f.p.s. W.S.W. = 67 ft. D (Max) = 1.9 ft.
Description: Bluff on One Bank, Gravel Bar on the Other

4-16 Location: At gaging station off U.S.-70 upstream from bridge near Kingston Springs, Tennessee on the Harpeth River

Quadrangle: White Bluff W.S.W. = 60 ft. D (Max) = 3.9 ft.
Description: Soil Banks with Rock and Gravel Bottom, Gravel Bar at Mid-Section

4-17 Location: 469 ft. downstream from gaging station at Kingston Springs, Tennessee; immediately downstream from bridge on U.S. 70 on the Harpeth River

Quadrangle: White Bluff W.S.W. = 108 ft. D (Max) = 4.6 ft.

4-18 Location: 1000 ft. downstream from gaging station at Kingston Springs on the Harpeth River

Quadrangle: White Bluff W.S.W. = 106 ft. D (Max) = 4.9 ft.

4-19 Location: 1500 ft. downstream from gaging station at Kingston Springs on the Harpeth River

Quadrangle: White Bluff W.S.W. = 143 ft. D (Max) = 4.1 ft.
Description: Soil Banks, Gravel Bottom, Rock Bluff on one Side

4-20 Location: 3500 ft. downstream from gaging station at Kingston Springs on the Harpeth River

Quadrangle: White Bluff W.S.W. = 66 ft. D (Max) = 2.5 ft.
Description: Soil Banks, Gravel Bottom, High Velocity due to Constriction Control

4-21 Location: Harpeth River at the Narrows, 3.5 miles north of Kingston Springs gaging station

Quadrangle: White Bluff V (Max) = 3.535 f.p.s. W.S.W. = 75 ft. D (Max) = 22 ft.
Description: Immediately upstream from Constriction Control Section

4-22 Location: 200 ft. upstream from new Petway Bridge, near Petway, Tennessee on the Harpeth River

Quadrangle: White Bluff V (Max) = 1.46 f.p.s. W.S.W. = 127 ft. D (Max) = 3.6 ft.
Description: Soil Banks, Gravel and Rock Bottom

4-23 Location: 1200 ft. downstream from U.S.G.S. gaging station, Columbia, Tennessee, on the Duck River

Quadrangle: Columbia W.S.W. = 180 ft. D (Max) = 8.3 ft.
Description: Steep, Rocky Slope on Left Facing Downstream

4-24 Location: 73 ft. downstream from U.S.G.S. gaging station at Columbia, Tennessee on the Duck River

Quadrangle: Columbia W.S.W. = 67 ft. D (Max) = 5.1 ft.
Description: Near Vertical Rock Bluff on Left Facing Downstream

4-25 Location: 5002 ft. downstream from U.S.G.S. gaging station at Columbia, Tennessee on the Duck River

Quadrangle: Godwin W.S.W. = 166 ft. D (Max) = 4.6 ft.
Description: Steep Rocky Slope on Left Facing Downstream

4-26 Location: 6026 ft. downstream from U.S.G.S. gaging station at Columbia, Tennessee on the Duck River

Quadrangle: Godwin W.S.W. = 114 ft. D (Max) = 3.5 ft.

4-27 Location: 6371 ft. downstream from U.S.G.S. gaging station at Columbia, Tennessee on the Duck River

Quadrangle: Godwin W.S.W. = 154 ft. D (Max) = 4.4 ft.
Description: Creek Channel Paralleling River on Right Side Facing Downstream

4-28 Location: 6605 ft. downstream from U.S.G.S. gaging station at Columbia, Tennessee on the Duck River

Quadrangle: Godwin W.S.W. = 145 ft. D (Max) = 5 ft.
Description: Downstream from Polk Creek Entrance into River

4-29 Location: At the gaging station near Donelson, Tennessee on the Stones River

Quadrangle: LaVergne W.S.W. = 118 ft. D (Max) = 3.1 ft.

4-30 Location: 400 ft. downstream from gaging station near Donelson, Tennessee on the Stones River

Quadrangle: LaVergne W.S.W. = 133 ft. D (Max) = 3.4 ft.

4-31 Location: 1200 ft. downstream from gaging station near Donelson, Tennessee on the Stones River

Quadrangle: LaVergne W.S.W. = 151 ft. D (Max) = 2.9 ft.

4-32 Location: 2567 ft. downstream from gaging station near Donelson, Tennessee on the Stones River

Quadrangle: LaVergne W.S.W. = 114 ft. D (Max) = 2.2 ft.

4-33 Location: 3000 ft. downstream from gaging station near Donelson, Tennessee on the Stones River

Quadrangle: LaVergne W.S.W. = 133 ft. D (Max) = 4.6 ft.
Description: Bluff on Right Side Facing Downstream, About 40 ft. High

4-34 Location: 4000 ft. downstream from gaging station near Donelson, Tennessee on the Stones River

Quadrangle: LaVergne W.S.W. = 133 ft. D (Max) = 4.6 ft.
Description: Bluff on Right Side Facing Downstream, about 18 ft. High

4-35 Location: 300 ft. upstream from bridge on Harts Bridge Road, southeast of Jackson, Tennessee on the South Fork of the Forked Deer River

Quadrangle: Beech Bluff V (Max) = 1.46f.p.s.W.S.W. = 60 ft. D (Max) = 1.0 ft.
Description: Banks and Channel are Sand and Clay. Man Made Channel.

4-36 Location: 50 ft. downstream from bridge; U.S. Highway 45; Jackson, Tennessee on the South Fork of the Forked Deer River

Quadrangle: Jackson South V (Max) = 1.586 f.p.s. W.S.W. = 94 ft. D (Max)= 1.9 ft.
Description: Banks and Bottom are Sand and Clay

4-37 Location: 200 ft. upstream from bridge on Boliver Road; Jackson, Tennessee, on the South Fork of the Forked Deer River

Quadrangle: Jackson South V (Max)= 2.262 f.p.s. W.S.W. = 62 ft. D (Max)= 3.6 ft.
Description: Man Made Channel. Banks and Bottom are Clay and Sand.

4-38 Location: 115 ft. downstream from bridge on Boliver Road; Jackson, Tennessee, on the South Fork of the Forked Deer River

Quadrangle: Jackson South V (Max)= 1.586 f.p.s. W.S.W.=70 ft. D (Max)=3.3 ft.
Description: Banks and Bottom are Sand and Clay. Man Made Channel

4-39 Location: 50 ft. upstream from bridge on I-40; Jackson, Tennessee on the South Fork of the Forked Deer River

Quadrangle: Adair V (Max)= 1.586 f.p.s. W.S.W.=71 ft. D (Max)= 4 ft.
Description: Banks and Bottom are Clay and Sand

4-40 Location: 150 ft. upstream from bridge on Austin Peay Memorial Highway (U.S. 79) Bells, Tennessee on the South Fork of the Forked Deer River

Quadrangle: Bells V (Max)= 2.065 f.p.s. W.S.W.= 70 ft. D (Max) = 2.1 ft.
Description: Banks and Bottom are Sand and Clay. Man Made Channel. Level on Both Sides.

4-41 Location: 50 ft. downstream from bridge on Tennessee Highway 54; Owl City, Tennessee, on the South Fork of the Forked Deer River

Quadrangle: Jones V (Max)= 1.924 W.S.W.= 71 ft. D (Max) = 2.3 ft.
Description: Banks and Bottom are Sand and Clay; Slough Type Swamps

4-42 Location: 50 ft. upstream from bridge on Tennessee Highway 88 at Lauderdale, Haywood and Crockett County lines on the South Fork of the Forked Deer River

Quadrangle: Chestnut Bluff V (Max)= 1.802 W.S.W.= 70 ft. D (Max)= 5.6 ft.
Description: Bottom of Channel is Mud and Sand.

4-43 Location: 300 ft. downstream from bridge on Holls Road, about 8 miles east of Holls, Tennessee, on the South Fork of the Forked Deer River

Quadrangle: Chestnut Bluff V (Max)= 1.856 f.p.s. W.S.W=79 ft. D (Max)= 2.1 ft.
Description: Banks are Loess, Bottom of Channel is Mud with a Little Sand.

4-44 Location: 1500 ft. downstream from mouth of Holls Creek, Holls, Tennessee Bridge 300 ft. downstream on the South Fork of the Forked Deer River

Quadrangle: Benicord V (Max)= 1.856 f.p.s. W.S.W.= 69 ft. D (Max)= 2.4 ft.
Description: Banks are Loess, Bottom of Channel is Mud. Man Made Channel.

4-45 Location 500 ft. upstream from bridge. About 0.5 miles west of Four Points, Tennessee (Intersection of U.S.-51 and Tenn.-20) on the South Fork of the Forked Deer River

Quadrangle: Fowlkes V (Max)= 1.38 f.p.s. W.S.W. = 54 ft. D (Max) = 5.8 ft.
Description: Banks are Loess, Bottom of Channel is Mud. Natural Channel.

4-46 Location: 1000 ft. upstream from mouth of Forked Deer River

Quadrangle: Hales Point V (Max)= .87 f.p.s. W.S.W.= 131 ft. D (Max)= 5.7 ft.
Description: Bottom of Channel is Mud and Organic Sediment. Natural Channel. Banks are Loess and Organic Silt.

4-47 Location: 300 ft. upstream from bridge at Chimneys camping area on the Little Pigeon River

Quadrangle: Cartertown W.S.W. = 42 ft. D (Max) = 2.6 ft.
Description: Sand and Dirt Banks with Small Pebbles, Many boulders in Stream Bed.

4-48 Location: 90 ft. downstream from bridge at Chimneys camping area on the Little Pigeon River

Quadrangle: Gatlinburg W.S.W.= 38 ft. D (Max)= 1.7 ft.
Description: Sand and Dirt Banks with Small Pebbles and Many Boulders. Gravel Bar Island in Stream Bed. Rapids.

4-49 Location: 200 ft. upstream from secondary road crossing West Prong of Little Pigeon upstream from mouth of Sugarland Branch

Quadrangle: Gatlinburg V (Max)= 3.535 f.p.s. W.S.W.= 48 ft. D (Max)= 2.1 ft.
Description: Sand and Dirt Banks with Small Pebbles, Stream Bed Full of Boulders.

4-50 Location: 1500 ft. downstream from bridge at mouth of Sugarland Branch on the Little Pigeon River

Quadrangle: Gatlinburg V(Max)= 3.34 f.p.s. W.S.W.= 29 ft. D (Max)= 2.4 ft.
Description: Sand and Dirt Banks with Small Pebbles, Many boulders in Stream Bed

4-51 Location: 3000 ft. downstream from bridge at mouth of Sugarland Branch on the Little Pigeon River

Quadrangle: Gatlinburg V (Max)= 4.77 f.p.s. W.S.W.= 26 ft. D (Max)= 2.0 ft.
Description: Island with Thick Vegetation in Middle of Stream. Sand and Dirt Banks with Small Pebbles, Many Boulders in Stream Bed.

4-52 Location: 3500 ft. downstream from bridge at mouth of Sugarland Branch on the Little Pigeon River

Quadrangle: Gatlinburg V (Max)= 5,285 W.S.W.= 53 ft. D (Max)= 2.2 ft.
Description: Sand and Dirt Banks with Small Pebbles, Many Boulders in Stream Bed

4-53 Location: Downstream 1700 ft. from Wiley Oakley Drive Bridge, off U.S. 441 on the Little Pigeon River

Quadrangle: Gatlinburg V (Max)= 2.915 f.p.s. W.S.W.= 90 ft. D (Max)= 1.3 ft.
Description: Banks Covered with Broken Rock and Stream Bed Contains Many Boulders

4-54 Location: 2200 ft. downstream from Wiley Oakley Drive Bridge, off U.S. 441 on the Little Pigeon River

Quadrangle: Gatlinburg V (Max)= 4.75 f.ps. W.S.W.= 51 ft. D (Max)= 1.8 ft.
Description: Banks of Broken Rock, Bed Containing Gravel and Small Boulders

4-55 Location: Northeast of Comerheights, Tennessee, 7500 ft. upstream from Pigeon Forge, Tennessee on the Little Pigeon River

Quadrangle: Pigeon Forge V (Max)=4.709 f.p.s. W.S.W.= 94 ft. D (Max)= 1.4 ft.
Description: Sandy Dirt Banks, Small Boulders in Stream Bed

4-56 Location: 300 ft. upstream from Chapman Highway Bridge; South of Pine Grove, Tennessee on the Little Pigeon River

Quadrangle: Pigeon Forge V (Max)= 1.48 f.p.s. W.S.W.= 62 ft. D (Max)= 1.9 ft.
Description: Mud Bottom Near Banks, Rocks and Gravel in Channel, No Rapids

4-57 Location: 300 ft. downstream from Chapman Highway Bridge, south of Pine Grove, Tennessee on the Little Pigeon River

Quadrangle: Pigeon Forge V (Max)= 2.23 f.p.s. W.S.W.=89 ft. D (Max)= 1.4 ft.
Description: Sandy Dirt Banks

4-58 Location: Due south of Shiloh Memorial Cemetary; near Pine Grove, Tennessee on the Little Pigeon River

Quadrangle: Pigeon Forge W.S.W.= 100 ft. D (Max)= 8.0 ft.
Description: Sandy Dirt Banks, Small Rocks in Stream Bed

4-59 Location: Due south of Shiloh Memorial Cemetary; near Pine Grove, Tennessee on the Little Pigeon River

Quadrangle: Pigeon Forge W.S.W.= 100 ft. D (Max)= 1.8 ft.
Description: Sandy Dirt Banks, Small Rocks and Gravel in Stream Bed

4-60 Location: Due south of Shiloh Memorial Cemerary; near Pine Grove, Tennessee on the Little Pigeon River

Quadrangle: Pigeon Forge W.S.W.= 40 ft. D (Max)= 0.5 ft.
Description: Sandy Dirt Banks, Small Rocks and Gravel in Stream Bed. Island in Middle of Stream

4-61 Location: South of Shiloh Memorial Cemetary; near Pine Grove, Tennessee on the Little Pigeon River

Quadrangle: Pigeon Forge W.S.W.= 137 ft. D (Max)= 2.7 ft.
Description: Sandy Dirt Banks, Small Rounded Stones and Gravel in Stream Bed

4-62 Location: North of Husky Branch and east of Burnt Mountain on the Little River

Quadrangle: Gatlinburg W.S.W.= 33 ft. D (Max)= 2.3 ft.
Description: Sand and Dirt Banks with Small Pebbles, and Many Boulders in Stream

4-63 Location: North of Husky Branch and east of Burnt Mountain on the Little River

Quadrangle: Gatlinburg W.S.W.= 35 ft. D (Max)= 9.2 ft.
Description: Sand and Dirt Banks with Small Pebbles, and Many Boulders in Stream

4-64 Location: North of Husky Branch and east of Burnt Mountain on the Little River

Quadrangle: Gatlinburg W.S.W.= 44 ft. D (Max)= 7.4 ft.
Description: Sand and Dirt Banks with Small Pebbles

4-65 Location: North of Husky Branch and east of Burnt Mountain on the Little River

Quadrangle: Gatlinburg W.S.W.= 59 ft. D (Max)= 2.5 ft.
Description: Sand and Dirt Banks with Small Pebbles and Many Boulders in Stream

4-66 Location: 200 ft. upstream from bridge on Wilson Pike on the Little Harpeth River

Quadrangle: Franklin W.S.W.= 6 ft. D (Max)= Negligible
Description: Dirt Banks and Limestone Bottom

4-67 Location: 100 ft. upstream from bridge on Collender Road on the Little Harpeth River

Quadrangle: Franklin V (Max)= 0.14 f.p.s. W.S.W.= 18 ft. D (Max)= 1.0 ft.
Description: Dirt Banks and Limestone Bottom

4-68 Location: Immediately upstream from bridge on U.S.-31 south of Brentwood, Tennessee on the Little Harpeth River

Quadrangle: Oak Hill V (Max)= 0.15 f.p.s. W.S.W.= 34 ft. D (Max)= 0.9 ft.
Description: Dirt Banks, Limestone Bottom

4-69 Location: Immediately downstream from bridge on McClanhan Road, southwest of Brentwood, Tennessee on the Little Harpeth River

Quadrangle: Oak Hill V (Max)= 0.0 f.p.s. W.S.W.= 32 ft. D (Max)= 1.7 ft.
Description: Dirt Banks and Limestone Bottom with Silt

4-70 Location: Near the approximate Williamson and Davidson County boundary; on the edge of Percy Warner Park on the Little Harpeth River

Quadrangle: Belleview V (Max)- 0.0 f.p.s. W.S.W.= 36 ft. D (Max)= 1.7 ft.
Description: Dirt Banks and Limestone Bottom

4-71 Location: Wilson Road Bridge on the downstream side, 200 ft. north of the Tennessee-Georgia boundary on the Chattanooga Creek

Quadrangle: Fort Oglethorpe V (Max)= .205 f.p.s. W.S.W.= 52 ft. D (Max)= 5.3 ft.
Description: Mud Banks, Organic Silt Bottom

4-72 Location: Downstream side of Central of Georgia R.R. Bridge, south of Hamill Road on the Chattanooga Creek

Quadrangle: Fort Oglethorpe V (Max)= .575 f.p.s. W.S.W.= 75 ft. D (Max)= 4 ft.
Description: Mud and Gravel Banks with Organic Silt on Bottom

TABLE 2

CORRELATION COEFFICIENTS FOR LEAST SQUARES

LINE OF BEST FIT FOR THE EXPRESSION

LOG STAGE = A LOG CUMULATIVE FREQUENCY + LOG B

Seasonal Period		Correlation Coefficients
Sept.	1 - 15	0.9750
	16 - 30	0.9649
Oct.	1 - 15	0.9923
	16 - 31	0.9804
Nov.	1 - 15	0.9942
	16 - 30	0.9955
Dec.	1 - 15	0.9936
	16 - 31	0.9767
Jan.	1 - 15	0.9637
	16 - 31	0.9869
Feb.	1 - 15	0.9572
	16 - 28	0.9713
Mar.	1 - 15	0.9797
	16 - 31	0.9878
Apr.	1 - 15	0.9919
	16 - 30	0.9956
May	1 - 15	0.9845
	16 - 31	0.9914
June	1 - 15	0.9822
	16 - 30	0.9561
July	1 - 15	0.9967
	16 - 31	0.9964
Aug.	1 - 15	0.9983
	16 - 31	0.9989