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I am submitting herewith a thesis written by Charles F. Glazzard entitled "Streamflow Characteristics Related to Channel Geometry of Selected Streams on the Cumberland Plateau, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

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We have read this thesis and recommend its acceptance:

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STREAMFLOW CHARACTERISTICS RELATED TO CHANNEL GEOMETRY OF SELECTED STREAMS ON THE CUMBERLAND PLATEAU, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

University of Tennessee, Knoxville

Charles F. Glazzard

March 1981

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ABSTRACT

Several different techniques have been developed to estimate average and peak discharges for ungaged streams using various basin and channel characteristics.

The channel-geometry technique of estimating stream discharge values is based on the relationship between the stream's channel geometry and the discharges that flow through the channel. This relationship is based on the assumption that the stream's discharges can be related to the dimensions of a particular channel form. The active-channel width was used in this study.

In this study, power-function equations were developed to estimate stream discharge values using channel-geometry and stream flow data for 41 streams on the Cumberland Plateau in Tennessee. The power-function equations were statistically developed using simple- and multiple-regression and structural analyses.

Two groups of power function equations were developed. The first group was developed using the data derived from this study. The second group was developed by imposing exponent values on the active-channel width as proposed by Osterkamp and Hedman (1979).

The results showed that most of the power-function equations derived from the data collected in this study may be used to estimate streamflow values for the ungaged streams on the Cumberland Plateau, but that the equations developed using Osterkamp and Hedman's exponents are invalid for estimating these values. The data also showed that many variables complicate the relationships developed in this study. An evaluation of the data gathering techniques, statistical techniques, and assumptions used in this study has also been made.

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CHAPTER I

INTRODUCTION

Stream discharge data are used in many hydrologic and engineering efforts. Estimation of the mean annual, 2, 5, 10, 25, 50, and 100 year peak discharges is most important in floodplain planning and development, in designing flood control projects for cities, and in almost any other land-use project. There are several methods of obtaining stream discharge data for drainage basins. The most accurate and expensive method is the installation and maintenance of continuous recording gaging stations. Unfortunately, not all rivers can be monitored in this way. Techniques for estimating this information, each with its own shortcomings and problems, include data manipulations that require transferring gaging station records from one site to another, or models based on drainage area, basin characteristics and rainfall runoff. These methods rely primarily on data collected outside the basin of interest or on data modified to fit the particular basin in question.

An alternative method of estimating stream discharge data is by the use of channel-geometry investigations. These data are collected at the particular site along the channel, and specific results are obtained for that individual channel. The use of channel-geometry data for estimating stream discharges is based on Leopold and Maddock's (1953) hydraulic-geometry concept, which assumes that the channel size and shape are determined primarily by the discharge and sediment load carried by the stream. Therefore, the measurement of

channel characteristics, i.e., channel-geometry, provides information about the stream's discharge characteristics. The measurement of channel characteristics at geomorphic control points in the field, and on topographic maps, as well as the collection and analysis of bed and bank sediment samples can be done easily and inexpensively. The desired discharge estimates can be quickly obtained by the use of a power-function equation. It is anticipated that these estimates can be as precise as gaging station records of 10-20 years duration.

Families of power-function equations have been developed to estimate discharges of streams, but have excluded the bedrock controlled reaches of the channel (Osterkamp, 1977; Osterkamp and Hedman, 1977). Since many of the streams on the Cumberland Plateau flow on bedrock, it was postulated that the published equations could not be used to estimate discharges of these streams and that it was necessary to develop another family of equations indicative of the channel conditions found in this area. The main purpose of this paper is to develop a family of power-function equations to predict mean annual, 2, 5, 10, 25, 50, and 100 year peak discharges, using channel-geometry data, for the ungaged streams on the Cumberland Plateau of east-central Tennessee. An evaluation of the channel-geometry techniques used to develop these equations has also been made.

CHAPTER II

LITERATURE REVIEW

The relationship between channel characteristics and stream discharge has long been recognized, but only recently has this relationship been quantified. Leopold and Maddock (1953) presented their simple power-function equations relating discharge to the hydraulic-geometry properties of a particular cross-section:

$$W = a'Q^{b'} \ *$$

$$D = cQ^{f}$$

$$V = kQ^{m}$$

where W is width, D is mean depth, V is mean velocity, and Q is discharge. Exponents b', f, m and coefficients a', c, k are defined such that:

$$b' + f + m = 1.0$$

and

$$a' \ c \ k = 1.0$$

They found that the values of their exponents ($b' = 0.5$, $f = 0.4$, and $m = 0.1$) were relatively constant, while the values of the coefficients varied between river systems. Their channel variables were based on the properties at a particular discharge rather than from dimensions based on a specific feature of the stream channel.

Wolman's (1955) work on the Brandywine Creek drainage of Pennsylvania related the hydraulic geometry to a recognizable channel

---

*$a'Q^{b'}$ was originally presented by Leopold and Maddock (1953) as aW^{b} but was modified here to avoid confusion with other coeffients and exponents quoted in this paper.

feature, the bankfull width. He found the recurrence intervals of flows exceeding bankfull stage ranged from one to three years and averaged 2.2 years.

The use of in-channel features as an index to discharges was proposed by W. B. Langbein in 1966 (written communication). Langbein's approach was to use a recognizable, unique, active channel feature that could respond to changes in the flow regime of the river as an index to the discharge. He proposed empirically relating a particular discharge characteristic, as the dependent variable, to dimensions of recognizable active features of the channel. Using this approach, estimates of a stream's discharge characteristics could be made at ungaged sites on the basis of the stream's channel geometry.

One of the first published works using an in-channel feature, the depositional-bar, was by Moore (1968) in Nevada. Work by Hedman (1970) in California, Kopaliani and Romashein (1970) in western Georgia, U. S. S. R., and Hedman and Kastner (1972) in Kansas also used the depositional-bar reference level to estimate mean annual runoff. Another study by Hedman, Moore, and Livingston (1972) in Colorado used the depositional-bar width to estimate mean annual runoff and flood frequency discharges. A later study by Hedman, Kastner, and Hejl (1974) used the active-channel width to estimate flood frequency discharges.

Hedman and Kastner's (1977) study in the Missouri River basin was a comparison of the results obtained by using the depositional-bar and active-channel reference levels for estimating mean annual runoff and flood frequency discharges. They concluded that both channel reference widths could be used.

Schumm (1960) described the relationship between alluvial channels and the sediment characteristics of the channel. His study showed that the percent silt and clay in the bed and bank material and the channel geometry of the channel can be related to a width-depth ratio which helps to define the shape or geometry of the channel. This ratio helps to distinquish between wide shallow rivers with sandy banks and narrower deeper rivers with silt and clay banks. Although the study showed the importance of the silt and clay fraction on the channel's geometry, the technique could not be used alone to estimate the stream discharge of ungaged basins. Hedman and Kastner (1977) observed that the streambed and bank material help to define the channel shapes and also affect the relationship of the channel-geometry and streamflow characteristics. They also observed that the more cohesive material may limit the rate of sculpturing, whereas, the less cohesive material may limit the rate of healing of the channels.

Osterkamp (1977) studied the effects of the silt and clay fraction in the bed and bank samples on the width-discharge relationship for some streams in Kansas. He found that by introducing the percentage of the silt-clay content found in the bed and bank samples into the simple power-function equation:

$$Q = aW^b$$

so that it became:

$$Q = aW^b \, SC_{bd}^x \, SC_{bk}^y$$

that the standard error of the discharge estimates was significantly reduced. In this same study, he proposed imposing a standard exponent of 1.98 on the width variable when estimating mean annual discharge.

This value, when corrected to two significant figures, is the same as the reciprocal of Leopold and Maddock's (1953) 0.5 (b') experimental value. The reciprocal value is used in channel-geometry studies because discharge is the dependent variable rather than the independent variable.

Osterkamp (1980) presented several observations about the relationship between the fluvial sediment characteristics and the channel morphology. He noted that a stream's minimum channel width is related to the discharges passing through the channel and to the amount and availability of the sediment load transported by the stream. He further states that a stream's maximum channel width is related to the percentage of medium- and coarse-grained sand in the system.

A study in England, Richards (1973), challenged the validity of the three simple power-function equations presented by Leopold and Maddock (1953) relating discharge and hydraulic-geometry characteristics. His objections were based on a study showing a nonlinear relationship between channel roughness and the stream's hydraulic geometry. He suggested that higher order, log-quadratic, equations were more appropriate than simple log-linear equations in describing the depth-discharge and velocity-discharge relationships.

Although the use of these higher order equations may help to refine these relationships, there is no evidence that these variables are not also log-linearly related. Richards did not question the log-linear relationship between width and discharge. Since other studies (Leopold and Maddock, 1953; Moore, 1968; Hedman, 1970; Brown, 1971; Osterkamp, 1977) have shown that such a relationship does exist, the use of the

log-linear width-discharge relationship, as it applies to the discharge-channel-geometry relationships, will be tested in this paper.

Many other papers have been written describing basin, channel, sediment, and discharge relationships as well as various methods of estimating stream discharge. Those studies in east Tennessee and the Cumberland Plateau in Tennessee include, Kilpatrick and Barnes (1969), Brown (1971), May, Wood, and Rima (1970), Randolph and Gamble (1976), Betson (1979), and Carey (1979).

CHAPTER III

THE STUDY AREA

I. LOCATION OF STUDY AREA

The Cumberland Plateau, in east-cntral Tennessee, is a highland area of Pennsylvanian rocks bounded by Georgia and Alabama on the south and Kentucky and Virginia on the north (Fig. 1). The Plateau is some 275 to 305 meters higher than the Highland Rim, which marks its western boundary, and the Valley and Ridge physiographic province to the east. With a length of 255 km and a width varying from 88 km in the north to 61 km in the south, the Plateau covers an area of some 12,950 km^2.

The study area is drained by two major drainage systems: the Cumberland River to the northwest, and the Tennessee River to the southeast. Gaging stations for each basin are identified by their U. S. Geological Survey station numbers. In Tennessee, those streams with station numbers less than 03455000 are found in the Cumberland River Basin, and those stations numbered 03455000 and greater are within the Tennessee River Basin. The study area includes 41 control stations and 9 experimental stations (Fig. 2). All but three of the drainage basins for the control sites lie either wholly or partially on the Plateau. These basins cover approximately 70 percent of the plateau region (Hollyday and Hansen, unpublished manuscript). Streamflow records for these stations range from seven to 59 years. Table 1 shows the range and mean values of several basin and channel characteristics for the control and experimental stations used in this study. The 41 control stations were chosen on the basis of their periods of record and the

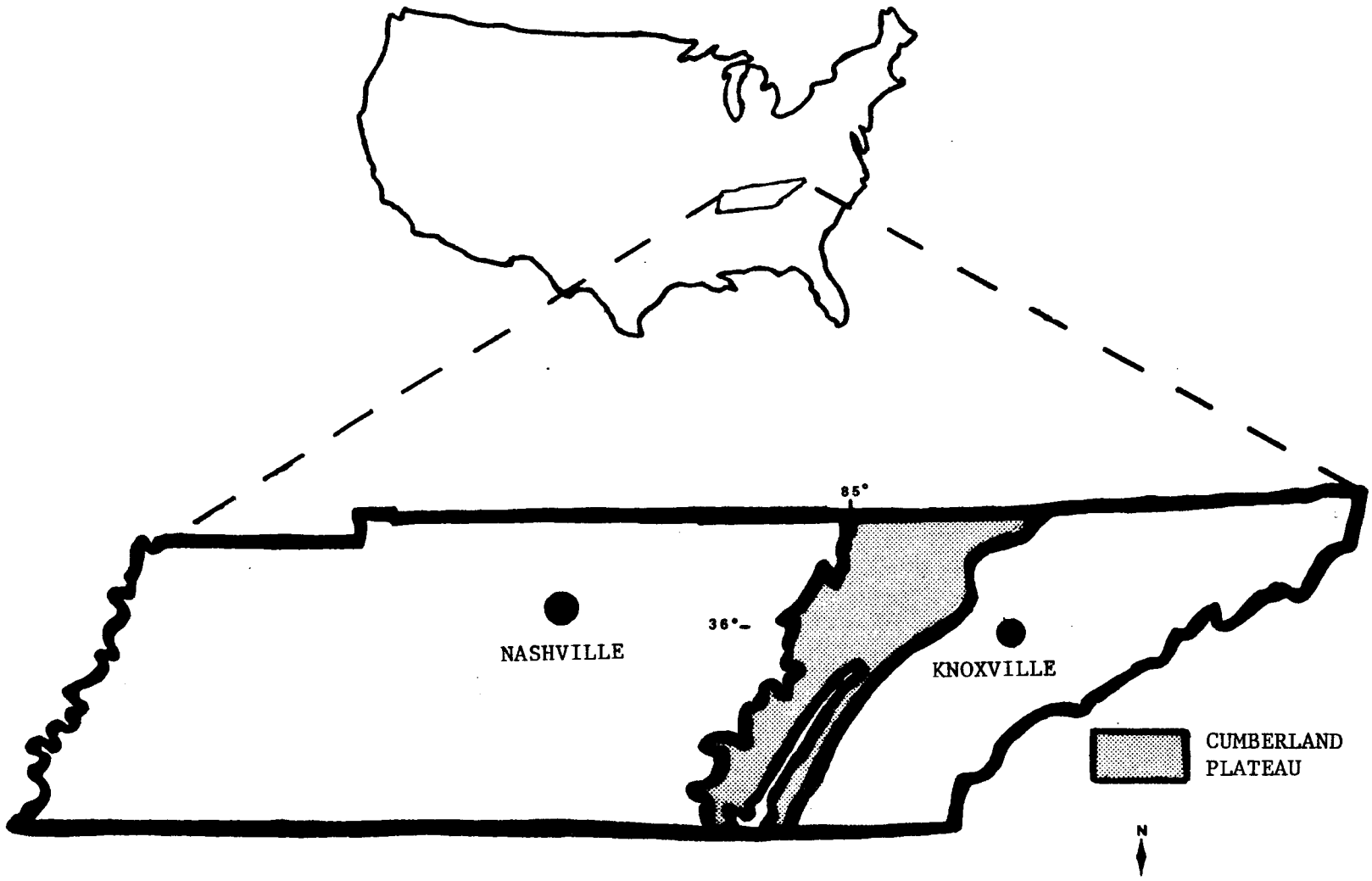


FIGURE 1. MAP SHOWING THE LOCATION OF THE CUMBERLAND PLATEAU IN EAST TENNESSEE.

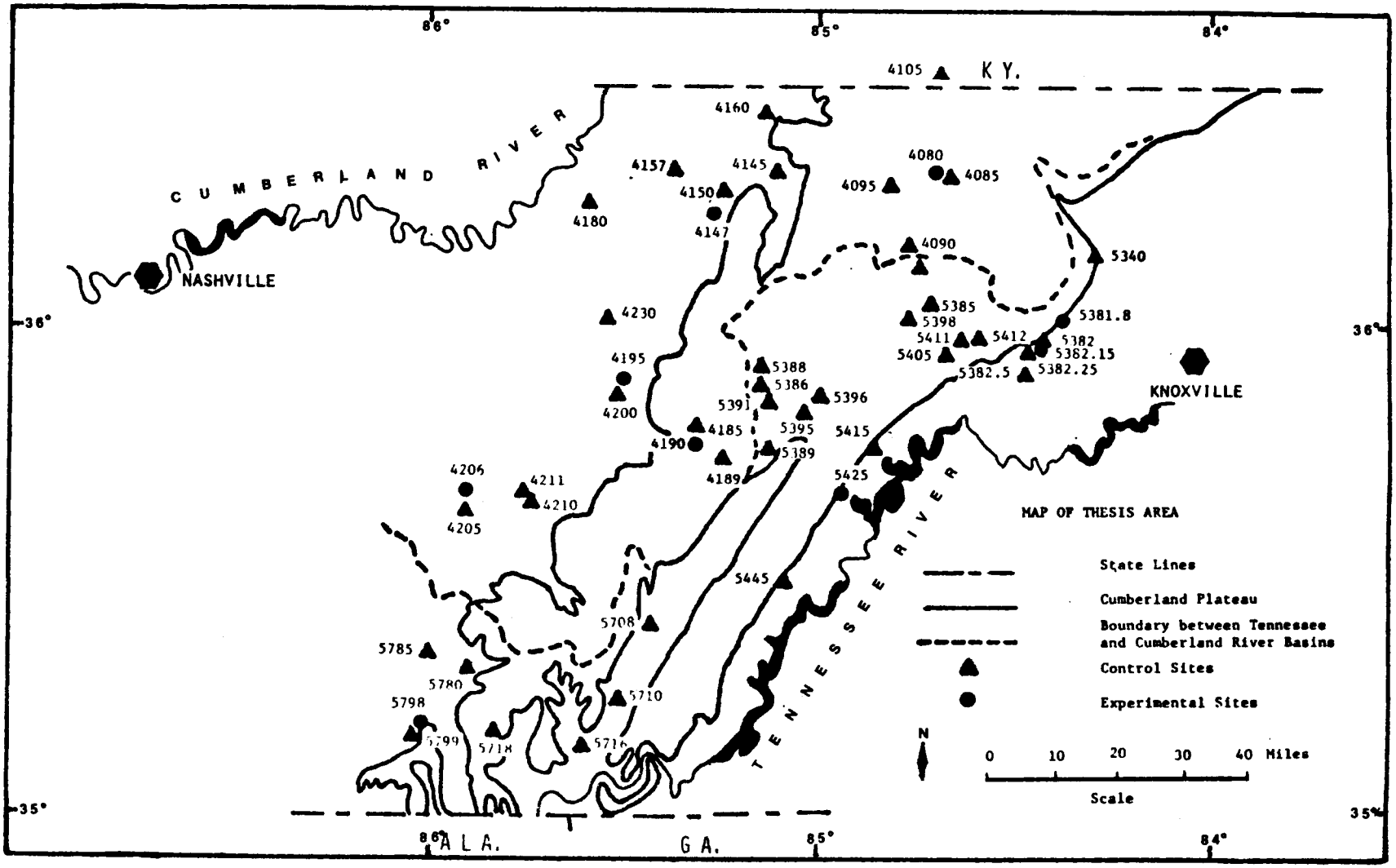


FIGURE 2. MAP SHOWING THE LOCATION OF THE CONTROL AND EXPERIMENTAL SITES.

TABLE 1. SOME STREAM AND BASIN CHARACTERISTICS OF THE CONTROL AND EXPERIMENTAL SITES.

STREAM/BASIN CHARACTERISTICS	41 CONTROL STATIONS	9 EXPERIMENTAL STATIONS
DRAINAGE AREA		
Maximum	2471 km^2 (954 mi^2)	813 km^2 (314 mi^2)
Minimum	1.74 km^2 (0.67 mi^2)	11.14 km^2 (4.30 mi^2)
Mean	363 km^2 (140 mi^2)	208 km^2 (80.1 mi^2)
GRADIENT		
Maximum	0.022	0.011
Minimum	0.00022	0.00046
Mean	0.0045	0.0034
CHANNEL TYPE		
Bedrock	23/41 = 56%	4/9 = 44%
Boulder-cobble	8/41 = 20%	2/9 = 22%
Sand, silt-clay	10/41 = 24%	3/9 = 33%
STREAM TYPE		
Meandering	38/41 = 93%	9/9 = 100%
Straight	3/41 = 7%	
COAL PRESENT	25/41 = 61%	6/9 = 66%

availability of average and peak discharge information from the U. S. Geological Survey Streamflow/Basin Characteristics File (program J-763). The nine experimental sites were chosen on the basis of their periods of record enabling estimates of their discharge values to be calculated.

Annual precipitation varies across the Plateau from 122 cm to 152 cm per year with a mean annual value of 130 cm. The temperature varies seasonally on the Plateau from a minimum January mean temperature of -2.0°C to a maximum July mean temperature of 30°C, giving a mean annual value of 12°C (Dickson, 1960).

Land-use on the Cumberland Plateau ranges from areas of intense timber harvesting and coal mining to areas of active farming or grazing. Urban areas constitute a relatively small percentage of the Plateau area. Unfortunately, the author was unable to locate any quantitative information as to actual percentages of land-use on the Plateau.

II. GEOLOGY OF THE CUMBERLAND PLATEAU

Stratigraphy

The rocks on the Cumberland Plateau range from Late Cambrian to Pennsylvanian in age. The oldest rocks are only exposed in areas of deep erosion such as the Sequatchie Valley, and along the eastern margin of the Plateau.

The Pennsylvanian rocks that cap the Cumberland Plateau have an aggregate thickness of more than 1220 m, of which the greater part has been removed by erosion (Luther, 1959). Stratigraphically, the rocks are divided into nine groups and numerous formations (Fig. 3). The various rock types are distributed throughout the stratigraphic section

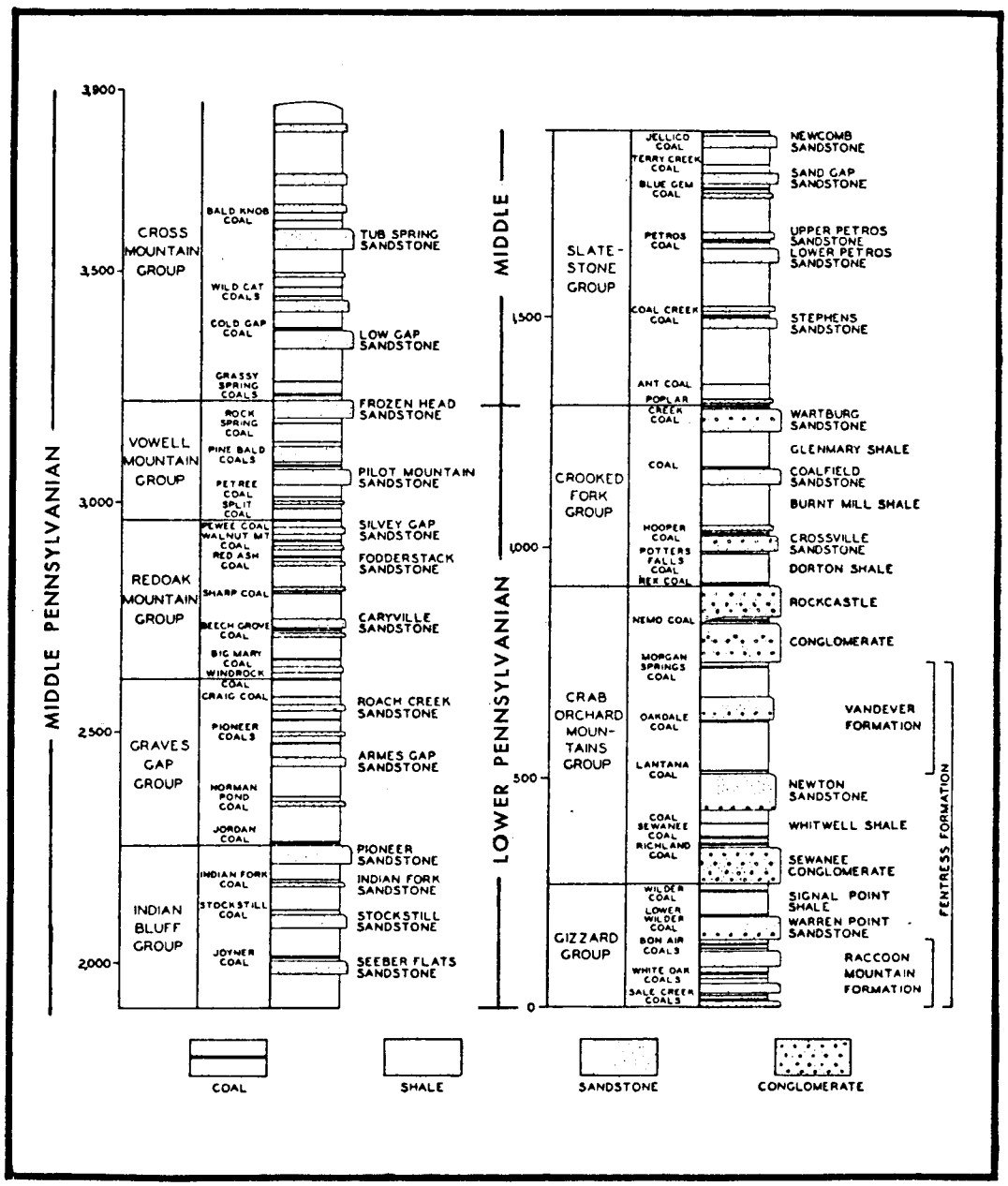


FIGURE 3. GENERALIZED STRATIGRAPHIC SEQUENCE OF PENNSYLVANIAN ROCKS IN TENNESSEE (from Luther, 1959).

with some lithologies more common in one part than in another. The stratigraphic section can be roughly divided into a lower sequence consisting of sandstones and conglomerates with equal amounts of shale, and an upper sequence with thinner sandstones and a higher percentage of shale, siltstone, and coal. The lower sequence crops out over more than three-quarters of the Cumberland Plateau, whereas the upper sequence is limited to the northeastern quarter of the Plateau within the Cumberland Mountains (Wilson, Jewell, and Luther, 1956).

Lithology

Pennsylvanian rocks in Tennessee are almost entirely terrigenous clastics. The most common rock types are sandstones and shales, but also present are siltstones, thin local limestone or siderite beds, and coal seams.

In the lower part of the sequence, the sandstones are usually massive thick bedded, well sorted and coarse grained. They may be interbedded with conglomerates. In the upper part of the sequence the sandstones are often thin bedded or discontinuous, poorly sorted, finer grained and are associated with a higher percentage of argillaceous rocks. The siltstones present are not as well bedded, laminated, nor fissile as the shales.

Shale is the most abundant rock type found. There are two distinct types present. The most common is a silty shale which is usually gray or brown in color. It is generally nonfissile, although it is finely and irregularly laminated. More rare are the clay shales which can be divided into two types: a light-gray, massive, structure-less variety associated with coal seams as an under clay and a

dark-gray to black, fissile, finely laminated variety overlying the coal seams and sometimes associated with the thin and locally present limestone or siderite beds.

Structure

Figure 4 shows the generalized structural features of the Cumberland Plateau. The Plateau south of the Cumberland Plateau overthrust is bisected by the Sequatchie Valley anticline into the Southern Cumberland Plateau and Walden Ridge (South). Northwest of the overthrust is the Northern Cumberland Plateau and to the northeast are the Wartburg Basin and the Cumberland Block. The following description of the structural subdivisions of the Cumberland Plateau has been summarized from Luther (1959) unless otherwise cited.

The Sequatchie Valley anticline is a prominent feature which is parallel to the Valley and Ridge province and extends about 290 km from Blount County, Alabama northeastward to Cumberland County, Tennessee. It is not a simple anticline but is faulted both along and across its axis (Milici, 1960). Over most of its length it has been breached by erosion, which exposes less resistant formations into which the Sequatchie Valley has been cut.

West of the Sequatchie Valley is a large area with a gentle easterly dip referred to as the Southern Cumberland Plateau. It is a broad, asymmetrical syncline, the axis of which parallels and lies near the western side of Sequatchie Valley.

Walden Ridge (South) is a narrower, though similar, asymmetrical syncline formed by the southeast dip of the Sequatchie Valley anticline on the west and the northwest dip from the Valley and Ridge province

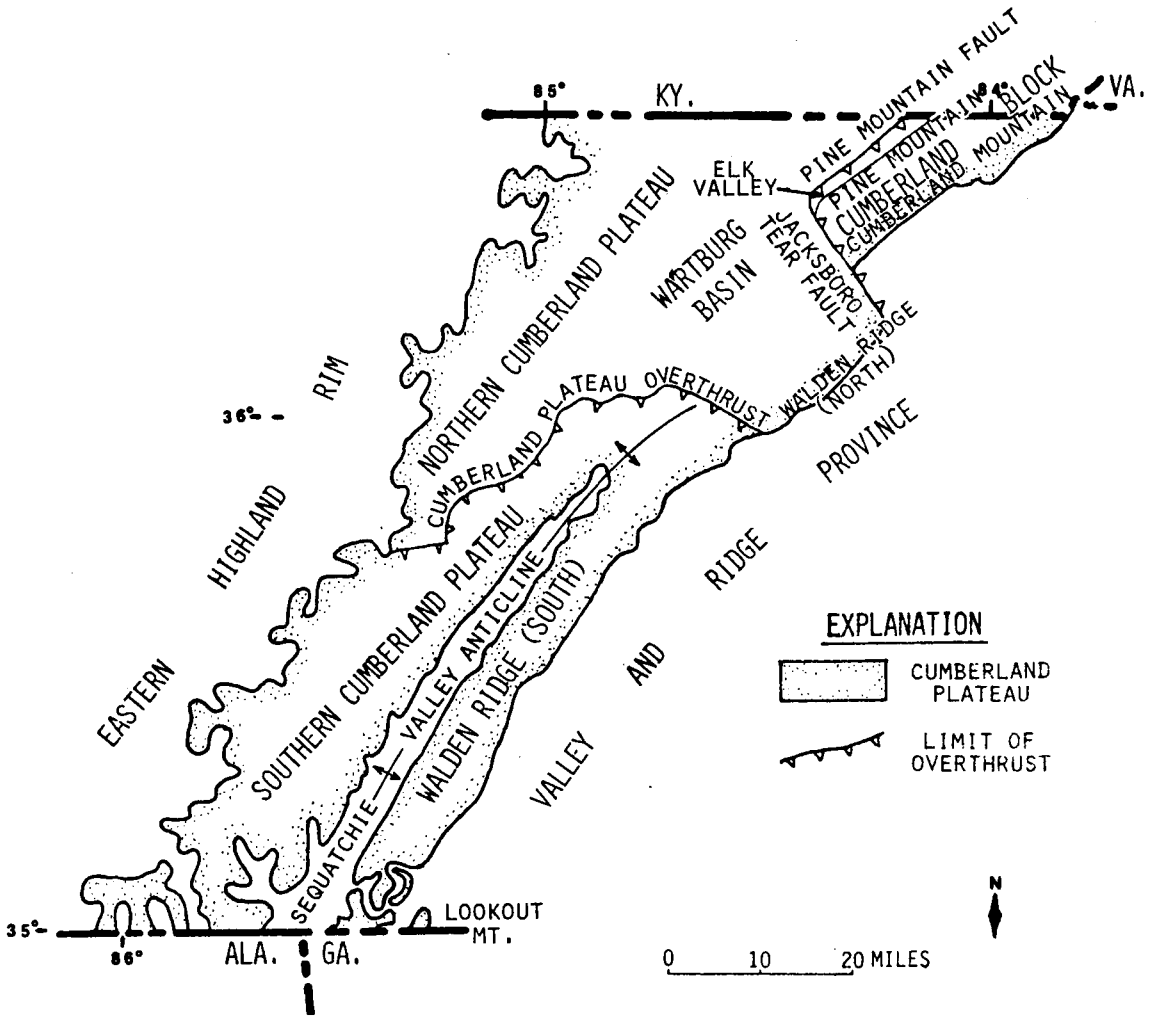


FIGURE 4. GENERALIZED STRUCTURAL FEATURES OF THE CUMBERLAND PLATEAU IN TENNESSEE (from Luther, 1959).

to the east. Throughout most of its length, the axis of the syncline lies closer to the western edge of the Valley and Ridge province except near the southern end where it is nearer the center.

The Northern Cumberland Plateau is structurally quite simple, being dominated by the easterly regional dip of the rocks. This subprovince is bounded on the south by the Cumberland Plateau overthrust, the Wartburg Basin to the east, the edge of the Plateau on the west, and extends into Kentucky on the north.

The Wartburg Basin is a structural low of considerable size. The beds dip gently into the basin from the Nashville dome to the west and the Cumberland overthrust to the south. To the east and northeast the basin is formed by the steeply dipping beds from Walden Ridge (North), the Jacksboro fault, and the Pine Mountain fault. The Wartburg Basin is bounded on the southeast by Walden Ridge (North), on the east by the Jacksboro-Pine Mountain fault system and on the south by the Cumberland overthrust. Westward the basin merges into the Northern Cumberland Plateau subprovince and extends into Kentucky on the north.

The Cumberland Block is a relatively flat-bottomed basin. It is primarily the result of the steep northwestward dip of the rocks along Cumberland Mountain which flatten and reverse in a short distance. The axis of the basin lies closer to Cumberland Mountain than to Pine Mountain. This basin is divided into two basins by a northward-trending anticline. Along the Jacksboro and Pine Mountain faults, the Cumberland Block has been displaced about 16 km to the northwest. The vertical displacement along the Jacksboro fault down-dropped the resistant beds of Lower Pennsylvanian rocks leaving at the surface steeply dipping but

nonresistant younger beds, most of which have been removed by erosion. The Pine Mountain fault, a low angle thrust fault, separates the Cumberland Block from the Northern Cumberland Plateau.

The Cumberland Plateau overthrust is an extensive mass, similar to the Cumberland Block, consisting of a complex system of thrust and crossfaults. This line of faulting marks the northern boundary of the Walden Ridge (South) and Southern Cumberland Plateau subprovinces. It is believed that all of the Cumberland Plateau south of this line has been displaced some distance to the north. Along the northern boundary, the horizontal displacement has been estimated to be as much as five kilometers. Although there is no conclusive evidence, it is believed that the amount of movement decreases to the south.

The control and experimental sites used in this study included streams from all of the previously defined areas of the Cumberland Plateau except the Cumberland Block area. This was due to the lack of sites with suitable periods of stream gaging records in this area.

CHAPTER IV

METHODOLOGY

There are many interrelated variables that affect stream discharge. For practical reasons, it is necessary to reduce these to a manageable and significant number. The variables chosen in this study for use in the regression analyses were based on several factors. First, the channel variables chosen must be significant in defining the discharges that flow through the channel. This requirement was initially satisfied by the work done by other authors and was later statistically tested by the regression structural relationships developed in this study. Second, the variables chosen must be common enough to be found in most natural channels. Third, the variables chosen must be measurable by a technique that can be easily and accurately replicated by personnel desiring discharge information for the ungaged streams on the Cumberland Plateau.

The channel variables chosen for this study to predict stream discharges are the active-channel stream widths measured in the field; the percent silt-clay content, with and without coal, of the active-channel banks as determined by a grain size analysis; and the gradient of the sampled channel reach, obtained from the U. S. Geological Survey or Tennessee Valley Authority 7 1/2 minute topographic maps.

I. ACTIVE-CHANNEL

Definition and Description

There are three geomorphic channel-width reference levels, bankfull, active-channel and depositional-bar, that are generally used to develop

channel-discharge relationships. The active-channel reference level was chosen for this study (Fig. 5).

The active-channel is an in-channel form that has been successfully used as a channel-width reference level in several channel-geometry studies of alluvial streams (Hedman, Kastner, and Hejl, 1974; Hedman and Kastner, 1977; Osterkamp, 1977; Osterkamp and Hedman, 1977). It is defined by Osterkamp and Hedman (1977) as:

> a short-term geomorphic feature subject to change by prevailing discharges. The upper limit is defined by a break in the relatively steep bank slope of the active-channel to a more gently sloping surface beyond the channel edge. The break in slope normally coincides with the lower limit of permanent vegetation so that the two features, individually or in combination, define the active-channel reference level. The section beneath the reference level is that portion of the stream entrenchment in which the channel is actively, if not totally, sculptured by the normal process of water and sediment discharge.

As it is an in-channel form, the active-channel responds to the hydraulic regime of the river and is free to adjust to the changes in the flow regime of the river through time. It represents a balance between the narrowing agents and the general regime of the stream (Hedman and Kastner, 1977). Although the active-channel is altered or destroyed during peak discharges, it tends to narrow and heal at lower discharges (Hedman, Kastner, and Hejl, 1974). This healing process is usually accomplished by the deposition of the silt-clay fraction of the sediment load carried by the stream and the binding together of the coarser, more unstable sand fraction of the bank material. Reduction of the channel width toward equilibrium with the hydraulic regime of the stream occurs much faster in humid regions that have ample vegetation. The vegetation helps to trap, bind, and stabilize the deposited sediment (Hedman and Kastner, 1977).

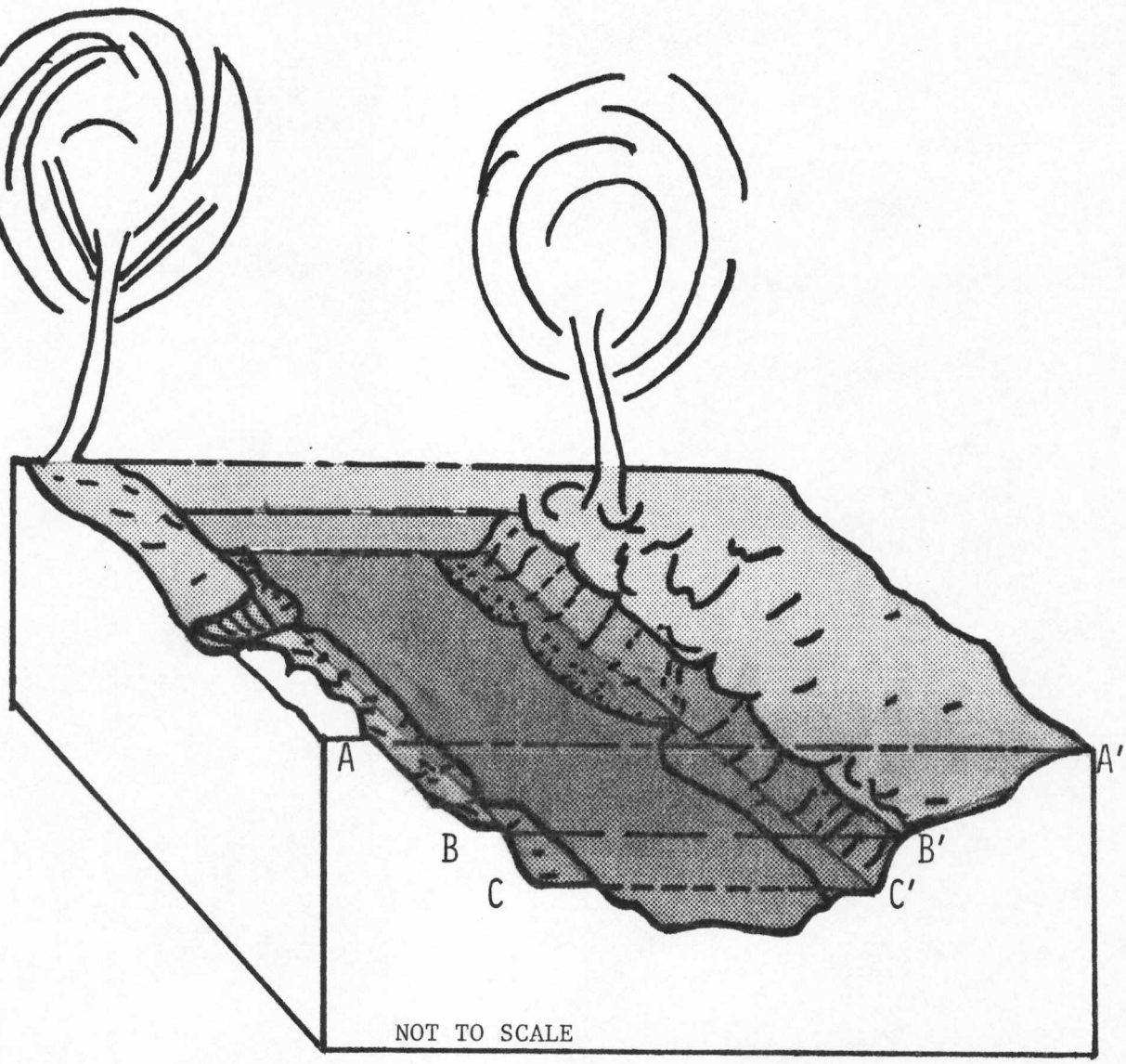


FIGURE 5. COMMONLY USED GEOMORPHIC REFERENCE LEVELS IN ALLUVIAL CHANNELS (After Osterkamp and Hedman, 1979).

Bankfull width. The bankfull width was not used in this study for several reasons.

One of the major problems with working with bankfull measurements is the definition of what exactly constitutes the bankfull stage. This geomorphic channel feature has been defined at least eleven different ways, depending on the type of study undertaken (Williams, 1978). Another problem in using the bankfull width is its susceptibility to modification and alteration from its natural state by human activity. This can be in the form of constructing roads or buildings on the floodplains or the construction of dikes or levees along the channel's banks. For approximately half the channels studied, the bankfull level was ill-defined due to bedrock.

Depositional-bar width. The depositional-bar is an in-channel form often used in studies relating a stream's geometry to its discharge characteristics (Moore, 1968; Hedman, 1970; Hedman and Kastner, 1972; Hedman, Moore, and Livingston, 1972; Hedman, Kastner, and Hejl, 1974; Hedman and Kastner, 1977). Its absence in the bedrock channels on the Cumberland Plateau precluded its use in this study. The use of the depositional-bar would also have conflicted with sediment sampling techniques used in this paper (Osterkamp, 1978b).

Data Collection

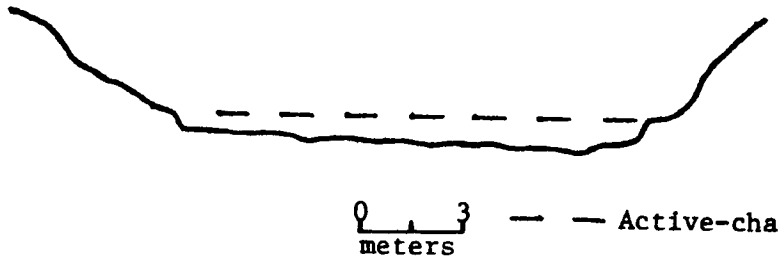
The active-channel measurements were made at sites as close to the gaged reaches of the stream as possible so that the discharge data would be of value. Site selection was biased towards reaches of the stream where the active-channel was adequately defined, where the channel was straight and stable for a distance at least twice its active-channel

width, and where the flow velocities were uniform across the channel width. Reaches of the channel that were protected by bedrock, altered by construction, braided, or widened by recent floods were avoided. If the channel had a pool-riffle sequence, care was taken to sample the reach of the channel either directly upstream or downstream of the riffle (Osterkamp, 1978b). The field techniques used for measuring the active-channel width are those outlined in Hedman, Kastner, and Hejl (1974), Hedman and Kastner (1977), and Osterkamp (1978b). Once a suitable site was chosen, the usual procedure was to tightly stretch a tape or tag line across and perpendicular to the channel, bank to bank, at the active-channel reference level. All active-channel values were converted from feet to meters before entry into the computer. A study by Wahl (1977) showed that replication of active-channel measurements could be made by trained personnel within an average standard error of 27 percent. Multiple field checks of the active-channel measurements used in this study had a standard error closer to 18 percent.

Channel cross-sections showing the active-channel form of four streams were established. These include two bedrock-controlled channels, one cobble channel, and one silt-clay channel. These are found in Figures 6, 7, 8, and 9.

II. BANK SILT-CLAY CONTENT

The relationship between the channel geometry and the percent silt-clay content in the bed and banks of alluvial channels has been long recognized. Osterkamp (1977) showed that by introducing this variable, along with the active-channel width, in a multiple-regression



0 3
meters

— — Active-channel level

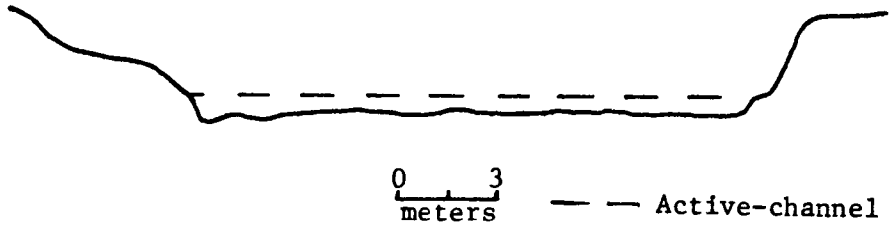
LOCATION OF CROSS-SECTION - Approximately 25 m upstream of old gaging station well.

CHANNEL TYPE AT CROSS-SECTION - Alluvial silt-clay bed and banks. Percent silt-clay in bed ∿ 40, in banks ∿ 90. Percent coal in bed ∿ 22, in banks ∿ 8. Abundant permanent vegetation helping to stabilize and armor banks. Three obvious sets of stream terraces.

ACTIVE-CHANNEL - Defined by break in bank slope and the lower limit of permanent vegetation. Width ∿ 16 m, cross-sectional area ∿ 9.48 m^2.

DEPOSTIONAL-BAR - None at cross-section.

FIGURE 6. CHANNEL CROSS-SECTION OF POPLAR CREEK NEAR OAK RIDGE, TENNESSEE (03538225) SHOWING ACTIVE-CHANNEL.



0 3
meters

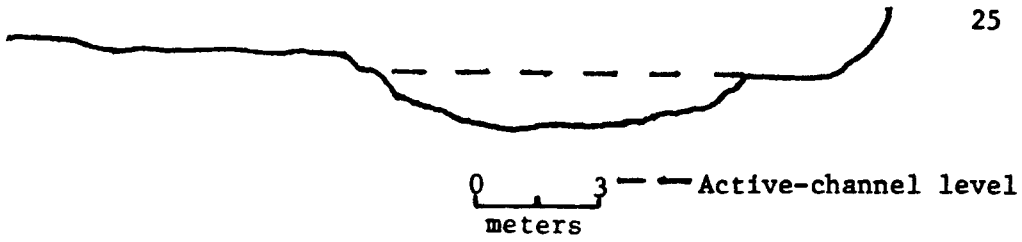
— — Active-channel level

LOCATION OF CROSS-SECTION - Approximately 120 m downstream of US 70 bridge.

CHANNEL TYPE AT CROSS-SECTION - Bedrock channel and alluvial banks, Percent silt-clay in banks ∿ 50, percent coal in banks ∿ 2. Bedrock - essentially horizontal in place - some large, broken salbs scattered in channel. Primarily sandstone. Abundant vegetation to help stabilize and armor banks.

ACTIVE-CHANNEL - Defined by break in bank slope of right bank and the lower limit of permanent vegetation on both banks. Width ∿ 16 m, cross-sectional area ∿ 5.32 m^2.

FIGURE 7. CHANNEL-CROSS SECTION OF DADDYS CREEK NEAR CRAB ORCHARD, TENNESSEE (03539500) SHOWING ACTIVE-CHANNEL.

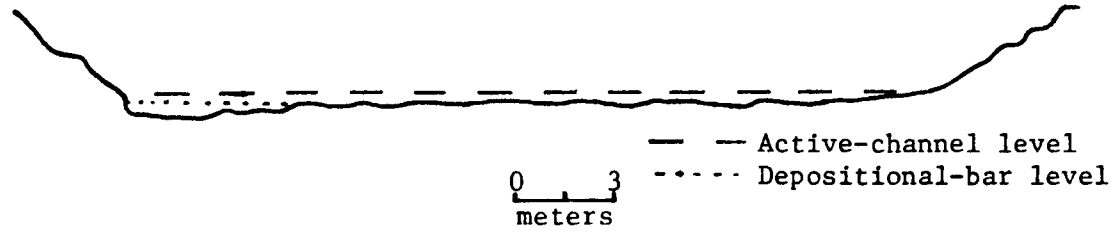


LOCATION OF CROSS-SECTION - Approximately 450 m downstream of crest-stage gage.

CHANNEL TYPE AT CROSS-SECTION - Bedrock channel and alluvial banks. Percent silt-clay in banks ∿ 50. Percent coal in banks ∿ 2. Bedrock - essentially horizontal in place - scattering of broken bedrock on top of bed. Primarily sandstone. Abundant vegetation stabilizing and armoring right bank. Vegetation on left bank is not as dense. No obvious stream terraces at cross-section.

ACTIVE-CHANNEL - Defined by a break in bank slope and the lower limit of vegetation on the right bank. Width ∿ 7.93 m, cross-sectional area ∿ 3.11 m^2.

FIGURE 8. CHANNEL CROSS-SECTION OF BITTER CREEK NEAR CAMP AUSTIN, TENNESSEE (03541100) SHOWING ACTIVE-CHANNEL.



LOCATION OF CROSS-SECTION - Approximately 80 m upstream of the crest-stage gage on US 27.

CHANNEL TYPE AT CROSS-SECTION - Bed is composed of small boulder, cobble, pebble and sand size sediment. The banks are armored with small cobbles and pebbles, percent silt-clay ∿ 40. Vegetation is not an armoring or stabilizing factor at the cross-section. No obvious stream terraces present.

ACTIVE-CHANNEL - Defined by a break in bank slope on left bank and by the lower limit of permanent vegetation on both banks. Width ∿ 26.5 m, cross-sectional area ∿ 21.4 m^2.

DEPOSITIONAL-BAR - Composed of cobble, pebble, and sand size sediment. May be classified as a planar or massive bar (Miall, 1977).

FIGURE 9. CHANNEL CROSS-SECTION OF PINEY RIVER AT SPRING CITY, TENNESSEE (03542500) SHOWING ACTIVE-CHANNEL.

analysis predicting stream discharge, that the standard error of the estimate for the resulting relationship was significantly lower than the error of the simple-regression relationship using only the active-channel width. However, in this study only the percent silt-clay content for the bank material was used in the regression analysis due to the bedrock nature of many of the streams on the Cumberland Plateau. The larger silt-clay percentage value of the two bank samples was used in the regression analysis. This value is believed to represent the most stable bank conditions because of the cohesive properties of the silt and clay.

The percent silt-clay in the bank samples were preferred to the median particle diameter of the bank samples because two different sediment samples can vary widely in mean size depending on the sorting of the sample and yet have the same median size. Using the percent silt and clay of each sample avoided the use of an absolute grain size value, the importance of which may be masked by the sorting of the sample (Schumm, 1960).

The boundary for the split between the silt-clay fraction of the sample and fine sand was the 0.0625 mm (4 phi or 230 mesh) sieve. Any grain size between 0.05 mm and 0.10 mm could have been used, but it has been found that at the 0.0625 mm size the soil becomes less well drained and that capillarity increases with an increased percentage of material of this size, making the sample more cohesive (Burmister, 1952).

In the field and during the sediment analysis procedure, it was noted in several samples that coal constituted a major (greater than 25 percent) portion of the coarser fraction (larger than 0.125 mm) of

the samples. Noting that there was no outcroping of coal seams in the immediate sampling area, it was reasoned that this material was possibly transported downstream from an area under active or recent surface-mining. A quantitative way to deal with this apparent influence of human activity was to remove the coal from the sample and to recompute the silt-clay percentages. A problem with this procedure was that there was no way to differentiate between the "natural coal" that would have entered the fluvial system by outcrop weathering and that put into the system by mining activity. Regression analyses were done using both silt-clay percentages with and without the coal present. The results of the analyses are in Table 4 (p. 51).

Field Data

Composite bed and bank sediment samples were collected at each site for grain size distribution analysis. No bed samples were collected at sites where the streambed was bedrock, and care was taken to sample sites where rock outcrops did not influence the active-channel. The sampling procedures used in this study are outlined by Osterkamp (1978b). Consistency in sampling techniques with other studies was necessary so there would be a basis for comparison of the regression results.

The weight of the samples averaged between 100 and 150 grams. Because the active-channel is interpreted to represent the channel width of the streams during average discharge (Hedman and Kastner, 1977; Osterkamp and Hedman, 1977), the bed and bank samples collected were expected to reflect the size range of the sediment transported and deposited by the stream during normal or average discharge. Care was

taken not to sample the sediment that may have been left draping the active-channel as the result of a recent receding peak discharge event. In several of the channels armored with cobbles where there was a bimodal distribution of sediment sizes, the finer fraction was collected and analyzed. The presence of the coarser fraction was noted but not quantified. This was done because of the armoring and channel stabilizing effects of the coarser material on the channel during average discharge and because of the problems of collating weight percent analyses with pebble-count analyses.

Laboratory Data

The bed and bank samples were first air or oven dried to remove the water. The dry samples were then disaggregated with a mortar and pestle or a rubber cork. An attempt was made not to crush or destroy any of the fine material nor to break apart any material that may have been cemented together. All samples weighing more than 100 gms were split to a weight between 30 and 100 gms with the use of a sample splitter.

At this stage, samples with a high organic content were treated with hydrogen peroxide (35 weight percent) to remove the organic content. Those samples were then again dried and disaggregated.

Sieving. All samples were sieved using U.S. Bureau of Standards 8" sieves and a Ro-Tap machine for 10 to 15 minutes. Sieve sizes 16 mm (-4ϕ), 8 mm (-3ϕ), 4 mm (-2ϕ), 2 mm (-1ϕ), 1 mm (0ϕ), 0.5 mm (1ϕ), 0.25 mm (2ϕ), 0.125 mm (3ϕ), and 0.0625 mm (4ϕ), and a pan to catch the material finer than 0.0625 mm were used. Each sieve

fraction was weighed to the nearest 0.01 gram on an O'Haus gram-o-matic balance. Each class weight was recorded in a cumulative manner from the coarsest to the finest fraction present in the sample. Cumulative percent fines calculations were determined for each size class and the percent silt-clay (pan fraction) was noted (Guy, 1969; Folk, 1974).

Coal removal. After the initial sieving, those samples with coal present were emptied into a 1000 ml beaker filled with approximately 500 ml of perchlorethylene and the coal and other organics were floated off. The samples were allowed to settle for 15 minutes before the coal, organics, and liquid were removed by the use of a peristaltic suction pump or decanted. It was necessary, for several samples, to repeat this procedure several times in order to remove all of the coal.

Perchlorethylene has a specific gravity of 1.62 which allows the denser silts and clays (S. G. ≃ 2.0) to settle while allowing the lighter coal and other organics (S. G. ≃ 1.30) to float. The density of the perchlorethylene can be reduced by a small amount of isopropyl alcohol. Although the perchlorethylene is relatively safe and non-toxic, all of the work with it was done under an exhaust hood while wearing light-weight rubber gloves.

The specific gravity of the coal was found by weighing, on a Jolly-balance, the coal in air (9.02 gms) and in water (2.20 gms). The difference of these two values (6.82 gms), gives the volume of the sample. The density of the coal is then calculated by dividing

its weight in air by the volume of the sample (S. G. ≈ 1.30):

$$\frac{W_{air}}{W_{air} - W_{water}} = \text{Specific Gravity}$$

To check the spceific gravity values, several coal samples were analyzed all with similar results.

Once the coal was removed, the samples were again dried, disaggregated and sieved. Note was taken of the net total weight prior to and after the coal was removed from the sample. The percent change in weight was attributed to the percent loss in coal removed.

Experimental control. Five samples without coal were run twice to note the percent loss due to experimental procedures. One sample showed no loss of material whatsoever and the other four samples showed a loss of material averaging about 2.0 gm/100 gms of sample. At least a part of this loss can be attributed to the loss of organic material and not to laboratory techniques.

Problems. With any experimental procedure there is inherent error. First, there is the possibility of losing the fine material during sieving, weighing, and coal removal processes, although this is thought to be minimal.

Second, is a problem with aggregated fines in the samples. They were only a problem in sieve sizes of 0.25 mm or less. If they were present, their percentages were estimated by a combination of visual, microscopic, and mechanical observations. This additional estimated quantity was added to the already calculated silt-clay percentages determined for that sample. There is also error when estimating

values, but these values were checked for accuracy by using the five control samples. The accuracy of replication in estimating the silt-clay percentage for the control group was between one and four percent.

A third problem is with the coal removal process. First, there is the possibility of loss of fines, but more importantly, there is a possibility that some of the coal, especially the lower grade coal, will have a density greater than the 1.62 of the perchlorethylene and will not float out. Thus, some of the heavier coal may have remained in the sample.

III. GRADIENT

The relationship between channel gradient and discharge is fundamental. Gradient has been shown to be a significant variable in predicting discharge (Osterkamp, 1978a) and in improving upon channel-geometry-discharge relationships in alluvial channels.

Channel gradient, the change in elevation of the channel over a given distance, was used as an independent variable in several of the regression analyses. The gradient value used was that for a reach of the channel at the sampling site and not for the entire length of the stream.

Topographic Maps

The gradient values were computed from U. S. Geological Survey or Tennessee Valley Authority 7 1/2 minute topographic maps, with an average standard error of 20 percent (Osterkamp, 1978a). The usual procedure was to bracket the reach of the sampled section with at least a 6.1 meter (20 ft) contour interval. The distance along the stream

between the two contour lines determined the length of the channel measured. The lengths of the channels, as measured by an opisometer, ranged from 0.92 km to 28 km. The longer distance usually represented the larger, low gradient streams, and the shorter distances were usually for the smaller, higher gradient streams. The contour interval generally used was 6.1 meters, however for several of the high gradient channels a contour interval up to 24.4 meters (80 ft) was used. Because a topographic map averages out local irregularities in the channel gradient less than the contour interval, the gradient value obtained may not represent the actual slope of the channel at the site, though it is an indicator of the discharge forming slope. Map gradients may not be as valid for channels where the gradient is high and the contour lines are close together or where the gradient is very low and stream and contour crossings are far apart (Betson, 1979).

Field Data

In order to determine how much the field gradient of the channel at the sampled site varies from the value obtained from the topographic map, field gradients at six experimental stations were measured. These six sites were chosen as representing the different channel and gradient conditions found in the study area. Figure 10 shows a longitudinal profile of approximately a 10 km reach for each channel including the sampled site. These profiles were obtained from topographic maps.

The measurement of the actual channel gradient value would be virtually meaningless due to the irregularities found in most streambeds. The measurement of the active-channel gradient was also not possible in this study because of the dense vegetation along the

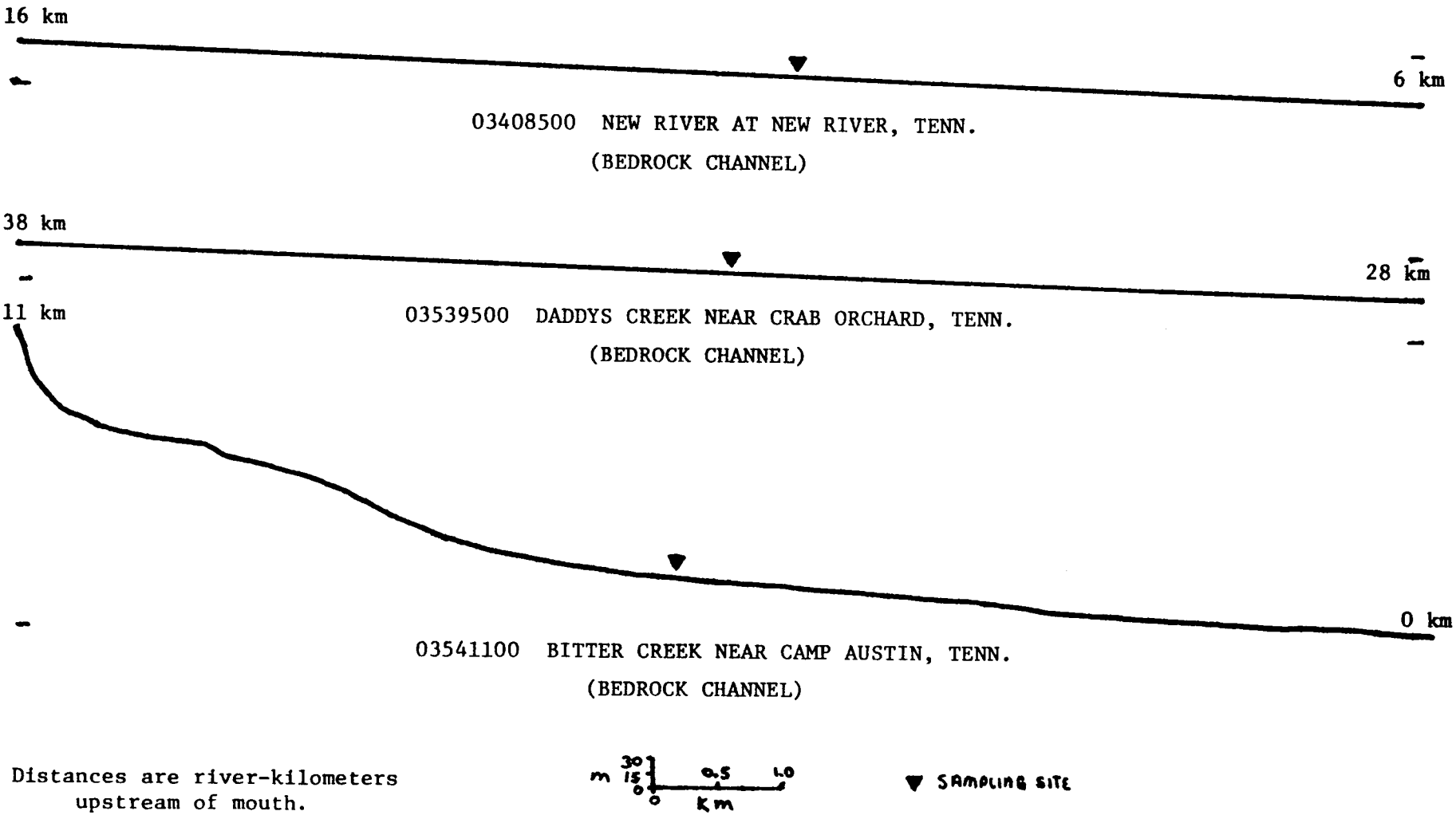


FIGURE 10. LONGITUDINAL CHANNEL PROFILES.

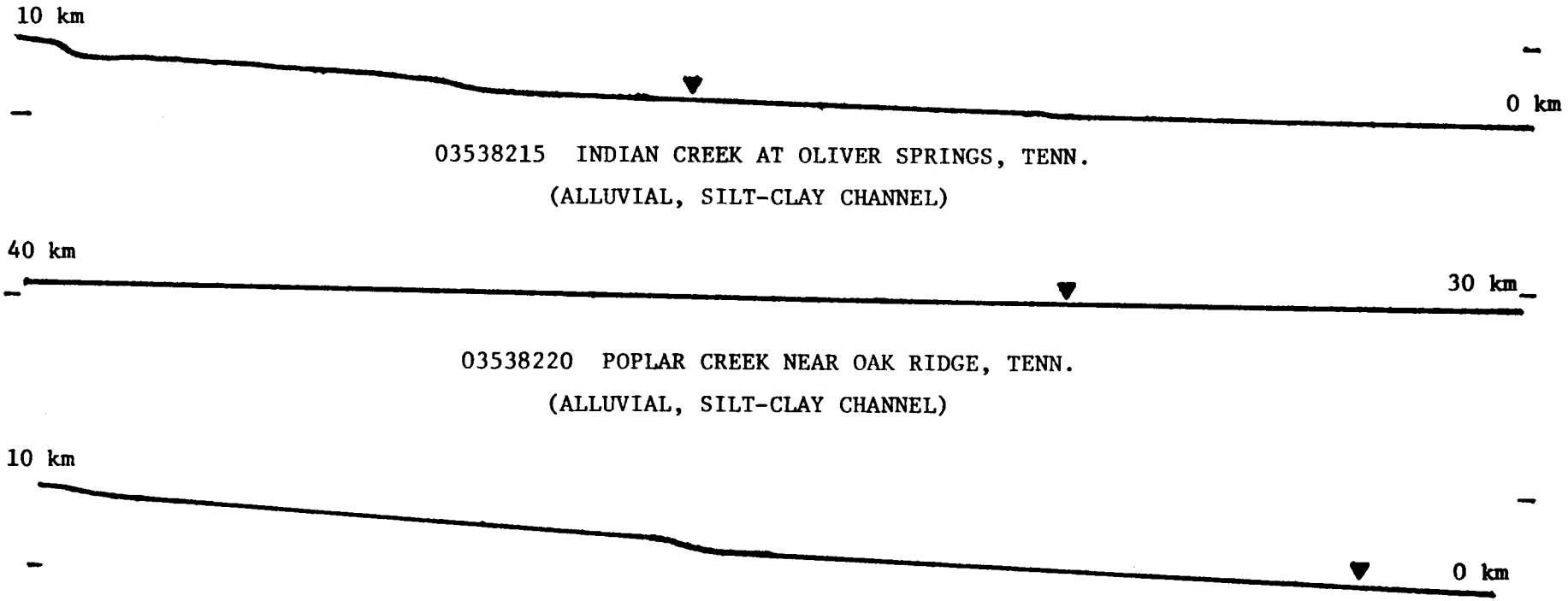


FIGURE 10 (CONTINUED)

banks, however, it may be a viable parameter in more arid climates. To help eliminate these problems, the hydraulic gradient at a low-flow discharge was measured. A low-flow hydraulic gradient was chosen due to the impracticability of obtaining peak discharge hydraulic gradients.

The low-flow hydraulic gradient values were obtained by the use of a Zeiss level and rod. Level readings were taken both upstream and downstream of the sampled site to get changes in elevation of the water surface as well as the distance. The length of the channel reach measured depended on the width of the active-channel. These distances ranged from 7 to 14, but averaged 10 times the active-channel width. The changes in elevation and distances were then converted into the gradient value for the stream at that site. The errors associated with such measurements vary greatly depending on the channel and hydrologic conditions under which the measurements are made as well as operator and instrument error. A reasonable average standard error for these types of measurements is about 20 percent.

Problems. There are problems in using the gradient values measured in the field. Aside from the errors involved in field measurements, there are other considerations. First, is a meaningful gradient value based on such a small reach of the channel actually representing the discharge forming gradient value of the channel at the sampled site? This problem was demonstrated at the Bitter Creek near Camp Austin site. Three successive gradient values were measured within a channel length of 174 m, a distance equal to 22 active-channel widths. The three measured sections represent channel lengths equal to seven, seven, and eight active-channel widths. The downstream

gradient values varied from 0.0015, to 0.0092, to 0.014, and averaged 0.0082. These local changes in gradient values did not correspond with any significant change in the active-channel width outside the standard error for the measurement of the active-channel. This may indicate a poorly defined relationship between the active-channel width and the hydraulic gradient of the stream, or it may indicate that the active-channel width is more closely related to a "regional" gradient value rather than a "local" gradient value. Measurement of such a relatively long channel reach was possible on a stream of this size but would be impracticable for a larger stream.

Second, is the problem in replication of the data gathering technique. If personnel are to use the regression equations developed in this study, they must be able to replicate the procedures used in establishing the regression relationships. With changes in hydraulic gradient during increasing or decreasing discharges, it is necessary to measure the hydraulic gradient under similar hydrologic conditions as measured in establishing the regression relationships. This would be particularly true when using a peak discharge hydraulic gradient. Although possible, this would be difficult to do because these equations are for use on ungaged streams for which these hydrologic conditions are unknown.

A third problem arises in attempting to establish meaningful relationships in studies of this type by combining channel-geometry data and hydraulic-geometry data. This must be attempted with extreme caution.

Comparisons. Table 2 is a comparison of the two gradient values obtained for the sampled reach of the six streams. In all cases the map value differs from the field value. This is particulary true for Poplar Creek near Oak Ridge (03538225), which is a low gradient stream. However, four other sites show that similar gradient values may be obtained with the standard error of estimate for each method (about 20 percent).

Although the gradient value taken from topographic maps may not represent the actual channel gradient at the site, it is representative of that value. Exceptions to this are the high and low gradient channels. In these cases, field measurements may be necessary to refine the gradient value obtained from the topographic map.

IV. DISCHARGE DATA

The dependent variables used in this study were the mean annual and the 2, 5, 10, 25, 50, and 100 year peak discharges. These data for the majority of the 41 control sites were obtained from the U. S. Geological Survey's Streamflow/Basin Characteristics File (USGS program J-763). For all stations, latitude, longitude, and drainage area were also obtained from this file. For several stations the mean annual discharge was obtained from various Water Resources Data Annual Reports published by the U. S. Geological Survey. The mean annual discharge data needed for the remaining 18 stations were estimated using Figure 11. Figure 11 is based on a study by Hollyday and Hansen (unpublished manuscript) of the streams on the Cumberland

TABLE 2. MAP AND FIELD GRADIENT VALUES.

STATION NUMBER	STATION NAME	CHANNEL TYPE AT CROSS SECTION	MAP GRADIENT	FIELD GRADIENT
03408500	NEW RIVER AT NEW RIVER, TENN.	BEDROCK	0.00058	0.00044
03538215	INDIAN CREEK AT OLIVER SPRINGS, TENN.	ALLUVIAL	0.0019	0.0018
03538225	POPLAR CREEK NEAR OAK RIDGE, TENN.	ALLUVIAL	0.00022	0.000031
03539500	DADDYS CREEK NEAR CRAB ORCHARD, TENN.	BEDROCK	0.0017	0.0016
03541100	BITTER CREEK NEAR CAMP AUSTIN, TENN.	BEDROCK	0.0067	0.0083*
03542500	PINEY RIVER AT SPRING CITY, TENN.	COBBLE	0.0033	0.0014

* average of three values taken in the vicinity of the sampled site.

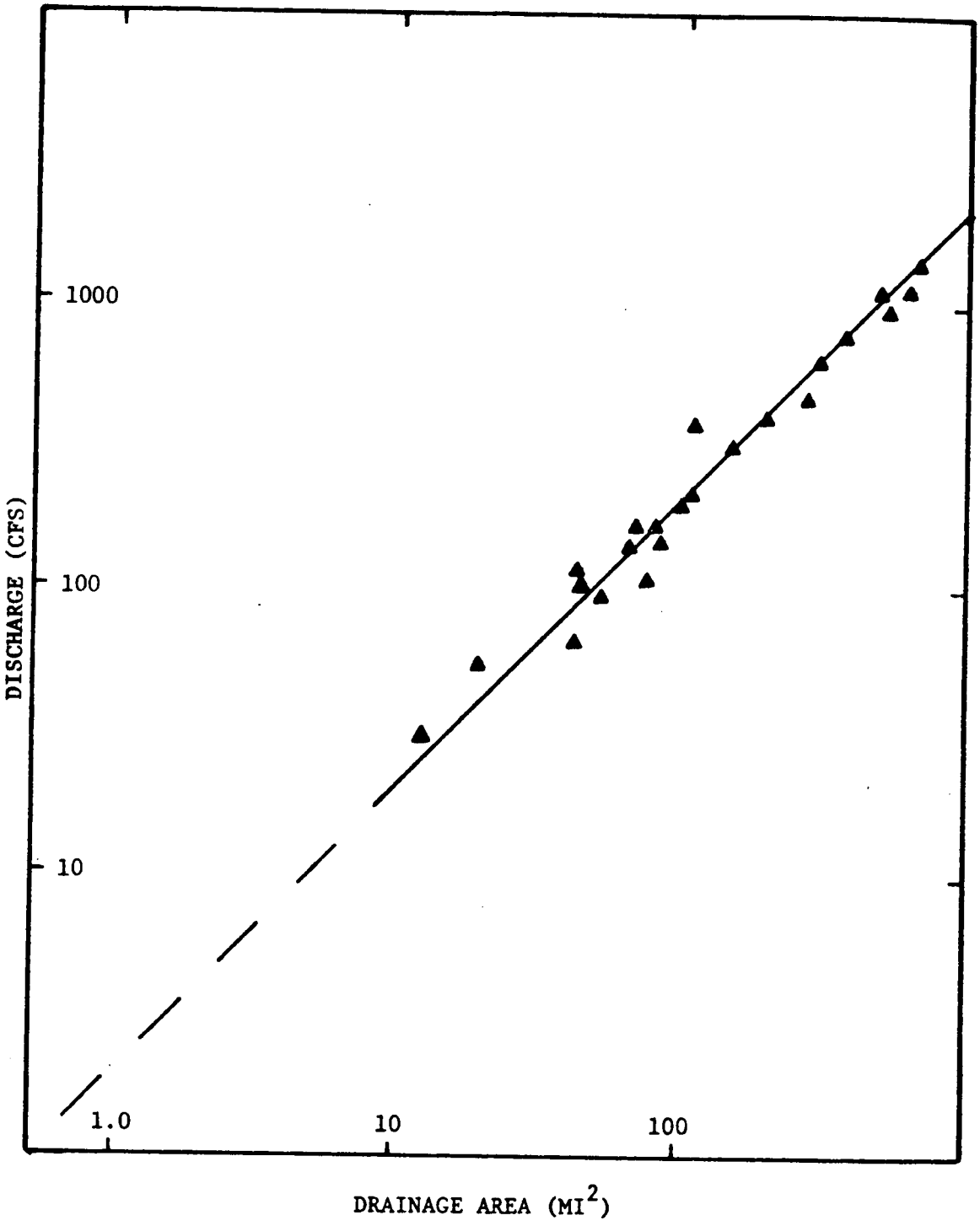


FIGURE 11. FIGURE USED TO ESTIMATE MEAN ANNUAL DISCHARGE VALUES FOR 18 CONTROL SITES.

Plateau which showed that the mean annual discharge and drainage basin area statistically correlate quite well (R^2 = 0.98). The data points are from the 23 control sites used in the present study for which the drainage area and mean annual discharge data were available. Peak discharge data not on file for two stations were obtained from May, Wood, and Rima (1970). Discharge data synthesized by Wibben (1976) were used for the five stations with less than 10 years of record. All discharge data were converted from cubic feet/second (ft^3/sec) to cubic meters/second (m^3/sec) before analysis.

A study by Jordan and Hedman (1970) estimated the standard errors associated with the streamflow data in Kansas. Table 3 shows the mean error values associated with stream flow data with 20 years of record.

TABLE 3. STANDARD ERRORS ASSOCIATED WITH STREAMFLOW DATA IN KANSAS.

EVENT	ERROR (LOG UNITS)	ERROR (PERCENT)
MEAN ANNUAL DISCHARGE, QA	0.10 to 0.12	23 to 27
2-YEAR FLOOD, Q2	0.15	35
5-YEAR FLOOD, Q5	0.15	35
10-YEAR FLOOD, Q10	0.16	38
25-YEAR FLOOD, Q25	0.16	38
50-YEAR FLOOD, Q50	0.17	40
100-YEAR FLOOD, Q100	0.20	48

The study showed a decrease in error values associated with longer periods of gaging record and an increase in error values associated with shorter periods of gaging records. Although these error values were derived from streams in Kansas, they give an approximation of the errors associated with the various discharge data used in this study.

V. OTHER VARIABLES

Other variables considered but not used in the regression analysis include the basin's drainage area, channel depth and cross-sectional area, and channel roughness.

Drainage Area

Drainage area was not used an an independent variable in the regression analyses primarily because of its use in defining several of the mean annual discharge (dependent variable) values (Fig. 11). A computer plot (Blair et al., 1979) of the logarithmic values for the active-channel width and drainage area of all 41 control stations, showed an approximately log-linear relationship indicating a positive correlation between the two variables (Fig. 12). Therefore little would be achieved if these variables were included in a regression analysis, as independent variables, defining discharge. A study by Brown (1971), using the bankfull width, found that channel capacity is superior to drainage area as an indicator of peak discharges with 5, 10, and 15 year recurrence intervals at 18 sites in Kentucky, Tennessee, and southern Minnesota.

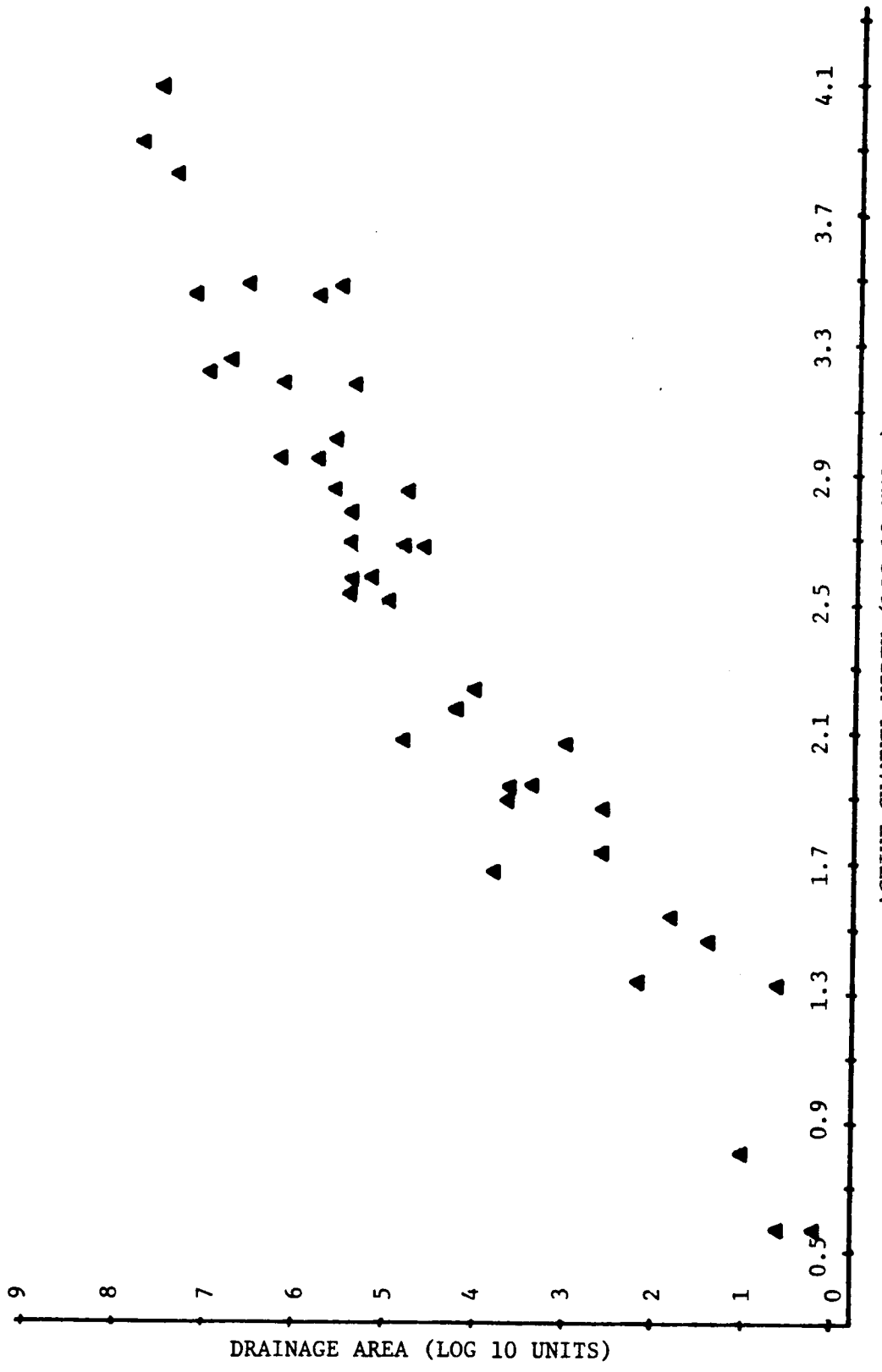


FIGURE 12. PROC PLOT OF THE ACTIVE-CHANNEL WIDTH AND DRAINAGE AREA.

Channel Depth and Cross-Sectional Area

A study by Wahl (1977) showed that trained personnel were able to measure channel widths more consistently than mean channel depth. Because channel width is generally measured more accurately than the mean channel depth, it is the preferred parameter. However, depth measurements were routinely made when the active-channel was measured. These measurements were usually made at ten to twenty equidistant points across the channel, and a cross-sectional area was computed. The cross-sectional area of the channel was not used in any of the regression analyses because of its direct relationship to the mean channel depth and because for larger streams and rivers it is a difficult parameter to measure without the use of a boat. The mean channel depth and cross-sectional area values can be found in Tables A-2 (p. 86) and B-2 (p. 104).

Channel Roughness

A channel roughness value was not used in the regression analyses for several reasons. This channel parameter proved to be impracticable for use in this study because the value changes with an increase in discharge as the stream flows out of its banks and onto its flood-plain. This value is also dependent upon such factors as land-use (forested or pasture land) and the season of the flooding event, making an absolute value difficult to obtain. A study of the streams on the Cumberland Plateau (Betson, 1979) pointed out that channel roughness values may be reasonably averaged out for any given physiographic province.

Other Characteristics

Other basin and channel characteristics, in particular vegetation type and percent coverage along the channel and in the drainage basin, land use in the basin, and precipitation are recognized as affecting channel-discharge relationships. Although inherited channel characteristics, such as stream terraces, may affect the overall channel morphology, the effects on the active-channel are unknown. Data gathering of these variables was not done because of the difficulty of quantifying them and the difficulty of gathering this type of information quickly and easily for later use in the regression equations.

CHAPTER V

REGRESSION AND STRUCTURAL ANALYSES

I. REGRESSION AND STRUCTURAL MODEL

The relationship between stream discharge and the hydraulic cross-section characteristics is usually represented by the following equation:

$$Q = W' D V$$

where Q is the discharge, W' is the width of the water surface, D is the mean water depth and V is the water velocity. Because these parameters are all linked to the discharge, any changes in W', D, and V with discharge would be at a constant rate allowing the relationship to be expressed by a multiple power-function equation:

$$Q = kW'^{b} D^{f} V^{m}$$

or by three simple power-function equations:

$$Q \sim W'^{b}$$

$$Q \sim D^{f}$$

$$Q \sim V^{m}$$

where k is a coefficient; b, f, and m are exponents (Osterkamp and Hedman, 1979).

Since in channel-geometry studies, the discharge estimates are usually calculated from widths measured at geomorphic reference points and not at the variable water surface, the results are assumed to be comparable and can be expressed by a simple power-function equation:

$$Q = aW^{b} \qquad (1)$$

where Q is the average or peak discharge of the stream and W is the

channel width at some geomorphic reference level (Osterkamp and Hedman, 1979).

Published exponents for width vary depending on the discharge estimated, but for mean annual discharge it generally ranges from 1.8 to 2.0. Imposing Osterkamp's (1977) proposed standard exponent of 1.98 upon the W variable when estimating mean annual discharge forces the coefficient "a" to compensate for all other variables affecting discharge. Osterkamp and Hedman (1979) proposed the use of the following exponents for estimating peak discharges with recurrence intervals of 2, 5, 10, 25, 50, and 100 years:

$$Q_2 = aW^{1.72}$$
$$Q_5 = aW^{1.61}$$
$$Q_{10} = aW^{1.53}$$
$$Q_{25} = aW^{1.44}$$
$$Q_{50} = aW^{1.37}$$
$$Q_{100} = aW^{1.32}$$

Equation (1) is the simpliest form by which channel-geometry relationships are expressed. Modification of this basic equation is made by introducing gradient, percent silt-clay content with coal and the percent silt-clay content without coal as additional independent variables. Introduction of these additional variables is to improve the results of the regression analyses by reducing the standard error of estimate for the different regression equations. This also refines the exponents and allows the coefficient "a" to compensate for all the other variables affecting discharge other than the independent

variables used in the regression analyses. The parameters of gradient (G), percent silt-clay with coal (SCC), silt-clay without coal (SC), modify equation (1) to:

$$Q = aW^b G^x \qquad (2)$$

$$Q = aW^b SCC^y \qquad (3)$$

$$Q = aW^b SC^z \qquad (4)$$

Equations (1), (2), (3), and (4) are such that Q is the dependent variable representing QA, Q2, Q5, Q10, Q25, Q50, and Q100. W, G, SCC, and SC are independent variables representing active-channel widths, gradient, and the percent silt-clay with and without coal present in the bank samples, respectively; "a" is the coefficient, and b and x, y, and z are exponents. All discharge and width values are metric, the gradient value is dimensionless, and the silt-clay percentage is a whole number between 0 and 100.

Prior to both the regression analyses, all values in equations (1), (2), (3), and (4) were transformed into their logarithmic (base 10) values:

$$\log Q = \log a + b \log W$$

$$\log Q = \log a + b \log W + x \log G$$

$$\log Q = \log a + b \log W + y \log SCC$$

$$\log Q = \log a + b \log W + z \log SC$$

This was done because the transformed values allow a linear relation to be approached when the variables are related to each other. This linear relationship was demonstrated by the use of the SAS PROC PLOT (Blair et al., 1974) procedure, which plotted the nontransformed and log-transformed values of the different discharge values against the nontransformed and log-transformed values for the active-channel widths. The plots of the

nontransformed values showed no linear trend or a very poorly defined one, while the corresponding transformed variable plot showed a good linear trend for all the different values of discharge and active-channel width. Figures 13 and 14 are plots of the untransformed and the log-transformed values of the 5-year discharge and the active-channel width. These are representative of the other PROC PLOT graphs.

II. REGRESSION ANALYSES

All computer analyses were done on an IBM 360 computer. The regression procedures used to analyze the data gathered in this study were the General Linear Models (GLM) and Systems Regressions (SYSREG) from the Statistical Analysis Systems (SAS) programs (Blair et al., 1979).

The GLM and SYSREG regression procedures handle both simple- and multiple-regression analyses. In regression analysis, the values of the dependent variables (QA, Q2, . . . Q100) are described or predicted in terms of the independent variables (active-channel width, gradient, silt-clay contents). By use of a least squares fit, this analysis defines a line between the different discharges and the channel characteristics. Several assumptions are necessary in order to use the statistical technique. First, the independent variables included in the analysis are significant, second, a straight line defines the relationship between the dependent and independent variables, and third, that the residuals, the difference between the observed and calculated value of the dependent variable, are normally and independently distributed with a mean value of zero and a constant variance (Hollyday and Hansen, unpublished manuscript).

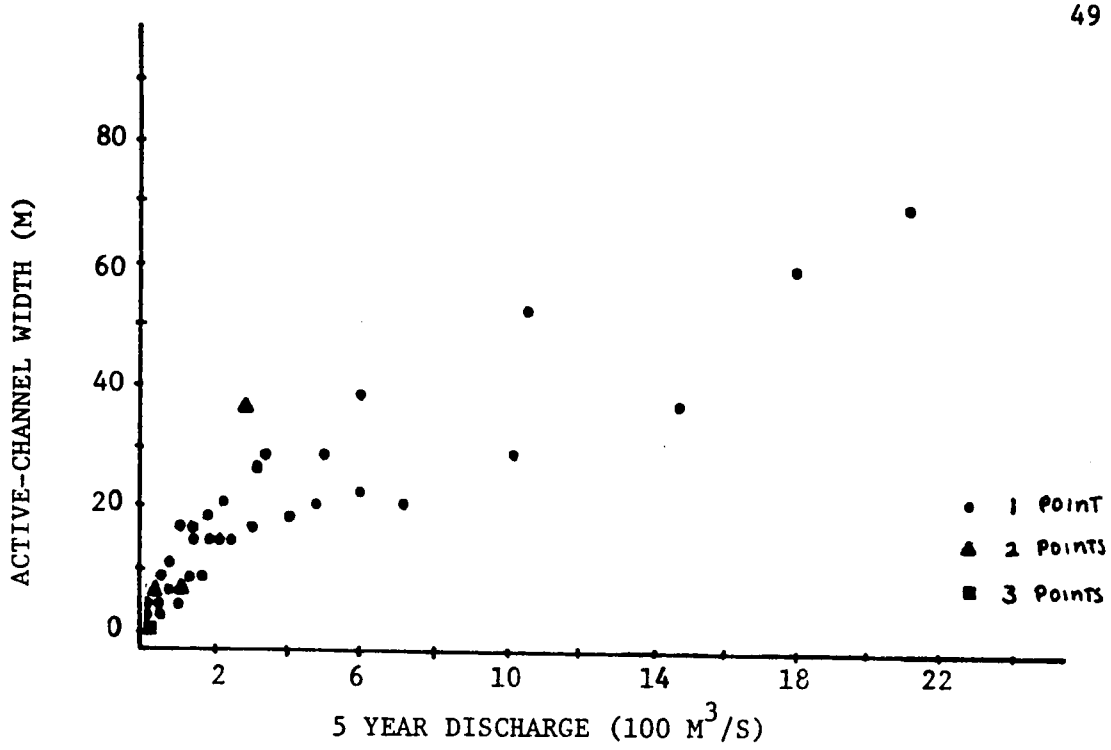


FIGURE 13. PROC PLOT OF UNTRANSFORMED Q5 AND ACTIVE-CHANNEL WIDTH VALUES.

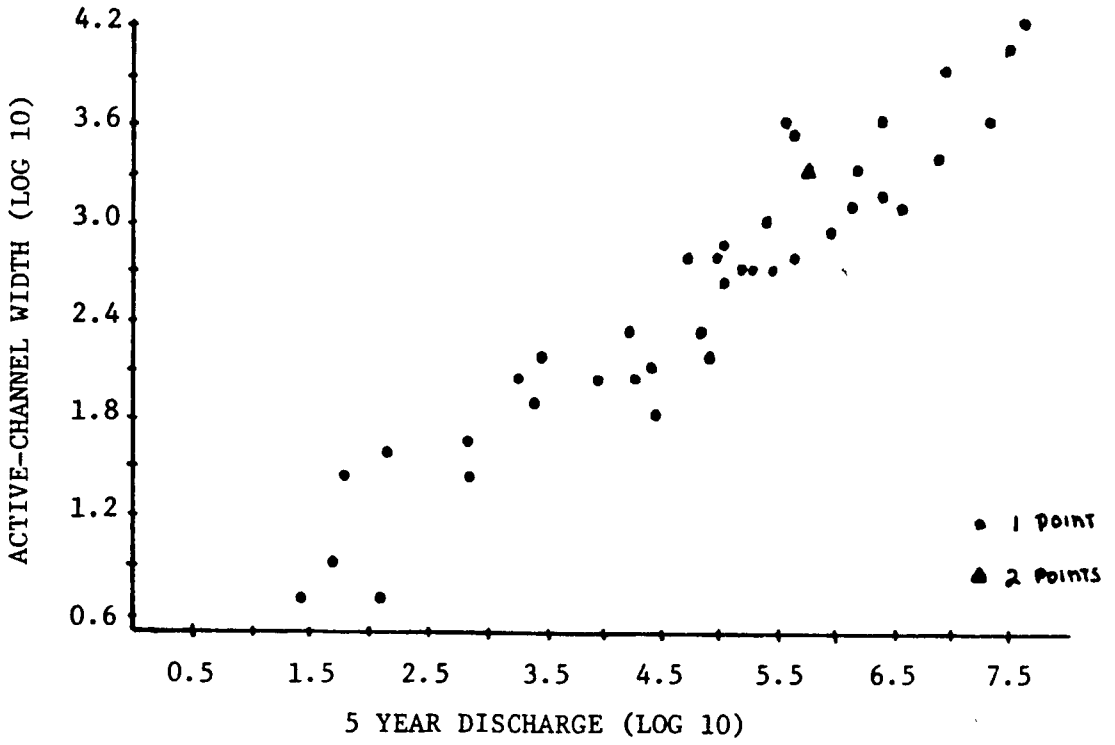


FIGURE 14. PROC PLOT OF LOG-TRANSFORMED Q5 AND ACTIVE-CHANNEL WIDTH VALUES.

GLM

The GLM regression procedure allows the computer to choose, within the limits of the input data, the coefficients and exponents for the independent variables that best predict the different values of the dependent variables. This procedure does not choose the best fit model as a stepwise-regression analysis would do, but merely provides a regression analysis for the variables provided, regardless of their significance in refining the proposed model.

SYSREG

The SYSREG procedure allows the use of certain restrictions upon the independent variables. In this study, Osterkamp and Hedman's (1979) exponents were imposed on the width variable for the different values of discharge. As with the GLM procedure, the regression is done on all the variables provided, no matter how significant they are.

Output

The results of the GLM and SYSREG procedures run on the log-transformed equations are tabulated in Table 4, where SE is the standard error of estimate for each regression equation.

Both the GLM and SYSREG computer outputs include the logarithmic form of the y-intercept and exponent values for the independent variables. The output also includes R-square, mean square, and standard error of the estimated values. The GLM printout provided F-values for the model and individual independent variables. These are statistical parameters which are used for determining the accuracy and significance of the variables and equations. These values are defined and can be found in Appendix C (p. 109).

TABLE 4. REGRESSION EQUATIONS.

DEPENDENT VARIABLES	INDEPENDENT VARIABLE(S) GLM ANALYSES	SYSREG ANALYSES
DISCHARGE	ACTIVE-CHANNEL WIDTH (W)	ACTIVE-CHANNEL WIDTH (W)
QA	$0.102\ W^{2.22}$ (SE = +92, -45, avg 64)	$0.134\ W^{1.98}$ (SE = +90, -48, avg 69)
Q2	$0.860\ W^{1.79}$ (SE = +78, -44, avg 61)	$0.877\ W^{1.77}$ (SE = +78, -44, avg 61)
Q5	$1.04\ W^{1.78}$ (SE = +74, -42, avg 58)	$1.27\ W^{1.61}$ (SE = +74, -42, avg 58)
Q10	$1.16\ W^{1.77}$ (SE = +74, -42, avg 58)	$1.57\ W^{1.51}$ (SE = +78, -44, avg 61)
Q25	$1.29\ W^{1.76}$ (SE = +74, -42, avg 58)	$1.88\ W^{1.44}$ (SE = +82, -45, avg 64)
Q50	$1.39\ W^{1.76}$ (SE = +74, -42, avg 58)	$2.18\ W^{1.37}$ (SE = +90, -48, avg 69)
Q100	$1.49\ W^{1.75}$ (SE = +74, -42, avg 58)	$2.46\ W^{1.32}$ (SE = +95, -49, avg 72)
DISCHARGE	ACTIVE-CHANNEL WIDTH (W) GRADIENT (G)	ACTIVE-CHANNEL WIDTH (W) GRADIENT (G)
QA	$0.057\ W^{2.06}\ G^{-.29}$ (SE = +74, -42, avg 58)	$0.059\ W^{1.98}\ G^{-.32}$ (SE = +70, -41, avg 55)
Q2	$0.584\ W^{1.76}\ G^{-.16}$ (SE = +74, -42, avg 58)	$0.580\ W^{1.77}\ G^{-.16}$ (SE = +74, -42, avg 58)
Q5	$0.732\ W^{1.75}\ G^{-.14}$ (SE = +70, -41, avg 55)	$0.780\ W^{1.61}\ G^{-.19}$ (SE = +70, -41, avg 55)
Q10	$0.820\ W^{1.75}\ G^{-.14}$ (SE = +70, -41, avg 55)	$0.902\ W^{1.53}\ G^{-.20}$ (SE = +74, -42, avg 58)
Q25	$0.929\ W^{1.74}\ G^{-.14}$ (SE = +70, -41, avg 55)	$1.06\ W^{1.44}\ G^{-.22}$ (SE = +78, -44, avg 61)
Q50	$1.01\ W^{1.73}\ G^{-.13}$ (SE = +70, -41, avg 55)	$1.18\ W^{1.37}\ G^{-.24}$ (SE = +82, -45, avg 64)
Q100	$1.09\ W^{1.72}\ G^{-.13}$ (SE = +74, -42, avg 58)	$1.30\ W^{1.32}\ G^{-.24}$ (SE = +86, -46, avg 66)

TABLE 4 (CONTINUED)

DEPENDENT VARIABLES	INDEPENDENT VARIABLE(S) GLM ANALYSES	SYSREG ANALYSES
DISCHARGE	ACTIVE-CHANNEL WIDTH (W) % SILT-CLAY AND COAL (SCC)	ACTIVE-CHANNEL WIDTH (W) % SILT-CLAY AND COAL (SCC)
QA	$0.092\ W^{2.22}\ SCC^{.06}$ (SE = +86, -46, avg 66)	$0.117\ W^{1.98}\ SCC^{.08}$ (SE = +90, -48, avg 69)
Q2	$0.748\ W^{1.78}\ SCC^{.08}$ (SE = +78, -44, avg 61)	$0.758\ W^{1.77}\ SCC^{.08}$ (SE = +78, -44, avg 61)
Q5	$0.885\ W^{1.78}\ SCC^{.10}$ (SE = +74, -42, avg 58)	$1.05\ W^{1.61}\ SCC^{.11}$ (SE = +74, -42, avg 58)
Q10	$1.03\ W^{1.77}\ SCC^{.11}$ (SE = +74, -42, avg 58)	$1.24\ W^{1.53}\ SCC^{.12}$ (SE = +78, -44, avg 61)
Q25	$1.07\ W^{1.76}\ SCC^{.11}$ (SE = +74, -42, avg 58)	$1.48\ W^{1.44}\ SCC^{.14}$ (SE = +82, -45, avg 64)
Q50	$1.14\ W^{1.75}\ SCC^{.12}$ (SE = +74, -42, avg 58)	$1.69\ W^{1.37}\ SCC^{.15}$ (SE = +90, -48, avg 69)
Q100	$1.21\ W^{1.75}\ SCC^{.12}$ (SE = +74, -42, avg 58)	$1.88\ W^{1.32}\ SCC^{.16}$ (SE = +95, -49, avg 72)
DISCHARGE	ACTIVE-CHANNEL WIDTH (W) % SILT-CLAY (SC)	ACTIVE-CHANNEL WIDTH (W) % SILT-CLAY (SC)
QA	$0.098\ W^{2.22}\ SC^{.08}$ (SE = +86, -46, avg 66)	$0.110\ W^{1.98}\ SC^{.12}$ (SE = +90, -48, avg 69)
Q2	$0.738\ W^{1.78}\ SC^{.09}$ (SE = +78, -44, avg 61)	$0.745\ W^{1.77}\ SC^{.09}$ (SE = +78, -44, avg 61)
Q5	$0.880\ W^{1.77}\ SC^{.10}$ (SE = +74, -42, avg 58)	$1.01\ W^{1.61}\ SC^{.13}$ (SE = +74, -42, avg 58)
Q10	$0.996\ W^{1.77}\ SC^{.11}$ (SE = +74, -42, avg 58)	$1.18\ W^{1.53}\ SC^{.15}$ (SE = +78, -44, avg 61)
Q25	$1.07\ W^{1.76}\ SC^{.12}$ (SE = +74, -42, avg 58)	$1.40\ W^{1.44}\ SC^{.17}$ (SE = +82, -45, avg 64)
Q50	$1.14\ W^{1.75}\ SC^{.12}$ (SE = +74, -42, avg 58)	$1.58\ W^{1.37}\ SC^{.19}$ (SE = +90, -48, avg 69)
Q100	$1.22\ W^{1.74}\ SC^{.12}$ (SE = +74, -42, avg 58)	$1.75\ W^{1.32}\ SC^{.20}$ (SE = +95, -49, avg 72)

III. STRUCTURAL ANALYSIS

Simple-regression and structural analysis are similar techniques for developing a linear relation from a bivariant group of data. When error components can be identified for both the independent and dependent variables, the structural analysis method is preferred (Osterkamp, McNellis, and Jordan, 1978).

In geomorphic studies, where many variables can be used as either dependent or independent variables, it is necessary to account for the error caused by both of the variables. In regression analysis, the error for the dependent variable is considered to be insignificant and is ignored leaving the independent variable(s) to compensate for all the error in the equation. If regression analysis data are available, the structural exponent (b_s) for the independent variable can be easily calculated. This conversion from regression to structural analysis is accomplished by the use of the following equation (Mark and Church, 1977):

$$b_s = \frac{(b_r^2 / R^2 - \lambda) + [(b_r^2 / R^2 - \lambda) + 4 \lambda b_r^2]^{1/2}}{2 b_r}$$

where b_r is the regression exponent for the independent variable, R is the correlation coefficient for the regression equation, and λ is a value describing the relative errors between the dependent and independent variables.

$$\lambda = \frac{e_y^2}{e_x^2}$$

such that e_y is the error of the independent variable obtained from the GLM printout. Its value is the standard error of estimate for the

variable in logarithmic form. The e_x value represents the error of the dependent variable, for this study, the different values of discharge. The logarithmic (base 10) error values of e_x used for the different discharges are (Osterkamp, personal communication):

QA = 0.10
Q2 = 0.12
Q5 = 0.12
Q10 = 0.14
Q25 = 0.16
Q50 = 0.16
Q100 = 0.20

The coefficient, a_s, for the structural equation is computed easily by applying b_s and mean values of the logarithms of dependent and independent variables to the equation:

$$\log_{10} a_s = (\log_{10} y)_m - b_s \, (\log_{10} x)_m$$

where $(\log_{10} y)_m$ and $(\log_{10} x)_m$ are the mean logarithmic values of the dependent and independent variables (Osterkamp, McNellis, and Jordan, 1978).

The standard error of estimate for a structural or regression analysis requires the calculation of a dependent variable value for each value of the independent variable used in the regression.

$$SE_s = [\Sigma(\log_{10} y - \log_{10} y_s)^2 \; / \; (n - 2)]^{1/2}$$

such that values of the difference between $\log_{10} y$, an input or observed value of the dependent variable, and $\log_{10} y_s$, the corresponding value of the dependent variable calculated from the structural power-function relation and an individual input value of the independent variable, are squared and summed; n is the number of data pairs used in the analysis. The standard error values for the structural analyses normally exceed those for the regression analyses although the differences may be very small (Osterkamp, McNellis, and Jordan, 1978).

This structural technique has only been developed to refine simple-regression analysis. The structural analysis was applied to the GLM and SYSREG simple-regression equations developed in this study. Table 5 shows the resulting structural equations.

TABLE 5. STRUCTURAL EQUATIONS.

DEPENDENT VARIABLES	INDEPENDENT VARIABLE(S)	
	GLM ANALYSES	SYSREG ANALYSES
DISCHARGE	ACTIVE-CHANNEL WIDTH (W)	ACTIVE-CHANNEL WIDTH (W)
QA	$0.0033\ W^{2.39}$ (SE = +86, -43, avg 66)	$0.104\ W^{2.20}$ (SE = +82, -45, avg 64)
Q2	$0.422\ W^{1.98}$ (SE = +82, -45, avg 64)	$0.672\ W^{2.00}$ (SE = +82, -45, avg 64)
Q5	$0.685\ W^{1.96}$ (SE = +74, -42, avg 58)	$0.841\ W^{1.81}$ (SE = +70, -41, avg 55)
Q10	$0.876\ W^{1.95}$ (SE = +74, -42, avg 58)	$1.22\ W^{1.73}$ (SE = +70, -41, avg 55)
Q25	$1.11\ W^{1.95}$ (SE = +74, -42, avg 58)	$1.44\ W^{1.67}$ (SE = +74, -42, avg 58)
Q50	$1.26\ W^{1.96}$ (SE = +78, -44, avg 61)	$1.65\ W^{1.61}$ (SE = +74, -42, avg 58)
Q100	$1.48\ W^{1.95}$ (SE = +78, -44, avg 61)	$1.81\ W^{1.58}$ (SE = +78, -44, avg 61)

CHAPTER VI

VALIDITY CHECKS AND APPLICATION OF THE REGRESSION AND STRUCTURAL EQUATIONS

To determine the validity of the regression and structural equations developed in this study, several analytical procedures were run.

I. LOG-LOG PLOTS

The regression and structural relations were plotted on 3 x 5 cycle log-log paper. Plots of the simple- and multiple-regression equations using both the GLM and SYSREG techniques as well as the structural equations are found in Appendix D (p. 116). The plots of each simple-regression and structural analysis show the relationship between the dependent variable, discharge, and the independent variable, active-channel width. The graph of each multiple-regression equation shows the relationship between the dependent variable, discharge, and the independent variables; active-channel width, percent silt-clay, and gradient.

Simple-regression and Structural Equations

The plots of the SYSREG simple-regression and structural equations, those using Osterkamp and Hedman's (1979) exponents show crossing regression lines. These crossing lines indicate that anomalous discharge values can be expected when estimating stream discharges using the corresponding regression or structural equations. These SYSREG equations are not valid for estimating stream discharges on the Cumberland Plateau.

The plots of the simple-regression structural GLM equations,

those with exponents derived from this study, show no crossing regression lines, indicating that they may be successfully used to estimate stream discharges on the Cumberland Plateau.

Multiple-regression

In order to graph the multiple-regression equations, certain restrictions on the independent variables had to be established.

Silt-clay. Plots of the multiple-regression equations using the percent silt-clay and active-channel width as independent variables were restricted to a silt-clay content greater than or equal to 50 percent. No corresponding plots for silt-clay values less than 50 percent were made because, in the absence of armoring, these values are interpreted to represent unstable bank conditions. Since the removal of coal from the sediment samples did little to change or improve the regression relations, (Table 4, p. 51) it would serve little purpose to plot both sets of regression equations. Therefore, only the equations using the percent silt-clay and coal were used.

The plots of these SYSREG multiple-regression equations show crossing regression lines indicating that they are useless for estimating stream discharge on the Cumberland Plateau. The plots of the corresponding GLM equations show no crossing regression lines, indicating that they may be successfully used to estimate stream discharges on the Plateau.

Gradient. Plots of the multiple-regression equations using the gradient and the active-channel width as the independent variables are divided into two groups: those with gradient values less than or

equal to the mean gradient value for the 41 control sites (0.0045) and those with gradient values greater than this mean value. Nine control sites had gradient values greater than 0.0045 and 32 sites had gradient values less than or equal to 0.0045.

Again, the plots of the SYSREG multiple-regression equations have crossing regression lines indicating that they are invalid for estimating stream discharges on the Cumberland Plateau. The plots of the GLM equations where the gradient values are greater than 0.0045 have no crossing regression lines indicating that they may be successfully used to estimate stream discharge values. The plot of the GLM equations where the gradient values are less than or equal to 0.0045 show crossing regression lines for the equations used to estimate the floods with 25 and 50 year recurrence intervals. These crossing regression lines indicate that anomalous discharge values could be obtained when using these equations for streams with gradient values less than or equal to 0.0045.

II. FIELD TESTS

To test empirically the proposed regression equations, channel-geometry data were gathered for nine experimental sites in the study area (Fig. 2, p. 10). Flood-frequency curves were developed, by the U. S. Geological Survey's District Office in Nashville, Tennessee, for this study by applying a Pearson Type III (USGS program J 407) distribution to the logarithms of the annual peak discharges, available from the USGS Peak Flow File (USGS program J 980) for these stations. For two stations no peak discharge data were available. In Appendix B (p. 101), the Pearson Type III discharge values are compared to the discharge

values obtained when using the equations proposed by Randolph and Gamble (1976) and the different GLM and structural equations developed in this study.

The discharge values obtained from the data collected from the experimental sites and the GLM and structural equations proposed in this paper confirm the information obtained from the log-log plots for the corresponding equations. This is exemplified by the discharge values obtained when using the GLM multiple-regression equations using the active-channel width and gradient as independent variables.

For the four experimental sites where gradient values were greater than 0.0045, no anomalous discharge values were obtained as predicted by Figure D-4 (p. 121). For the remaining five experimental sites, whose gradient values were less than 0.0045, anomalous values were obtained for the Q25 and Q50 discharges as predicted in Figure D-3 (p. 120). Although no discharge values for the SYSREG equations are found in Appendix B, a check of these equations confirms the information provided by the data plots indicating that anomalous discharge values may result when using the corresponding regression equations. No anomalous values were found using those equations whose data plots indicated that reliable results could be obtained.

III. STATISTICAL EVALUATION

Regression and Structural Models

Statistically, the regression and the structural relationships developed in this study were quite sound. For all equations, R-square values ranged from 0.834 to 0.926, the mean square values from 0.052

log units to 0.085 log units, the standard error of estimate values from 0.228 log units to 0.289 log units, and F-values, for the GLM models, from 146 to 411. F-values for the independent variables on the unrestricted equations (GLM) showed that the active-channel width was the most significant variable used in the models, followed by gradient and silt-clay percentages.

The statistically most accurate model was the multiple-regression relationship using the active-channel and gradient to predict stream discharges. This model had the highest R-square values and the lowest mean square error and standard error of estimate values. Ironically, this was the only GLM model to show crossing regression lines in the log-log plots (Fig. D-3, p. 120). Statistical values for the individual equations can be found in Appendix C (p. 109).

The regression and structural relationships developed in this study are based on statistically sound models. The major problems with the relationships appear when "unnatural" restrictions are imposed upon them, such as Osterkamp and Hedman's (1979) exponents.

Standard Exponents

The SYSREG equations, using Osterkamp and Hedman's exponents, were found to be of little use in estimating stream discharges on the Cumberland Plateau. This problem is further demonstrated by the use of the following equation:

$$b \pm 2S_b = R$$

where b is the exponent on the width variable as obtained from the range of data used in this study (GLM exponents), S_b is the standard error of the b value (from the GLM printout), and R is the probable range of

exponent, b, values that could be successfully imposed upon the width variable given the range of data used in this study. Use of this equation shows that many of Osterkamp and Hedman's (1979) exponents are outside the expected range of acceptable exponent values (Table 6). This is particularly true for those exponents proposed to estimate discharges with 10, 25, 50, and 100 year recurrence intervals.

These results help to explain the crossing regression lines for the simple- and multiple-regression SYSREG equations. Unfortunately, this technique does not explain the presence of the crossing regression lines in the GLM multiple-regression equations using the active-channel and gradient to estimate the 25 and 50 year peak discharges, nor does it explain the crossing regression lines for the structural equations modified from the SYSREG simple-regression equations. All of the exponents in these equations fall within the predicted range of acceptable values.

IV. APPLICATION OF THE REGRESSION AND STRUCTURAL EQUATIONS

The discharge values obtained by using these equations are, at best, estimates of discharge values that might be expected for a particular channel. The use of, and the accuracy of the regression and structural equations presented in this paper is restricted to the limitations of the data and techiques used to derive the equations. The equations' accuracy can best be maintained when working with stream with drainage basins between 1.74 km^2 and 2,371 km^2, gradients greater than 0.0045, active-channel widths between 2.135 m and 70.15 m, bank silt-clay percentages greater than 50 percent, and hydrologic conditions that

TABLE 6. PROBABLE RANGE OF EXPONENTS FOR ACTIVE-CHANNEL WIDTH.

DISCHARGE	PROPOSED EXPONENTS OSTERKAMP & HEDMAN(1979)	$a W^b$			$a W^b G^x$			$a W^b SCC^y$ (or SC^z)		
		b	S_b	R	b	S_b	R	b	S_b	R
QA	1.98	2.22	.110	2.44 2.00	2.06	.112	2.28 1.84	2.22	.111	2.44 2.00
Q2	1.77	1.79	.104	2.00 1.56	1.76	.116	1.99 1.53	1.78	.105	1.99 1.57
Q5	1.61	1.78	.098	1.98 1.58	1.75	.108	1.97 1.53	1.77	.099	1.97 1.57
Q10	1.53	1.77	.097	1.96 1.58	1.75	.108	1.97 1.53	1.77	.098	1.97 1.57
Q25	1.44	1.76	.098	1.96 1.56	1.74	.109	1.96 1.52	1.76	.099	1.96 1.56
Q50	1.37	1.76	.098	1.96 1.56	1.73	.111	1.95 1.51	1.75	.099	1.95 1.55
Q100	1.32	1.75	.099	1.95 1.55	1.72	.112	1.94 1.50	1.74	.100	1.94 1.54

fall within the range of discharges for each recurrence interval. Most of the ungaged streams on the Cumberland Plateau fall within these limitations. The best results can also be expected when utilizing the same data gathering techniques used in defining these regression and structural relationships.

CHAPTER VII

INTERPRETATIONS AND CONCLUSIONS

I. REGRESSION AND STRUCTURAL RELATIONSHIPS

Regression and Structural Equations

The regression and structural relationships developed in this study show several trends. First, the validity checks of the regression and structural equations indicate that those equations using Osterkamp and Hedman's (1979) exponents are invalid for estimating stream discharges on the Cumberland Plateau. This suggests that a log-linear relationship between the active-channel width and discharge may not exist over a wide range of geologic, hydrologic and channel conditions. Second, The GLM simple-regression and structural equations show that a log-linear relationship does exist between the discharges and the active-channel widths of the streams in the study area. This indicates that a log-linear relationship between the active-channel width and discharge may be maintained by using a limited range of geologic, hydrologic, and channel conditions. Third, the GLM multiple-regression equations show that the simple-regression relationships may be further enhanced by the introduction of additional independent variables. The exception to this was the relationship using the active-channel width and gradient values less than or equal to 0.0045. Although gradient was statistically more significant than silt-clay percentages in the regression equations (Appendix C, p. 109), the percent silt-clay may be a more reliable parameter than gradient for refining the simple regression relationships due to the inconsistencies

found when using the multiple-regression equations with gradient (p. 57).

Standard Exponents

The use of standard exponents (Osterkamp and Hedman, 1979) for estimating various discharges is not supported by this study.

Osterkamp and Hedman's exponents were developed from and represent a wide range of geologic, hydrologic and channel conditions that do not adequately describe the range of geologic, hydrologic and channel conditions found in the study area. These exponents represent such a wide range of data that the width-discharge relationship is probably more curvilinear than log-linear. However, the log-linear relationship between width and discharge may be maintained by restricting the range of hydrologic, geologic, and channel conditions such as in this study.

The limited data collected for this study is not sufficient to discredit the use of Osterkamp and Hedman's exponents entirely, but the data do show that care must be used when applying them.

Validity Tests

These tests, besides showing the problems involved in using Osterkamp and Hedman's exponents, demonstrate the problems with using regression analysis to describe geomorphic relationships. These relationships may be more precisely described by using structural analysis but unfortunately this technique has been only developed for modification of the simple-regression relationships.

The log-log plots of the SYSREG equations using Osterkamp and Hedman's exponents, showed without exception crossing regression lines, indicating that they are invalid for estimating stream discharges on the Cumberland Plateau. With one exception, the log-log

plots of the GLM equations indicate that they may be successfully used to estimate discharge values for the streams on the Cumberland Plateau. The exception is the multiple-regression relationship using the active-channel width and gradient values less than or equal to 0.0045.

The crossing regression lines in the log-log plots could indicate several problems. First, the data available in this study are insufficient to accurately define a log-linear relationship between the variables. Second, this relationship, if well defined, is a non-linear one. Third, the gradient value for low gradient streams may not be as reliable as first expected or that other channel or hydrologic characteristics such as channel roughness or hydraulic head may describe the discharges of low gradient channels more realistically. Fourth, other unquantified channel or hydrologic variables may be disrupting this relationship.

The field checks substantiated the results of the log-log plots as did the equation used to predict the range of acceptable exponent values that could be imposed upon the width variables.

Standard Error of Estimate

Although the standard error of estimate for the regression and structural equations seem high (Table 4, p. 51), they are similar to the error values obtained in other studies of this type (Osterkamp, 1977; Osterkamp and Hedman, 1979).

For all the regression and structural families developed in this study, the standard estimate error is lower, or at least as low, for the five year discharge than for the other discharge estimates. This low standard error of estimate for the five year peak discharge

indicates that the active-channel forming discharge may be closer to the five-year peak discharge than the mean annual discharge for the streams in the study area.

This apparent relationship is partially the result of the channel conditions found in the study area. Since a bedrock bed is essentially a rigid structure and is not susceptible to "normal" erosion or scour during peak discharges, most of the channel modification must be made laterally instead of laterally and vertically which results in extreme widening of the banks. Under these conditions, the narrowing of the active-channel may take more time to approach equilibrium conditions with the mean annual discharge. The rate that the active-channel would regain an equilibrium condition with the mean annual flow of the stream would vary from stream to stream depending on basin, channel, hydrologic and sediment characteristics.

There were no significant changes in the standard error of estimate values for the simple-regression equations when they were modified by the structural analysis.

There are numerous sources of error associated with these standard error values. First, are the errors associated with inaccurate or misleading discharge data (Table 6, p. 62). If measurement of the independent variables used in this study could be made without error, the regression relationships would still be subject to standard errors at least as large as those associated with the various discharge values. Second, error may be introduced by inconsistent channel-geometry data resulting from improper site selection or differences in measuring or analyzing techniques between sites or

samples. Third, are the problems of discharge variability between different sites and the time elapsed since the previous erosive flood event. Fourth, is the problem with omission of other, unquantified, variables such as vegetation along the channel, that affect the regression and structural relationships developed in this study.

II. EVALUATION OF THE ASSUMPTIONS AND PRINCIPLES USED IN THIS STUDY

The major purpose of this study was to develop, using techniques that could be easily, quickly, and accurately replicated, a family of power-function equations to predict stream discharges on the Cumberland Plateau in Tennessee. The following section discusses possible inaccuracies, inconsistencies, or invalidities in the assumptions of the methods used in this study.

Data Collection

To insure uniform sampling at the different stations it was necessary to standardize the sampling techniques used.

Active-channel. Measurement of the active-channel was biased to a particular reach of the channel (p. 22). The active-channel has been interpreted as representing the stream's channel width that is in equilibrium with the normal flow regime of the stream. The active-channel is also believed to respond to changes in the stream's flow regime through time (Hedman and Kastner, 1977; Osterkamp and Hedman, 1977). The time necessary for a stream to respond to changes in the flow regime depends on many variables such as the sediment, channel and hydrologic characteristics of the stream as well as the presence of and

influence of vegetation.

On the Cumberland Plateau, most of the stream banks were "armored" by vegetation which may inhibit the active-channel from quickly responding to slight or moderate changes in the stream's flow regime. Because no quantitative technique has been developed to evaluate the influence of vegetation on the width-discharge relationship, it was not used in any of the regression analyses. Qualitatively, the bank stabilizing effect of any given community of vegetation may be similar regardless of the channel's size and the effects of the vegetation on the width-discharge relationships probably decrease as discharge values increase.

Using the lower limit of permanent vegetation as an indicator of the active-channel was questioned in this study. For four of the channels investigated, 03538180, 03538200, 03538225, and 03538250, the lower limit of permanent vegetation encroached into the channel below the break in channel slope associated with identification of the active-channel or the vegetation was at a level equal to the stream's low-flow stage. This suggests that the use of vegetation for identification of the active-channel level may need to be redefined for humid areas.

Although care was taken in selecting the sampling sites, the effects of bedrock in the bedrock channels undoubtedly affected the width-discharge relationships developed in this study. These effects could be direct, as in precluding the formation of the active-channel feature, or indirect, as in inciting extreme widening of the channel during peak discharges. However, careful site selection is thought to have kept this problem to a minimum.

The effects of inherited channel characteristics such as stream

terraces is acknowledged but the effects of these on the active-channel are unknown. Although inherited characteristics may influence the active-channel morphology and sediment characteristics, to date there is no way to quantitatively evaluate this influence.

Sediment samples. The sediment sampling techniques used in this study are those outlined by Osterkamp (1978b). The sediment sampling techniques were intended to sample the bed load transported by the stream during normal discharge and the bank samples were to represent the suspended material transported by the stream during normal discharge. To prove this relationship it would be necessary to sample the bed and suspended sediment loads of each stream during normal discharge. This would be impracticable because of the problems in replication of the data gathering techniques on ungaged streams. Qualitatively, the sediment samples collected in this study did appear to represent the intended sediment characteristics.

Use of Osterkamp's (1978b) sampling techniques may lead to contamination of the sediment samples with sediment transported and deposited in the bed or banks during discharges other than the mean annual flow. The sample may also be contaminated by colluvium that has been transported down bank by soil creep. Careful sampling and site selection may help to reduce these problems.

When using these sediment sampling techniques, the armoring effects of the silt and clay were quantified, but there was no quantification of the armoring effects of the coarser sediment fraction. For a larger population of streams it is possible to group the streams according to their sediment characteristics and develop regression relationships for each group (Osterkamp, 1977; Osterkamp and Hedman, 1979).

The removal of the coal from the sediment samples did little to improve or reduce the standard error of estimate for the regression equations (Table 4, p. 51).

A survey of the stream basins used in this study by the Office of Surface Mining (H. Johnson, written communication) showed that 18 of the 41 control stations and five of the nine experimental stations reported mining activity in their basins (Table A-3, p. 91 and Table B-3, p. 105). The bank sediment samples from the unmined basins had coal percentages averaging 1 to 2 percent. This is probably due to the weathering of the coal seam cropping out along the stream and may be interpreted to represent the amount of coal that is naturally added to the sediment load of the stream. The bank sediment samples from the basins with known mining activities had coal percentages averaging 4 to 5 percent.

Gradient. The gradient values from the topographic maps represent an average gradient value for the measured reach of the stream (p. 37). For four of the field gradient values that were collected at six sites, the map and field values were similar with the standard errors of measurement for each technique (Table 2, p. 38). For the streams with bedrock channels, the use of the map gradient values must be used with increased caution. It is possible that the map gradient value of the channel at the sampled site could be different from the actual channel gradient value because of the presence of nick points in the channel near the sampled site that are not represented on the map. This problem can be reduced in the field by careful site selection. Another problem with using gradient values taken from topographic maps was illustrated at a low gradient channel (03538225). For low gradient or high gradient

channels, the topographic map values have their highest error because of the spacing of the contour lines. For these types of channels, field gradient values may be necessary to refine the gradient value obtained from the topographic map.

Statistical Techniques

In order to use the statistical tools of regression and structural analyses in this study, several assumptions were made (p. 48). The assumptions that the independent variables used in the analyses were significant and that the residuals were normally and independently distributed with a mean value of zero and a constant variance held true for the range of data used in this study. However, the assumption that a straight line defines the relationship between the dependent and the independent variables was challenged.

The initial problems came in attempting to use Osterkamp and Hedman's (1979) exponents to predict stream discharges on the Cumberland Plateau. The validity checks of these equations showed lines that were invalid for estimating stream discharges in the study area. Since these exponents were developed using data from a wide range of geologic, hydrologic, and channel conditions, this suggests that a log-linear relationship between discharge and channel characteristics does not exist across a wide spectrum of geologic, hydrologic or channel conditions.

The simple-regression equations developed from the data gathered in the study area showed that a log-linear relationship could be maintained between the discharges and the active-channel width under restricted conditions. This relationship was supported by the multiple-

regression equation using the active-channel width and silt-clay percentages to predict discharge. However, when the gradient parameter was used with the active-channel width a problem arose. The validity checks of the equations for predicting a 25 or 50 year flood, when using gradient values less than 0.0045, showed that anomalous discharge values could be obtained. An evaluation of this situation has been noted on page 66.

An underlying assumption in the development of all these relationships is that an equilibrium or quasi-equilibrium situation exists between the active-channel and the mean annual flow of the channel. The low standard errors for the five-year floods indicate that this may not be the case. This relationship is influenced not only by the geologic, hydrologic, sediment and channel characteristics but it is also affected by the presence of vegetation along the banks and land-use in the drainage basins. At any given point in time it is difficult to tell if the active-channel is actually in equilibrium with the normal flow regime of the stream, but it is assumed that the stream and channel are approaching an equilibrium condition with all the hydrologic and channel variables. This assumption of equilibrium could be the cause for much of the error in these relationships.

The use of the structural analysis technique is supported by this author because of the ability to assign error values to both the dependent and independent variables. However, its use as a statistically superior alternative to regression analyses was not statistically supported in this study.

IV. FUTURE WORK

The problems of obtaining reliable discharge data for ungaged streams both quickly and inexpensively are minimized by the use of channel-geometry-discharge relationships. However, the data in this study suggests that more work needs to be done in establishing these relationships for streams with different geologic, hydrologic, and channel characteristics.

More work needs to be done on establishing and documenting the processes of formation of the active-channel and the relationships between the hydrologic and sediment characteristics of the stream and channel. A study of how the active-channel is formed and modified, and to what extent it is influenced by the suspended sediment load transported and deposited by the stream needs to be undertaken. This could be attempted by the collection and analyses of suspended sediment and active-channel bank sediment data using coal as a tracer. These studies should be expanded to streams representing different geologic, hydrologic, and channel conditions.

It may be possible to estimate paleo-fluvial hydrologic conditions by the use of channel-geometry discharge relationships. This depends on the preservation and later identification of the appropriate channel forms.

Many other projects could be done in the future to complement the work done in this study. These include the refinement of the regression relationships by the introduction of other independent variables, in particular, quantifying the influence of vegetation, mining, and land-use activities in the drainage basin. This could be done with LANDSAT

or other remote-sensing techniques. Further work on establishing the relationships between the channel gradient and the hydraulic gradients of the various discharges flowing through the channel would also be of value.

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APPENDICES

APPENDIX A

EXPLANATION OF DATA IN APPENDIX A

The data contained in Appendix A are for the 41 control stations and are the data used in the regression and structural analysis in this study. Table A-1 gives the name and locations of control sites, Table A-2, the basin and channel characteristics, Table A-3, the period of record and sediment characteristics, and Table A-4, the discharge values used. The top discharge values are in cubic meters/second and the values in parenthesis are in cubic feet/second. All references in Table A-3 to left and right banks are made looking downstream.

TABLE A-1. CONTROL STATIONS NAME, NUMBER, AND LOCATION.

STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	TOPOGRAPHIC QUADRANGLE (NUMBER)
03408500	NEW RIVER AT NEW RIVER, TENN.	36°23'08"	84°33'17"	ONEIDA SOUTH (128A-NE)
03409000	WHITE OAK CREEK AT SUNBRIGHT, TENN.	36°14'38"	84°40'14"	PILOT MOUNTAIN (122 NW)
03409500	CLEAR FORK NEAR ROBBINS, TENN.	36°23'18"	84°37'49"	HONEY CREEK (128A-NW)
03410500	SOUTH FORK CUMBERLAND RIVER NEAR STEARNS, KY.	36°37'37"	84°32'00"	BARTHELL (KY) (336 NE)
03414500	EAST FORK OBEY RIVER NEAR JAMESTOWN, TENN.	36°24'58"	85°01'35"	RIVERTON (334 NE)
03415000	WEST FORK OBEY RIVER NEAR ALPINE, TENN.	36°23'49"	85°10'28"	ALPINE (334 NW)
03415700	BIG EAGLE CREEK NEAR LIVINGSTON, TENN.	36°26'57"	85°16'27"	LIVINGSTON (330 NE)
03416000	WOLF RIVER NEAR BYRDSTOWN, TENN.	36°33'37"	85°04'23"	MOODYVILLE (333 SE)
03418000	ROARING RIVER NEAR HILHAM, TENN.	36°20'24"	85°25'46"	WINDLE (330 SW)
03418500	CANEY FORK AT CLIFTY, TENN.	35°53'28"	85°13'05"	PLEASANT HILL (109 NW)
03418900	RACOON CREEK NEAR OLD WINESAP, TENN.	35°47'12"	85°08'40"	HERBERT DOMAIN (109 SW)
03420000	CALFKILLER RIVER BELOW SPARTA, TENN.	35°54'31"	85°28'46"	SPARTA (332 NW)
03420500	BARREN FORK NEAR TROUSDALE, TENN.	35°39'55"	85°53'00"	CENTERTOWN (92 NW)
03421000	COLLINS RIVER NEAR MCMINNVILLE, TENN.	35°42'32"	85°43'46"	MCMINNVILLE (92 NE)

TABLE A-1 (CONTINUED)

STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	TOPOGRAPHIC QUADRANGLE (NUMBER)
03421100	SINK TRIB. AT MCMINNVILLE, TENN.	35°41'47"	85°46'47"	MCMINNVILLE (92 NE)
03423000	FALLING WATER RIVER NEAR COOKEVILLE, TENN.	36°04'38"	85°31'17"	BURGESS FALLS (326 SE)
03534000	COAL CREEK AT LAKE CITY, TENN.	36°13'14"	84°09'27"	LAKE CITY (137 NW)
03538200	POPLAR CREEK NEAR OLIVER SPRINGS, TENN.	36°01'20"	84°18'37"	WINDROCK (129 SE)
03538225	POPLAR CREEK NEAR OAK RIDGE, TENN.	36°00'15"	84°15'24"	BETHYL VALLEY (130 NE)
03538250	EAST FORK POPLAR CREEK NEAR OAK RIDGE, TENN.	35°57'58"	84°21'30"	BETHYL VALLEY (130 NE)
03538300	ROCK CREEK NEAR SUNBRIGHT, TENN.	36°11'54"	84°39'39"	PILOT MOUNTAIN (122 NW)
03538500	EMORY RIVER NEAR WARTBURG, TENN.	36°06'46"	84°36'54"	CAMP AUSTIN (122 SW)
03538600	OBED RIVER AT CROSSVILLE, TENN.	35°57'27"	85°03'00"	CROSSVILLE (109 NE)
03538800	OBED RIVER TRIB. NEAR CROSSVILLE, TENN.	35°58'59"	85°03'31"	CROSSVILLE (109 NE)
03538900	SELF CREEK NEAR BIG LICK, TENN.	35°47'54"	85°02'33"	VANDEVER (109 SW)
03539100	BYRD CREEK NEAR CROSSVILLE, TENN.	35°53'40"	85°03'38"	CROSSVILLE (109 NE)
03539500	DADDYS CREEK NEAR CRAB ORCHARD, TENN.	35°55'33"	84°54'47"	DORTON (117 NW)
03539600	DADDYS CREEK NEAR HEBBERTSBURG, TENN.	35°59'53"	84°49'25"	OZONE (117 NE)

TABLE A-1 (CONTINUED)

STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	TOPOGRAPHIC QUADRANGLE (NUMBER)
03539800	OBED RIVER NEAR LANCING, TENN.	36°04'53"	84°40'15"	LANCING (122 SW)
03540500	EMORY RIVER AT OAKDALE, TENN.	35°58'59"	84°33'29"	HARRIMAN (123 NE)
03541100	BITTER CREEK NEAR CAMP AUSTIN, TENN.	36°00'53"	84°31'33"	CAMP AUSTIN (122 SW)
03541200	FORKED CREEK NEAR OAKDALE, TENN.	36°00'12"	84°30'45"	CAMP AUSTIN (122 SW)
03541500	WHITES CREEK NEAR GLEN ALICE, TENN.	35°47'49"	84°45'37"	RODDY (117 SE)
03544500	RICHLAND CREEK NEAR DAYTON, TENN.	35°30'17"	85°01'20"	MORGAN SPRINGS (110 SE)
03570800	LITTLE BRUSH CREEK NEAR DUNLAP, TENN.	35°24'15"	85°23'18"	SAVAGE POINT (104 NW)
03571000	SEQUATCHIE RIVER NEAR WHITWELL, TENN.	35°12'22"	85°29'48"	KETNER GAP (105 NW)
03571600	BROWN SPRING BRANCH NEAR SEQUATCHIE, TENN.	35°08'55"	85°33'28"	WHITWELL (100 NE)
03571800	BATTLE CREEK NEAR MONTEAGLE, TENN.	35°08'03"	85°46'15"	MONTEAGLE (94 NE)
03578000	ELK RIVER NEAR PELHAM, TENN.	35°17'48"	85°52'12"	BURROW COVE (93 SE)
03578500	BRADLEY CREEK NEAR PRAIRIE PLAINS, TENN.	35°21'21"	85°58'45"	ALTO (93 SW)
03579900	BOILING FORK CREEK AT COWAN, TENN.	35°09'45"	86°00'20"	WINCHESTER (87 NE)

TABLE A-2. CONTROL STATIONS BASIN AND CHANNEL CHARACTERISTICS.

STATION NUMBER	DRAINAGE AREA	GRADIENT	CHANNEL TYPE AT CROSS SECTION	ACTIVE CHANNEL WIDTH	MEAN CHANNEL DEPTH	CHANNEL AREA
03408500	989 km^2 (382 mi^2)	0.00058	BEDROCK	30.80 m (101 ft)	0.830 m (2.72 ft)	25.55 m^2 (275 ft^2)
03409000	34.97 km^2 (13.5 mi^2)	0.0036	ALLUVIAL	8.540 m (28.0 ft)	0.366 m (1.20 ft)	3.121 m^2 (33.6 ft^2)
03409500	704 km^2 (272 mi^2)	0.0033	BEDROCK	39.65 m (130 ft)	0.543 m (1.78 ft)	21.50 m^2 (231 ft^2)
03410500	2471 km^2 (954 mi^2)	0.0012	BEDROCK	60.39 m (198 ft)	2.440 m* (8.0 ft)*	147.2 m^2 * (1584 ft^2)*
03414500	508 km^2 (196 mi^2)	0.0011	BEDROCK	22.88 m (75.0 ft)	0.516 m (1.69 ft)	11.89 m^2 (128 ft^2)
03415000	210 km^2 (81 mi^2)	0.0029	BEDROCK	17.69 m (58.0 ft)	0.540 m (1.77 ft)	9.569 m^2 (103 ft^2)
03415700	20.67 km^2 (7.98 mi^2)	0.0057	BEDROCK	9.608 m (31.5 ft)	0.445 m (1.46 ft)	4.273 m^2 (46.0 ft^2)
03416000	274 km^2 (106 mi^2)	0.0032	BEDROCK	20.74 m (68.0 ft)	0.436 m (1.43 ft)	9.030 m^2 (97.2 ft^2)
03418000	204 km^2 (78.7 mi^2)	0.018	BEDROCK	19.22 m (63.0 ft)	0.355 m (1.16 ft)	6.791 m^2 (73.1 ft^2)
03418500	288 km^2 (111 mi^2)	0.0044	BEDROCK	38.74 m (127 ft)	0.573 m (1.88 ft)	22.20 m^2 (239 ft^2)

TABLE A-2 (CONTINUED)

STATION NUMBER	DRAINAGE AREA	GRADIENT	CHANNEL TYPE AT CROSS SECTION	ACTIVE CHANNEL WIDTH	MEAN CHANNEL DEPTH	CHANNEL AREA
03418900	3.95 km^2 (1.52 mi^2)	0.0034	BEDROCK	5.216 m (17.1 ft)	0.546 m (1.79 ft)	2.833 m^2 (30.5 ft^2)
03420000	453 km^2 (175 mi^2)	0.00074	BEDROCK	28.98 m (95.0 ft)	1.006 m (3.30 ft)	29.17 m^2 (314 ft^2)
03420500	326 km^2 (126 mi^2)	0.00068	COBBLE ARMORING	22.88 m (75.0 ft)	0.528 m (1.73 ft)	12.08 m^2 (130 ft^2)
03421000	1658 km^2 (640 mi^2)	0.00070	COBBLE ARMORING	54.90 m (180 ft)	1.068 m* (3.50 ft)*	58.53 m^2* (630 ft^2)*
03421100	1.22 km^2 (0.47 mi^2)	-	ALLUVIAL	2.135 m (7.0 ft)	0.204 m (0.67 ft)	0.437 m^2 (4.70 ft^2)
03423000	119 km^2 (45.9 mi^2)	0.00046	BEDROCK	9.608 m (31.5 ft)	0.512 m (1.68 ft)	5.017 m^2 (54.0 ft^2)
03534000	63.46 km^2 (24.5 mi^2)	0.0012	ALLUVIAL	10.68 m (35.0 ft)	0.421 m (1.38 ft)	4.487 m^2 (48.3 ft^2)
03538200	145 km^2 (55.9 mi^2)	0.0029	ALLUVIAL	15.10 m (49.5 ft)	0.537 m (1.76 ft)	8.175 m^2 (88.0 ft^2)
03538225	214 km^2 (82.5 mi^2)	0.00022	ALLUVIAL	16.01 m (52.5 ft)	0.592 m (1.94 ft)	9.476 m^2 (102 ft^2)
03538250	50.50 km^2 (19.5 mi^2)	0.0011	ALLUVIAL	11.28 m (37.0 ft)	0.854 m (2.88 ft)	10.03 m^2 (108 ft^2)

TABLE A-2 (CONTINUED)

STATION NUMBER	DRAINAGE AREA	GRADIENT	CHANNEL TYPE AT CROSS SECTION	ACTIVE CHANNEL WIDTH	MEAN CHANNEL DEPTH	CHANNEL AREA
03538300	14.35 km^2 (5.54 mi^2)	0.0034	BEDROCK	7.015 m (23.0 ft)	0.412 m (1.35 ft)	2.889 m^2 (31.1 ft^2)
03538500	216 km^2 (83.2 mi^2)	0.0079	COBBLE ARMORING	29.28 m (96.0 ft)	0.403 m (1.32 ft)	8.918 m^2 (127 ft^2)
03538600	31.08 km^2 (12.0 mi^2)	0.0024	BEDROCK	8.388 m (27.5 ft)	0.424 m (1.39 ft)	3.484 m^2 (37.5 ft^2)
03538800	1.86 km^2 (0.72 mi^2)	0.0081	ALLUVIAL	4.575 m (15.0 ft)	0.427 m (1.40 ft)	1.951 m^2 (21.0 ft^2)
03538900	9.84 km^2 (3.80 mi^2)	0.0034	BEDROCK	4.575 m (15.0 ft)	0.415 m (1.48 ft)	2.062 m^2 (22.2 ft^2)
03539100	2.85 km^2 (1.10 mi^2)	0.0017	ALLUVIAL	2.745 m (9.0 ft)	0.198 m (0.65 ft)	0.548 m^2 (5.90 ft^2)
03539500	242 km^2 (93.5 mi^2)	0.0017	BEDROCK	16.01 m (52.5 ft)	0.332 m (1.09 ft)	5.318 m^2 (57.25 ft^2)
03539600	360 km^2 (139 mi^2)	0.0045	BEDROCK	37.52 m (123 ft)	0.558 m (1.83 ft)	20.90 m^2 (225 ft^2)
03539800	1342 km^2 (518 mi^2)	0.0042	BEDROCK	38.12 m (125 ft)	0.948 m (3.11 ft)	36.09 m^2 (388 ft^2)
03540500	1979 km^2 (764 mi^2)	0.0010	BEDROCK	70.15 m (230 ft)	0.976 m* (3.20 ft)*	68.37 m^2* (736 ft^2)*

TABLE A-2 (CONTINUED)

STATION NUMBER	DRAINAGE AREA	GRADIENT	CHANNEL TYPE AT CROSS SECTION	ACTIVE CHANNEL WIDTH	MEAN CHANNEL DEPTH	CHANNEL AREA
03541100	14.32 km^2 (5.53 mi^2)	0.0067	BEDROCK	7.930 m (26.0 ft)	0.497 m (1.29 ft)	3.112 m^2 (33.5 ft^2)
03541200	6.32 km^2 (2.44 ft)	0.016	BEDROCK	5.673 m (18.6 ft)	0.380 m (1.01 ft)	1.691 m^2 (18.2 ft^2)
03541500	280 km^2 (108 mi^2)	0.0034	BEDROCK	24.40 m (80.0 ft)	0.884 m* (2.90 ft)*	21.55 m^2* (232 ft^2)*
03544500	130 km^2 (50.2 mi^2)	0.0089	BOULDER CHANNEL	21.04 m (69.0 ft)	0.424 m (1.39 ft)	8.918 m^2 (96.0 ft^2)
03570800	39.89 km^2 (15.4 mi^2)	0.022	BOULDER CHANNEL	8.388 m (27.5 ft)	0.464 m (1.52 ft)	3.818 m^2 (41.1 ft^2)
03571000	995 km^2 (384 mi^2)	0.00041	ALLUVIAL	29.58 m (97.0 ft)	0.915 m* (3.00 ft)*	1.951 m^2* (291 ft^2)*
03571600	1.74 km^2 (0.67 mi^2)	0.022	ALLUVIAL	2.135 m (7.0 ft)	0.159 m (0.52 ft)	0.339 m^2 (3.65 ft^2)
03571800	130 km^2 (50.4 mi^2)	0.0028	COBBLE CHANNEL	17.84 m (58.5 ft)	0.464 m (1.52 ft)	8.259 m^2 (88.9 ft^2)
03578000	170 km^2 (65.6 mi^2)	0.00050	BEDROCK	15.86 m (52.0 ft)	0.793 m (2.60 ft)	12.62 m^2 (136 ft^2)
03578500	107 km^2 (41.3 mi^2)	0.00049	COBBLE CHANNEL	17.38 m (57.0 ft)	0.348 m (1.14 ft)	6.187 m^2 (66.6 ft^2)

TABLE A-2 (CONTINUED)

STATION NUMBER	DRAINAGE AREA	GRADIENT	CHANNEL TYPE AT CROSS SECTION	ACTIVE CHANNEL WIDTH	MEAN CHANNEL DEPTH	CHANNEL AREA
03579900	44.03 km^2 (17.0 mi^2)	0.0027	COBBLE CHANNEL	6.558 m (21.5 ft)	0.366 m (1.20 ft)	2.341 m^2 (25.2 ft^2)

*estimated values.

TABLE A-3. CONTROL STATIONS PERIOD OF RECORD AND SEDIMENT CHARACTERISTICS.

STATION NUMBER	PERIOD OF RECORD WATER YEAR	LENGTH	PERCENT SILT-CLAY (COAL REMOVED) LEFT BANK	RIGHT BANK	BED	PERCENT WEIGHT LOSS WHEN COAL REMOVED LEFT BANK	RIGHT BANK	BED
03408500*	1934-current	46	53 (57)	68 (70)	– –	4	3	–
03409000*	1955-current	25	38 (39)	50 (46)	2 (2)	1	3	45
03409500*	1930-current	46	51 (52)	52 (56)	– –	1	8	–
03410500*	1943-current	37	54 (62)	59 (68)	– –	8	2	–
03414500*	1943-current	37	58 (58)	7 (7)	– –	4	2	–
03415000	1943-1971	28	57 (62)	59 (60)	– –	1	1	–
03415700	1955-1978	23	29 –	28 –	– –	–	–	–
03416000*	1943-current	37	68 (68)	82 (83)	– –	1	2	–
03418000	1932-1975	43	41 –	18 –	– –	–	–	–
03418500*	1930-1949	19	50 (50)	62 (63)	– –	2	3	–

TABLE A-3 (CONTINUED)

STATION NUMBER	PERIOD OF RECORD WATER YEAR	RECORD LENGTH	PERCENT SILT-CLAY (COAL REMOVED) LEFT BANK	RIGHT BANK	BED	PERCENT WEIGHT LOSS WHEN COAL REMOVED LEFT BANK	RIGHT BANK	BED
03418900	1972-current	8	56 -	40 -	- -	-	-	-
03420000	1940-1971	31	1 (1)	3 (5)	- -	1	1	-
03420500	1932-1958	26	69 -	70 -	2 -	-	-	-
03421000	1924-current	56	61 (62)	65 (66)	11 (03)	1	2	1
03421100	1955-current	25	70 -	70 -	3 -	-	-	-
03423000	1932-1952	20	57** -	57 -	- -	-	-	-
03534000*	1955-current	25	84 (88)	89 (91)	2 (3)	1	6	9
03538200*	1951-current	29	82 (83)	63 (78)	4 (1)	4	4	32
03538225	1960-current	20	96 (97)	76 (76)	42 (59)	14	3	22
03538250	1960-current	20	96 (97)	97 (97)	10 (10)	2	1	1

TABLE A-3 (CONTINUED)

STATION NUMBER	PERIOD OF RECORD WATER YEAR	LENGTH	PERCENT SILT-CLAY (COAL REMOVED) LEFT BANK	RIGHT BANK	BED	PERCENT WEIGHT LOSS WHEN COAL REMOVED LEFT BANK	RIGHT BANK	BED
03538300*	1955-1971	16	42 (45)	51 (54)	- -	6	7	-
03538500*	1934-current	46	68 (71)	59 (61)	1 (1)	5	2	22
03538600	1955-current	25	35 -	43 -	- -	-	-	-
03538800	1955-1970	15	47 -	60 -	2 -	-	-	-
03538900	1967-1974	7	54 -	51 -	- -	-	-	-
03539100	1967-1975	8	36 -	38 -	- -	-	-	-
03539500*	1930-1958	28	47 (50)	54 (56)	-	2	3	-
03539600*	1957-1968	11	71 (79)	60 (62)	- -	2	2	-
03539800	1957-current	23	1 -	65 -	- -	-	-	-
03540500*	1927-current	53	66 (70)	40 (40)	- -	6	2	-

TABLE A-3 (CONTINUED)

STATION NUMBER	PERIOD OF RECORD WATER YEAR	LENGTH	PERCENT SILT-CLAY (COAL REMOVED) LEFT BANK	RIGHT BANK	BED	PERCENT WEIGHT LOSS WHEN COAL REMOVED LEFT BANK	RIGHT BANK	BED
03541100 *	1967-current	13	31 (34)	36 (37)	- -	2	1	-
03541200 *	1967-1975	8	25 (29)	52 (51)	- -	6	2	-
03541500 *	1934-1978	44	2 (2)	45 (45)	- -	3	2	-
03544500	1934-1978	44	24 (26)	4 (8)	1 (2)	1	1	1
03570800 *	1959-current	21	14 (16)	14 (16)	3 (2)	2	3	2
03571000 *	1921-current	59	84 (88)	85 (85)	- -	3	2	-
03571600	1955-1977	22	55 -	35 -	13 -	-	-	-
03571800	1955-current	25	36 -	12 -	1 -	-	-	-
03578000	1951-current	29	84 -	55 -	- -	-	-	-
03578500	1951-current	29	77 -	72 -	- -	-	-	-

TABLE A-3 (CONTINUED)

STATION NUMBER	PERIOD OF RECORD WATER YEAR	LENGTH	PERCENT SILT-CLAY (COAL REMOVED) LEFT BANK	RIGHT BANK	BED	PERCENT WEIGHT LOSS WHEN COAL REMOVED LEFT BANK	RIGHT BANK	BED
03579900	1955-1979	24	38	25	1	-	-	-
			-	-	-			

* Coal mining activities reported in the basin by US Office of Surface Mining (H. Johnson, written communication, 1980).

** estimated value.

TABLE A-4. CONTROL STATIONS DISCHARGE CHARACTERISTICS.

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE
03408500	20.02 (707)	710.8 (25,100)	996.8 (35,200)	1198 (42,300)	1458 (51,500)	1660 (58,600)	1866 (65.900)
03409000	0.680* (24.0)*	54.94 (1940)	79.58 (2810)	96.85 (3420)	119.5 (4220)	137.4 (4850)	155.5 (5490)
03409500	13.17 (465)	382.3 (13,500)	580.6 (20,500)	725.0 (25,600)	917.6 (32,400)	1068 (37,700)	1226 (43,300)
03410500	50.92 (1798)	1289 (45,500)	1773 (62,600)	2098 (74,100)	2509 (88,600)	2815 (99,400)	3115 (110,000)
03414500	10.93 (386)	478.6 (16,900)	702.3 (24,800)	860.9 (30,400)	1068 (37,700)	1229 (43,400)	1393 (49,200)
03415000	4.503 (159)	198.2 (7000)	286.0 (10,100)	342.7 (12,100)	419.1 (14,800)	475.8 (16,800)	532.4 (18,800)
03415700	0.396* (14.0)*	20.19 (713)	32.00 (1130)	40.50 (1430)	52.39 (1850)	61.74 (2180)	71.65 (2530)
03416000	5.013 (177)	224.6 (7930)	376.7 (13,300)	489.9 (17,300)	645.7 (22,800)	770.3 (27,200)	900.6 (31,800)
03418000	3.002 (106)	94.02 (3320)	152.9 (5400)	196.3 (6930)	255.4 (9020)	303.0 (10,700)	351.2 (12,400)
03418500	5.862 (207)	119.8 (4230)	258.3 (9120)	317.2 (11,200)	390.8 (13,800)	450.3 (15,900)	509.8 (18,000)

TABLE A-4 (CONTINUED)

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE
03418900**	0.081* (2.85)*	5.381 (190)	8.411 (297)	10.65 (376)	13.65 (482)	16.09 (568)	18.69 (660)
03420000	10.48 (370)	216.9 (7660)	308.7 (10,900)	371.0 (13,100)	453.1 (16,00)	515.4 (18,200)	580.6 (20,500)
03420500	6.174 (218)	271.3 (9580)	461.6 (16,300)	603.2 (21,300)	790.1 (27,900)	937.4 (33,100)	1085 (38,300)
03421000	32.28 (1140)	679.7 (24,000)	1045 (36,900)	1297 (45,800)	1620 (57,200)	1864 (65,800)	2110 (74,500)
03421100	0.0232* (0.82)*	5.409 (191)	8.043 (284)	9.912 (350)	12.38 (437)	14.30 (505)	16.28 (575)
03423000	3.144 (111)	96.57 (3410)	133.1 (4700)	155.2 (5480)	180.7 (6380)	198.2 (7000)	214.7 (7580)
03534000	1.260* (44.5)*	81.00 (2860)	121.8 (4300)	151.2 (5340)	190.6 (6730)	221.8 (7830)	254.3 (8980)
03538200	3.115* (110)*	97.99 (3460)	148.7 (5250)	186.9 (6600)	240.7 (8500)	286.0 (10,100)	334.2 (11,800)
03538225	5.013 (177)	129.1 (4560)	194.0 (6850)	240.2 (8480)	303.0 (10,700)	351.2 (12,400)	402.1 (14,200)
03538250***	1.484 (52.4)	43.61 (1540)	64.57 (2280)	79.30 (2800)	99.12 (3500)	114.4 (4040)	130.6 (4610)

TABLE A-4 (CONTINUED)

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE
03538300	0.238* (10.0)*	21.13 (746)	29.45 (1040)	35.40 (1250)	42.76 (1510)	48.43 (1710)	54.09 (1910)
03538500	4.135 (146)	200.5 (7080)	314.4 (11,100)	402.1 (14,200)	532.4 (18,800)	642.9 (22,700)	764.6 (27,00)
03538600	0.595* (21.0)*	18.80 (664)	25.94 (916)	30.87 (1090)	36.81 (1300)	41.63 (1470)	46.16 (1630)
03538800	0.037* (1.30)*	3.427 (121)	5.919 (209)	7.930 (280)	10.88 (384)	13.34 (471)	16.03 (566)
03538900**	0.204* (7.20)*	9.527 (338)	16.37 (578)	21.24 (750)	27.84 (983)	33.42 (1180)	39.36 (1390)
03539100**	0.057* (2.00)*	2.719 (96)	4.984 (176)	6.684 (236)	9.176 (324)	11.33 (400)	13.65 (482)
03539500	4.928 (174)	137.1 (4840)	226.6 (8000)	294.5 (10,400)	390.8 (13,800)	470.1 (16,600)	557.9 (19,700)
03539600	7.561 (267)	217.2 (7670)	369.6 (9520)	303.0 (10,700)	342.7 (12,100)	371.0 (13,100)	396.5 (14,000)
03539800	30.27 (1069)	983.7 (34,700)	1458 (51,500)	1798 (63,500)	2249 (79,400)	2603 (91,900)	2974 (105,000)
03540500	39.93 (1410)	1317 (46,500)	2090 (73,800)	2668 (94,200)	3455 (122,000)	4106 (145,000)	4758 (168,000)

TABLE A-4 (CONTINUED)

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE
03541100**	0.283* (10.0)*	28.60 (1010)	52.11 (1840)	70.23 (2480)	96.28 (3400)	119.2 (4210)	144.4 (5100)
03541200**	0.113* (4.0)*	9.487 (335)	16.31 (576)	21.47 (758)	28.89 (1020)	35.40 (1250)	42.12 (1490)
03541500	6.089 (215)	322.8 (11,400)	577.7 (20,400)	790.1 (27,900)	1116 (39,400)	1402 (49,500)	1725 (60,900)
03544500	3.030 (107)	124.6 (4400)	209.6 (7400)	273.9 (9670)	362.5 (12,800)	433.3 (15,300)	509.8 (18,000)
03570800	0.765* (27.0)*	54.66 (1930)	71.08 (2510)	81.56 (2880)	94.31 (3330)	103.7 (3660)	112.7 (3980)
03571000	20.62 (728)	322.8 (11,400)	475.8 (16,800)	580.6 (20,500)	716.5 (25,300)	818.4 (28,900)	920.4 (32,500)
03571600	0.044* (1.55)*	2.889 (102)	4.078 (144)	4.871 (172)	5.919 (209)	6.683 (236)	7.476 (264)
03571800	2.690* (95.0)*	102.2 (3610)	141.9 (5010)	168.2 (5940)	201.9 (7130)	227.1 (8020)	252.3 (8910)
03578000	3.795 (134)	118.7 (4190)	176.2 (6220)	216.6 (7650)	269.9 (9530)	311.5 (11,000)	354.0 (12,500)
03578500	1.866* (65.9)*	70.52 (2490)	109.6 (3870)	138.2 (4880)	177.0 (6250)	207.6 (7330)	237.9 (8400)

TABLE A-4 (CONTINUED)

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE
03579900	0.850* (30.0)*	52.62 (2070)	84.68 (2990)	102.5 (3620)	125.7 (4440)	143.6 (5070)	161.7 (5710)

* estimated from Figure 11, page 39.
** estimated from Wibben (1976).
*** estimated from Randolph and Gamble (1976).

APPENDIX B

EXPLANATION OF DATA IN APPENDIX B

The data in Appendix B are for the nine experimental stations used in this study. Table B-1 gives the name and location of the experimental sites, Table B-2, the basin and channel characteristics, Table B-3 the period of record and the sites sediment characteristics, and Table B-4 different estimated discharge values.

Discharge values:

A are from the Pearson III Analysis,

B are calculated from the equations presented in Randolph and Gamble (1976),

C are from the GLM equation with Width only (Table 4, p. 51),

D are from GLM equation with Width and Gradient (Table 4, p. 51),

E are from the GLM equation with Width and Silt-clay and coal percentages (Table 4, p. 51),

F are from the GLM structural equations (Table 5, p. 55).

All references in Table B-3 to left and right banks are made looking downstream.

TABLE B-1. EXPERIMENTAL STATIONS NAME, NUMBER, AND LOCATION.

STATION NUMBER	STATION NAME	LATITUDE	LONGITUDE	TOPOGRAPHIC QUADRANGLE (NUMBER)
03408000	NEW RIVER NEAR NEW RIVER, TENN.	36°23'12"	84°32'30"	ONEIDA SOUTH (128A-NE)
03414700	PUNCHEON CAMP CREEK AT ALLRED, TENN.	36°19'35"	85°11'10"	CRAWFORD (334 SW)
03419000	BEE CREEK AT HERBERT, TENN.	35°45'46"	85°15'10"	HERBERT DOMAIN (109 SW)
03419500	CALFKILLER RIVER AT SPARTA, TENN.	35°56'02"	85°27'32"	SPARTA (332 NW)
03420600	OWEN BRANCH NEAR CENTERTOWN, TENN.	35°42'30"	85°53'05"	MCMINNVILLE (92 NE)
03538180	BRUSHY FORK AT DOSSETT, TENN.	36°04'11"	84°13'40"	CLINTON (137 SW)
03538215	INDIAN CREEK AT OLIVER SPRINGS, TENN.	36°02'45"	84°20'48"	WINDROCK (129 SE)
03542500	PINEY RIVER AT SPRING CITY, TENN.	35°41'59"	84°51'17"	SPRING CITY (118 NE)
03579800	MILLER CREEK NEAR COWAN, TENN.	35°10'17"	85°59'00"	SEWANEE (94 NW)

TABLE B-2. EXPERIMENTAL STATIONS BASIN AND CHANNEL CHARACTERISTICS.

STATION NUMBER	DRAINAGE AREA	GRADIENT	CHANNEL TYPE AT CROSS SECTION	ACTIVE CHANNEL WIDTH	MEAN CHANNEL DEPTH	CHANNEL AREA
03408000	813 km^2 (314 mi^2)	0.00050	BEDROCK	32.02 m (105 ft)	0.549 m (1.80 m)	17.55 m^2 (189 ft^2)
03414700	40.2 km^2 (15.5 mi^2)	0.0047	BEDROCK	19.52 m (64.0 ft)	0.351 m (1.15 ft)	6.968 m^2 (75.0 ft^2)
03419000	262 km^2 (101 mi^2)	0.0025	BEDROCK	17.69 m (58.0 ft)	0.543 m (1.78 ft)	9.662 m^2 (104 ft^2)
03419500	407 km^2 (157 mi^2)	0.00046	BEDROCK	22.88 m (75.0 ft)	0.976 m * (3.30 ft)*	6.986 m^2* (240 ft^2)*
03420600	11.91 km^2 (4.60 mi^2)	0.011	ALLUVIAL	2.898 m (9.50 ft)	0.201 m (0.660 ft)	0.585 m^2 (6.30 ft^2)
03538180	26.42 km^2 (10.2 mi^2)	0.0012	COBBLE ARMORING	7.625 m (25.0 ft)	0.336 m (1.10 ft)	2.555 m^2 (27.5 ft^2)
03538215	47.66 km^2 (18.4 mi^2)	0.0019	ALLUVIAL	8.235 m (27.0 ft)	0.549 m (1.80 ft)	4.441 m^2 (47.8 ft^2)
03542500	248 km^2 (95.9 mi^2)	0.0033	BOULDER CHANNEL	26.54 m (87.0 ft)	0.808 m (2.65 ft)	21.37 m^2 (230 ft^2)
03579800	11.14 km^2 (4.30 mi^2)	0.0055	ALLUVIAL	5.185 m (17.0 ft)	0.351 m (1.15 ft)	1.821 m^2 (19.6 ft^2)

TABLE B-3. EXPERIMENTAL STATIONS PERIOD OF RECORD AND SEDIMENT CHARACTERISTICS.

STATION NUMBER	PERIOD OF RECORD WATER YEAR	LENGTH	PERCENT SILT-CLAY (COAL REMOVED) LEFT BANK	RIGHT BANK	BED	PERCENT WEIGHT LOSS WHEN COAL REMOVED LEFT BANK	RIGHT BANK	BED
03408000*	1922-1934	12	59 (59)	78 (84)	- -	2	7	-
03414700	1955-current	25	58 (58)	66 (66)	- -	1	4	-
03419000*	1930-1937	7	22 (22)	16 (18)	- -	1	11	-
03419500*	1932-1941	9	27 (30)	41 (43)	- -	6	2	-
03420600	1955-current	25	58 -	74 -	61 -	-	-	-
03538180	1961-1970	9	69 -	80 -	3 -	-	-	-
03538215*	1961-1972	11	38 (36)	73 (79)	2 (9)	12	6	1
03542500*	1955-current	25	41 -	31 -	1 -	-	-	-
03579800	1955-current	25	82 -	84 -	2 -	-	-	-

* Coal mining reported in the basin by US Office of Surface Mining (H. Johnson, written communication, 1980).

TABLE B-4. COMPARISON OF ESTIMATED DISCHARGE VALUES.

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE	
03408000	158.8	562.5	853.4	1062	1339	1560	1788	A
	17.90*	406.1	659.0	841.0	1140	1340	1524	B
	224.0	425.8	497.4	535.9	575.6	620.2	642.2	C
	652.0	879.3	914.4	1024	1121	1091	1137	D
	262.6	506.9	654.3	768.4	771.0	828.8	879.7	E
	13.08	403.7	611.4	755.2	957.0	1175	1276	F
03414700				NO DATA AVAILABLE				A
	0.729**	43.30	73.52	95.52	125.8	150.0	175.7	B
	74.72	175.6	206.1	223.2	420.9	259.6	270.1	C
	121.7	255.7	279.7	313.3	334.6	344.8	361.2	D
	86.66	207.3	266.7	314.2	316.8	341.6	362.6	E
	4.006	151.5	231.8	287.7	364.6	426.3	486.1	F
03419000	44.38	147.6	219.5	270.3	337.7	390.2	444.3	A
	5.579*	174.6	288.3	270.4	486.8	577.1	674.9	B
	60.06	147.2	173.0	187.5	202.6	218.3	227.4	C
	120.6	239.3	258.6	289.6	318.9	317.2	332.7	D
	65.21	159.3	200.5	233.9	236.1	252.1	267.6	E
	3.166	124.7	191.1	237.4	300.9	351.5	401.2	F
03419500	59.52	176.3	251.7	303.2	369.8	420.5	472.0	A
	8.213*	242.5	397.6	509.5	669.4	792.5	926.4	B
	106.3	233.3	273.4	295.6	318.6	243.3	356.6	C
	334.3	493.2	513.8	575.5	632.0	616.6	645.0	D
	119.8	264.7	337.3	394.9	397.6	426.1	452.2	E
	5.856	207.5	316.4	392.1	496.9	582.0	662.5	F

TABLE B-4 (CONTINUED)

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE	
03420600	1.130	13.08	31.33	48.09	76.01	102.3	133.3	A
	0.244**	17.53	30.33	39.70	52.34	62.62	73.46	B
	1.083	5.776	6.911	7.627	8.392	9.043	9.591	C
	1.896	7.888	8.880	9.947	11.15	11.46	12.24	D
	1.264	7.014	9.045	10.87	11.18	12.30	13.06	E
	0.042	3.470	5.513	6.976	8.839	10.14	11.78	F
03538180				NO DATA AVAILABLE				A
	5.515**	20.62	32.94	42.28	55.05	65.70	77.00	B
	1.818	32.64	44.35	48.44	52.74	56.83	59.65	C
	26.01	60.76	65.29	73.14	81.20	80.90	85.56	D
	10.88	39.49	51.01	60.78	61.87	67.48	71.63	E
	0.424	23.56	36.72	46.01	58.30	67.54	77.74	F
03538215	11.37	65.56	118.4	161.7	226.3	281.5	343.1	A
	0.935**	32.14	50.81	64.94	84.14	100.1	117.0	B
	11.00	37.46	44.35	48.44	52.74	56.83	59.65	C
	27.08	65.18	70.56	79.03	87.68	87.66	92.62	D
	12.83	44.96	57.96	68.95	70.13	76.37	80.06	E
	0.509	27.44	42.70	53.46	67.74	78.54	90.32	F
03542500	56.24	259.1	431.1	563.6	751.4	905.4	1072	A
	4.956**	111.2	171.0	215.7	275.8	325.5	377.2	B
	147.8	304.3	356.1	384.4	413.7	445.7	462.4	C
	205.1	413.1	453.9	508.5	557.5	558.3	602.5	D
	166.6	344.7	439.3	513.5	516.2	552.4	586.3	E
	8.349	278.4	423.2	523.7	663.6	778.4	884.8	F

TABLE B-4 (CONTINUED)

STATION NUMBER	AVERAGE YEARLY DISCHARGE	2 YEAR PEAK DISCHARGE	5 YEAR PEAK DISCHARGE	10 YEAR PEAK DISCHARGE	25 YEAR PEAK DISCHARGE	50 YEAR PEAK DISCHARGE	100 YEAR PEAK DISCHARGE	
03579800	8.810	35.41	56.34	71.97	93.57	111.0	129.4	A
	0.224**	16.68	28.86	37.81	49.84	59.64	69.98	B
	3.937	16.36	19.47	21.36	23.36	25.18	26.55	C
	7.652	24.32	27.03	34.28	33.74	34.25	36.36	D
	4.634	19.96	25.80	30.88	31.55	34.56	36.69	E
	0.168	10.98	17.24	21.69	27.48	31.72	36.65	F

* values from USGS Water Resources Data Publications.
** values estimated from Figure 11, page 39.

APPENDIX C

EXPLANATION OF DATA IN APPENDIX C

The data contained in Appendix C are from the regression and structural analyses. All values are in logarithmic form. Table C-1 are the data from the GLM procedures, Table C-2, data from the SYSREG procedures, and Table C-3 are data from the structural analysis. The statistical parameters in Appendix C include:

The R-square which

measures how much variation in the dependent variable can be accounted for by the model. Specifically, R-square is the ratio of the sum of squares for the dependent variable that can be attributed to the model divided by the total sum of the squares for the dependent variable. It can range from 0 to 1, and in general the larger it is, the better the model fit. A value of 0.9761 indicates that we can account for 97 percent of that stream-flow characteristic just by knowing the corresponding independent variable(s) (Hollyday and Hansen, unpublished manuscript).

The Mean Square Error which

is an estimate of δ^2, the variance of the true residuals. It is the ratio of the sum of squares for the dependent variable that can not be attributed to the model divided by the degrees of freedom. Its value is partly dependent upon the magnitude of values in the dependent variable but, in general, the smaller it is, the better the model fit (Hollyday and Hansen, unpublished manuscript).

The Standard Error of Estimate

of the dependent variable, or the standard Error is another measure of the equation accuracy and is a range or error such that the value of stream-flow estimated by the equation is within this range at about two out of three gaging sites, and is within twice this range at about 19 out of 20 sites for the sample population (Hollyday and Hansen, unpublished manuscript).

The standard error in logarithmic units was converted to percent by using Table E-2 (p. 131).

The F-value is a ratio of the explained to the unexplained variance in the dependent variable, generally the larger the value, the greater the significance.

TABLE C-1. GLM REGRESSION DATA.

VARIABLES AND STATISTICS	$Q = a W^{b}$ QA	Q2	Q5	Q10	Q25	Q50	Q100
Y-INTERCEPT	-2.287	-0.151	0.044	0.147	0.258	0.332	0.398
ACWLOG	2.222	1.787	1.780	1.773	1.765	1.758	1.753
R-SQUARE	0.913	0.884	0.895	0.895	0.893	0.891	0.888
MEAN SQUARE	0.070	0.063	0.555	0.055	0.056	0.056	0.576
STANDARD ERROR	0.265	0.250	0.236	0.235	0.236	0.238	0.240
F-VALUE (MODEL)	411	297	333	332	326	319	311

	$Q = a W^{b} G^{x}$						
Y-INTERCEPT	-2.866	-0.539	-0.312	-0.198	-0.074	0.010	0.086
ACWLOG	2.063	1.758	1.755	1.747	1.740	1.734	1.729
GRADLOG	-0.294	-0.159	-0.145	-0.141	-0.136	-0.132	-0.128
R-SQUARE	0.926	0.891	0.900	0.899	0.896	0.893	0.890
MEAN SQUARE	0.056	0.058	0.052	0.052	0.053	0.054	0.056
STANDARD ERROR	0.236	0.241	0.228	0.228	0.230	0.232	0.236
F-VALUE (MODEL)	230	151	167	165	160	155	149
(ACWLOG)	448	298	330	327	317	307	149
(GRADLOG)	11.9	3.32	3.11	2.95	2.68	2.46	2.25

TABLE C-1 (CONTINUED)

VARIABLES AND STATISTICS	$Q = a\ W^{b}\ SCC^{y}$ QA	Q2	Q5	Q10	Q25	Q50	Q100
Y-INTERCEPT	-2.389	-0.291	-0.122	-0.030	0.068	0.133	0.193
ACWLOG	2.220	1.784	1.777	1.769	1.760	1.754	1.745
SCCLOG	0.061	0.083	0.099	0.106	0.114	0.119	0.123
R-SQUARE	0.914	0.885	0.896	0.896	0.895	0.893	0.890
MEAN SQUARE	0.072	0.064	0.056	0.056	0.056	0.057	0.058
STANDARD ERROR	0.268	0.253	0.237	0.236	0.237	0.239	0.241
F-VALUE (MODEL)	201	146	164	164	162	159	154
(ACWLOG)	402	292	328	328	323	317	308
(SCCLOG)	0.14	0.29	0.46	0.54	0.61	0.66	0.69

	$Q = a\ W^{b}\ SC^{z}$						
Y-INTERCEPT	-2.415	-0.304	-0.128	-0.034	0.066	0.133	0.194
ACWLOG	2.217	1.781	1.774	1.766	1.757	1.751	1.745
SCLOG	0.077	0.092	0.104	0.110	0.116	0.120	0.123
R-SQUARE	0.914	0.885	0.896	0.896	0.894	0.893	0.890
MEAN SQUARE	0.072	0.064	0.056	0.056	0.056	0.057	0.085
STANDARD ERROR	0.268	0.253	0.237	0.236	0.238	0.239	0.212
F-VALUE (MODEL)	201	146	164	164	161	158	154
(ACWLOG)	402	292	328	328	322	316	307
(SCLOG)	0.18	0.28	0.41	0.46	0.51	0.54	0.55

TABLE C-2. SYSREG REGRESSION DATA.

VARIABLES AND STATISTICS	QA	Q2	Q5	Q10	Q25	Q50	Q100
			$Q = a\ W^{b}$				
Y-INTERCEPT	-2.001	-0.132	0.241	0.452	0.634	0.781	0.898
ACWLOG	1.980	1.770	1.610	1.510	1.440	1.370	1.320
R-SQUARE	0.902	0.884	0.887	0.875	0.863	0.848	0.834
MEAN SQUARE	0.077	0.061	0.058	0.064	0.070	0.077	0.084
STANDARD ERROR	0.278	0.247	0.242	0.253	0.264	0.278	0.289
			$Q = a\ W^{b}\ G^{x}$				
Y-INTERCEPT	-2.830	-0.544	-0.248	-0.103	0.058	0.170	0.265
ACWLOG	1.980	1.770	1.610	1.530	1.440	1.370	1.320
GRADLOG	-0.318	-0.155	-0.186	-0.203	-0.221	-0.235	-0.244
R-SQUARE	0.924	0.891	0.895	0.888	0.875	0.862	0.850
MEAN SQUARE	0.055	0.056	0.053	0.056	0.062	0.068	0.074
STANDARD ERROR	0.235	0.238	0.230	0.236	0.249	0.261	0.271

TABLE C-2 (CONTINUED)

$Q = a\ W^{b}\ SCC^{y}$

VARIABLES AND STATISTICS	QA	Q2	Q5	Q10	Q25	Q50	Q100
Y-INTERCEPT	-2.144	-0.276	0.049	0.214	0.395	0.525	0.630
ACWLOG	1.980	1.770	1.610	1.530	1.440	1.370	1.320
SCCLOG	0.080	0.084	0.112	0.125	0.139	0.149	0.156
R-SQUARE	0.903	0.885	0.889	0.880	0.866	0.851	0.838
MEAN SQUARE	0.078	0.062	0.059	0.062	0.070	0.077	0.084
STANDARD ERROR	0.280	0.249	0.243	0.251	0.264	0.278	0.290

$Q = a\ W^{b}\ SC^{z}$

Y-INTERCEPT	-2.212	-0.294	0.012	0.167	0.338	0.459	0.558
ACWLOG	1.980	1.770	1.610	1.530	1.440	1.370	1.320
SCLOG	0.119	0.094	0.132	0.151	0.172	0.187	0.197
R-SQUARE	0.903	0.885	0.889	0.880	0.866	0.851	0.838
MEAN SQUARE	0.078	0.062	0.059	0.063	0.070	0.077	0.084
STANDARD ERROR	0.280	0.249	0.243	0.250	0.264	0.278	0.289

TABLE C-3. STRUCTURAL ANALYSES DATA.

VARIABLES AND STATISTICS	QA	Q2	Q5	Q10	Q25	Q50	Q100
GLM: $Q = a\ W^{b}$							
Y-INTERCEPT	-2.481	-0.375	-0.164	-0.058	0.044	0.099	0.169
ACWLOG	2.390	1.980	1.960	1.950	1.950	1.96	1.950
R-SQUARE	0.908	0.874	0.886	0.886	0.883	0.880	0.877
MEAN SQUARE	0.072	0.067	0.059	0.058	0.059	0.061	0.062
STANDARD ERROR	0.268	0.259	0.242	0.242	0.244	0.247	0.249
SYSREG: $Q = a\ W^{b}$							
Y-INTERCEPT	-2.261	-0.400	0.009	0.197	0.368	0.504	0.597
ACWLOG	2.200	2.000	1.810	1.730	1.670	1.610	1.580
R-SQUARE	0.913	0.872	0.895	0.894	0.891	0.885	0.880
MEAN SQUARE	0.069	0.067	0.054	0.054	0.056	0.058	0.060
STANDARD ERROR	0.262	0.260	0.233	0.232	0.236	0.241	0.246

APPENDIX D

EXPLANATION OF THE FIGURES IN APPENDIX D

The figures in Appendix D are graphical representations of the regression and structural equations presented in this paper. As noted in the text (p. 57), not all of the regression equations were plotted and therefore are not found in this appendix.

Each of the figures is identified by the general form of the regression or structural equation that it represents. The regression lines for the individual discharges are identified by the appropriate symbol, i.e., QA, Q2, ..., etc.. The corresponding GLM and SYSREG equations are found in Table 4, p. 51, and the corresponding structural equations are found in Table 5, p. 55. The GLM equations use exponents derived from this study. The SYSREG equations use the imposed exponents (Osterkamp and Hedman, 1979).

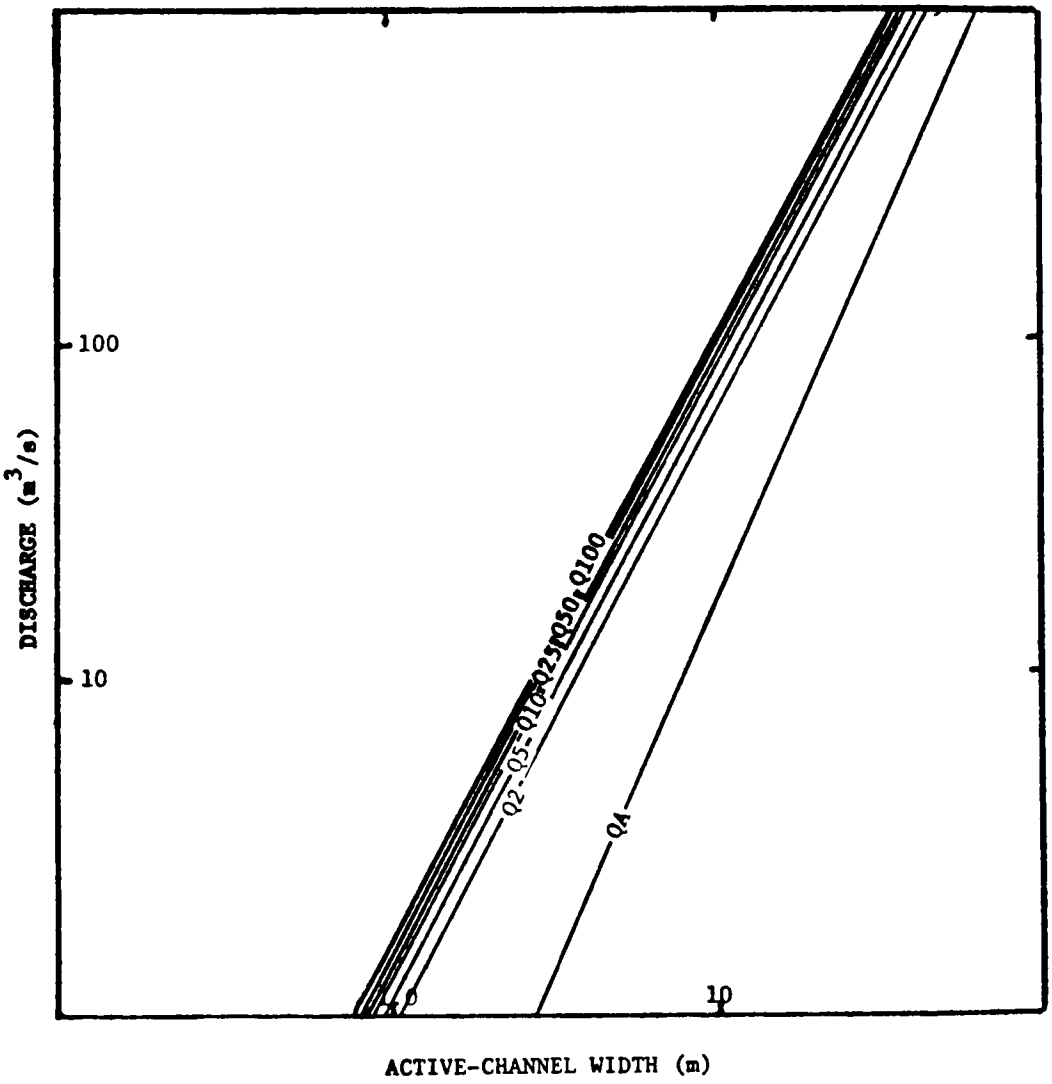


FIGURE D-1. REGRESSION RELATIONS FOR GLM EQUATION: $Q = a W^{b}$.

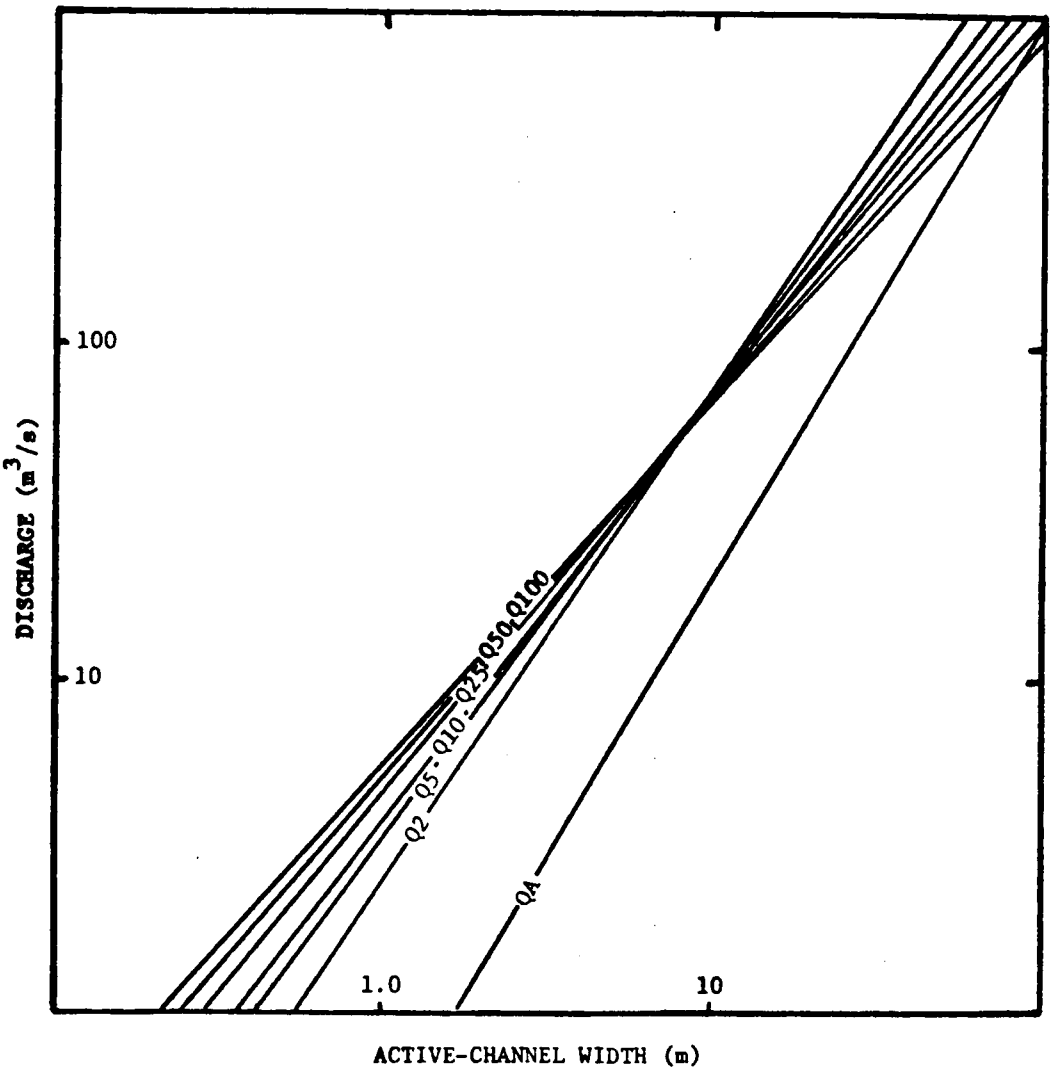


FIGURE D-2. REGRESSION RELATIONS FOR SYSREG EQUATION: $Q = a\ W^{b}$.

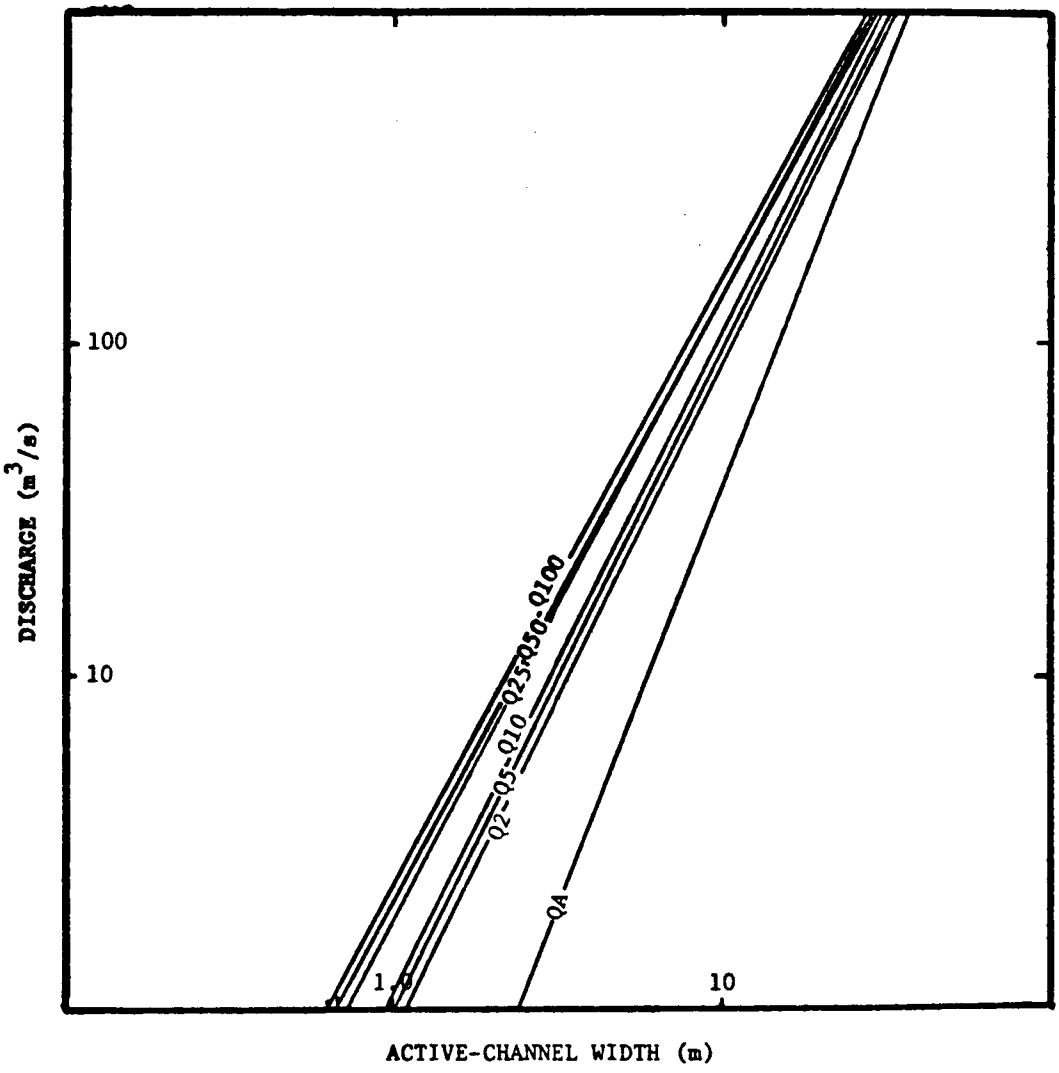


FIGURE D-3. REGRESSION RELATIONS FOR GLM EQUATION: $Q = a\ W^{b}\ G^{x}$, WHERE $G \leq 0.0045$.

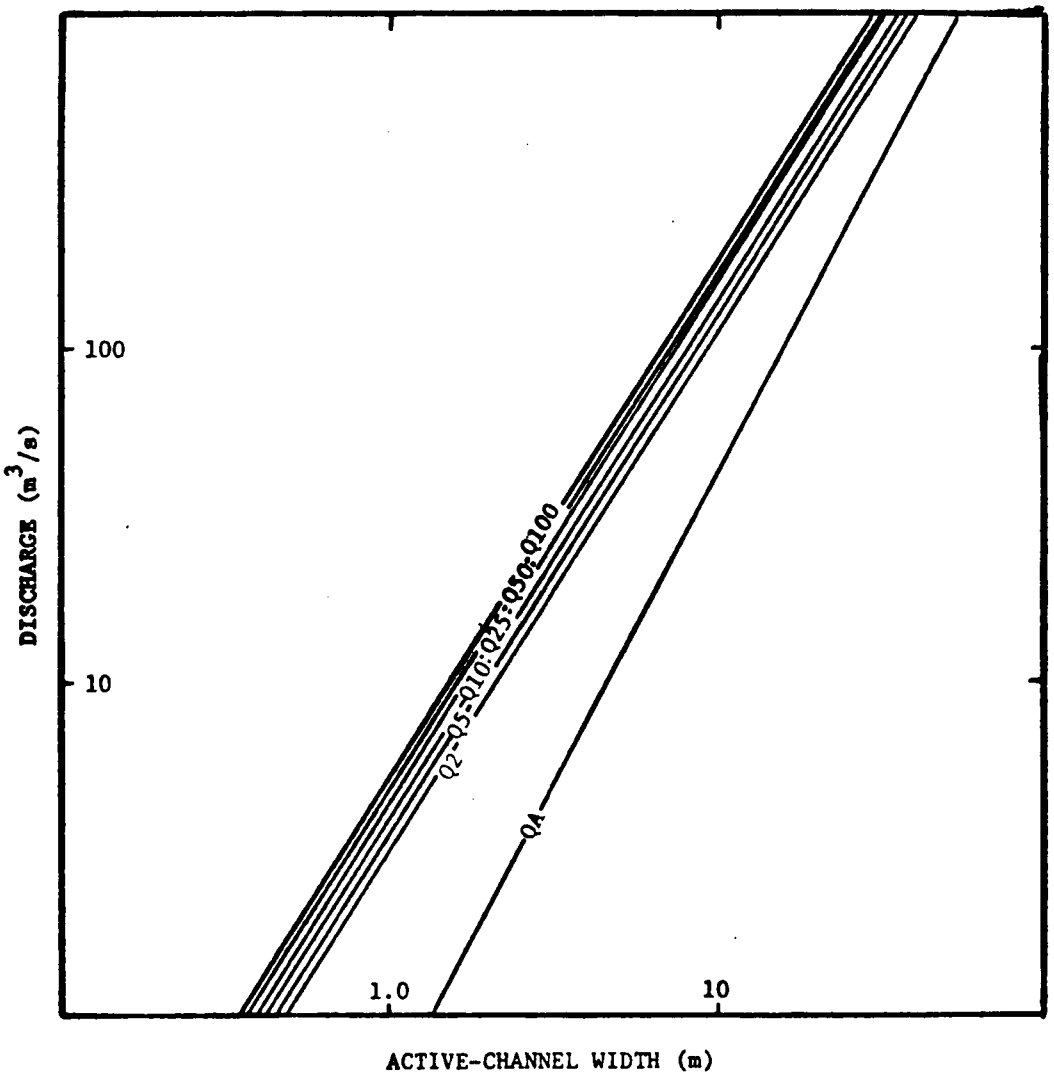


FIGURE D-4. REGRESSION RELATIONS FOR GLM EQUATION: $Q = a W^b G^x$, WHERE $G > 0.0045$.

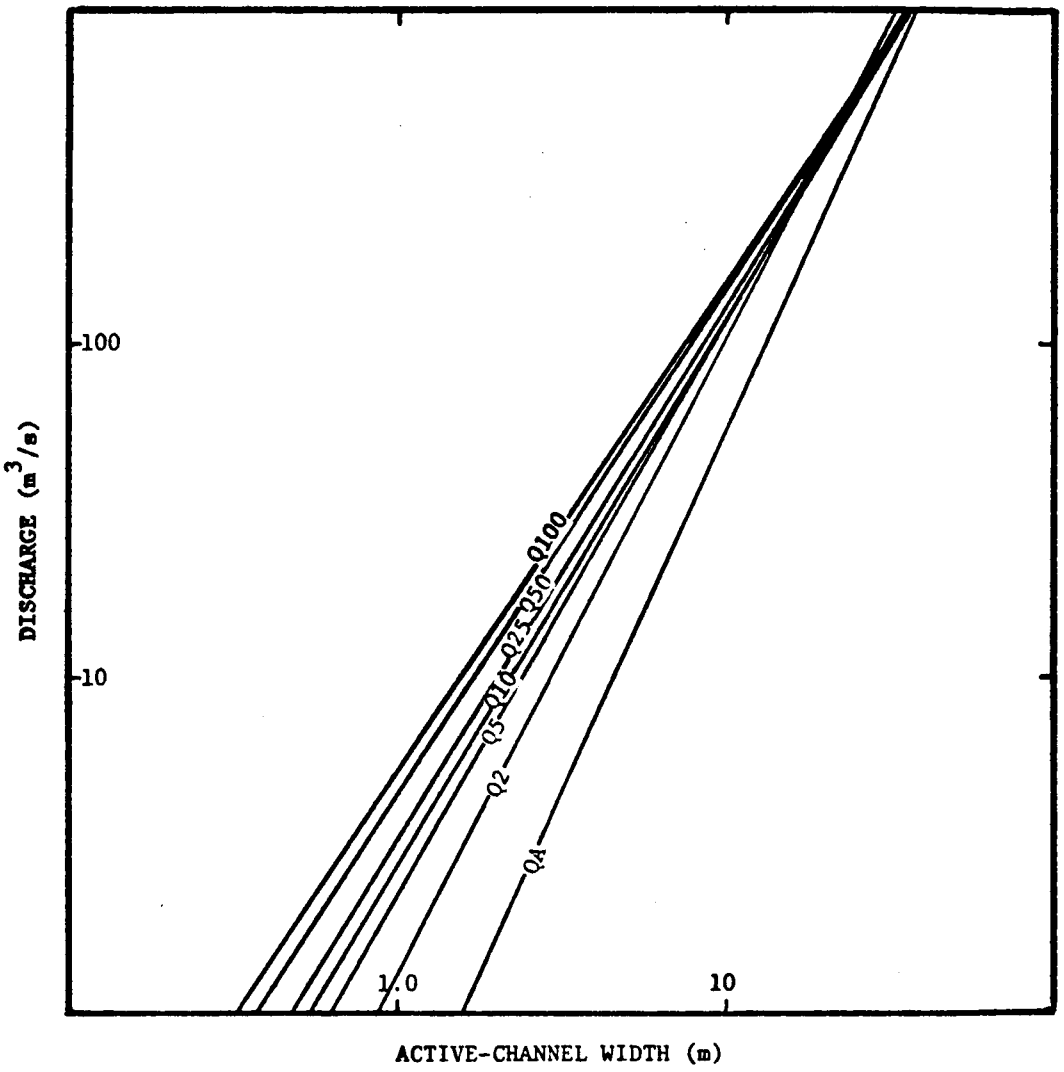


FIGURE D-5. REGRESSION RELATIONS FOR SYSREG EQUATION: $Q = a\ W^{b}\ G^{x}$, WHERE $G \leq 0.0045$.

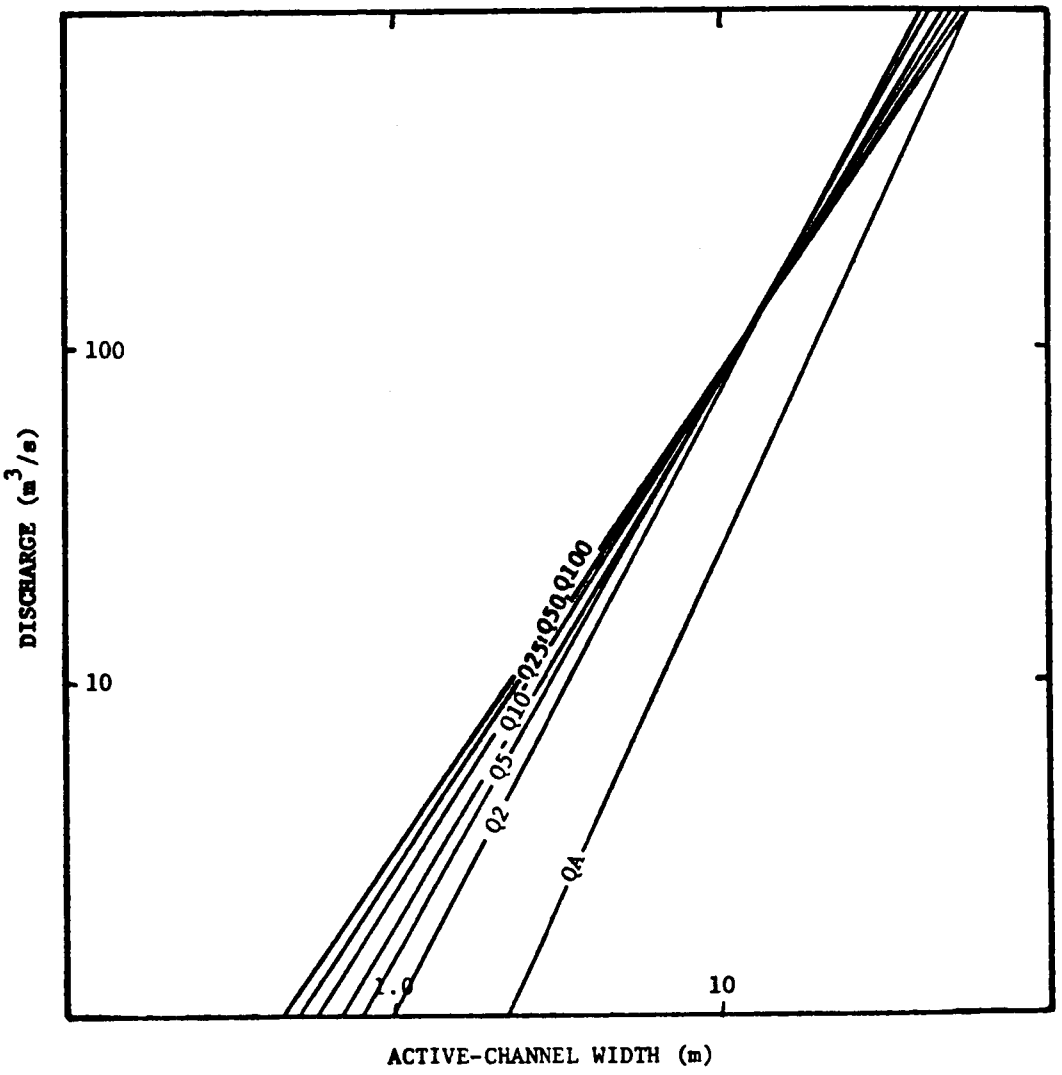


FIGURE D-6. REGRESSION RELATIONS FOR SYSREG EQUATION: $Q = a\ W^{b}\ G^{x}$, WHERE $G > 0.0045$.

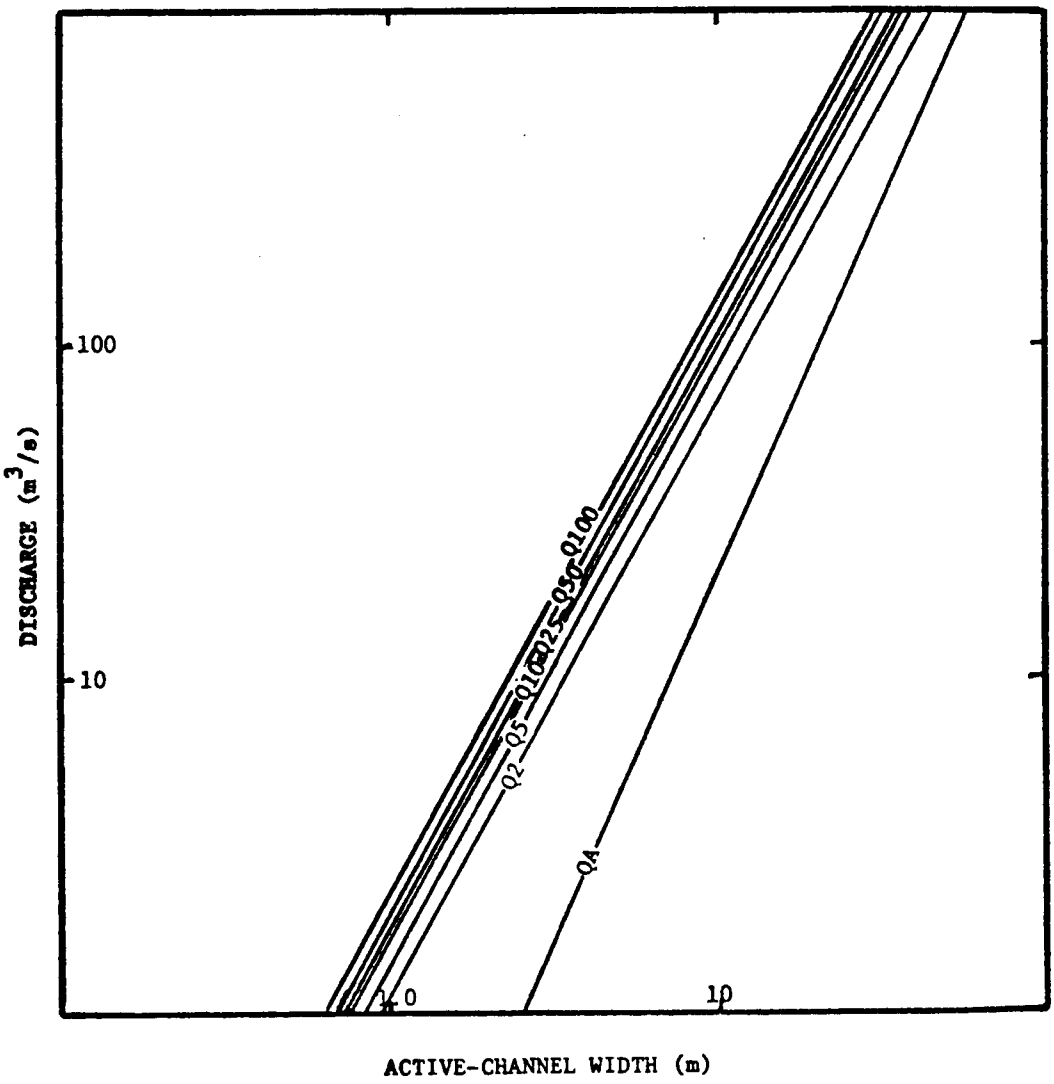


FIGURE D-7. REGRESSION RELATIONS FOR GLM EQUATION: $Q = a\ W^{b}\ SCC^{y}$, WHERE SCC $\geq$ 50 PERCENT.

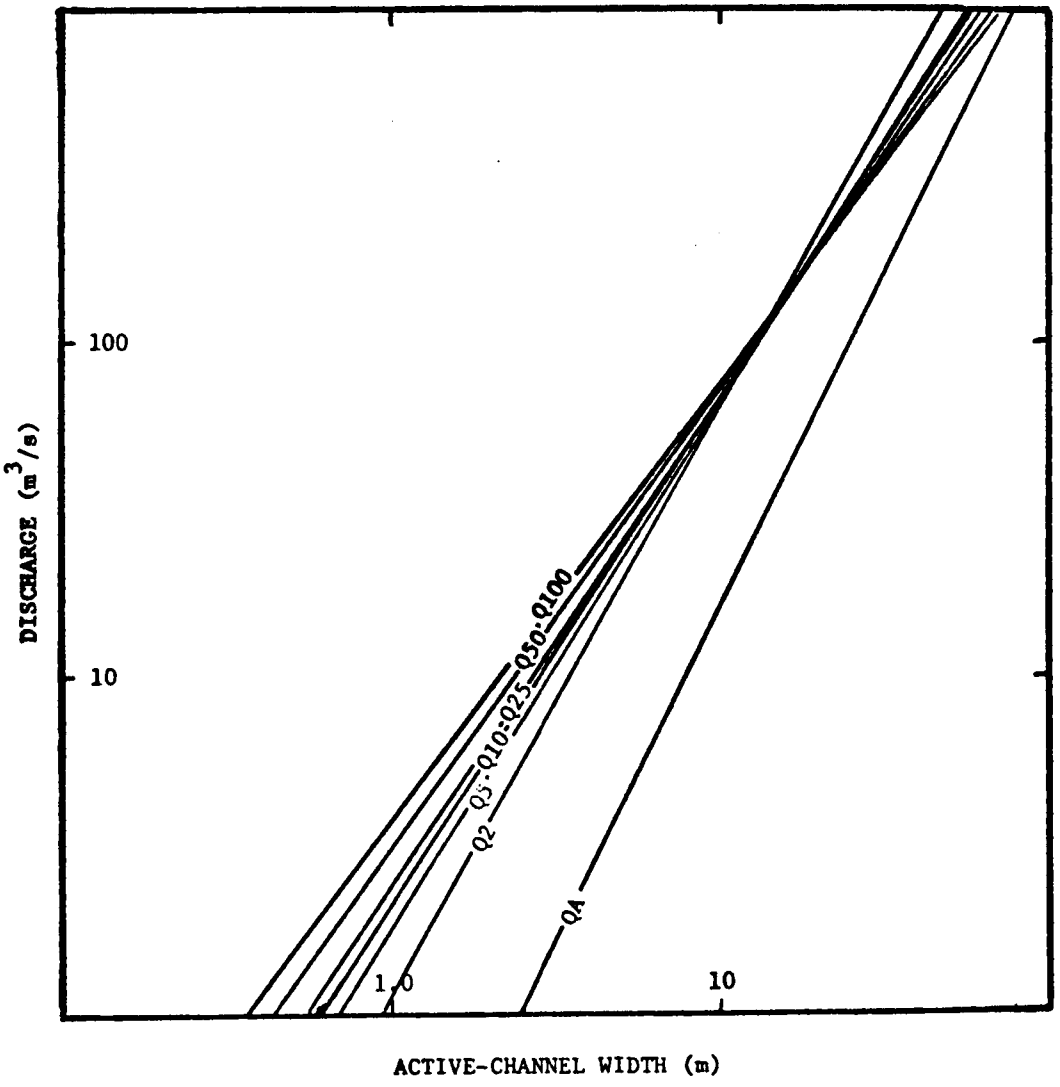


FIGURE D-8. REGRESSION RELATIONS FOR SYSREG EQUATION: $Q = a\ W^{b}\ SCC^{y}$, WHERE SCC $\geq$ 50 PERCENT.

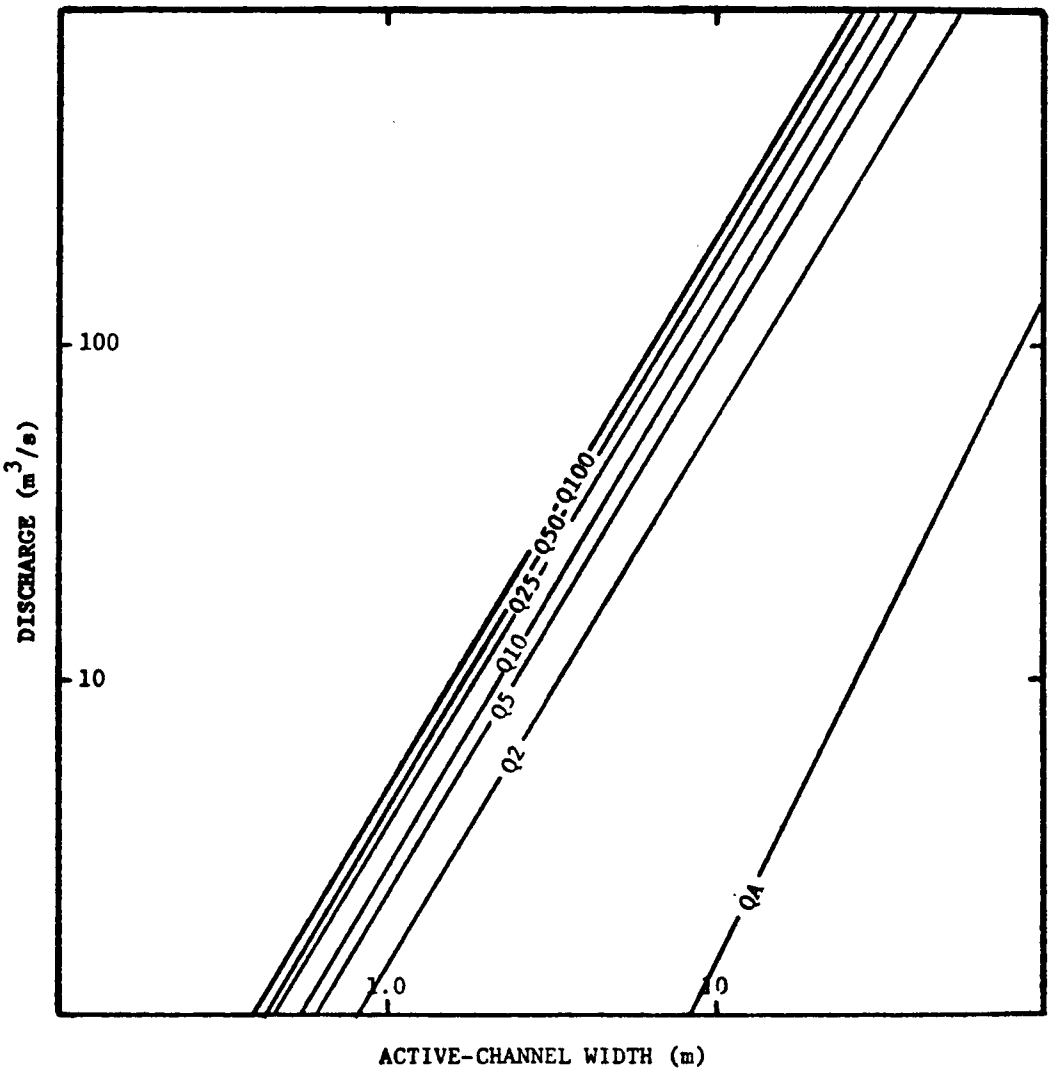


FIGURE D-9. STRUCTURAL RELATIONS FOR GLM EQUATION: $Q = a W^{b}$.

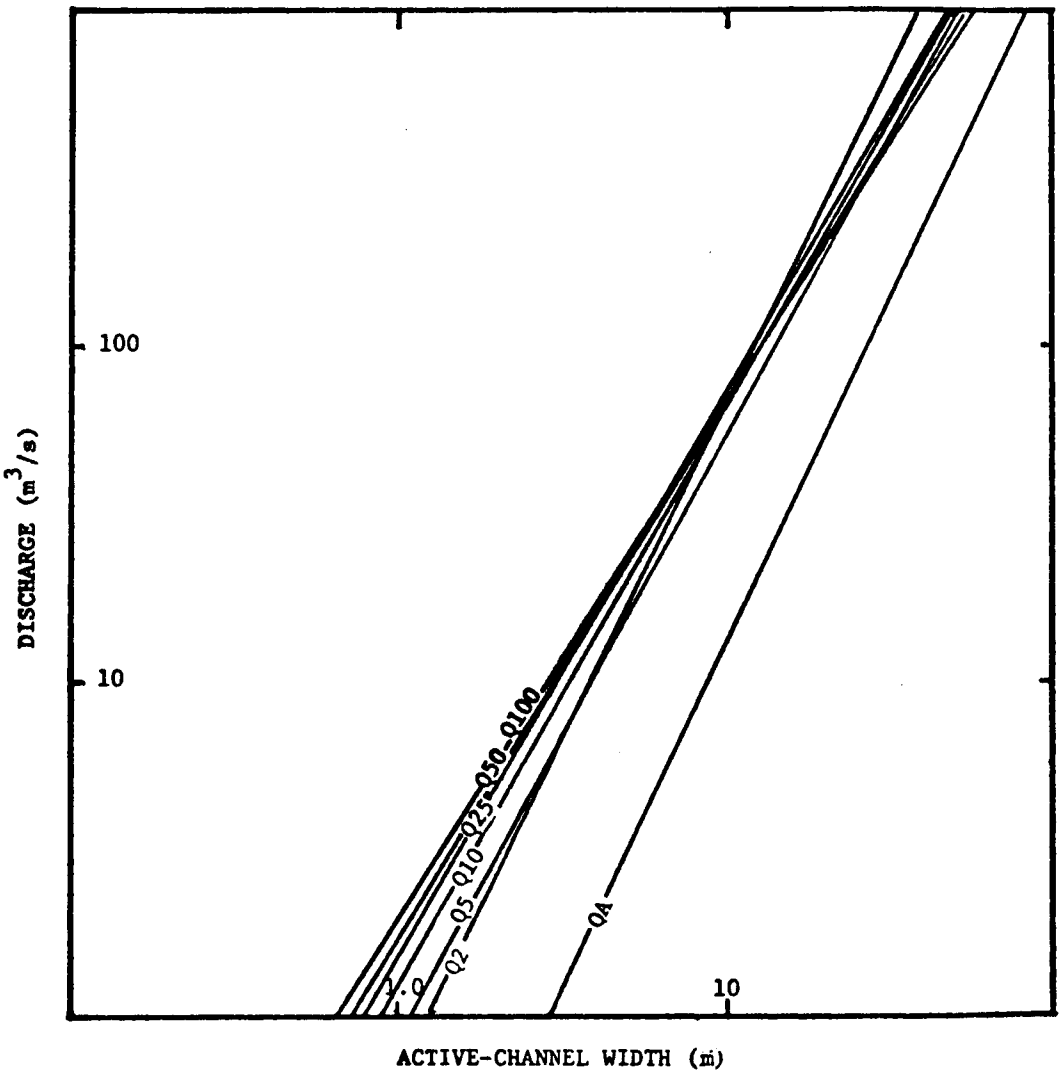


FIGURE D-10. STRUCTURAL RELATIONS FOR SYSREG EQUATION: $Q = a\ W^{b}$.

APPENDIX E

EXPLANATION OF DATA IN APPENDIX E

The data in Appendix E are conversion factors. Table E-1 gives the standard to metric conversion values used in this paper. Table E-2 gives the conversion of standard error values in logarithmic values to percent values.

TABLE E -1. CONVERSION FACTORS.

MULTIPLY ENGLISH UNITS	BY	FOR METRIC UNITS
INCHES (IN)	2.54	CENTIMETERS (CM)
FEET (FT)	.305	METERS (M)
MILES (MI)	1.61	KILOMETERS (KM)
SQUARE FEET (FT^2)	.0929	SQUARE METERS (M^2)
SQUARE MILES (MI^2)	2.59	SQUARE KILOMETERS (KM^2)
CUBIC FEET PER SECOND (FT^3/SEC)	.02832	CUBIC METERS PER SECOND (M^3/SEC)
DEGREES FARENHEIT (^oF)	5/9 after subtracting 32	DEGREES CELSIUS (^oC)

TABLE E-2. CONVERSION OF LOGARITHMIC VALUES TO PERCENT.

log units	Percent +	Percent -	Percent ave.	Diff.	log units	Percent +	Percent -	Percent ave.	Diff.
0.01	2.3	2.3	2.3	2.3	0.21	62.2	38.3	50.2	2.6
.02	4.7	4.5	4.6	2.3	.22	66.1	39.7	52.8	2.6
.03	7.2	6.6	6.9	2.3	.23	69.8	41.1	55.4	2.7
.04	9.5	8.8	9.2	2.4	.24	73.8	42.5	58.1	2.7
.05	12.2	10.9	11.6	2.3	.25	77.8	43.8	60.8	2.7
.06	14.8	12.9	13.9	2.3	.26	81.9	45.0	63.5	2.7
.07	17.4	14.9	16.2	2.3	.27	86.5	46.3	66.2	2.8
.08	20.2	16.8	18.5	2.4	.28	90.5	47.5	69.0	2.8
.09	23.1	18.7	20.9	2.3	.29	95.0	48.7	71.8	2.7
.10	25.9	20.6	23.2	2.4	.30	99.5	49.9	74.7	2.9
.11	28.8	22.4	25.6	2.4	.31	104.2	51.0	77.6	2.9
.12	31.8	24.1	28.0	2.4	.32	108.9	57.1	80.5	3.0
.13	34.9	25.9	30.4	2.4	.33	113.8	53.2	83.5	3.0
.14	38.0	27.6	32.8	2.4	.34	118.8	54.3	86.5	3.1
.15	41.3	29.2	35.2	2.4	.35	123.9	55.3	89.6	Diff. %
.16	44.5	30.8	37.6	2.5					16.1 .322
.17	47.9	32.4	40.1	2.5	.40	151.2	60.2	105.7	17.4 .348
.18	51.4	33.9	42.6	2.5	.45	181.8	64.5	123.1	19.2 .354
.19	54.9	35.4	45.1	2.5	.50	216.2	68.4	142.3	21.0 .420
.20	58.5	36.9	47.6	2.5	.55	254.8	71.8	163.3	23.2 .464

Proportional Parts

Diff.	1	2	3	4	5	6	7	8	9
2.3	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.8	2.1
2.4	.2	.5	.7	1.0	1.2	1.4	1.7	1.9	2.2
2.5	.2	.5	.8	1.0	1.2	1.5	1.8	2.0	2.2
2.6	.3	.5	.8	1.0	1.3	1.6	1.8	2.1	2.3
2.7	.3	.5	.8	1.1	1.4	1.6	1.9	2.2	2.4
2.8	.3	.6	.8	1.1	1.4	1.7	2.0	2.2	2.5
2.9	.3	.6	.9	1.2	1.4	1.7	2.0	2.3	2.6
3.0	.3	.6	.9	1.2	1.5	1.8	2.1	2.4	2.7
3.1	.3	.6	.9	1.2	1.6	1.9	2.2	2.5	2.8

VITA

Charles F. Glazzard was born in Ann Arbor, Michigan on February 9, 1954. He received his elementary education in the Topeka, Kansas public school system and his secondary education in the Burlington, Iowa public school system. He graduated from Burlington Community High School in May 1972. He attended Southeast Iowa Community College in Burlington, Iowa and Johnson County Community College in Overland Park, Kansas. In August 1974, he entered the University of Kansas in Lawrence, Kansas, and graduated with a Bachelor of Arts degree, with a major in Geology, in December 1977.

In January 1979, he entered graduate school at the University of Tennessee in Knoxville, Tennessee where he served as a teaching assistant during his entire enrollment. He received a Master of Science degree, with a major in Geology, in March 1981.

He has worked as a Hydrologic Technician with the U. S. Geological Survey's Water Resources Division District Office in Lawrence, Kansas from October 1977, to November 1978, and in the Knoxville, Tennessee Subdistrict Office from January 1979, to January 1981.

He was wed to Yoshiko Suzuki of Kyoto, Japan in July 1980.