A TECHNIQUE FOR DETERMINING DEPTHS FOR T-YEAR DISCHARGES IN RIGID-BOUNDARY CHANNELS

U. S. GEOLOGICAL SURVEY

Water-Resources Investigations 77-83

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle A TECHNIQUE FOR DETERMINING DEPTHS FOR T-YEAR DISCHARGES IN RIGID-BOUNDARY CHANNELS			5. Report Date December 1977 6.
7. Author(s) Durl E. Burkham			8. Performing Organization Rept. No. USGS/WRI 77-83
9. Performing Organization Name and Address U.S. Geological Survey Water Resources Division 345 Middlefield Road Menlo Park, CA 94025			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey Water Resources Division 345 Middlefield Road Menlo Park, CA 94025			13. Type of Report & Period Covered Final 14.
15. Supplementary Notes			

16. Abstracts A simplified technique for determining T-year flood-boundary altitudes for natural channels having channel controls is presented in this report. Channel-control conditions usually exist during T-year discharges in natural rigid-boundary channels; therefore the simplified technique probably would be applicable for flood-inundation studies for many rigid-boundary channels. The technique requires that T-year discharge for a reach of interest be known or readily available; also a channel-shape factor, a width at a reference depth, channel-bottom slope (or water-surface slope) and the Manning's roughness factor, n, must be estimated or determined at representative cross sections. The standard error of estimate or the flood-boundary altitudes determined according to the simplified technique is not known; however, it is probably about 25 to 30 percent. In comparison, the standard error of estimate for the flood-boundary altitudes determined according to guidelines given in the report Flood Insurance Study, Guidelines and Specifications by U.S. Department of Housing and Urban Development is about 23 percent.

17. Key Words and Document Analysis. 17a. Descriptors

*Floods, *Hydraulics, Natural streams, Discharge, Roughness (hydraulic), Flood profiles, Flood frequency, Flood plain zoning

17b. Identifiers/Open-Ended Terms

100-year discharge, FIA flood studies, Simplified flood-mapping technique

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution.	UNCLASSIFIED	43
	20. Security Class (This Page) UNCLASSIFIED	22. Price

A TECHNIQUE FOR DETERMINING DEPTHS FOR T-YEAR DISCHARGES IN RIGID-BOUNDARY CHANNELS

By Durl E. Burkham

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 77-83

December 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

For additional information write to:

District Chief
Water Resources Division
U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	*By*	*To obtain metric unit*
ft (feet)	0.3048	m (meters)
ft^2 (square feet)	.0929	m^2 (square meters)
ft^3/s (cubic feet per second	.02832	m^3/s (cubic meters per second)
mi (miles)	1.609	km (kilometers)

A TECHNIQUE FOR DETERMINING DEPTHS FOR T-YEAR DISCHARGES IN RIGID-BOUNDARY CHANNELS

By Durl E. Burkham

ABSTRACT

A simplified technique is presented for determining depths for *T*-year discharges (the discharge that will occur, on an average, once in *T*-years--10 years, 50 years, 100 years) for natural channels (channels not significantly affected by manmade structures) having channel-control conditions and rigid boundaries (channels having a low probability of change that would significantly affect the hydraulic characteristics of a *T*-year discharge). Channel-control conditions usually exist during *T*-year discharges in natural rigid-boundary channels and, therefore, the simplified technique probably would be applicable for flood-inundation studies for many natural rigid-boundary channels. The technique requires that the *T*-year discharge for a reach of interest be known or readily available; also, a channel-shape factor, a width at a reference altitude, a channel-bottom slope (or a water-surface slope), and the Manning's roughness factor, n, must be estimated or determined at representative sections having channel-control conditions. The standard error of estimate for depths determined according to the simplified technique is not known; however, it is probably 25-30 percent. In comparison, the standard error of estimate for the depths determined according to the step-backwater procedure and to guidelines and specifications for flood-insurance studies of the Federal Insurance Administration is about 23 percent.

INTRODUCTION

Public Law 93-235, Flood Disaster Protection Act of 1973, requires the U.S. Geological Survey and other selected Federal agencies to assist the Federal Insurance Administration (FIA) of the U.S. Department of Housing and Urban Development (HUD) in identifying flood-prone areas. Present study guidelines (U.S. Department of Housing and Urban Development, 1976) for mapping flood-prone areas require detailed and time-consuming analyses, which only a few Federal agencies and a limited number of private engineering firms have the competence to perform. An acceptable simplified approach that would have a broad application for mapping flood plains and for making floodway analyses could alleviate manpower stresses.

Several simplified methods for determining flood-boundary altitudes have been developed by the U.S. Geological Survey. However, these simplified methods are not directly applicable for nonnatural channels--channels affected by bridges, lined canals, dams, reservoirs; for sheet flow; for movable-boundary channels--channels that have a high probability of temporal change that would significantly affect the hydraulic characteristics of a T-year discharge; and for floodway analyses.

This report is a result of studies concerned with the development of a simplified technique that would be applicable to mapping of flood plains along natural and nonnatural channels. The discussions that are presented in the present report, however, are pertinent only to the development of equations for T-year depths in rigid-boundary channels having channel-control characteristics during a T-year discharge and to the application of the equations to a selected study reach. Unless otherwise stated, a T-year depth for a site of interest is the water-surface altitude for a T-year discharge minus the channel-bottom altitude (point of zero flow, altitude at which water ceases to move in the channel). A T-year discharge for a site or reach of interest is the discharge that will occur, on an average once in T-years--10 years, 50 years, 100 years.

The term "control" (or control of flow) means the establishment of definite flow conditions in the channel or, more specifically, a definite relation between discharge and depth of flow. True controls in an open channel are of two types, channel and section. A true channel control exists when the physical characteristics of a reach of a uniform channel downstream from a site of interest determines the relation between discharge and depth at the site. A true section control exists when the physical characteristics of a single cross section of a stream control the relation between discharge and depth. True controls may exist in a natural channel. Typically, however, for a site in a natural rigid-boundary channel a relatively short length of channel having the characteristics of a section control exists for relatively low flows and a relatively long length of channel having the characteristics of a channel control is effective for relatively high discharges. The section-control condition for low flows in a natural channel may be the result of a single riffle or the result of a restricted width for a single short length of channel. The channel-control condition for high flows may be the result of a long reach of a fairly uniform channel; however, it ordinarily results from the composite effects of restricted width at several relatively short lengths of channel. This report deals primarily with relatively high discharges; therefore, the remaining discussions in this report, unless otherwise stated, pertain primarily to relatively high discharges in natural rigid-boundary channels having channel-control conditions.

APPROACH TO SOLUTION

Introduction

The approach used to determine *T*-year depths in a reach of interest is based on the premise that:

1. A *T*-year discharge is known or is readily obtainable.

2. Depth for a *T*-year discharge usually does not vary greatly in a relatively long reach of a natural rigid-boundary channel; the water-surface profile approximately parallels the channel-bottom profile and the average depth can adequately represent (errors introduced are not prohibitive) depth in the reach.

3. Depth of flow is a function of discharge and the physical characteristics--channel size, shape, slope, and roughness--of lengths of channel in the reach that are partial or true controls.

4. Depth of flow in a length of channel having the characteristics of a partial control can be adequately determined using a small amount of field data.

5. The average of computed depths for a few representative partial controls can be used to represent average depth in the reach.

Six basic steps are required in determining depths for *T*-year discharges in a reach of interest:

1. Determine a *T*-year discharge.

2. Develop a channel-bottom profile.

3. Determine the locations of partial (or true) controls in the reach.

4. Compute depths for *T*-year discharges by equations for representative cross sections for a few of these partial controls; to do this a small amount of field data must be obtained.

5. Average the depths determined in step 4.

6. Develop a water-surface profile by graphically adding the average depth, obtained in step 5, to the channel-bottom profile developed in step 2.

The development of an inundation map would involve an additional step (step 7), the transfer of altitudes from the water-surface profile to a topographic map.

A brief description of steps 1, 2, and 3 follows in this section. A detailed discussion concerned with the development of equations to be used to compute depths at representative cross sections in lengths of channel that have the characteristics of controls (step 4) is presented in the section "Depths for *T*-year discharges in channels having channel-control conditions." Step 5 is self-explanatory. Descriptions of steps 6 and 7 are presented by an example in the section "Application of method."

T-Year Discharge

A *T*-year discharge determination for a reach of interest is based on a flood-frequency analysis. If a long-term record of discharge is available for a site, the flood-frequency analysis consists of the development of a flood-frequency curve from which the *T*-year discharge is obtained directly (U.S. Water Resources Council, 1976). For a typical case, however, records are not available and flood-frequency information must be transferred from gaged sites to ungaged sites.

Flood information based on long-term records for a gaged site can be transferred to a site of interest on the same gaged stream by one of several schemes. Generally, however, T-year discharges at sites near gaging stations on the same stream are computed by the following equation:

$$Q_{T_{(u)}} = \left(\frac{A_u}{A_g}\right)^X Q_{T_{(g)}} \qquad (1)$$

where

$Q_{T_{(u)}}$ = T-year discharge at an ungaged site on a gaged stream;

$Q_{T_{(g)}}$ = T-year discharge at a gaged site;

A_u = drainage area for the ungaged site;

A_g = drainage area at a gaged site; and

X = exponent.

The value of X to be used for a hydrologic region must be evaluated or estimated. Generally, X will range from 0.5 to 0.8.

The transfer of T-year information from gaged sites to ungaged sites on other streams is usually done by regression of the T-year floods on the physical and climatic characteristics of drainage basins. A characteristic regression equation has the following form:

$$Q_T = aA^b P^c S^d \qquad (2)$$

where

Q_T = T-year discharge;

A = size of drainage area;

P = precipitation index;

S = slope of the principal channel; and

a, b, c, d = regression constants.

The U.S. Geological Survey, in 1970, made state-by-state studies to define regression equations for T-year discharges for ungaged streams. The details for the equations obtained by the regression study are shown in open-file reports available at the 47 district offices of the U.S. Geological Survey (Benson and Carter, 1973).

Channel-Bottom Profile

The altitudes and distances needed to develop a channel-bottom profile for a reach of interest may be scaled from a topographic map, which shows altitude contours, or they can be determined by field surveys. When altitudes and distances are taken from a topographic map, the accuracy of the contours must be considered. The standard error of ground altitudes taken from topographic maps is about one-fourth the contour interval. Generally, field surveys are made if topographic maps having a contour interval smaller than about 5 ft are not available. In field surveys, point altitudes can be determined very accurately; however, for practical purposes, thalweg altitudes are not usually determined closer than about ±0.5 ft.

Controls

The criteria for locating sites at which depths for a given flow rate can be computed by equations are, in general, the same as those for slope-area measurements (Dalrymple and Benson, 1967). A reconnaissance-level survey of the study reach is necessary for the selection of sites. Experience, good judgment, and a thorough knowledge of the hydraulic principles of open-channel flow are essential for the proper selection of the sites. The channel-bottom profile developed in step 3, contour maps, and aerial photographs are useful aids.

DEPTHS FOR T-YEAR DISCHARGES IN CHANNELS HAVING CHANNEL-CONTROL CONDITIONS

Introduction

The relation between discharge and depth for relatively high flows (T-year events) in channels having channel-control conditions usually can be adequately represented as a straight line on logarithmic graph paper; this is one method to extend rating curves when high-discharge measurements are not available. The general equation for the discharge-depth relation is

$$d = CQ^f \tag{3}$$

or

$$\log d = \log C + f \log Q \tag{4}$$

in which

d = depth of water;

C = a coefficient; equals effective depth when Q equals 1;

f = slope of the discharge-depth relation; and

Q = discharge.

Both the coefficient and the exponent for the logarithmic straight-line equation are functions of the physical characteristics of the controls of flow. Theoretical considerations, experience, judgment, and a minimal amount of field data are the basis for estimating values for the coefficient, C, and exponent, f, in the discharge-depth relation.

Development of Equation

The thesis of this report is that, providing the T-year discharge is known, Manning's discharge equation can be used to make reasonably accurate estimates of C and f for channel-control conditions without obtaining detailed field information. Manning's discharge equation for English units is

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2} \tag{5}$$

in which

n = a roughness coefficient;

A = cross-sectional area, in square feet;

R = hydraulic radius at a cross section, in feet; equals the cross-sectional area, in square feet, divided by the wetted perimeter, in feet;

S = energy gradient.

Manning's discharge equation was developed for uniform flow in which the water-surface profile and energy gradient are parallel to the streambed, and the area, hydraulic radius, and depth remain constant throughout the reach. The equation is considered valid for nonuniform conditions, such as that for most natural channels, if the energy gradient or friction slope is modified to reflect only losses due to boundary friction (Barnes, 1967, p. 5). Manning's discharge equation is widely used for conditions of channel control to compute flow rates; however, detailed data pertinent to channel boundary characteristics must be measured in the field.

Several assumptions and simplifications must be made before Manning's equation can be used to estimate C and f. For a T-year discharge it is assumed that R can be adequately represented by the mean cross-sectional depth, $\bar{d}$, and S can be represented by the channel slope, S_o, or by the water-surface slope, S_w. The area, A, in equation 5 is represented by the mean depth, $\bar{d}$, multiplied by the top width, W.

Width in a rigid-boundary channel is a function of depth. For a wide range of flood depths in typical rigid-boundary channels, a depth-width relation can be represented as a straight line on logarithmic graph paper. As used in this study, the general equation for logarithmic straight-line relation is

$$W = a_1(d)^x \tag{6}$$

or

$$\log W = \log a_1 + x \log d \tag{7}$$

The parameter x is a function of channel shape; it is 0 for a rectangular shape, 1/2 for a parabolic shape, and 1 for a triangular shape.

Considering the assumptions and simplifications presented in the preceding paragraphs, Manning's discharge equation can be represented by

$$Q = a_1 \frac{1.49}{n} \left(\overline{d}\right)^{5/3} (d)^x S_o{}^{1/2} \tag{8}$$

A further simplification is made; $\overline{d}$ is represented by the formula "$\overline{d} = a_2 d$." The parameter a_2 also is a function of channel shape; it is 1 for a rectangular shape, 1/2 for a triangular shape, and 2/3 for a parabolic shape. The depth, d, now can be represented by

$$d = \left(\frac{n}{a_1(a_2)^{5/3}(1.49)(S_o)^{1/2}}\right)^{3/(5+3x)} (Q)^{3/(5+3x)} \tag{9}$$

Equation 9 is directly comparable to equation 3 and, therefore,

$$C = \left(\frac{n}{a_1(a_2)^{5/3}(1.49)(S_o)^{1/2}}\right)^f \tag{10}$$

and

$$f = \left(\frac{3}{(5+3x)}\right) \tag{11}$$

Equations 9, 10, and 11 are approximately correct for stage-discharge relations for high discharges in uniform channels. They are assumed to be adequate in approximating depths for high discharges at partial-control sites (restricted sections) in natural channels having channel-control conditions. The value x would range from 0 to 1 and, therefore, f would range from 0.60 to 0.38 for rigid-boundary channels. The typical natural channel is approximately parabolic in shape, for which f would be 0.46. The writer determined that the average value of f was 0.42 for the high-discharge segment of 539 stage-discharge relations for selected sites in Iowa, Maryland, Minnesota, New York, North Carolina, Ohio, and Wisconsin; the standard deviation for the 539 sites was 0.12.

Testing of Equation

Data from a report by Barnes (1967) were used to test the algebraic form of equation 9. For the Barnes data, Q, d, n, and S_w were known or were readily obtainable for sites in 50 stream channels in the United States. In the test analyses a parabolic cross-sectional shape was assumed for each site, and therefore a_2 is 2/3, x is 1/2, and f is 0.46.

Equation 6 was used to compute values for a_1; this required a reference depth, d_r, and a reference width, W_r. For a cross section of interest, a reference altitude was assumed, d_r was determined, and the corresponding value for W_r was scaled from the appropriate graph in Barnes' report. The assumed reference altitude was based on a judgment that the formula $\frac{W}{(d)^x} = a_1 \approx \frac{W_r}{(d_r)^x}$ was adequately satisfied.

The procedures for estimating a_1 using equation 6 and for estimating d using equation 9 are presented by use of a sample computation. The data from Barnes (1967) for reach 3-4 in the stream channel at the gaging station "South Fork Clearwater River near Grangeville, Idaho" are used for this purpose. Section 4 represents a restricted section in the reach. The peak discharge for the flood of May 28, 1948, at this site is 12,600 ft ^{3}/s (Barnes, 1967, p. 158-159); n is 0.05; measured depth, d_m, is 12 ft; and the slope of the water surface, S_w, is 0.0080 (2.85 divided by 357). Values of n and S_w for cross-section 4 were needed for the computation; however, these values were not available. The use of 0.05 and 0.0080, which are for the reach 3-4, probably introduces errors in the computation. Above an altitude of 20 ft (fig. 1), equation 6 probably adequately represents width because there is no abrupt increase in width with an increase in depth. The reference depth, d_r, therefore, is taken to be 7.0 ft and was determined by subtracting the channel-bottom altitude 13.0 ft from 20.0 ft. The width, W_r, is 124 ft at 20.0 ft altitude (fig. 1). When these values for depth and width are entered in equation 6, the computed a_1, which represents the apparent width at 1.0 depth, is 46.9 ft. When the 46.9 ft for a_1 and the other pertinent numerical values described in this paragraph are entered in equation 9, the computed depth is 11.3 ft, which is 0.7 ft less than the measured depth.

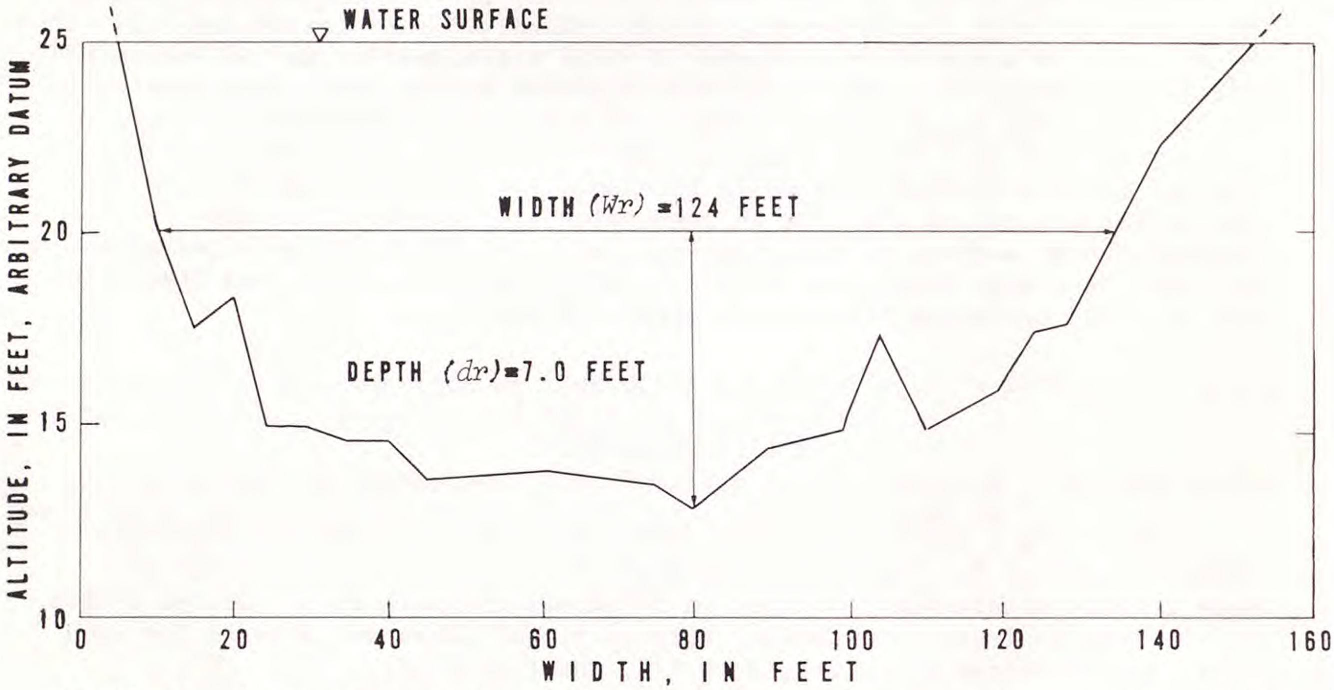

FIGURE 1.--Cross section, South Fork Clearwater River near Grangeville, Idaho. (Modified from Barnes, 1967, p. 159, cross section 4.)

The computed depths, flood characteristics, and cross-sectional properties for the Barnes data are presented in table 1. Except for the site "Columbia River at Vernita, Wash." (not shown in table), flood depths were computed for all sites. An apparent discrepancy exists for the Columbia River data; for cross-section 3 (Barnes, 1967, p. 11), the mean depth is shown to be approximately equal to the maximum depth. For the site "Beaver Kill at Cooks Falls, N.Y.," an apparent discrepancy exists for cross-section 7 (Barnes, 1967, p. 59); the vertical axis for altitude is not calibrated correctly. Data for cross-section 6 were used in the computation for Beaver Kill.

The standard error of estimate for computed depths for the Barnes data is about 10 percent; apparently there is little, if any, overall bias in computed depths (fig. 2). The standard error of estimate for computed flood depths for most sites in natural channels, however, probably would be larger than 10 percent. The Manning's n is unknown for most sites in natural channels and estimate of n would have to be made for these sites in order to use equation 9. Errors would be introduced with these estimates.

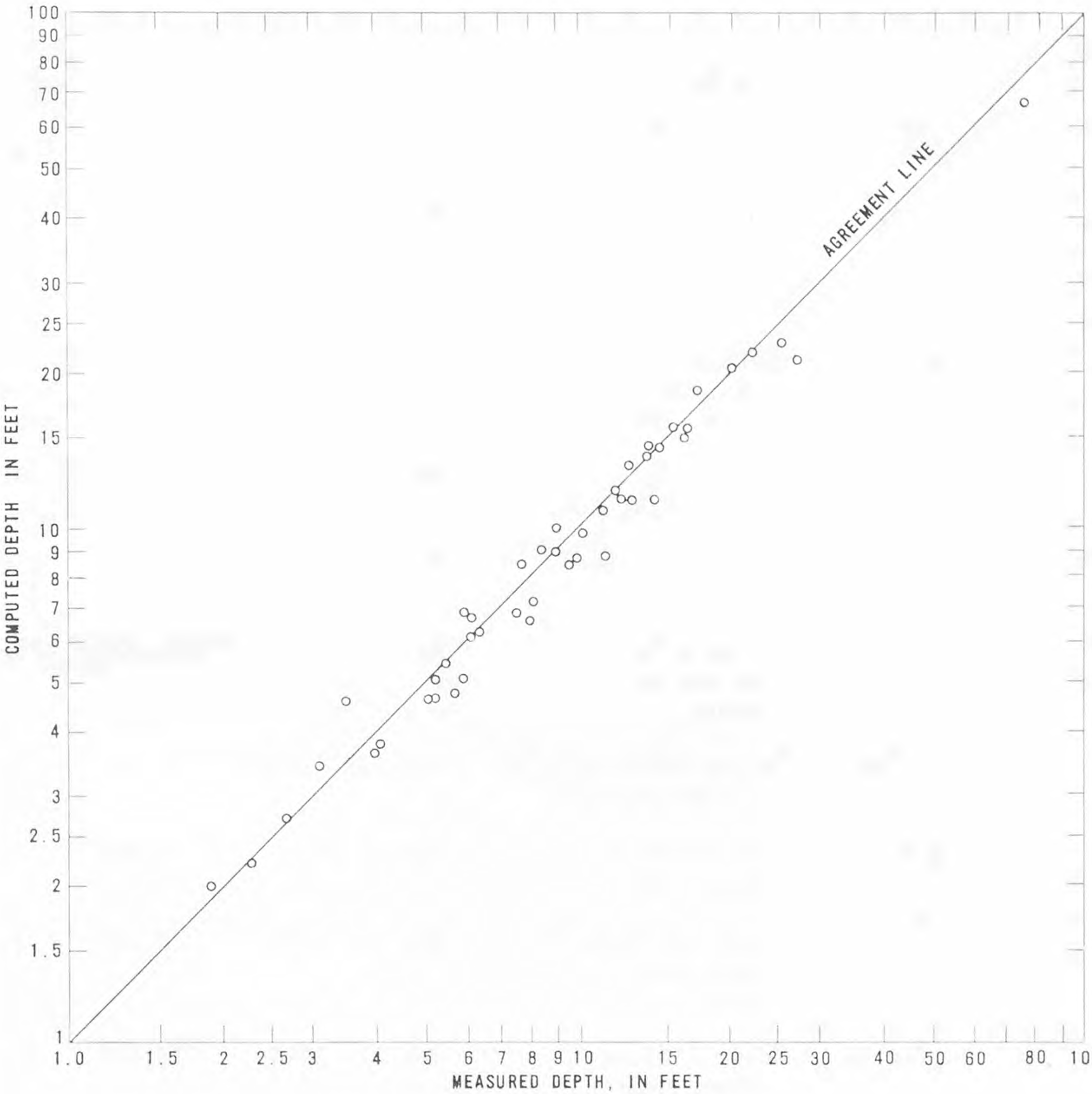

FIGURE 2.—Computed depth compared with measured depth.

Table 1.--*Flood characteristics, cross-sectional properties, and*

Station		Flood characteristics		
Number	Name	Date	Discharge (ft^3/s)	Measured depth d_m (feet)
3-1215.	Indian Fork below Atwood Dam, near New Cumberland, Ohio	May 11, 1948	768	6.3
8-1235.	Champlin Creek near Colorado City, Tex.	May 17, 1949	2,390	5.7
12-3545.	Clark Fork at St. Regis, Mont.	May 24, 1948	68,900	20.0
12-3405.	Clark Fork above Missoula, Mont.	May 23, 1948	31,500	13.5
14-1057.	Columbia River at The Dalles, Oreg.	May 31, 1948	1,000,000	75.0
1-3625.	Esopus Creek at Coldbrook, N.Y.	Mar. 22, 1948	13,900	7.2
6-8030.	Salt Creek at Roca, Nebr.	May 2, 1954	1,860	13.5
12-3385.	Blackfoot River near Ovando, Mont.	May 22, 1948	8,200	7.5
12-4120.	Coeur d'Alene River near Pritchard, Idaho	May 21, 1948	11,300	10.0
8-2900.	Rio Chama near Chamita, N. Mex.	Mar. 24, 1950	1,060	5.2
9-5020.	Salt River below Stewart Mountain Dam, Ariz.	Mar. 24, 1950	1,280	2.7

computed depths for stream-channel sites described by Barnes (1967)

Station Number	Manning's roughness coefficient, n	Cross-sectional properties: Water-surface slope, S_w	Reference depth, d_r (feet)	Reference width, W_r (feet)	Coefficient a_2	a_1	C	Computed depth (feet)
3	0.026	0.00025	1.5	40	0.67	33.2	0.28	6.1
4	.027	.00480	1.0	42	.67	42.0	.13	4.7
3	.028	.00073	5.0	300	.67	134	.12	20.2
4	.030	.00061	2.5	260	.67	168	.12	13.8
4	.030	.00029	25.0	1,250	.67	250	.12	66.4
2	.030	.00340	3.0	220	.67	130	.09	7.2
3	.030	.00037	2.0	19	.67	13.4	.42	13.6
2	.031	.00230	2.0	160	.67	110	.11	6.7
4	.032	.00300	4.5	130	.67	62.2	.13	9.6
2	.032	.00120	1.7	60	.67	46.0	.19	4.6
7	.032	.00340	1.0	110	.67	110	.10	2.7

Table 1.--*Flood characteristics, cross-sectional properties, and*

Station		Flood characteristics		
Number	Name	Date	Discharge (ft^3/s)	Measured depth d_m (feet)
1-4205.	Beaver Kill at Cooks Falls, N.Y.	Mar. 22, 1948	15,500	9.0
13-3390.	Clearwater River at Kamiah, Idaho	May 29, 1948	99,000	25.0
2-3890.	Etowah River near Dawsonville, Ga.	Jan. 22, 1959	2,260	14.0
12-3425.	West Fork Bitterroot River near Conner, Mont.	May 29, 1948	3,880	5.9
12-4845.	Yakima River at Umtanum, Wash.	May 29, 1948	27,000	14.0
5-Misc.	Middle Fork Vermilion River near Danville, Ill.	May 1, 1956	1,620	3.2
12-4570.	Wenatchee River at Plain, Wash.	May 29, 1948	22,700	12.5
12-3065.	Moyie River at Eastport, Idaho	May 24, 1948	8,030	8.5
12-4225.	Spokane River at Spokane, Wash.	May 31, 1948	39,600	22.0
2-2135.	Tobesofkee Creek near Macon, Ga.	Mar. 7, 1958	2,540	12.5
8-1185.	Bull Creek near Ira, Tex.	June 1, 1948	3,220	9.8

computed depths for stream-channel sites described by Barnes (1967)--Continued

Station Number	Cross-sectional properties: Manning's roughness coefficient, n	Water-surface slope, S_w	Reference depth, d_r (feet)	Reference width, W_r (feet)	Coefficient: a_2	a_1	C	Computed depth (feet)
6	0.033	0.00230	3.0	210	0.67	121	0.10	8.9
3	.033	.00120	11.0	460	.67	139	.11	22.6
11	.041	.00084	5.0	50	.67	22.4	.32	11.1
3	.036	.00460	1.0	82	.67	82.0	.11	5.0
3	.036	.00280	5.0	180	.67	78.0	.13	14.1
3	.037	.00330	1.0	96	.67	96.0	.11	3.4
3	.037	.00230	5.0	200	.67	89.4	.13	12.9
4	.038	.00470	5	115	.67	51.4	.14	8.9
4	.038	.00130	10	230	.67	72.7	.16	21.1
17	.043	.00077	3.5	60	.67	39.5	.22	11.1
2	.041	.00120	2.0	65	.67	46.0	.21	8.7

Table 1.--*Flood characteristics, cross-sectional properties, and*

Station		Flood characteristics		
Number	Name	Date	Discharge (ft^3/s)	Measured depth d_m (feet)
12-3557.	Middle Fork Flathead River near Essex, Mont.	May 22, 1948	14,500	11.0
2-2175.	Middle Oconee River near Athens, Ga.	May 31, 1959	6,110	16.0
6-3940.	Beaver Creek near Newcastle, Wyo.	May 30, 1953	1,600	13.0
13-3200.	Catherine Creek near Union, Oreg.	May 27, 1948	1,740	5.2
12-4565.	Chiwawa River near Plain, Wash.	May 29, 1948	5,880	8.0
1-3625.	Esopus Creek at Coldbrook, N.Y.	Mar. 22, 1948	13,900	11.0
13-3190.	Grande Ronde River at La Grande, Oreg.	May 22, 1948	4,620	7.6
2-2210.	Murder Creek near Monticello, Ga.	Feb. 7, 1958	840	8.0
10-1550.	Provo River near Hailstone, Utah	June 13, 1952	1,200	4.1
3-3015.	Rolling Fork near Boston, Ky.	Mar. 11, 1949	6,090	27.0
2-1885.	South Beaverdam Creek near Dewy Rose, Ga.	Nov. 26, 1957	820	6.1

computed depths for stream-channel sites described by Barnes (1967)--Continued

Station Number	Manning's roughness coefficient, n	Water-surface slope, S_w	Reference depth, d_r (feet)	Reference width, W_r (feet)	Coefficient a_2	Coefficient a_1	Coefficient C	Computed depth (feet)
	Cross-sectional properties							
5	0.041	0.00250	2.5	127	0.67	80.3	0.14	11.1
5	.042	.00055	5.0	100	.67	58.5	.20	15.3
2	.043	.00124	2.0	18	.67	12.7	.39	11.5
3	.043	.00620	1.0	37	.67	37.0	.16	5.0
4	.043	.00680	2.5	105	.67	66.4	.12	6.5
2	.043	.00450	4.0	139	.67	70.0	.13	10.6
3	.043	.00240	3.0	88	.67	50.8	.17	8.4
8	.045	.00260	3.5	23	.67	12.3	.34	7.5
9	.045	.00970	1.0	40	.67	40	.14	3.8
6	.046	.00038	5.0	60	.67	26.8	.37	20.4
5	.052	.00094	2.0	43	.67	30.4	.30	6.6

Table 1.--*Flood characteristics, cross-sectional properties, and*

Station		Flood characteristics		
Number	Name	Date	Discharge (ft^3/s)	Measured depth d_m (feet)
2-1005.	Deep River at Ramseur, N.C.	Dec. 28, 1958	8,300	16.0
6-7195.	Clear Creek near Golden, Colo.	May 26, 1958	1,380	5.1
2-3310.	Chattahoochee River near Leaf, Ga.	Feb. 7, 1959	5,100	9.0
13-3380.	South Fork Clearwater River near Grangeville, Idaho	May 29, 1948	12,600	12
11-4510.	Cache Creek near Lower Lake, Calif.	Jan. 24, 1951	3,840	11.2
4-2750.	East Branch Ausable River at Au Sable Forks, N.Y.	Mar. 31, 1951	7,790	9.5
1-1805.	Middle Branch Westfield River at Gross Heights, Mass.	Mar. 22, 1948	3,400	3.5
12-4620.	Mission Creek near Cashmere, Wash.	May 19, 1955	123	2.3
2-935.	Haw River near Benaja, N.C.	Dec. 29, 1958	1,000	6.0
12-1135.	North Fork Cedar River near Lester, Wash.	Dec. 15, 1959	996	4.0
3-4485.	Hominy Creek at Candler, N.C.	June 16, 1949	6,460	15.2

Station Number	Cross-sectional properties: Manning's roughness coefficient, *n*	Water-surface slope, S_w	Reference depth, d_r (feet)	Reference width, W_r (feet)	Coefficient a_2	Coefficient a_1	Coefficient *C*	Computed depth (feet)
7	0.049	0.00091	5.0	112	0.67	50.0	0.23	14.6
15	.050	.01410	2.0	40	.67	28.3	.16	4.6
5	.051	.00104	2.5	115	.67	73.0	.19	9.9
4	.051	.00800	7.0	124	.67	46.9	.15	11.3
3	.053	.0500	8.8	33	.67	11.1	.19	8.5
2	.055	.00560	3.0	125	.67	72.2	.14	8.4
2	.056	.00870	1.0	93	.67	93.0	.11	4.6
3	.057	.01500	1.0	13	.67	13.2	.24	2.2
7	.059	.00130	5.0	75	.67	33.0	.28	6.8
4	.059	.0230	1.0	30	.67	30.0	.15	3.6
3	.060	.00176	4.0	62	.67	31.0	.23	15.6

Table 1.--*Flood characteristics, cross-sectional properties, and*

Station		Flood characteristics		
Number	Name	Date	Discharge (ft^3/s)	Measured depth d_m (feet)
12-3455.	Rock Creek Canal near Darby, Mont.	Sept. 23, 1948	138	1.9
11-2645.	Merced River at Happy Isles Bridge, near Yosemite, Calif.	June 17, 1950	1,950	6.4
3-3020.	Pond Creek near Louisville, Ky.	Feb. 14, 1950	1,480	17.0
12-3215.	Boundary Creek near Porthill, Idaho	May 28, 1948	2,530	6.2
12-3450.	Rock Creek near Darby, Mont.	May 27, 1948	1,500	5.5

computed depths for stream-channel sites described by Barnes (1967)--Continued

Station Number	Cross-sectional properties: Manning's rough-ness coeffi-cient, n	Water-surface slope, S_w	Reference depth, d_r (feet)	Reference width, W_r (feet)	Coefficient: a_2	a_1	C	Computed depth (feet)
7	0.060	0.0170	1.0	19	0.67	19.0	0.20	2.0
4	.065	.00861	2.0	46	.67	32.0	.19	6.2
7	.070	.00048	5.0	25	.67	11.0	.62	17.8
4	.073	.01530	1.0	32	.67	32.0	.18	6.6
3	.075	.0520	4	33	.67	16.5	.19	5.4

The accuracy of an estimated roughness coefficient, *n*, is unknown. Because the only bases for selecting a roughness coefficient are judgment, experience and a set of guidelines, and because its value during flow in a natural channel depends on a number of time-variant and space-variant factors, the accuracy may not be good. Some of the factors in a reach that probably exert the greatest influence on the roughness coefficient are: (1) Flow-boundary roughness, (2) size and shape of stream channel and flood plain, (3) stream-channel irregularity and alinement, (4) vegetation, (5) obstructions, (6) flow depth and rate, (7) filling and scouring, (8) size and concentration of sediment in the flow, and (9) bed form. Conditions encountered in natural channels are outside the range of "judgment and experience" at times.

Data were not available or readily obtainable so that the standard error of estimate for estimated roughness coefficient could be determined directly. Data for the 50 sites described by Barnes (1967), however, were used to obtain a number that was used to represent the standard error of estimate for estimated roughness coefficient *n*. The number obtained is assumed to be only a rough approximation of the standard error because the procedure used to obtain the number did not have rigid controls to insure against biasing the results. For each of the sites, the photographs, description of the channel, the plan sketch, and the graph of the cross section were used by six hydrologists as a basis for selecting *n* values independently. In estimating *n* values, the experience of the six ranged from a veteran to a beginner. The report by Barnes (1967) was not available to the six hydrologists while they were estimating *n* values.

The *n* values estimated by the six hydrologists ranged from 54 to 203 percent, and averaged 100 percent, of the verified values. The square root of the mean variance for the 300 individual percentages was 18.7. The variance of estimates of *n* reported by Riggs (1976) at 20 of the 50 sites was also computed; these selections were made in the field before the *n* verifications reported by Barnes (1967) were made. The estimated *n* values taken from the report by Riggs (1976) ranged from 76 to 155 percent, and averaged 103 percent, of the verified values. The square root of the mean variance for the 56 individual percentages from Riggs' report was 18.

The 18.7 percent (square root of the mean variance) probably is significantly larger than the standard error of estimate that would have been obtained if a better controlled experiment had been run. For example, it is agreed by most hydrologists that pictures are a very poor substitute for actually viewing a reach in the field, and a beginner would generally have someone with which to discuss field-selected values. Furthermore, the experiment totally disregards the review process set up to review the *n* values selected.

The 18.7 percent was used to represent the standard error of estimate even though the value probably is larger than the true standard error. The 18.7 percent, however, is not applicable directly to the current problem; the standard error in percentage of depth that results because of errors in the n value is needed for this study. By ignoring the interrelation between n and the other variables on the right side of equation 9, the standard error in log d resulting from errors in log n can be represented as

$$(\log d)_{\text{ERROR}} = f\ (\log n)_{\text{ERROR}} \qquad (12)$$

Equation 12 says that the standard error in depth, d, in log units resulting because of errors in n is f times the standard error in n in log units. The log-unit equivalent of 18.7 percent is 0.081; 0.46 was used to represent f even though it probably is larger than the true value for a typical natural stream (see page 9). The resulting standard error in d, in log units, is 0.037, which represents an error of 8 percent.

The standard error of estimate for computed depths for the sites described by Barnes (1967) probably would be insignificantly less than 13 percent (of the depth) if the n value were estimated. The 13 percent was determined using the formula "standard error = $\left((10)^2+(8)^2\right)^{\frac{1}{2}}$" in which 10 represents the standard error (in percent of depth) for computed depths when n values are known and 8 represents a standard error (in percent of depth) for estimated n values. The errors, represented by the 8 and 10 percentages, are assumed to be independent. The 13 percent is considered a reasonable approximation of the true standard error of estimate for equation 9 but only when the equation is used to estimate T-year depths at sections having partial-control characteristics.

APPLICATION OF METHOD

A 9.67-mi reach of Little Sugar Creek in North Carolina was selected to demonstrate the simplified technique for determining 100-year depths. The North Carolina reach is one of three suggested by E. J. Kennedy (oral commun., 1976) for a demonstration study. A report describing the results of a HUD type-15 study for the reach is being prepared (W. H. Eddins, written commun., 1976); therefore, data for the demonstration study were readily available.

Ordinarily, data needed to determine T-year depths by the simplified method would be obtained during a field survey. These data are: an average value of n; assumed values for x and a_2 based on channel shape; measured width for an assumed depth; and channel or water-surface slopes. For the demonstration study, however, data extracted from those obtained for the HUD type-15 study were used (U.S. Department of Housing and Urban Development, 1976).

The data for the study reach furnished by W. H. Eddins (written commun., 1976) consisted of topographic maps; physiographic properties listed on computer printouts; 10-, 50-, 100-year discharges; a stream-channel profile; and water-surface profiles for 10-, 50-, and 100-year floods. The topographic maps, which are at a scale of 1:4,800 for subreach A and 1:2,400 for subreach B, show the locations of 113 cross sections, altitude contours at 4-ft intervals for subreach A, and altitude contours at 2-ft intervals for subreach B. Subreach A extends from the South Carolina State boundary to about 0.6 mi north of the northern boundary of Pineville City (fig. 3). Subreach B extends from about 0.6 mi north of Pineville City to the bridge at Park Road in Charlotte, N. C.

The computer printouts showed data pertinent to step-backwater computations (Bailey and Ray, 1966) which are required for detailed flood-inundation studies according to the U.S. Department of Housing and Urban Development (1976) guidelines. These data included ground altitudes and distances along the 113 cross sections; n values for subsections of the cross sections; distances between cross sections; and cross-sectional properties--area, conveyance, alpha, width, wetted perimeter, distances for the left and right edges of water for different water-surface altitudes for each of the cross sections.

Equations 3, 6, 9, 10, and 11 were used to determine 100-year depths at 11 selected cross sections in subreach A (fig. 3). The 11 cross sections were selected because they were representative of "restrictive" widths in the total reach and, therefore, probably represent partial controls. The average of the 11 depths was used to represent the average depth for the 9.67-mi reach. For the analysis, parabolic cross-sectional shape was assumed and, therefore, 2/3 was used to represent a_2 in equation 9, 1/2 was used to represent x in equations 6 and 9, and 0.46 was used to represent f in equations 3, 10, and 11.

Data extracted from those furnished by Eddins for the 11 cross sections were roughness coefficients, reference widths needed to compute a_1, and channel slope, S_o. A roughness coefficient for a cross section was obtained by averaging the n values given for the subsections of a section. A value of a_1 for a cross section was determined according to the following steps:

1. A reference depth of 14 ft was obtained by using 0.2 for C and 10,900 ft^3/s for discharge in equation 3. The average of C values shown in table 1 is 0.2, and the 10,900 ft^3/s is the 100-year discharge for the study reach (W. H. Eddins, written commun., 1976).

2. The reference depth was added to the channel-bottom altitude to give a reference altitude.

3. The channel width at the reference altitude was determined directly from data shown on the computer printouts.

4. The reference depth, the reference width, and x equal to 1/2 were used in equation 6 to compute a_1.

The reference depth normally would have been selected on the basis of cross-sectional shape. In order to eliminate the task of developing cross-section profiles for the 11 sections, the 14-ft reference depth was used.

The method used to determine 100-year depths at a "restrictive" width in the study reach is illustrated by use of the computations for cross section 14 (fig. 3). The roughness coefficient used in the computation was represented by 0.065, the average of the n values for subsections A (0.075), B (0.045), and C (0.075), respectively (fig. 4). The channel-bottom altitude for cross section 14 is 527.6 ft; therefore, the reference altitude is 541.6 ft. The channel width at altitude 541.6 ft is 180 ft. A value for a_1, determined by dividing 180 by $\sqrt{14}$, is 48.1 ft. The channel-bottom slope, 0.00138, for the site was obtained by dividing the difference in channel-bottom altitude at cross sections 3 and 4 by the length of channel between the two cross sections. The 100-year depth for cross-section 4 was determined to be 18.2 ft.

The procedure of determining a value of n for a section by averaging the n values for subsections probably introduces errors in the computation. According to H. F. Matthai (written commun., 1977), a value to represent n for a section determined by weighting n values by conveyance of subsections or by subsection areas would be preferable to an arithmetic average. Weighted averages were not determined for the following reasons:

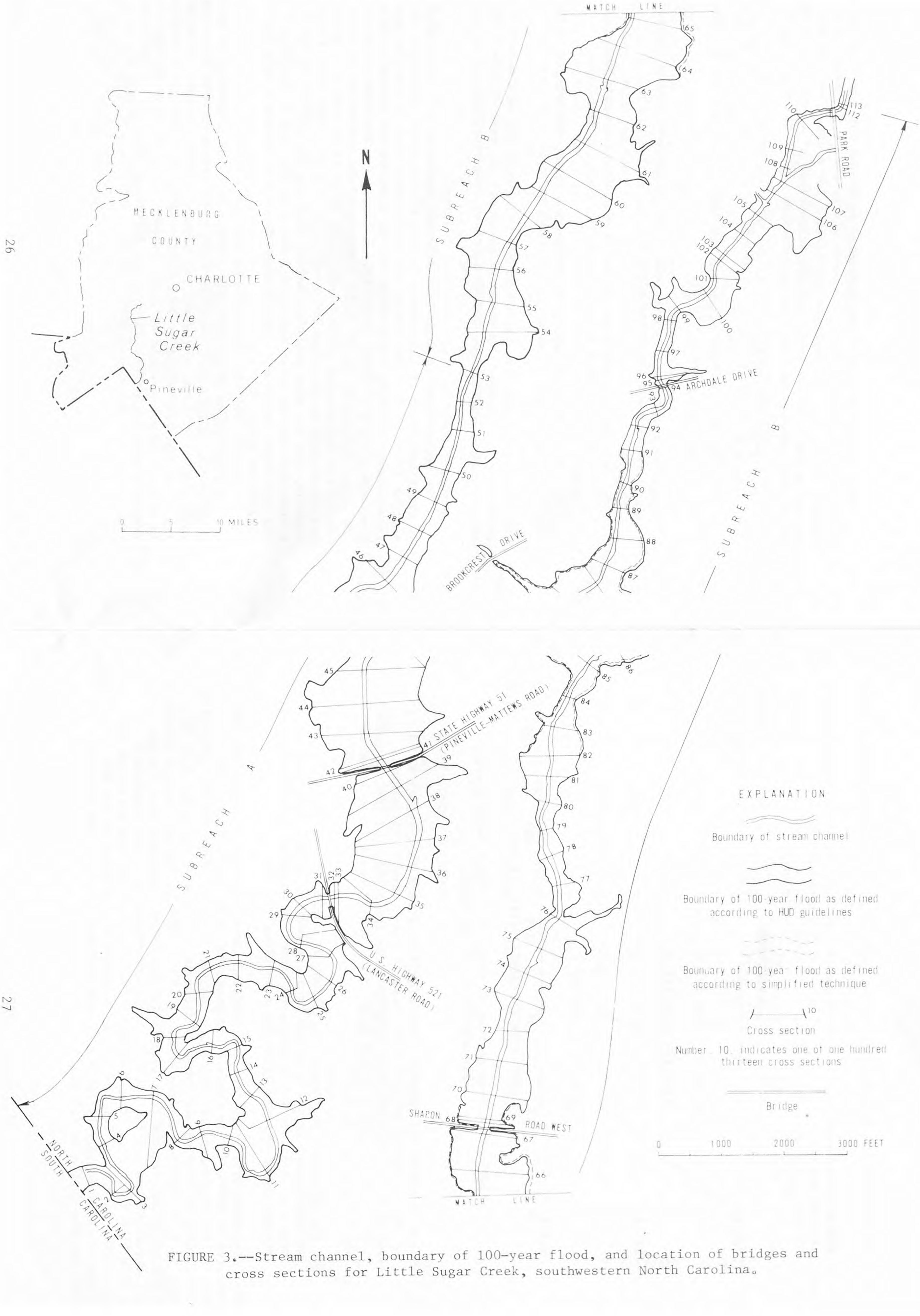

FIGURE 3.--Stream channel, boundary of 100-year flood, and location of bridges and cross sections for Little Sugar Creek, southwestern North Carolina.

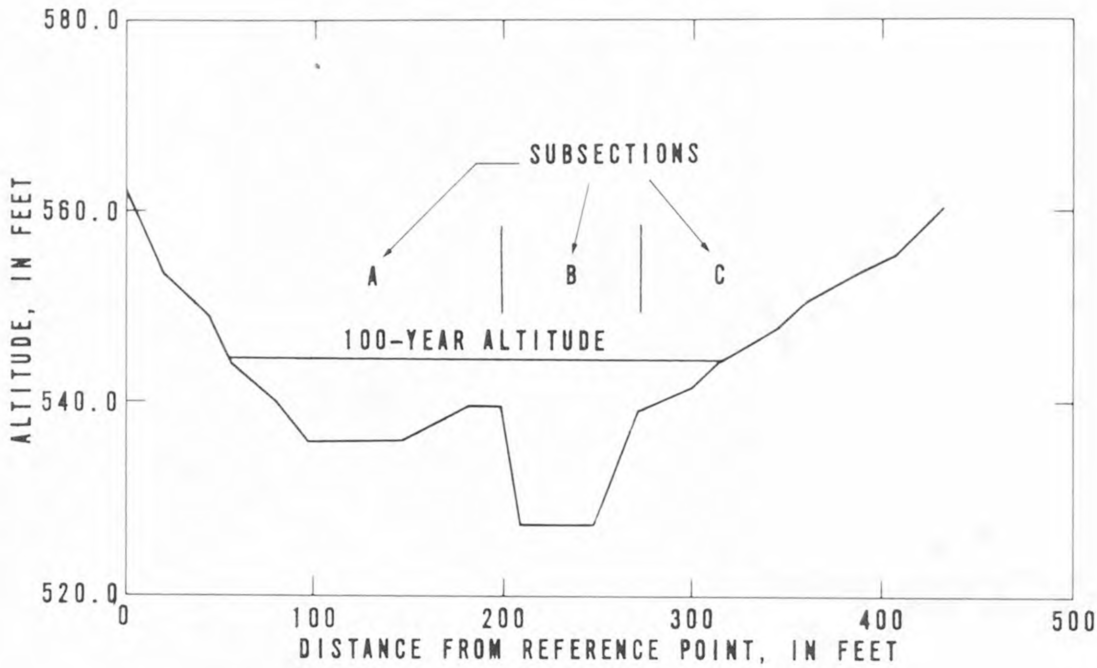

FIGURE 4.--Cross section 14 (fig. 3), Little Sugar Creek, southwestern North Carolina.

1. Errors in depth (in percent) resulting from errors in *n* values would be significantly smaller than those in the *n* values (in percent). For example, assuming that equation 9 is applicable and that *f* equals 0.46, a 20-percent standard error for *n* would result in an error of about 9 percent in depth.

2. For the procedure to remain simplified, it would not be practical to mathematically weight *n* values by conveyance or area. This does not mean that *n* values for subsections cannot be weighted intuitively when estimating an average value for a section.

The cross-sectional properties and computed depths for the 11 cross sections are presented in table 2. In table 2, computed 100-year depths determined according to the step-backwater procedure (Bailey and Ray, 1966) and HUD guidelines (U.S. Department of Housing and Urban Development, 1976) were extracted from data furnished by W. H. Eddins (written commun., 1976). The 11 depths computed according to the HUD guidelines ranged from 14.3 ft to 18.1 ft and averaged 16.3 ft; the standard deviation was 1.2 ft. The 11 depths determined by using equation 9 ranged from 11.6 ft to 21.4 ft and averaged 16.5 ft; the standard deviation was 2.8 ft. Depths determined for the 113 cross sections according to the HUD guidelines ranged from 13.9 ft to 19.4 ft and averaged 16.8 ft; the standard deviation for the depths is 1.1 ft.

Table 2.--*Cross-sectional properties and computed depths for controls in subreach A (fig. 3)*

Cross-section number	Cross-sectional properties					Computed 100-year depth	
	Roughness coefficient	Channel-bottom altitude (ft)	Reference		Channel slope	According to HUD guidelines (ft)	Equation 9 (ft)
			Altitude (ft)	Width (ft)			
1	0.065	519.6	533.6	242	0.00136	18.1	15.9
8	.065	524.3	538.3	263	.00175	17.8	14.4
10	.065	525.5	539.5	245	.00058	17.4	19.3
14	.065	527.6	541.6	180	.00138	17.0	18.2
15	.065	528.2	542.2	188	.00062	17.0	21.4
21	.053	533.2	547.2	342	.00106	15.4	12.9
22	.053	533.8	547.8	389	.00019	15.5	17.9
23	.053	533.9	547.9	343	.00021	15.8	18.5
51	.050	541.0	555.0	407	.0010	14.3	11.6
52	.060	541.5	555.5	249	.00115	14.5	15.4
53	.060	542.1	556.1	267	.00115	16.1	14.9
					Average----	16.3	16.4

The differences between corresponding depths shown in table 2 apparently are about the magitude that should be expected on an average. The square root of the mean variance (Σ[(depth determined according to HUD guidelines) minus (depth determined according to simplified procedure)]^2 divided by the number of sets of data) for the 11 sets of data is 2.4 ft. Assuming that 8 percent (of the depth) is the standard error of estimate, SE_D, for the step-backwater procedure and 13 percent (p. 23) is the standard error of estimate, SE_S, for the simplified procedure, the expected value (on an average) for the square root of the mean variance, SE_{D-S}, is 2.5 ft. The 2.5 ft was obtained using the formula

$$SE_{D-S} = \left(\bar{d}\sqrt{(SE_D)^2 + (SE_S)^2}\right) \Big/ 100 = 16.3 \text{ ft}\sqrt{(8)^2 + (13)^2} \Big/ 100$$

in which $\bar{d}$ is the average depth and $(SE_D)^2$ and $(SE_S)^2$ are variances.

The 9.67-mi study reach along Sugar Creek apparently satisfies premise 2 (p. 3). The 1.1-ft standard deviation for depths for the 100-year discharge at the 113 cross sections probably is representative of true changes in depth along the reach; however, the value is relatively small. For the given discharge the standard error for depths, computed according to the step-backwater procedure, would be larger than the 1.1 ft on an average; 8 percent of 16.8 ft (average of the 113 depths) is 1.3 ft.

A graphical representation of the 100-year depths is given in figure 5. Except for the standard error of estimate, the remaining values shown on figure 5 are self-explanatory. The standard error of estimate for the computed 100-year depths determined according to the step-backwater procedure and the HUD guidelines should be considered only as a rough approximation of the true standard error of estimate. The standard error is represented by the equation

$$(SE)_{tot} = \sqrt{(SE_q)^2 + (SE_d)^2} \qquad (13)$$

in which

$(SE)_{tot}$ = total standard error of estimate for the 100-year depth;

SE_q = standard error for the 100-year discharge; and

SE_d = standard error for depths determined according to the step-backwater procedure and HUD guidelines.

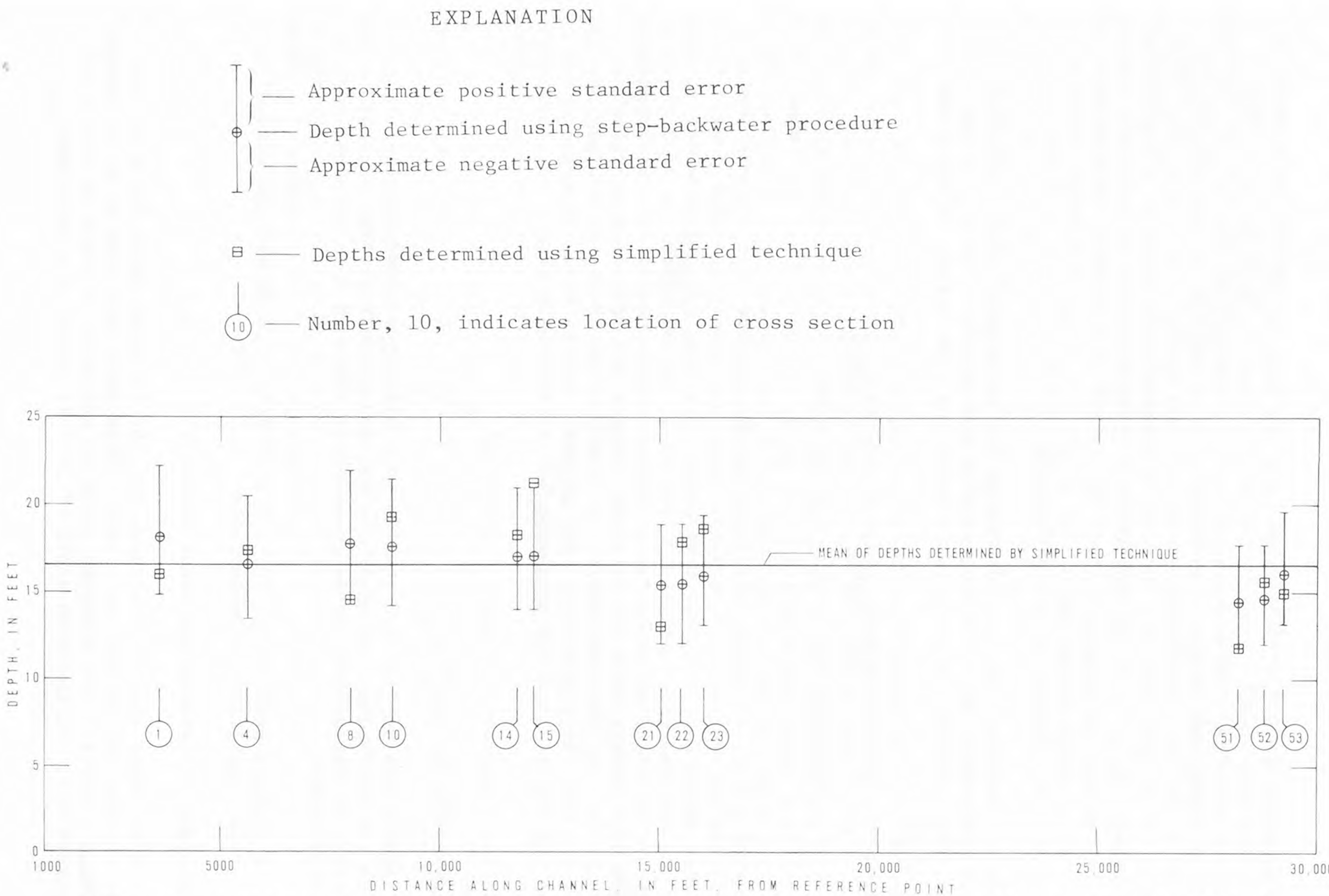

FIGURE 5.--Graph showing depths for the 100-year discharge computed according to the simplified technique and mean of these depths; and depths for the 100-year discharge determined according to the step-backwater procedure and to HUD guidelines and standard error graphically added to these depths for Little Sugar Creek, southwestern North Carolina.

To use equation 13, SE_q and SE_d must have the same units; for this study percentage of 100-year depth is used. SE_d was assumed to be 8 percent. For streams in North Carolina, the standard error of estimate for the 50-year discharge determined by a regression equation apparently is 43 percent of the discharge--average of +51.8 and -34.2 percentages--(Benson and Carter, 1973, fig. 9). The standard error of estimate for the 100-year discharge determined by a regression equation is assumed to be only insignificantly different from 43 percent. The method used to convert the standard error in percent of discharge to standard error in percent of depth makes use of the slope of a stage-discharge relation for a typical natural channel in North Carolina.

The relation between depth and discharge for relatively high discharges, as previously discussed, can be represented by equation 4. For a relation of this form, the standard error in log d resulting from errors in log Q can be represented as

$$(\log d)_{ERROR} = f\ (\log Q)_{ERROR} \tag{14}$$

which says that the standard error in d, in log units, resulting because of errors in Q is f times the standard error in Q, in log units. The value of f for natural channels has a wide range. For streams in North Carolina, the average value of f for 118 gaging station-sites apparently is 0.45; the standard deviation for the 118 values of f is 0.15. When a value of 0.45 for f and 0.182 (log unit equivalent of 43-percent error) for $(\log Q)_{ERROR}$ is used in equation 14, the resulting standard error in d, in log units, is 0.082, which represents an error of 19 percent. A rough approximation of the standard error for 100-year depths in North Carolina, determined according to the step-backwater procedure and HUD guidelines, is 20.6 percent of the depth (average of +23.0 percent and -18.2 percent). The standard errors shown in figure 5 are based on the +23.0 and -18.2 percentages and computed depths.

Information presented in figure 6 includes:

1. Channel-bottom profile;

2. Water-surface profile for the 100-year discharge determined according to the step-backwater procedure and HUD guidelines; the standard error of estimate which is graphically added to this 100-year profile;

3. Water-surface profile for the 100-year discharge determined according to the simplified technique; and

4. Locations of bridges and cross sections.

Except for the standard error of estimate for the 100-year depth (item 2) and item 3, this information is derived directly from data furnished by W. H. Eddins (written commun., 1976). The standard error of estimate is based on the +23.1 and -18.2 percentages and the mean depth of 16.8 ft previously described.

The 100-year water-surface profile for the simplified technique was developed by graphically adding 16.5 ft to the channel-bottom profile. Except for the distance between cross-sections 53 and 64, the stream-channel profile presented by Eddins was used to represent the channel-bottom profile. According to the definition for channel bottom (p. 2), the stream-channel profile from about cross-section 53 to cross-section 64 cannot be a channel-bottom profile. A smooth "sketched in" curve is used to represent the channel-bottom profile for the distance between the two sections.

The 100-year profile for the simplified technique probably is not significantly different from that determined according to the step-backwater procedure and HUD guidelines except perhaps for the relatively short distance from about cross-section 64 to cross-section 69 and from cross-section 80 to cross-section 92.

The effects of bridges, if any, were not considered in the development of the 100-year profile according to the simplified technique. Bridges, however, usually affect the water-surface profile for a 100-year discharge. Determining the effects of bridges on Sugar Creek was beyond the scope of this study.

To delineate the inundated areas, altitudes taken from a water-surface profile can be transferred to maps on the basis of contours on topographic maps or on the basis of field surveys. The steps, when the latter procedure is used, are: (1) The horizontal and vertical extent of the 100-year flood is determined by field survey for selected sites on the flood plain; these sites are flagged so they can be spotted on aerial photographs; (2) aerial photographs are obtained and the boundary of the 100-year flow is outlined on the photographs; and (3), the boundary of the 100-year flood then is transferred to topographic maps or, if such maps are not available, to a mosaic compilation of the photographs.

The boundary of the 100-year flood obtained according to the simplified technique apparently is not significantly different from that obtained according to the step-backwater procedure and HUD guidelines except perhaps for the distances from about cross-section 64 to cross-section 69 and from about cross-section 80 to cross-section 92 (fig. 6). The boundary for the 100-year flood for the study reach on Little Sugar Creek (fig. 6) was based on water-surface profiles for the 100-year discharge and topographic maps showing contours at 2- or 4-ft intervals.

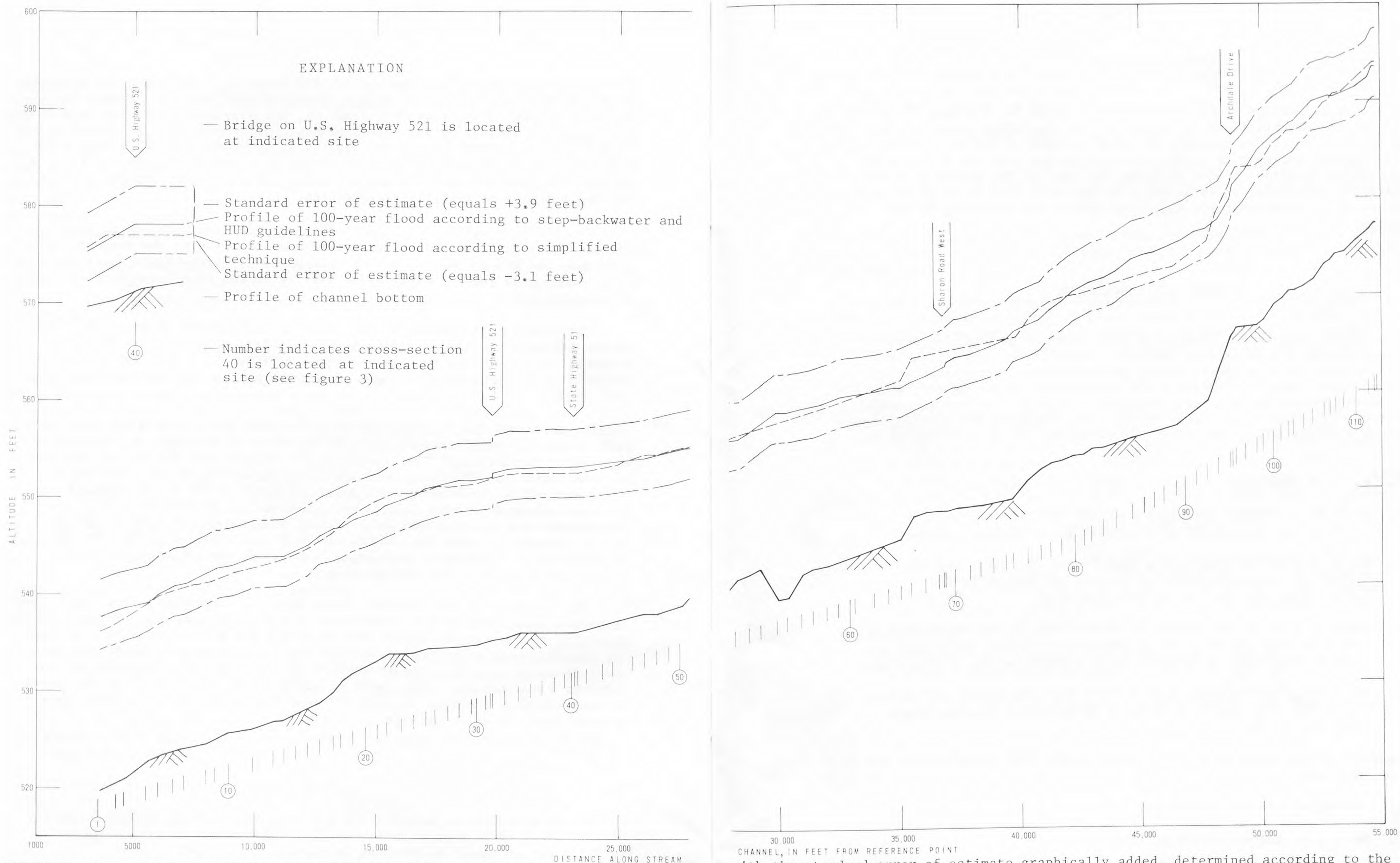

FIGURE 6.--Channel-bottom profile; water-surface profile for the 100-year discharge, with the standard error of estimate graphically added, determined according to the step-backwater procedure and HUD guidelines; water-surface profile for the 100-year discharge determined according to the simplified technique; and locations of bridges and cross sections for Little Sugar Creek, southwestern North Caroline (fig. 3).

OVERALL ACCURACY

The overall average standard error of estimate for 100-year flood-boundary altitudes determined according to the simplified technique is not known; however, it is probably 25 to 30 percent of the depth. The 25 to 30 percent estimate is based on the criterion that the accuracy of the simplified technique should be about the same as the accuracy of the physiographic procedure, which is about 27 percent. The 25 to 30 percent is comparable to 23 percent for altitudes determined according to the detailed method.

SUMMARY AND CONCLUSIONS

The report describes a simplified technique for determining depths for *T*-year discharges in natural channels (channels not significantly affected by manmade structures) having channel-control conditions and rigid boundaries (channels having a low probability of change that would significantly affect the hydraulic characteristics of a *T*-year discharge). Channel-control conditions usually exist during relatively high discharges in natural rigid-boundary channels. The technique is based on the premise that:

1. A *T*-year discharge is known or is readily obtainable.

2. Depth for a *T*-year discharge does not vary greatly in a relatively long reach of a natural rigid-boundary channel.

3. Depth of flow is primarily a function of discharge and the physical characteristics of lengths of channel in the reach that are partial or true controls.

4. Depth of flow in the length of channel having the characteristics of a partial control can be adequately (errors introduced are not prohibitive) determined using a small amount of field data.

5. The average of computed depths for a few representative partial controls in a reach can be used to represent average depth for the reach.

Six basic steps are required in determining depths for *T*-year discharges in a reach of interest:

1. Determine a *T*-year discharge.

2. Develop a channel-bottom profile.

3. Determine the locations of partial (or true) controls in the reach.

4. Compute depths for *T*-year discharges by equations for representative cross sections for a few of these partial controls; to do this a small amount of field data must be obtained.

5. Average the depths determined in step 4.

6. Develop a water-surface profile by graphically adding the average depth obtained in step 5 to the channel-bottom profile developed in step 2.

The development of a map of the areas inundated would involve an additional step (step 7)--the transfer of altitudes from the water-surface profile to a topographic map.

The simplified technique for determining depths for 100-year discharges was demonstrated using data for a 9.67-mi reach of Little Sugar Creek in North Carolina. Data for the demonstration study were readily available from a report describing the results of a HUD-15 study for the reach.

Conclusions reached as a result of this study are:

1. The simplified technique for determining depths for *T*-year discharges and the corresponding water-surface profiles and flood boundaries probably could be used for HUD flood-inundation studies for many natural rigid-boundary channels. The use of the simplified technique instead of the step-backwater procedure (Bailey and Ray, 1966) and HUD guidelines (U.S. Department of Housing and Urban Development, 1976) would sacrifice some accuracy to alleviate manpower stresses.

2. The standard error of estimate for the flood-boundary altitudes is not known; however, it probably would be 25 to 30 percent of the depth, which is only slightly larger than the 23 percent for the flood-boundary altitudes determined according to the step-backwater procedure and HUD guidelines.

3. Experience, good judgment, and a thorough knowledge of the hydraulic principals of open-channel flow that are required for HUD type-15 studies would also be essential in order to obtain adequate results when the simplified technique is used.

REFERENCES CITED

Bailey, J. F., and Ray, H. A., 1966, Definition of stage-discharge relation in natural channels by step-backwater analysis: U.S. Geol. Survey Water-Supply Paper 1869-A, 24 p.

Barnes, H. H., 1967, Roughness characteristics of natural streams: U.S. Geol. Survey Water-Supply Paper 1849, 213 p.

Benson, M. S., and Carter, R. W., 1973, A national study of the streamflow data-collection program: U.S. Geol. Survey Water-Supply Paper 2028, 44 p.

Dalrymple, Tate, and Benson, M. A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geol. Survey Techniques Water-Resources Inv., Book 3, Chap. A2, 12 p.

Riggs, H. C., 1976, A simplified slope-area method for estimating flood discharges in natural channels: U.S. Geol. Survey Jour. Research, vol. 4, no. 3, p. 285-291.

U.S. Department of Housing and Urban Development, 1976, Flood insurance study, guidelines and specifications: Federal Insurance Adm., 275 p.

U.S. Water Resources Council, 1976, Guidelines for determining flood flow frequency: U.S. Water Resources Council, Hydrology Committee, Bull. 17, 26 p.

WRI 77-83 Burkham— A TECHNIQUE FOR DETERMINING DEPTHS FOR T-YEAR DISCHARGES IN RIGID-BOUNDARY CHANNELS

RETURN IF NOT DELIVERED
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
California District Office—Water Resources Division
855 Oak Grove Avenue
Menlo Park, California 94025

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF THE INTERIOR
INT 413

01

U.S. GEOLOGICAL SURVEY LIBRARY
NATIONAL CENTER, MAIL STOP # 950
12201 SUNRISE VALLEY DR.
RESTON VA 22092