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U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter A2

MEASUREMENT OF PEAK DISCHARGE by the SLOPE-AREA METHOD

By Tate Dalrymple and M. A. Benson

Book 3

APPLICATIONS OF HYDRAULICS

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

First printing 1968
Second printing 1968
Third printing 1976
Fourth printing 1989

UNITED STATES GOVERNMENT PRINTING OFFICE : 1984

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

PREFACE

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TABLE

SYMBOLS AND UNITS

Symbol	*Definition*	*Unit*
A	Area.	ft^2
a_i	Area of individual subsection.	ft^2
d_m	Mean depth.	ft
$\mathbf{F}$	Froude number.	
g	Gravitational constant (acceleration).	ft/sec^2
h	Static or piezometric head above an arbitrary datum.	ft
h_v	Velocity head at a section.	ft
K	Conveyance of a section.	ft^3/sec
K_T	Conveyance of total cross section.	ft^3/sec
K_w	Weighted conveyance for a reach.	ft^3/sec
k	Coefficient for energy loss.	
L	Length of reach of channel.	ft
n	Manning roughness coefficient.	ft$^{1/6}$
P	Wetted perimeter of cross section of flow.	ft
Q	Total discharge.	ft^3/sec
q	Part of the total discharge.	ft^3/sec
R	Hydraulic radius.	ft
S	Friction slope.	
V	Mean velocity of flow in a section.	ft/sec
$_{1,\,2}$	Subscripts which denote the location of cross sections or section properties in downstream order.	
α	Velocity head coefficient.	
Δ	Difference in values, as Δh is the difference in head.	
Σ	Summation of values.	

MEASUREMENT OF PEAK DISCHARGE BY THE SLOPE-AREA METHOD

By Tate Dalrymple and M. A. Benson

Abstract

This chapter describes application of the Manning equation to measure peak discharge in open channels. Field and office procedures limited to this method are described. Selection of reaches and cross sections is detailed, discharge equations are given, and a complete facsimile example of computation of a slope-area measurement is also given.

Introduction

A slope-area measurement is the most commonly used form of indirect measurement. In the slope-area method, discharge is computed on the basis of a uniform-flow equation involving channel characteristics, water-surface profiles, and a roughness or retardation coefficient. The drop in water-surface profile for a uniform reach of channel represents losses caused by bed roughness.

In application of the slope-area method, any one of the well-known variations of the Chezy equation might well be used. The Geological Survey uses the Manning equation. This equation was originally adopted because of its simplicity of application. The many years of experience in its use that have now been accumulated show that reliable results can be obtained from it.

Basic Equations

The Manning equation, written in terms of discharge, is

$$Q=\frac{1.486}{n}AR^{2/3}S^{1/2}, \qquad (1)$$

where

Q=discharge,
A=cross-sectional area,
R=hydraulic radius,
S=friction slope, and
n=roughness coefficient.

The Manning equation was developed for conditions of 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. Lacking a better solution, it is assumed that the equation is also valid for nonuniform reaches that are invariably encountered in natural channels, if the energy gradient is modified to reflect only the losses due to boundary friction. The energy equation for a reach of nonuniform channel between sections 1 and 2 shown on figure 1 is

$$(h+h_v)_1=(h+h_v)_2+(h_f)_{1\text{-}2}+k(\Delta h_v)_{1\text{-}2}, \qquad (2)$$

where

h=elevation of the water surface at the respective sections above a common datum,
h_v=velocity head at the respective section$=\alpha V^2/2g$,
h_f=energy loss due to boundary friction in the reach,
Δh_v=upstream velocity head minus the downstream velocity head,
$k(\Delta h_v)$=energy loss due to acceleration or deceleration in a contracting or expanding reach, and
k=a coefficient.

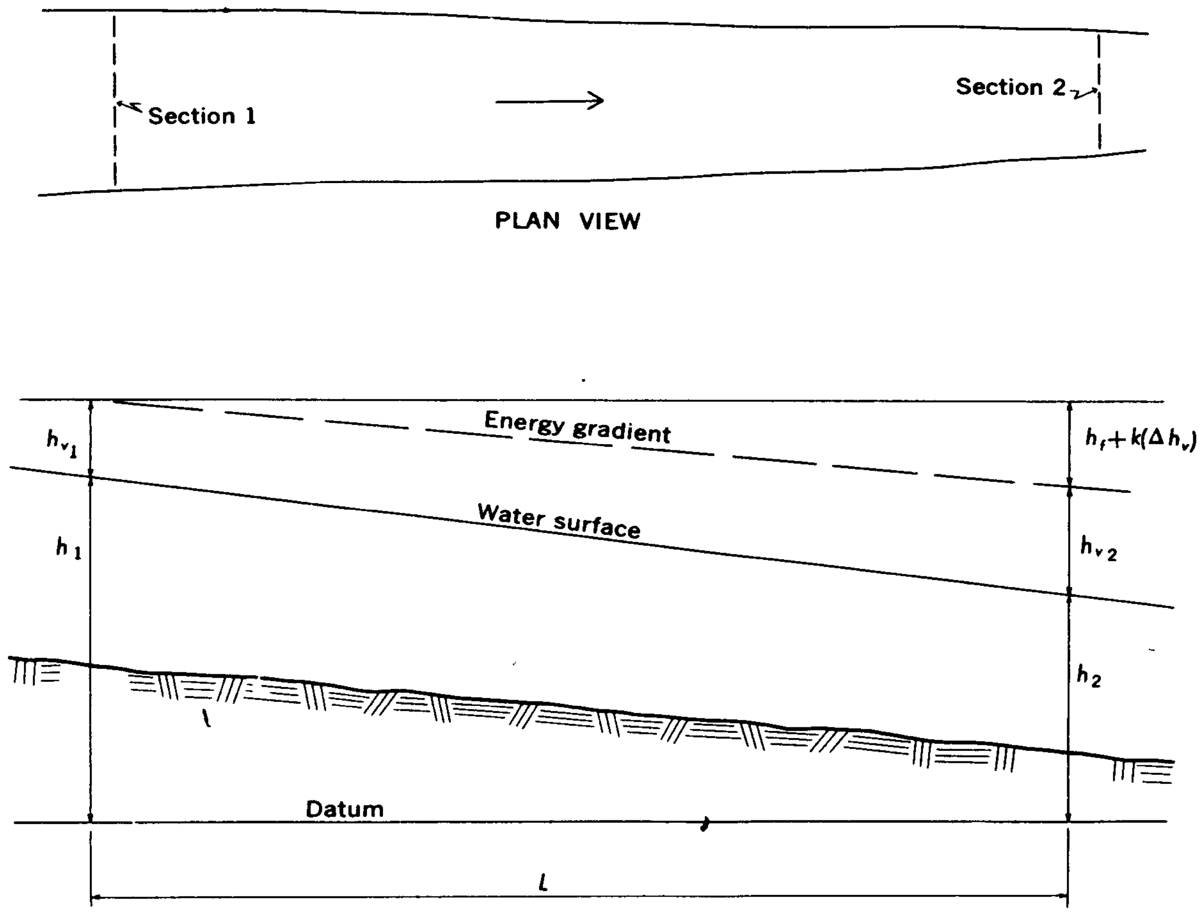

Figure 1.—Definition sketch of a slope-area reach.

The friction slope S to be used in the Manning equation is thus defined as

$$S=\frac{h_f}{L}=\frac{\Delta h+\Delta h_v-k(\Delta h_v)}{L}, \qquad (3)$$

where Δh is the difference in water-surface elevation at the two sections, and L is the length of the reach.

In using the Manning equation the quantity $(1.486/n)AR^{2/3}$, termed conveyance, K, is computed for each cross section. The mean conveyance in the reach is then computed as the geometric mean of the conveyance at the two sections. This procedure is based on the assumption that the conveyance varies uniformly between sections. The discharge is computed by the equation

$$Q=\sqrt{K_1K_2S}, \qquad (4)$$

where S is the friction slope as previously defined.

Computation of Friction Slope

The computation of the friction slope by equation 3 involves the determination of the water-surface elevation and velocity heads at each section and an evaluation of the loss due to contraction or expansion. Water-surface elevations are taken from the profile defined by high-water marks as described in chapter A1 by Benson and Dalrymple (1967). The velocity head (h_v) at each section is computed as

$$h_v=\frac{\alpha V^2}{2g}, \qquad (5)$$

where V is the mean velocity in the section and α is the velocity-head coefficient. The value of α is assumed to be 1.0 if the section is not subdivided. The value of α in subdivided channels is computed as

$$\alpha=\frac{(\Sigma K_i^3/a_i^2)}{K_T^3/A_T^2}, \tag{6}$$

where the subscript i refers to the conveyance or area of the individual subsections and T to the area or conveyance of the entire cross section.

The energy loss due to contraction or expansion of the channel in the reach is assumed to be equal to the difference in velocity heads at the two sections (Δh_v) times a coefficient k. The value of k is taken to be zero for contracting reaches and 0.5 for expanding reaches. However, both the procedure and the coefficient are questionable for expanding reaches and thus major expansions are avoided, if possible, in selecting sites for slope-area measurements.

The value of Δh_v is computed as the upstream velocity head minus the downstream velocity head; thus, the friction slope to be used in the Manning equation is computed algebraically as

$$S=\frac{\Delta h+(\Delta h_v/2)}{L} \text{ (when } \Delta h_v \text{ is positive)}, \tag{7}$$

and

$$S=\frac{\Delta h+\Delta h_v}{L} \text{ (when } \Delta h_v \text{ is negative)}. \tag{8}$$

Selection of Reach

The selection of a suitable reach is probably the most important element of a slope-area measurement. Ideal reaches are difficult to find, and usually it is a matter of selecting the best reach available.

Good high-water marks are basic to a reliable slope-area computation, so that the presence or quality of high-water marks is an important consideration. A steep-sided rock channel might have near-perfect hydraulic qualities, yet if the walls did not retain high-water marks, it would be useless as a slope-area reach. If heavy rains have followed the peak prior to the survey, marks on clean banks may have been destroyed or washed to a lower elevation, whereas marks within wooded parts of the channel might have been little affected. The selection of a reach is thus first governed by the availability of high-water marks.

The geometry of the channel in the reach is also important. Marked changes in the shape of the channel along a reach should be avoided because of the uncertainties regarding the value of the velocity-head coefficient. The channel should be as uniform as possible, but in any event, the changes in channel conveyance should be fairly uniform from section to section in order to be consistent with the assumption that the mean conveyance is equal to the geometric mean of the conveyance at the end sections. It is desirable that flow be confined within a simple trapezoidal channel, because n values have been determined for such conditions. However, compound channels can be used if they are properly subdivided. The reach should be contracting rather than expanding if there is a choice. Straight reaches are preferred, but they are seldom found in nature.

The method assumes that the cross-sectional area is fully effective and is carrying water in accordance with the conveyance for various portions of the section. For this reason it is desirable that the cross section be uniform for some distance above the reach, so that discharge will be distributed in accordance with channel depths, roughness, and shape. Conditions, either upstream or downstream from a reach, which will cause an unbalanced distribution should be avoided. For example, for some distance downstream from a bridge which constricts the width, the effective flow will be contained within the center of the channel; the sides of the channel will not carry water in proportion to the computed conveyance and may even have negative velocity. Natural channel constrictions or protrusions may have the same effect. A sudden deepening of the channel may also represent a noneffective area. Such situations should be watched for and avoided as slope-area reaches.

Sometimes slope-area reaches must be selected in mountainous areas where the channels are very rough and steep and may have free fall over riffles and boulders. The Manning equation is not applicable when free fall exists. However, free fall may or may not be indicated by the high-water profiles or by inspection of the reach. Cross sections may be located to eliminate any part of a reach in which free fall is indicated; but when the reach includes stretches in which free fall might have occurred, the reliability of the computed discharge will be low.

Channel bends often govern the length of a suitable reach. The influence of the bend on velocity distribution, slope, and water-surface elevations continues some distance downstream from the bend. If a straight reach away from the influence of bends cannot be found, it is best to choose a long reach that includes one or more channel bends with terminal sections in straight portions of the channel.

The reach should be long enough to develop a fall which is well beyond the range of error due to alternate interpretations of the high-water profile, or to uncertainties regarding the computation of velocity head. In general, the accuracy of a slope-area measurement will improve as the length of the reach is increased. However, the length of a desirable reach is often governed by the geometry of the channel and the practical difficulties of surveying long reaches of river channel. One or more of the following criteria should be met, if possible, in selecting the length of a slope-area reach:

1. The length of the reach should be equal to or greater than 75 times the mean depth in the channel.
2. The fall in the reach should be equal to or greater than the velocity head.
3. The fall in the reach should be equal to or greater than 0.50 foot.

Selection of Cross Sections

Cross sections represent samples of the geometry of the reach; thus, the accuracy of the measurement will to some extent depend on the number of sections taken. A minimum of three cross sections is recommneded. Criteria for location of cross sections are given in chapter A1 by Benson and Dalrymple (1967).

Computations

In general, perform the computations as described by Benson and Dalrymple (1967) beginning on page 24. Specifically for slope-area measurements the following considerations apply.

Fall

To compute the fall, Δh, average the elevations on both banks at each cross section. Show the computations for fall on the profile sheet. There may be occasions when high-water marks show that a ridge in the middle of a stream divides the flow, so that different water-surface elevations are in effect for both banks, or a raised shelf may maintain overbank flow at a higher elevation for some distance. Under such conditions the fall may be obtained by weighting the separate falls in accordance with the conveyance in each portion.

Length of reach

For a reach in a straight or nearly straight channel, compute the length from the stationing of the ends of the cross section or scale the length from the plan. If the channel is curving and has nearly uniform depths, measure the length on the curved line along the center of the channel. If the main channel lies closer to the outside of the bend, use the length along the center of the deep channel. The centroid of conveyance may be computed for each cross section and a line drawn along its approximate position between the sections. In some places a meandering main channel lies within a fairly straight flood plain. If the water is entirely within the main channel, use the main channel length. If the flood plain also carries water, weight the curving length along the main channel and the shorter length along the flood plain in proportion to the approximate amount of water flowing in each portion. Show computations of length for the individual subreaches on the profile sheet.

Discharge

Compute the conveyance, the velocity-head coefficient α for each cross section, and the weighted conveyance of each subreach on the form as shown on figure 7. First, use the two-section formula given in table 1 to compute directly the discharge for each two-section subreach. The computed values will most likely differ for each subreach. Then, using the appropriate discharge as the "assumed" value on the form, complete for each subreach the computation of the various heads, slope, and "computed" discharge. The "computed" discharge will agree exactly with the "assumed" if computations are made correctly. This procedure provides an interim check and gives considerable insight into the transformation of energy and energy loss from section to section along the reach. Consistency of results among the subreaches is made evident.

Use one of the equations shown in table 1 to compute the final value of discharge. These equations are based on the energy equation and the Manning equation applied throughout the reach. The values of k in the equations are 0.5 if Δh_v is positive and 0 if Δh_v is negative in the given subreach. The value of Δh_v for each subreach was determined in the previous computations and may be used to determine the values of k in the multisection equation.

After the final value of discharge has been determined, use that value to compute the subsection discharges for subdivided sections, the corresponding velocities, and the mean velocities for all sections. Enter the computations in the two columns at the right of the computation form. Computed velocities should be compatible with the appearance of the channel after the flood. Gross errors can be recognized in some instances if velocities are greatly different from those expected.

Froude Number

The value of the Froude number should be computed for each cross section after the final discharge has been determined. The Froude number is defined as

$$\mathbf{F}=\frac{V}{\sqrt{gd_m}}, \tag{9}$$

where V is the mean velocity and d_m is the average depth in the cross section.

The Froude number is an index to the state of flow in the channel. For example, in a rectangular channel the flow is tranquil if the Froude number is less than 1.0 and is rapid if the Froude number is greater than 1.0. The slope-area method may be used for both tranquil and rapid flow. The Froude numbers for the various sections or for subsections of compound sections should be examined to determine the state of flow in the reach.

Table 1.—Discharge equations for use in slope-area measurements

Number of cross sections

2

$$Q=K_2\sqrt{\frac{\Delta h}{\frac{K_2}{K_1}L+\frac{K_2^2}{2gA_2^2}\left[-\alpha_1\left(\frac{A_2}{A_1}\right)^2(1-k)+\alpha_2(1-k)\right]}}$$

3

$$Q=K_3\sqrt{\frac{\Delta h}{\frac{K_3}{K_2}\left(\frac{K_3}{K_1}L_{1\text{-}2}+L_{2\text{-}3}\right)+\frac{K_3^2}{2gA_3^2}\left[-\alpha_1\left(\frac{A_3}{A_1}\right)^2(1-k_{1\text{-}2})+\alpha_2\left(\frac{A_3}{A_2}\right)^2(k_{2\text{-}3}-k_{1\text{-}2})+\alpha_3(1-k_{2\text{-}3})\right]}}$$

Multiple (n)

$$Q=K_n\sqrt{\frac{\Delta h}{A+B}},\ \text{where}$$

$$A=K_n^2\frac{L_{1\text{-}2}}{K_1K_2}+K_n^2\frac{L_{2\text{-}3}}{K_2K_3}+\ \ldots\ \frac{K_n^2L_{(n-2)\text{-}(n-1)}}{K_{(n-2)}K_{(n-1)}}+\frac{K_n^2L_{(n-1)\text{-}n}}{K_{(n-1)}K_n}$$

$$B=\frac{K_n^2}{A_n^2 2g}\left[-\alpha_1\left(\frac{A_n}{A_1}\right)^2(1-k_{1\text{-}2})+\alpha_2\left(\frac{A_n}{A_2}\right)^2(k_{2\text{-}3}-k_{1\text{-}2})+\alpha_3\left(\frac{A_n}{A_3}\right)^2(k_{3\text{-}4}-k_{2\text{-}3})+\ \ldots\right.$$

$$\left.+\alpha_{(n-1)}\left(\frac{A_n}{A_{(n-1)}}\right)^2(k_{(n-1)\text{-}n}-k_{(n-2)\text{-}(n-1)})+\alpha_n(1-k_{(n-1)\text{-}n})\right].$$

Variable Discharge

Sometimes the best possible reach might have variable discharge, such as when a tributary enters within the reach, or when water leaves through a break in a levee along the bank. It is necessary first to compute independently the discharge added or diverted, such as by a slope-area measurement for the tributary flow, or by computing the flow over the levee embankment. The table at the bottom of the computation form (fig. 7) can then be used to compute the discharge as follows:

1. Assume a discharge Q, in section 1, and use it to compute the upstream velocity head.
2. Add Q_1 and Q_a (flow in the tributary or diversion) to obtain Q_2, and use this to compute the downstream velocity head.
3. The computed Q should be the average of Q_1 and Q_2; if not, assume a new Q_1 and recompute.

Evaluation of Results

The resulting discharge should be examined and evaluated on the basis of the intrinsic merits of the computation. If the state of flow changes from tranquil ($\mathbf{F}<1$) to rapid ($\mathbf{F}>1$) or vice versa, there is cause for further examination of the base data. A change from rapid to tranquil flow indicates the possibility of the presence of a hydraulic jump, with its uncertain energy losses. Such a reach would be suspect. A change from tranquil to rapid flow might indicate a sharp contraction within the reach, with attendant contraction losses which have not been evaluated, or might indicate the presence of "free fall," caused by a series of riffles, which means a discontinuous water-surface slope not related to the discharge as in the Manning formula. Examination of the high-water profiles might show sharp drops which bear out either of the two latter possibilities, and the computed discharge would then be known to be at fault. On the other hand, a gradual transition from tranquil to rapid flow is possible; a continuous water-surface profile would bear this out, in which case the discharge computations may be accepted as valid.

The consistency of results from separate subreaches is some indication of the reliability of the answer. If the spread in discharges exceeds 25 percent, the results would be classified as poor.

Adequacy of the high-water marks, amount of fall, presence of bends in the reach, and the magnitude of the velocity head in relation to the fall are other factors which should be examined in rating the accuracy of the measurement.

Example

The computation sheets for a slope-area measurement of the flood of February 21, 1956, on Snake Creek near Connell, Wash., are shown on figures 2–7. This example illustrates the sheets used in plotting and computations, and how the results of a slope-area measurement should be presented. A study of this example will further clarify the entire procedure used in making this type of measurement.

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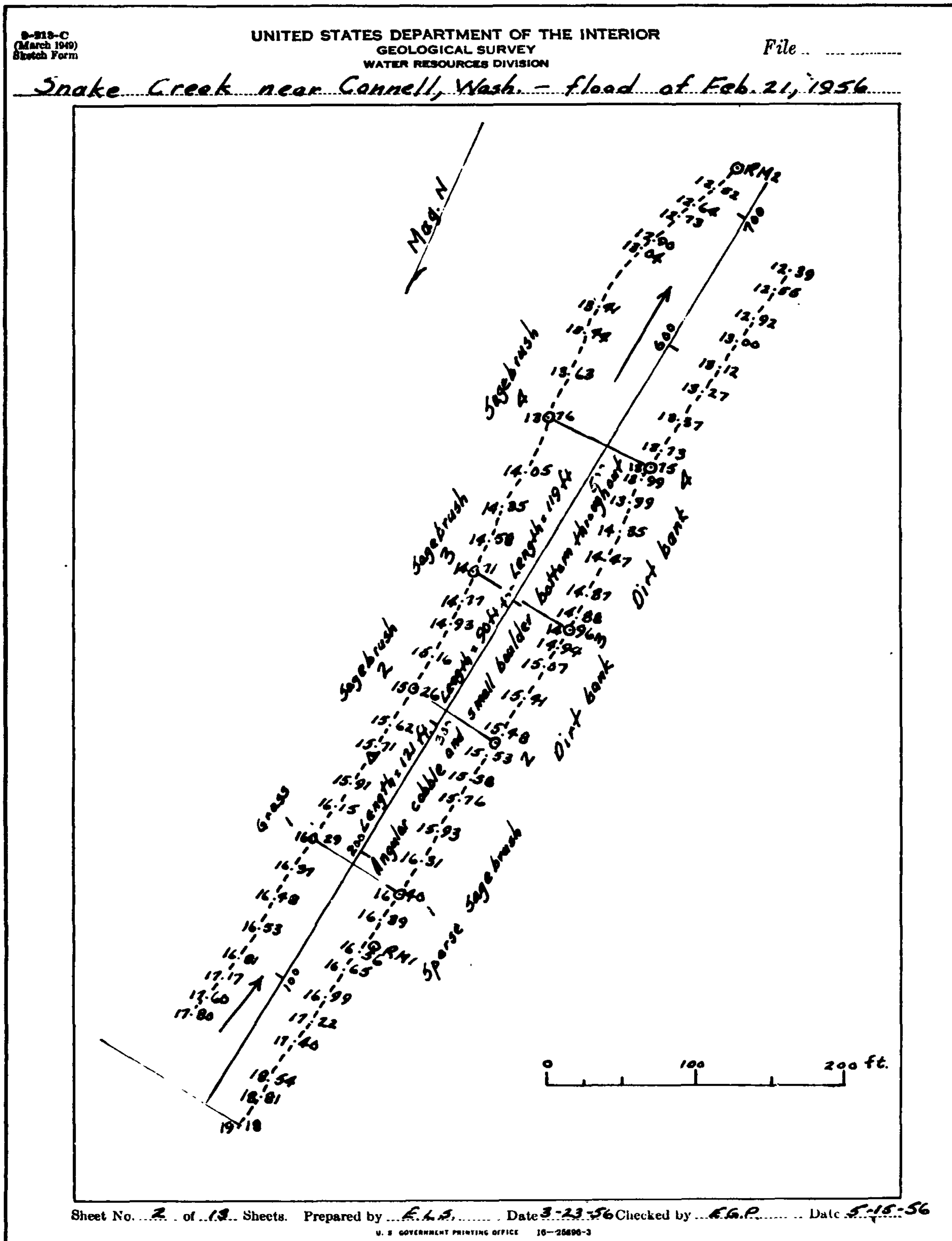

Figure 2.—Sample slope-area computation, plan view of reach.

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

File No. { Washington ______ District ______

Snake Creek near Connell, Wash. – flood of Feb. 21, 1956

Highwater marks							
Left bank				Right bank			
Sta.	Elev.	Sta.	Elev.	Sta.	Elev.	Sta.	Elev.
47	17.80	423	14.58	0	19.18	372	15.07
63	17.60	449	14.35	24	18.81	388	14.94
80	17.17	478	14.05	36	18.54	401	(sec 3)
97	16.81	502	13.96	67	17.40	402	14.96
120	16.53	510	13.84	84	17.22	412	14.88
142	16.48	517	(sec 4)	103	16.99	428	14.87
165	16.37	517	13.76	127	16.65	454	14.47
190	(sec 1)	548	13.63	141	16.56	476	14.35
190	16.29	578	13.44	167	16.39	496	13.99
218	16.15	600	13.41	188	(sec 1)	516	13.49
237	15.91	638	13.04	188	16.40	521	13.67
267	15.71	654	12.90	215	16.31	522	(sec 4)
284	15.62	678	12.73	239	15.93	524	13.75
312	(sec 2)	689	12.64	264	15.76	536	13.73
312	15.66	707	12.62	281	15.58	561	13.87
338	15.16			300	15.53	585	13.27
365	14.93			308	15.51	604	13.12
380	14.77			309	(sec 2)	627	13.00
401	(sec 3)			318	15.48	644	12.92
402	14.71			345	15.41	668	12.55
						684	12.39

E.L.S. 3-19-56

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Figure 3.—Sample slope-area computation, listing of high-water marks.

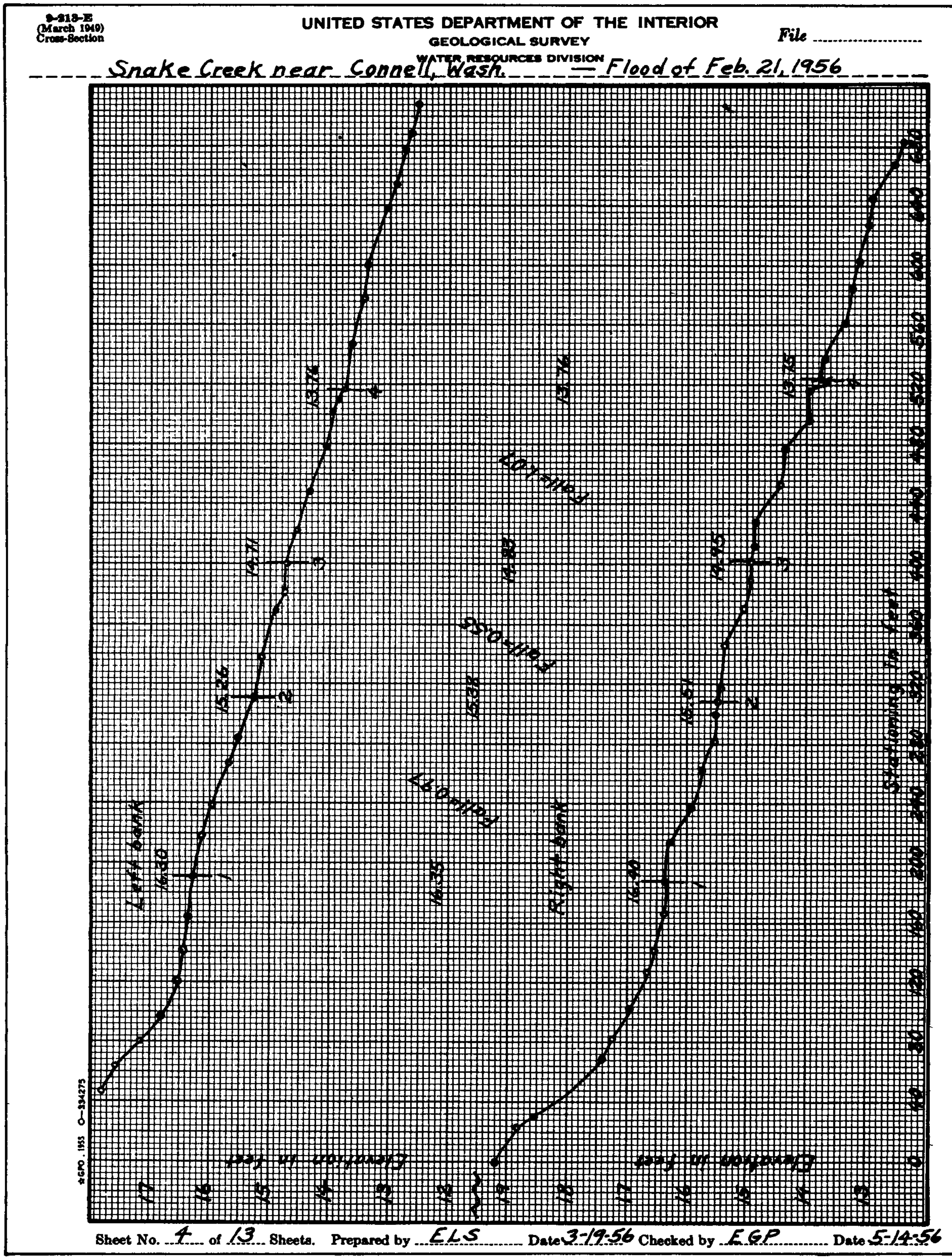

Figure 4.—Sample slope-area computation, high-water profile.

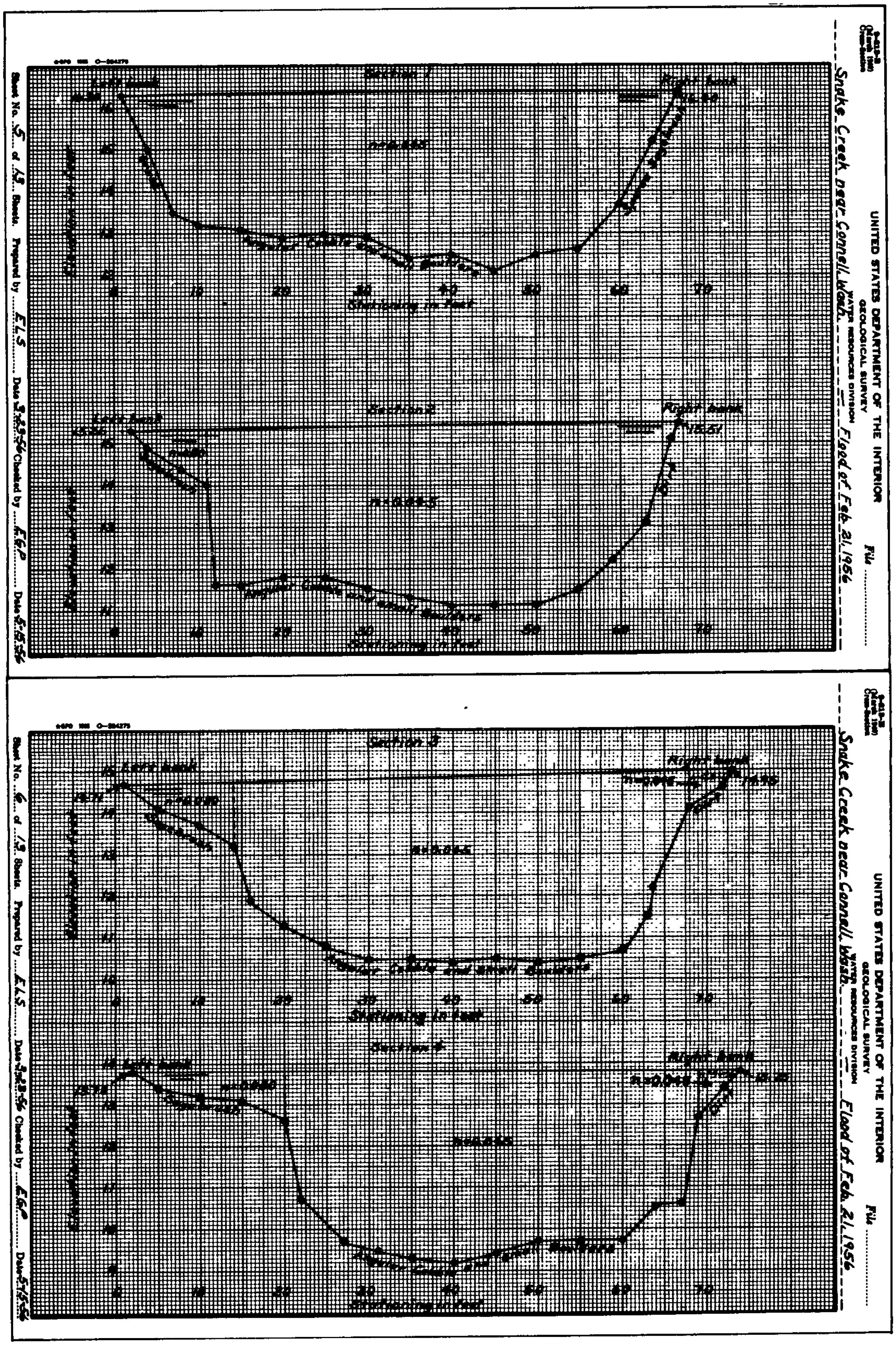

Figure 5.—Sample slope-area computation, cross sections.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

File

Snake Creek near Connell, Wash. FLOOD OF Feb. 21, 1956

SECTION.— 1

STA.	DIST	W. S. ELEV	ELEV	DEPTH	MEAN DEPTH	AREA		W. P		
L.B. 1	—	16.30	16.3	0	—	—		—		
4	3		15.0	1.3	0.6	1.8		3.3		
7	3		13.5	2.8	2.0	6.0		3.4		
10	3		13.2	3.1	3.0	9.0		3.0		
15	5		13.1	3.2	3.2	16.0		5.0		
20	5		12.9	3.4	3.3	16.5		5.0		
25	5		13.0	3.3	3.4	17.0		5.0		
30	5	16.3	12.9	3.4	3.4	17.0		5.0		$r = \frac{208}{67.3} = 3.09$
35	5	16.4	12.4	4.0	3.7	18.5		5.0		
40	5		12.5	3.9	4.0	20.0		5.0		
45	5		12.1	4.3	4.1	20.5		5.0		
50	5		12.5	3.9	4.1	20.5		5.0		
55	5		12.6	3.8	3.8	19.0		5.0		
60	5		13.7	2.7	3.2	16.0		5.1		
64	4		15.2	1.2	2.0	8.0		4.3		
67	3	16.40	16.4	0	.6	1.8		3.2		
	66					207.6		67.3		
67 -1 66										

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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

File

Snake Creek near Connell, Wash. FLOOD OF Feb. 21, 1956

SECTION — 2

STA.	DIST	W. S. ELEV	ELEV	DEPTH	MEAN DEPTH	AREA		W P		
L.B. 2	—	15.26	15.3	0	—	—		—		
4	2	15.3	14.9	0.4	0.2	0.4		2.0		
8	4		14.4	.9	.6	2.4		4.0		$r = \frac{6.1}{9.0} = 0.68$
11	3		14.0	1.3	1.1	3.3	6.1	3.0	9.0	
12	1		11.6	3.7	2.5	2.5		2.6		
15	3		11.6	3.7	3.7	11.1		3.0		
20	5		11.8	3.5	3.6	18.0		5.0		
25	5	15.3	11.8	3.5	3.5	17.5		5.0		
30	5	15.4	11.5	3.9	3.7	18.5		5.0		
35	5		11.3	4.1	4.0	20.0		5.0		
40	5		11.1	4.3	4.2	21.0		5.0		
45	5		11.1	4.3	4.3	21.5		5.0		$r = \frac{203}{58.5} = 3.47$
50	5	15.4	11.1	4.3	4.3	21.5		5.0		
55	5	15.5	11.5	4.0	4.2	21.0		5.0		
59	4		12.2	3.3	3.6	14.4		4.1		
63	4		13.1	2.4	2.8	11.2		4.1		
66	3	15.5	15.1	.4	1.4	4.2		3.6		
67	1	15.51	15.5	0	.2	.2	202.6	1.1	58.5	
	65									
67 -2 65										

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File

Snake Creek near Connell, Wash. FLOOD OF Feb. 21, 1956

SECTION.— 3

STA.	DIST	W. S. ELEV	ELEV	DEPTH	MEAN DEPTH	AREA		W P		
L.B. 1	—	14.71	14.7	0	—	—		—		
5	4	14.7	14.1	0.6	0.3	1.2		4.0		
10	5	.	13.7	1.0	.8	4.0		5.0		$r = \frac{10.0}{13.0} = 0.77$
14	4	14.7	13.2	1.5	1.2	4.8	10.0	4.0	13.0	
16	2	14.8	11.9	2.9	2.2	4.4		2.4		
20	4		11.3	3.5	3.2	12.8		4.0		
25	5		10.8	4.0	3.8	19.0		5.0		
30	5		10.5	4.3	4.2	21.0		5.0		
35	5		10.5	4.3	4.3	21.5		5.0		$r = \frac{212}{55.4} = 3.83$
40	5	14.8	10.4	4.4	4.4	22.0		5.0		
45	5	14.9	10.5	4.4	4.4	22.0		5.0		
50	5		10.4	4.5	4.4	22.0		5.0		
55	5		10.5	4.4	4.4	22.0		5.0		
60	5		10.7	4.2	4.3	21.5		5.0		
63	3		11.5	3.4	3.8	11.4		3.1		
66	3		12.2	2.7	3.0	9.0		3.1		
68	2		14.1	.8	1.8	3.6	212.2	2.8	55.4	
72	4	14.9	14.6	.3	.6	2.4		4.0		$r = \frac{2.6}{5.1} = 0.51$
73	1	14.95	15.0	0	.2	.2	2.6	1.1	5.1	
	72									
73 -1 72										

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File

Snake Creek near Connell, Wash. FLOOD OF Feb. 21, 1956

SECTION — 4

STA.	DIST	W S ELEV	ELEV	DEPTH	MEAN DEPTH	AREA		W P		
L.B. 2	—	13.78	13.8	0	—	—		—		
5	3	13.8	13.4	0.4	0.2	0.6		3.0		
10	5		13.2	.6	.5	2.5		5.0		$r = \frac{11.1}{18.0} = 0.62$
15	5		13.1	.7	.6	3.0		5.0		
20	5		12.6	1.2	1.0	5.0	11.1	5.0	18.0	
22	2		10.7	3.1	2.2	4.4		2.8		
27	5		9.7	4.1	3.6	18.0		5.1		
31	4		9.5	4.3	4.2	16.8		4.0		
35	4		9.3	4.5	4.4	17.6		4.0		
40	5		9.2	4.6	4.6	23.0		5.0		$r = \frac{193}{50.9} = 3.79$
45	5		9.4	4.4	4.5	22.5		5.0		
50	5		9.7	4.1	4.2	21.0		5.0		
55	5		9.7	4.1	4.1	20.5		5.0		
60	5		9.7	4.1	4.1	20.5		5.0		
64	4		10.5	3.3	3.7	14.8		4.1		
67	3		10.6	3.2	3.2	9.6		3.0		
69	2		12.7	1.1	2.2	4.4	193.1	2.9	50.9	
72	3	13.8	13.4	.4	.8	2.4		3.1		$r = \frac{2.8}{5.1} = 0.55$
74	2	13.75	13.8	0	.2	.4	2.8	2.0	5.1	
	72									
74 -2 72										

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Figure 6.—Sample slope-area computation, cross-section properties.

9-193
Slope-area measurement
December 1960

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

File ________

Meas. No. ________

Slope-area measurement of Snake Creek near Connell, Wash. (Miscellaneous site) for flood of Feb. 21, 1956

Reach between sections	1-2	2-3	3-4
Length of reach (L), ft	121	90	119
Fall in reach (Δh), ft	0.97	0.55	1.07

Gage height, — ft
Discharge[1] 1,380 cfs
Drainage area, 115 sq mi

SECTION PROPERTIES

Section	n	$\frac{1.486}{n}$	a	r	$r^{2/3}$	$K=\frac{1.486}{n}ar^{2/3}$	K^3/a^2	α [2]	q [3]	v
1 sta. 1-67	.045	33.0	208	3.09	2.12	14,550		1.00	1,380	6.64
2 2-11	.080	18.6	6.1	.68	.77	90	0.196		8	1.31
11-67	.045	33.0	203	3.47	2.29	15,340	876		1,370	6.75
			209.1			15,430	876 .196	1.04		
							842			
3 1-14	.080	18.6	10.0	.77	.84	160	.410		13	1.30
14-68	.045		212	3.83	2.45	17,140	1 122		1,360	6.42
68-73	.045		2.6	.51	.64	50	.185		4	1.54
			224.6			17,350	1 122 .595	1.08		
							1 035			
4 2-20	.080	18.6	11.1	.62	.73	150	.274		13	1.17
20-69	.045		193	3.79	2.43	15,480	996		1,360	7.05
69-74	.045		2.8	.55	.67	60	.275	1.10	4	1.43
			206.9			15,690	996 .549			
							901			

Weighted conveyance[4] (K_w). 1-2: 14,930 2-3: 16,360 3-4: 16,500

COMPUTATION OF DISCHARGE

Reach	Assumed Q	h_v [5]	Δh_v [6]	h_f [7]	$S=h_f/L$	$S^{1/2}$	Computed Q $=K_w S^{1/2}$
1-2	1,330	Upstr. .636 Dwnstr. .655	-0.019	0.951	0.00786	0.0887	1,330
2-3	1,320	Upstr. .645 Dwnstr. .580	.065	.582	.00647	.0804	1,320
3-4	1,460	Upstr. .710 Dwnstr. .852	-.142	.928	.00780	.0883	1,460

[1] DISCHARGE (by formula) 1,380 ...., or ....

FORMULAS

2 $\alpha = \Sigma(K^3/a^2) \div K^3_{total}/A^2_{total}$

3 $q = Q\,(K/K_{total})$

4 $K_w = \sqrt{K_{Upstr.} \times K_{Dwnstr.}}$

5 $h_v = \alpha\, V^2/2g$

6 $\Delta h_v = \text{Upstr. } h_v - \text{Dwnstr. } h_v$

7 When Δh_v is positive, $h_f = \Delta h + \frac{1}{2}\Delta h_v$
When Δh_v is negative, $h_f = \Delta h + \Delta h_v$

Summary of factors influencing measuring conditions (floodmarks, surge, scour, fill, channel configuration, angle of flow, selection of n, etc.): ________

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Figure 7.—Sample slope-area computation, discharge.