SAMPLE ROUGHNESS COEFFICIENTS FOR USE IN DETERMINING MAXIMUM FLOW IN WESTERN OREGON STREAMS

by

CHARLES WESLEY DANE

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of

the requirements for the

degree of

MASTER OF SCIENCE

June 1958

APPROVED:

Redacted for privacy

Professor and Head of the Department of Forest Engineering

In Charge of Major

Redacted for privacy

Chairman of School Graduate Committee

Redacted for privacy

Dean of Graduate School

Date thesis is presented May 9, 1958

The author wishes to acknowledge the careful editing and review work done by Dr. George H. Barnes and Dr. J. R. Dilworth. Special acknowledgment should be given to Professor William A. Davies who kept me from "drawing my time".

Table of Contents

SAMPLE ROUGHNESS COEFFICIENTS FOR USE IN DETERMINING MAXIMUM FLOW IN WESTERN OREGON STREAMS

Introduction

In designing forest roads, logging engineers must select the proper size culverts to handle stream flow. Culverts too small to carry the expected flow (called the design flow) may wash out. This may require additional expense in replacing the culvert and fill. Culverts too large for the design flow will tie up money that might better be spent elsewhere. Determination of the optimum size culvert should be reduced to a mathematical procedure that eliminates over or under-design. This requires (1) determination of the design flow expected from the stream and (2) determination of the culvert size to handle this design flow.

Tables and graphs published by culvert manufacturers show the quantity of flow a culvert can handle (1, p. 193-241). Therefore the problem is determination of the design flow expected from the stream. A technique of determining a unitgraph may be used to arrive at the design flow if enough years of streamflow and rainfall records are available (3, p. 134-159). However not enough records are available to build unitgraphs on small watersheds (7). Instead, logging engineers have had to resort to less scientific means.

One of these methods is the use of Talbot's formula. Talbot's formula empirically predicts streamflow by measurement of the watershed area and estimation of a coefficient (1, p. 194-195). This has not proved too successful in practice due to the wide variation in coefficients between adjacent watersheds (8, p. 209).

A more rational approach is achieved by use of Manning's formula (1, p. 209) which determines actual flow by measurement of three factors and an estimate of another. Manning's formula states that:

$$Q = A \frac{1.486}{n} R^{2/3} S^{1/2}$$

where Q = discharge in cubic feet per second.

A = cross sectional area of flow in square feet.

R = mean hydraulic radius in feet.

$= \frac{A}{\text{wetted perimeter in feet.}}$

S = slope of water level in feet per foot.

n = coefficient of roughness of the wetted perimeter.

Logging engineers obtain these stream measurements at selected points that show indications of previous high water and then compute the high water flow. This high water flow is used as the design flow. This technique is open to one major criticism. No one has yet determined the relation between indications of previous high water and any selected design flow.

The only estimate required in Manning's formula is the roughness of the stream bottom (n). This estimate can be important. In one sample problem, the roughness coefficient was varied from 0.04 to 0.10. This is not an uncommon variation in roughness for stream bottoms in Western Oregon. Assuming a 0.04 roughness coefficient, a 54 inch diameter culvert would have been required to handle the high water flow. Increasing the roughness coefficient to 0.10 reduced the culvert diameter needed to 42 inches. The variation in culvert size becomes even greater with large streams.

Previous experimental work in determining this roughness coefficient has been done on canals and on streams that may not be similar to Western Oregon streams (2,5 and 6). Two of these references (5 and 6) contain photographs that illustrate various roughness coefficients.

Objective

The objective of this thesis is to experimentally determine the value of stream bottom roughness coefficients of sample streams in Western Oregon and to present photographs of the stream bottoms with their corresponding roughness coefficients.

Procedure

Sixty-five Western Oregon stream spots were selected at which the stream bottom material remained consistent for a five to thirty-foot reach up and down stream. Representative stream bottom types were selected whenever the material forming the bottom seemed to differ enough from previous types to possibly cause a variation in the roughness coefficient. If possible, each type was sampled at three stream spots. Stream spots were located in the Soap Creek and Oak Creek drainages of OSC's McDonald Forest, the Rock Creek drainage of the City of Corvallis' watershed and in the South Santiam drainage. This is not a wide distribution nor does it sample all the possible variation in Western Oregon stream bottoms. The samples do represent stream bottoms commonly occuring in Western Oregon's forested watersheds; and, therefore, the results should be of some use to logging engineers.

Each stream spot was photographed at low water level to visually indicate the character of the stream bottom. At each of these stream spots, the roughness coefficient of the stream bottom was determined by solving the following formula (3, p. 266).

$$n = \frac{1.486\, R_m^{2/3} \left[S - \frac{\left(\frac{B_2 V_2^2}{2g} + d_2\right) - \left(\frac{B_1 V_1^2}{2g} + d_1\right)}{L} \right]^{1/2}}{V_m}$$

where n = roughness coefficient of the stream bottom.
R_m = mean hydraulic radius of downstream and upstream cross sections.
S = slope of bottom of channel in feet per foot.
B = ratio of the mean of the squares of the velocities divided by the square of the mean velocity. Subscript 1 refers to upstream cross section; subscript 2 refers to downstream cross section.
v = mean velocity of the cross section.
g = 32.16 feet per second per second.
d = depth of water at cross section in feet.
L = length of reach in feet.
V_m = mean of mean velocities at upstream and downstream cross sections.

The measurements used to solve the formula were taken at high water level since the logging engineer would be interested in appraising the roughness coefficient that affects high water flow.

At high water, two cross sections were established at the ends of a straight length of stream that provided visual indications of steady flow. Steady flow was assumed in derivation of the roughness coefficient formula. Visual indications of steady flow are gradually accelerating, gradually decelerating or uniformly flowing bodies of water with straight free surfaces. Each set of data was tested mathematically for steady flow after the measurements were made. Of the 65 stream spots located during low stage, only 40 gave indication of steady flow at high water.

Each cross section was established perpendicular to the flow by ocular estimation. At each cross section, a straight, wooden, 2" x 4" plank was placed across the stream. The plank's ends were leveled to the nearest hundreth of a foot by a dumpy, wye or hand level using correct surveying procedures. The elevation of the bottom of the plank was referred to as the bench mark (B. M. in the data sheets). At 0.20-foot intervals along the plank, lines were drawn perpendicular to the plank's long axis.

At each of these marked intervals, a pitot tube was lowered vertically by aligning the tube with the lines marked on the plank. The pitot tube consisted of a "kinetic" tube facing upstream and a "static" tube normal to the direction of flow and flush with the tube's head. (For details on pitot tubes, their construction and operation refer to 3, p. 108-113). The tube's coefficient (C_p) was 1.00. Sections of the "kinetic" tube and "static" tube were made of glass and joined at the top to a clamp valve to allow evacuation.

When the tubes were slightly evacuated, the differential height of the water could be seen.

Marks were made along the edge of the pitot tube to allow measurement of distances along the length of the tube to hundreths of a foot. By lowering the pitot tube vertically, the vertical distance below the bench mark to the stream's water surface was measured to the nearest hundreth of a foot. This measurement was recorded on the data sheet as shown on page 12. Then at 0.10-foot intervals occuring at exact tenths of a foot below the bench mark, the differential height of the water in the two tubes was measured to the nearest hundreth of a foot with a plastic scale and recorded on the data sheet. The vertical distance to the bottom of the stream was noted to the nearest two-hundreths of a foot and indicated by the position of the letters "Btm" on the data sheet. At the cross section's deepest depth, the vertical distance was measured to the nearest hundreth of a foot and noted on the data sheet (the figure below the deepest "Btm" notation).

The horizontal distance along the stream's centerline between the two cross sections was measured directly with a metallic cloth tape to hundreths of a foot. This reading was recorded on the data sheet. The difference in elevation between the upstream and downstream bench marks was determined to the nearest hundreth of a foot with a rod and wye, dumpy or hand level using correct surveying procedures. This reading was recorded on the data sheet.

From the readings of the differential height of the water in the pitot tubes, a mean velocity and coefficient for each cross section was computed. A work sheet showing a sample calculation is shown on page 13. For each cross section a plat was drawn on 10 x 10 cross section paper and the area and wetted perimeter were measured directly from this plat. A sample plat is shown on page 14. The area was determined by use of a compensating polar planimeter and the wetted perimeter was determined by the use of a map measurer. The hydraulic radius of the section was determined mathematically from the area and wetted perimeter.

Each set of data was tested to determine if steady flow did exist by computing the quantity of flow past each cross section. The mean velocity times the area of the cross section equals the quantity of flow. For steady flow to exist, the quantity of flow passing the upstream cross section should pass the downstream cross section. If any set of data varied enough in flow to change the solution of the roughness coefficient formula by five-thousandths, the set of data was discarded. Data from 28 stream spots survived this test.

Some of the variation from steady flow was probably caused by errors in measurement or recording. Some variation probably existed because of unnoticed seepage into the stream somewhere between the upstream and downstream cross sections. In some cases the variation was due to the heavy precipitation during the time of the measurements. In other cases it was evident the variation was due to movement of water underneath the stream bed.

Those sets of data surviving the test were adjusted to conform to steady flow by adjusting the area of the cross section. This adjustment was made since the error probably existed in incorrectly measuring the sinuosities of the wetted perimeter rather than in the measurement of the differential height of the water in the pitot tubes.

After adjustment the roughness coefficient formula was solved. A sample solution is shown.

$$n = \frac{1.486 \; R_m^{2/3} \left[S - \frac{\left(\frac{B_2 V_2^2}{2g} + d_2\right) - \left(\frac{B_1 V_1^2}{2g} + d_1\right)}{L} \right]^{1/2}}{V_m}$$

Substituting:

$$n = \frac{1.486}{1.60} \, 0.322^{2/3} \left[\frac{0.20}{5.25} - \frac{\left(\frac{2.01 \cdot 1.01^2}{2 \cdot 32.16} + 0.61\right) - \left(\frac{1.27 \cdot 2.19^2}{2 \cdot 32.16} + 0.57\right)}{5.25} \right]^{1/2}$$

$$n = 0.929 \cdot 0.470 \left[\frac{0.20 - \left(\frac{2.05}{64.32} + 0.61\right) + \left(\frac{6.10}{64.32} + 0.57\right)}{5.25} \right]^{1/2}$$

$$n = 0.437 \left[0.04\right]^{1/2}$$

$$n = 0.09$$

Results

Photographs of sample Western Oregon streams are shown on pages 15 to 21 with descriptions of the material forming the bottom. The value of n (the roughness coefficient) at high water level is indicated below each photograph. Where several stream spots of the same type contributed to a variation in the roughness coefficient, the range of the variation is shown.

Use of the Results

By selecting a point in a stream where the stream bottom material is fairly consistent for a distance of 15 or 20 feet up and down stream, a logging engineer may measure the cross sectional area, wetted perimeter and slope of the high water flow. These data plus an estimate of the roughness coefficient will provide the necessary information for determining the quantity of high water flow through the use of Manning's formula.

Study of the photographs will aid in estimating roughness coefficients. The following rules-of-thumb developed from the measurements made for this thesis may serve as further guides.

1. Very few stream bottoms have roughness coefficients below 0.05.
2. Roughness coefficients of clay and/or small rock (3-inch diameter and smaller) stream bottoms average 0.05 unless modified by debris.

3. Roughness coefficients of streams with mild bank debris that is flooded in high water, large rock (1-foot diameter and larger) stream bottoms, and streams with scattered large rock average 0.09.

4. Stream bottoms with logging debris, branches and vegetation never have roughness coefficients below 0.09 and sometimes go as high as 0.40. These stream bottoms give erratic results and should be avoided in making measurements of past high water flows.

Summary

Logging engineers need to estimate the design flow to correctly determine culvert size for logging roads. The most rational method available to logging engineers is the use of Manning's formula. All the information needed to solve Manning's formula may be measured at or near the stream crossing site except the stream bottom roughness. This has to be estimated by the logging engineer.

To aid the logging engineer, this thesis experimentally determined the value of stream bottom roughness coefficients and presented photographs of some sample stream bottoms in Western Oregon with the value of n (the roughness coefficient) indicated below each photograph.

Each stream spot selected was photographed at low water level to visually indicate the character of the stream bottom. Then at high water, two cross sections were established at each end of a length of stream that gave indications of steady flow. At each cross section by the use of a pitot tube, the velocities were measured at 0.10-foot depth intervals at cross-stream intervals of 0.20-feet. From these readings, a mean velocity and coefficient were computed on a worksheet for each cross section and a cross sectional plat was drawn. From this plat, the area and wetted perimeter were measured. The difference in water level, length between cross sections and depth were directly measured in the field.

Using these data, the following formula was solved to determine the stream bottom roughness.

$$n = \frac{1.486\, R_m^{2/3}\left[S - \frac{\left(\frac{B_2 V_2^2}{2g} + d_2\right) - \left(\frac{B_1 V_1^2}{2g} + d_1\right)}{L}\right]^{1/2}}{V_m}$$

where n = roughness coefficient of the stream bottom.

R_m = mean hydraulic radius of downstream and upstream cross sections.

S = slope of bottom of channel in feet per foot.

B = ratio of the mean of the squares of the velocities divided by the square of the mean velocity. Subscript 1 refers to upstream cross section; subscript 2 refers to downstream cross section.

v = mean velocity of the cross section.

g = 32.16 feet per second per second.

d = depth of water at cross section in feet.

L = length of reach in feet.

V_m = mean of mean velocities at upstream and downstream cross sections.

SAMPLE DATA SHEET

Stream Soap Cr. trib. - south side **Date** 12/21/57 **No** 59 U

Approximate Location NW¼ SW¼ Sec 5, T 11 S, R 5 W, W M

Description of Bottom Clay with mild debris on flood plain

Elevation - Upstream B. M.	99.93
BS	3.84
HI	103.77
FS	4.60
Elevation - Downstream B. M.	99.17

Length 5.25

DIFFERENTIAL HEIGHT OF WATER IN PITOT TUBES in hundreths of a foot

Horizontal Distances in Tenths of a Foot

Vertical Distances Below B. M. in tenths of a foot	1	3	5	7	9	11	13	15	17	19	21
1											
2											
14	Water Level										
15	15	15	14	16	19	3	2	2	1		
16	16	14	14	16	18	9	2	1	1		
17	13	14	13	15	18	5	3	2 Btm	0 Btm		
18	11	16	13	13	17	1	8 Btm				
19	12 Btm	0 Btm	13	13	1 Btm	-1 Btm					
			Btm	Btm							
20											

19.7

SAMPLE WORK SHEET

Differential Height of Water in Pitot Tubes in hundreths of a foot	Frequency of Reading	Equivalent Velocity in ft/sec *	Col 3 x Col 2	Col 4 x Col 2
h	f	v	fv	fv^2
-1	1	-0.8	-0.8	-0.64
0	2	0.0	0.0	0.00
1	5	0.8	4.0	3.20
2	4	1.1	4.4	4.84
3	2	1.4	2.8	3.92
4	-	1.6	-	-
5	1	1.8	1.8	3.24
6	-	2.0	-	-
7	-	2.1	-	-
8	1	2.3	2.3	5.29
9	1	2.4	2.4	5.76
10	-	2.5	-	-
11	1	2.7	2.7	7.29
12	1	2.8	2.8	7.84
13	6	2.9	17.4	50.46
14	4	3.0	12.0	36.00
15	3	3.1	9.3	28.83
16	4	3.2	12.8	40.96
17	1	3.3	3.3	10.89
18	2	3.4	6.8	23.12
19	1	3.5	3.5	12.25
	40		87.5	243.25
		Mean =	2.19	6.08
		$Mean^2$ =	4.80	
		B =	$\frac{6.08}{4.80}$	= 1.27

* $v = C_p \sqrt{2gh}$

where:

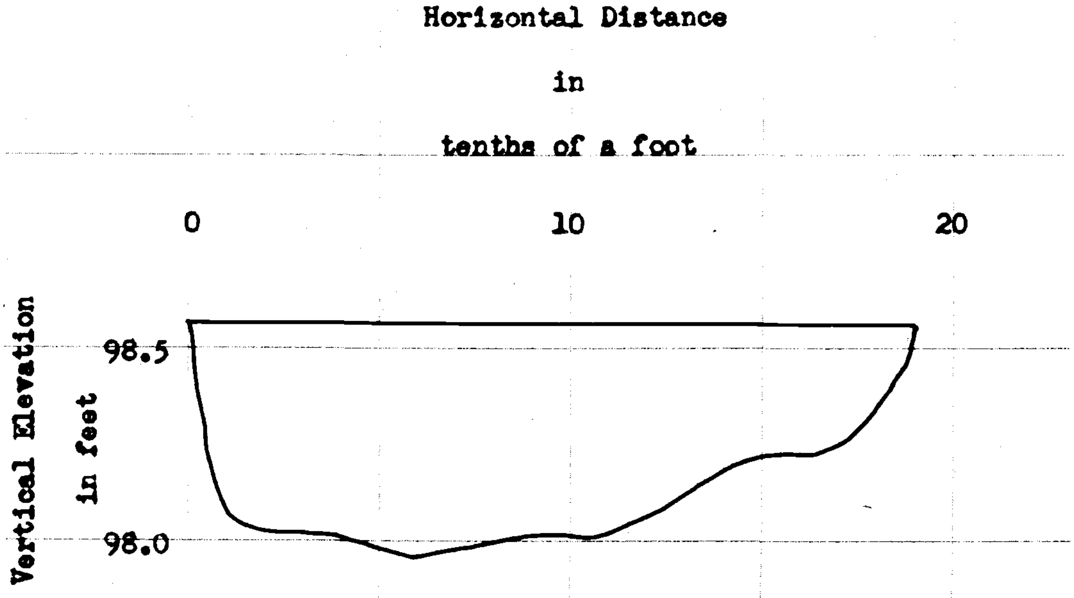
C_p = coefficient of pitot tube. = 1.00

g = 32.16 feet per second per second.

h = differential height of water in pitot tubes in feet.

CROSS SECTION PLAT
of

SAMPLE NUMBER 59 - UPSTREAM



Area	=	0.820 sq ft
Wetted perimeter	=	2.50 ft
Hydraulic radius	=	0.328 ft

Small rock (3-inch diameter and smaller) bottom with little debris.

A yardstick is used for a size-guage.

n = 0.045

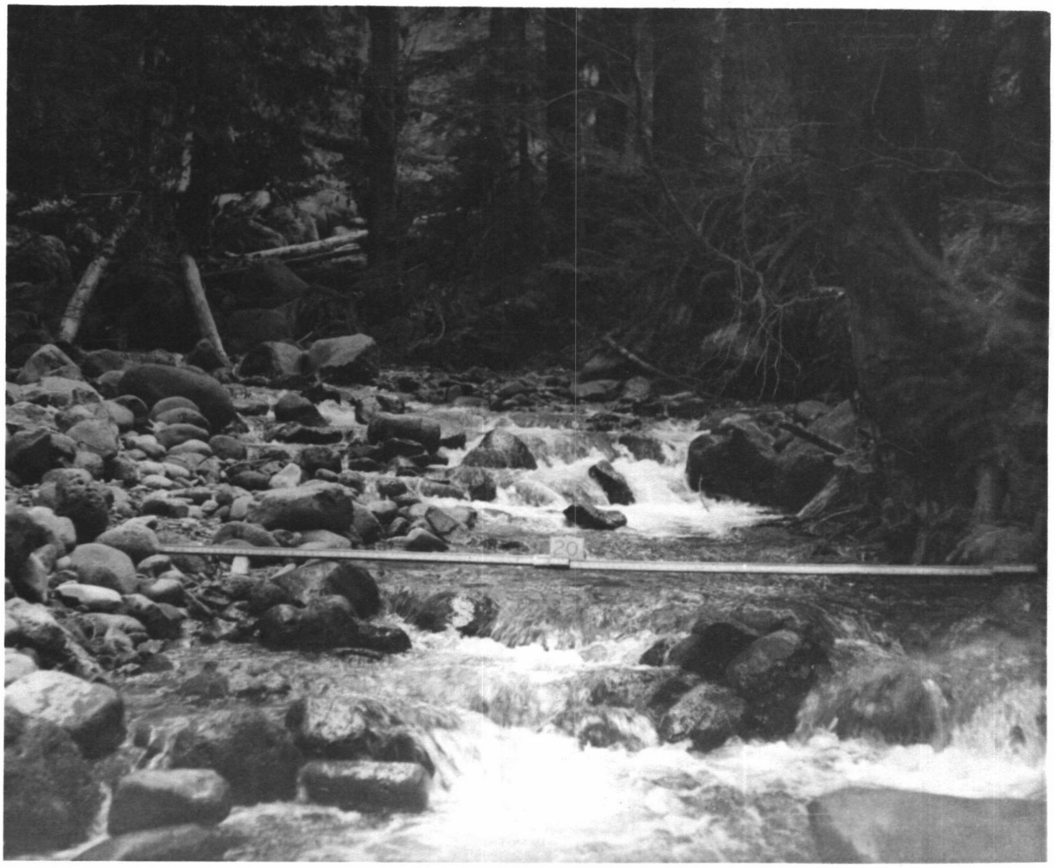
Clay bottom with mild debris. A yardstick is used as a size-guage.

$n = 0.09$

Mixed_size rock (3 to 12-inch diameter) bottom with little debris.

A 3.8-foot rod is used as a size guage.

n = 0.09 to 0.10



Large rock (1-foot diameter and larger) bottom with no debris.

A 13.0-foot rod is used as a size guage.

n = 0.10

Clay bottom with ten percent of the surface covered with

large rock (1-foot diameter).

Mild bank debris.

A yardstick is used as a size-guage.

n = 0.10

Large rock (1-foot diameter and larger) bottom with little debris.

A yardstick is used as a size-guage.

$n = 0.10$ to 0.16

Mixed-size rock (1 to 12-inch diameter) bottom with chunks, sticks, and log debris. A yardstick is used as a size-guage.

n = 0.10 to 0.38

Bibliography

1. Armco Drainage and Metal Products, Inc. Handbook of culvert and drainage practice. Rev. ed. Chicago, R. R. Donnelley and Sons Company, 1950. 474 p.

2. Horton, Robert E. Some better Kutter's formula coefficients. Engineering News 75: 373-374, 862-863. 1916.

3. Johnstone, Don and William P. Cross. Elements of applied hydrology. New York, Ronald Press, 1949. 276 p.

4. King, Horace W., Chester O. Wisler and James G. Woodburn. Hydraulics. 5th ed. New York, Wiley, 1948. 351 p.

5. Ramser, C. E. Flow of water in drainage channels. Washington, U. S. Government Printing Office, 1929. 101 p. (U. S. Department of Agriculture. Technical Bulletin no. 129.)

6. Scobey, Fred C. The flow of water in irrigation channels. Washington, U. S. Government Printing Office, 1915. 68 p. (U. S. Department of Agriculture. Bulletin no. 194.)

7. U. S. Geological Survey. Surface water supply of the United States, 1955. Part 14. Washington, U. S. Government Printing Office, 1957. 279 p. (Geological Survey Water Supply Paper no. 1398.)

8. U. S. National Resources Committee. Water Resources Committee. Low dams. Washington, U. S. Government Printing Office, 1939. 431 p.