FOREST RESEARCH LABORATORY

RESEARCH NOTE 67

STREAMFLOW ESTIMATES IN CULVERTS

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INTRODUCTION

Streamflow measurement in mountain streams is often difficult because the typical succession of pools, riffles, meanders, large rocks, and organic debris creates nonuniform flows throughout a reach. Because channel irregularities, obstructions to flow, and movable beds cause substantial variability in the relationship between elevation of the water surface (stage) and streamflow (discharge), artificial control sections are often constructed in channels where accurate streamflow records are essential. Control sections provide a stable channel geometry and thus a stable stage-to-discharge relation (rating curve). For estimating streamflow on many mountain watersheds where roads cross streams and drainage ways, culverts may substitute for more elaborate artificial control sections. The procedures outlined in this note for calculating the velocity and cross-sectional area of flow and the discharge through culverts may be useful to road engineers, fisheries biologists, hydrologists, foresters, and others needing field estimates of streamflow.

STREAMFLOW CALCULATIONS

Streamflow is calculated as the product of water velocity (V) and cross-sectional area (A):

$$Q = AV.$$

Cross-sectional area (A) of a stream confined in a round culvert can be calculated from

$$A = \frac{\pi r^2 \beta}{180} - (r^2 - rd) \sin \beta$$

where r is the culvert radius in feet, d is the measured depth of flow in feet, and β is the angle in degrees between radial lines to the bottom of the culvert and to the water surface (Figure 1). This angle can be calculated from

$$\beta = \cos^{-1} \left(\frac{r - d}{r}\right).$$

Flow velocities (V) can be estimated with Manning's equation, initially developed in

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1889 and now widely used in the design of pipes, culverts, bridges, and open channels that convey water. It provides an estimate of velocity if the channel cross-section, roughness, and slope are constant over a sufficient distance to establish uniform flow (Highway Task Force 1967). These conditions are often met just upstream from the outlet of culverts installed on mountain roads. The equation for calculating average water velocity (ft/sec) in culverts is:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where n is the roughness coefficient (Table 1), S is the slope or grade (ft/ft) of the culvert, and R is hydraulic radius (ft^2/ft). When flow is uniform (i.e., at constant velocity) in a culvert, the slope of the culvert is the same as the slope of the water surface. The hydraulic radius (R) in Manning's equation is the ratio of the cross-sectional area of flow (A) to the wetted perimeter (WP), which is the length of contact between the water and the containing channel measured at right angles to the direction of flow. Because of the symmetrical radial geometry of round culverts, the hydraulic radius can be calculated from depth of flow (d) and culvert diameter (D):

$$R = \frac{A}{WP} = \frac{r}{2} - \frac{90\,(r - d)\sin\beta}{\pi\beta}$$

The preceding equations can be combined and programmed into many hand-held calculators (an example program is given in the Appendix, page 4).

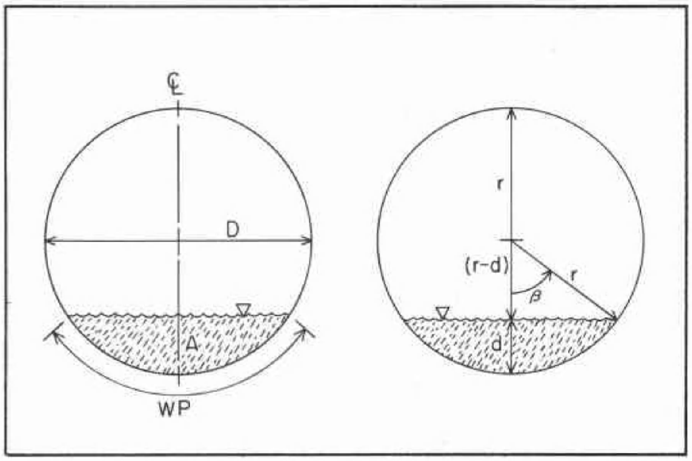

Figure 1.

DEFINITION SKETCH OF VARIABLES USED IN FLOW CALCULATIONS.

TABLE 1.

VALUES OF COEFFICIENT OF ROUGHNESS (n) FOR CULVERTS (HIGHWAY TASK FORCE 1967: 108–134).

Culvert diameter	Annular corrugations	n
Corrugated metal		
1 to 8 ft	$2^2/_3 \times {}^1/_2$ in.	0.024
3 to 8 ft	3 x 1 in.	0.027
Concrete		
All diameters	---	0.012

FIELD MEASUREMENTS

The procedure given here for determining flow rate is appropriate only for round culverts. Before any measurements are made, the culvert should be checked for ponding or backwater effects on the downstream end. Such forms of outlet control invalidate the procedure for calculating streamflow. Sediment deposition in the culvert will also invalidate the procedure. Also, if culverts have been bent or deformed, this method should not be applied. If such conditions do not exist, several simple measurements of flow depth and culvert dimensions suffice:

1. Determine depth of flow (d) upstream from the outlet at a distance at least 1 to 2 times the measured depth. Avoid measurement nearer the outlet where accelerating flow influences water depth. In a metal culvert, measure depth from the ridge, not the valley, of an annular corrugation (Figure 2).

2. Measure inside culvert diameter (D). The radius (r) is half the diameter.

3. Measure the slope (S) of the culvert or water surface with an Abney level or clinometer. It is important to measure the slope accurately.

4. In a metal culvert, measure the annular corrugations: depth from ridge to valley and interval from ridge center to ridge center.

Once these measurements are obtained, the cross-sectional area, velocity, or streamflow can be quickly made in the field.

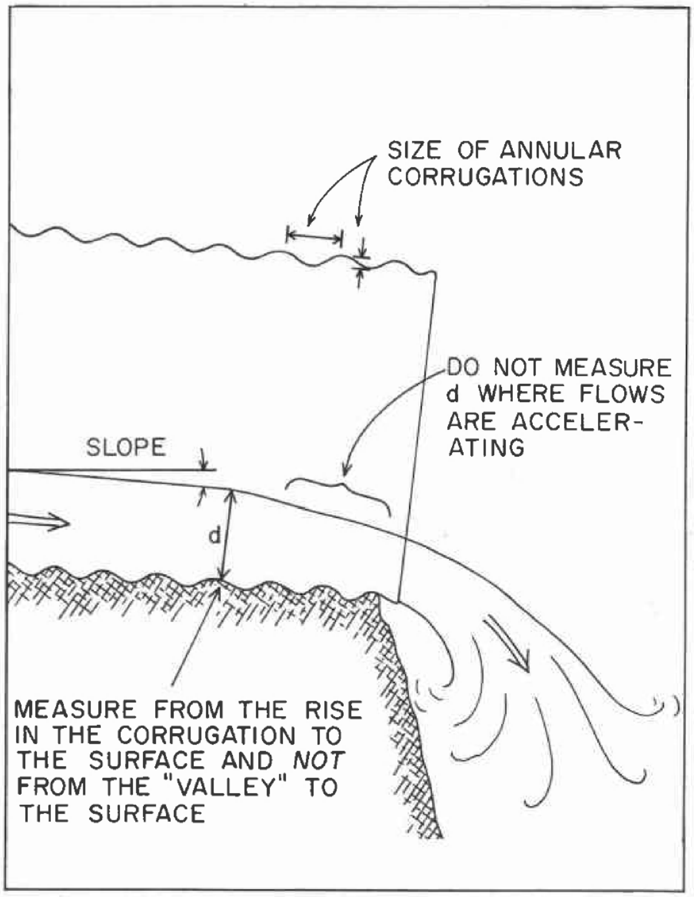

Figure 2.
SCHEMATIC OF CULVERT OUTLET.

LITERATURE CITED

HIGHWAY TASK FORCE. 1967. Handbook of steel drainage and highway construction products. American Iron and Steel Institute, 150 East 2nd Street, New York. 368 p.

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APPENDIX: PROGRAM FOR HP 33E

A program for computing cross-sectional area of flow, average flow velocity, and discharge. Although the program shown is for an HP33E calculator, it can be used with other programmable calculators with minor modifications.

Step	Program Entry	Step	Program Entry
01	π	26	ENTER
02	RCL 4	27	ENTER
03	x^2	28	π
04	x	29	RCL 4
05	RCL 1	30	x
06	÷	31	RCL 7
07	RCL 4	32	x
08	RCL 0	33	RCL 1
09	−	34	2
10	RCL 4	35	÷
11	÷	36	÷
12	$\cos^{-1}$	37	÷
13	STO 7	38	RCL 3
14	x	39	y^x
15	RCL 4	40	RCL 2
16	x^2	41	RCL 6
17	RCL 4	42	÷
18	RCL 0	43	x
19	x	44	RCL 5
20	−	45	$\sqrt{x}$
21	RCL 7	46	x
22	SIN	47	PAUSE
23	x	48	x
24	−	49	GTO 00
25	PAUSE		

To initialize the program, store constants and variable values in appropriate registers:

d	STO 0	d = flow depth, ft
180	STO 1	
1.49	STO 2	
0.667	STO 3	
r	STO 4	r = radius of culvert, ft
S	STO 5	S = slope of culvert, ft/ft
n	STO 6	n = roughness of culvert; see Table 1
	GTO 00	

To run the program, press the R/S key. Program output is displayed in the sequence:

1st PAUSE	Cross-sectional area (A, ft^2)
2nd PAUSE	Velocity (V, ft/sec)
Final display	Stream discharge (Q, ft^3/sec)

Calculations for other conditions of d, r, S, or n can be made by entering new values for these variables and starting the program with the R/S key.