

603307

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

**Preparation of Input Data
for Automatic Computation
of Stage-Discharge Relations
at Culverts**

BOOK 7

CHAPTER C3



PRELIMINARY REPORT FOR U.S. GOVERNMENT USE ONLY



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

Chapter C3

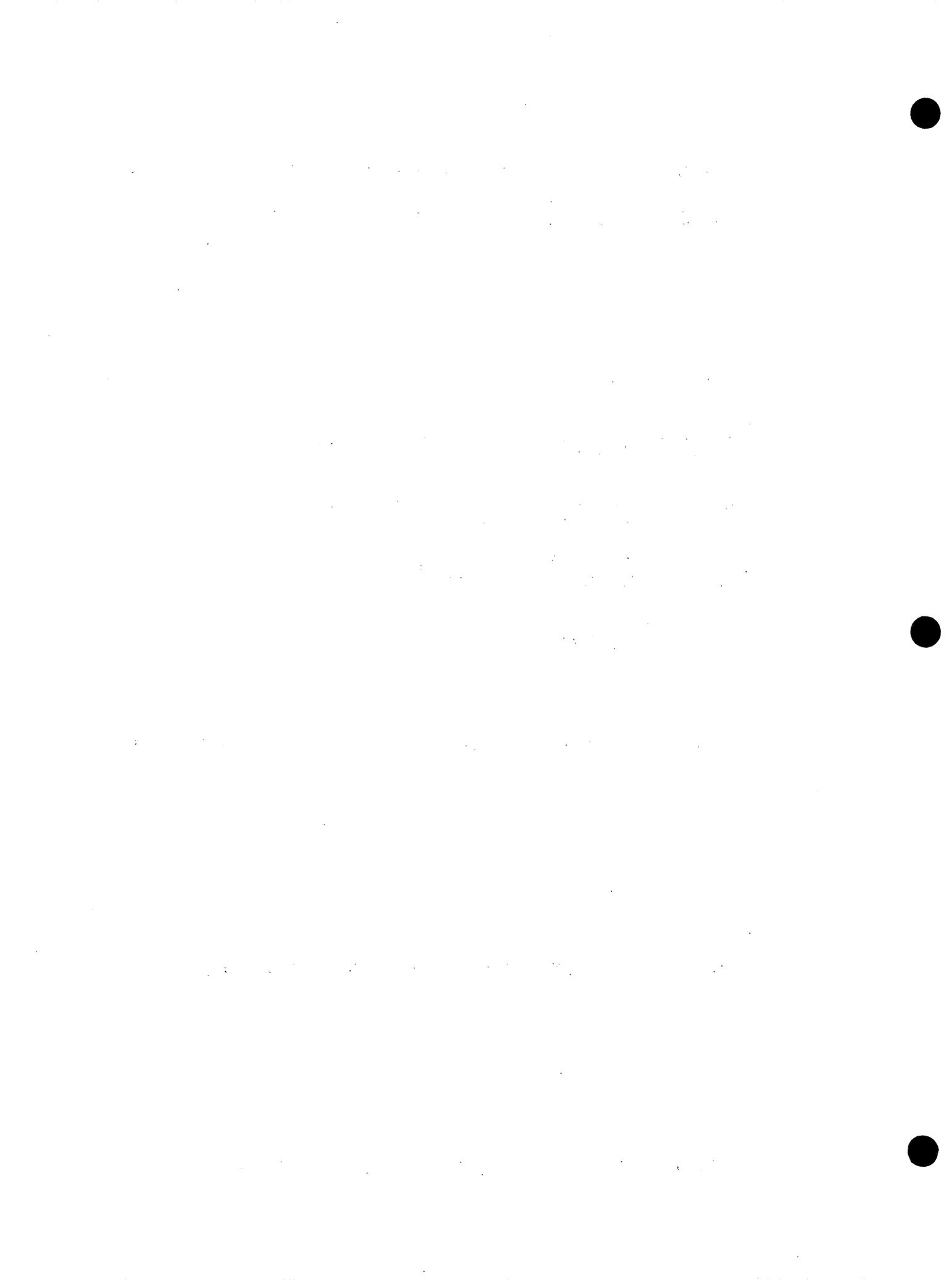
Preparation of Input Data
for Automatic Computation of
Stage-Discharge Relations
at Culverts

By Howard F. Matthai, Harold E. Stull and Jacob Davidian

BOOK 7

AUTOMATED DATA PROCESSING AND COMPUTATIONS

PRELIMINARY REPORT FOR U.S. GOVERNMENT USE ONLY

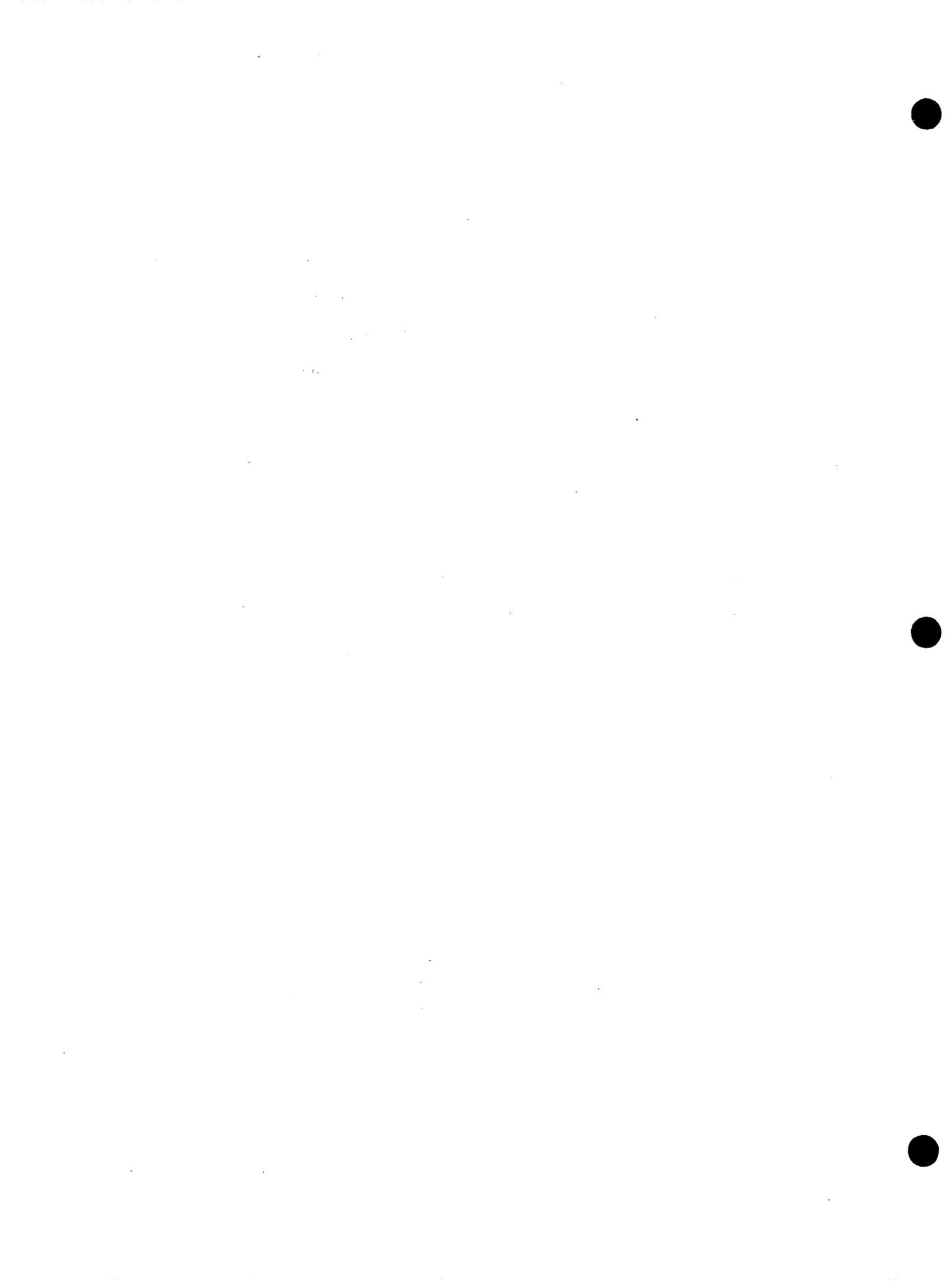


PREFACE

The primary purpose of the series, "Techniques of Water Resources Investigations," is to provide members of the Water Resources Division with information on procedures that will assist and guide them in planning and executing specialized work. As techniques change from time to time, final publication will be by books and chapters to permit ready revision when appropriate. This manual is a preliminary version of one of the chapters. Instructions contained in the manual are considered provisional and subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment.

Judgment must be used in deciding how closely to adhere to instructions. Instructions which include information on preparation of data for use in a computer program must be closely followed. Instructions on methods of analysis are generally less binding and are not to be utilized to the extent of inhibiting initiative or stifling progressive development. However, before using a technique which differs substantially from one which has been recommended, it should be discussed with the office of the appropriate Branch Chief.

When the final edition of this manual is issued, publication will be announced in "New Publications of the Geological Survey" and the report will be for sale by the Superintendent of Documents.



CONTENTS

	Page		Page
Preface	iii	Procedures—Continued	
Abstract	1	Preparation of data—Continued	
Introduction	1	Card 7 - Discharge coefficients-	
Computer program	2	types 1, 2, 3.....	10
Basic equations and computation		Card 8 - Discharge coefficients-	
methods	2	types 4, 5, 6.....	11
Part 1	2	Card 9 - Culvert barrel data....	11
Part 2	3	Checking input data	12
Part 3	3	Transmittal	12
Type 1 flow	4	Computation	13
Type 2 flow	4	Card deck	13
Type 3 flow	5	Printout	13
Type 4 flow	5	Application of results.....	14
Type 5 flow	5	Special conditions.....	14
Type 6 flow	6	Mitered culverts	14
Procedures	6	Culverts with 90° wingwalls	14
Field data	6	Unusual culvert entrances.....	15
Roughness coefficients.....	6	Culverts with fillets	15
Coefficients of discharge	6	Multiple culverts.....	15
Adjustment for degree of con-		Nonstandard conditions	16
traction.....	7	Example	16
Office computations	7	Messages	16
Preparation of data.....	7	Systems codes	16
Card 2 - Stream heading card ...	8	Input-card errors	16
Card 3 - Approach cross-section		Edit-directed messages	19
data	9	Numeric-check messages	20
Card 4 - Subarea roughness		Computational messages	21
coefficients.....	10	References.....	22
Card 5 - Discharges.....	10	Symbols and units.....	23
Card 6 - Tailwater elevations ...	10		

FIGURES

	Page
1. Classification of culvert flow	vi
2. Data-input form 9-1695, stage-discharge relation at culverts	8
3. Completed data form.....	17
4. Computer printout--properties of approach cross section.....	17
5. Computer printout--properties of culvert barrel.....	18
6. Computer printout--discharges, headwater and tailwater elevations, depths, types of flow, and discharge coefficients.....	18
7. Stage-discharge relation derived from computer printout (figure 6)	19

TABLE

	Page
1. Riveted and multiplate pipe-arch sizes to be used in culvert barrel description.....	13

TYPE	EXAMPLE	TYPE	EXAMPLE
I CRITICAL DEPTH AT INLET $\frac{h_1 - z}{D} < 1.5$ $\frac{h_4}{h_c} < 1.0$ $S_0 > S_c$	<p>$Q = CA_3 \sqrt{2g(h_1 + \alpha_1 \frac{V_1^2}{2g} - h_c - h_{1,2})}$</p>	IV SUBMERGED OUTLET $\frac{h_1 - z}{D} > 1.0$ $\frac{h_4}{D} > 1.0$	<p>$Q = CA_4 \sqrt{\frac{2g(h_1 - h_4)}{1 + \frac{29C^2 L}{R^4}}}$</p>
II CRITICAL DEPTH AT OUTLET $\frac{h_1 - z}{D} < 1.5$ $\frac{h_4}{h_c} < 1.0$ $S_0 < S_c$	<p>$Q = CA_2 \sqrt{2g(h_1 + \alpha_1 \frac{V_1^2}{2g} - h_c - h_{1,2} - h_{2,3})}$</p>	V RAPID FLOW AT INLET $\frac{h_1 - z}{D} \geq 1.5$ $\frac{h_4}{D} \geq 1.0$	<p>$Q = CA_5 \sqrt{2g(h_1 - z)}$</p>
III TRANQUIL FLOW THROUGHOUT $\frac{h_1 - z}{D} < 1.5$ $\frac{h_4}{D} \geq 1.0$ $\frac{h_4}{h_c} > 1.0$	<p>$Q = CA_3 \sqrt{2g(h_1 + \alpha_1 \frac{V_1^2}{2g} - h_3 - h_{1,2} - h_{2,3})}$</p>	VI FULL FLOW FREE OUTFALL $\frac{h_1 - z}{D} \geq 1.5$ $\frac{h_4}{D} \geq 1.0$	<p>$Q = CA_6 \sqrt{2g(h_1 - h_3 - h_{2,3})}$</p>

Figure 1.--Classification of culvert flow.

PREPARATION OF INPUT DATA FOR AUTOMATIC COMPUTATION OF STAGE-DISCHARGE RELATIONS AT CULVERTS

By Howard F. Matthai, Harold E. Stull, and Jacob Davidian

ABSTRACT

Detailed instructions are given on the preparation of input data for automatic computation of stage-discharge relations at culverts. The program follows standardized methods of computing headwater elevations, given discharges, tailwater elevations, and the geometries of the approach cross section and the culvert. The basic energy equations are programmed for solutions for single-barreled circular pipes, riveted or multi-plate pipe-arches, and rectangular box culverts with or without webs.

A full stage-discharge relationship can be developed for the range of discharges and tailwater elevations selected. A computation option that is independent of culvert discharge can be used to obtain section properties either of a defined channel cross section, or of both the approach cross section and of the culvert barrel. One example demonstrates the technique.

INTRODUCTION

For convenience in computation, culvert flow has been classified into six types on the basis of the location of the control section and the relative heights of the headwater and tailwater elevations. The six types of flow are illustrated in figure 1. The procedures given by Bodhaine (1968) for computation of peak discharge at culverts have been adapted by R. W. Carter and W. P. Somers to compute headwater elevations at the approach section for given discharges and tailwater elevations. The output of the program is a headwater elevation for each selected discharge for all automatically determined types of flow. A stage-discharge relationship, or rating, can be plotted and tabulated from the output. A family of curves is necessary for type 3 flow where tailwater elevation partially controls the headwater

elevation, and a differential head-discharge relation is used for type 4 flow.

The procedures are applicable to most sites where a culvert is used as a metering device. Peak discharges and runoff during floods are determined frequently at culverts where crest-stage gages or water-stage recorders are installed. The full rating for the site can be obtained from a judicious selection of discharges and tailwater elevations. The peak discharge of an actual flood is determined by applying the elevation of high-water marks, preferably near the approach section, to the computed stage-discharge relation. If the gage is not at the approach section, the relation between the computed headwater elevation and the recorded stage must be established.

The program may be used to compute cross-section properties without regard to the flow in the culvert provided there are no more than four subareas.

The computation techniques and detailed instructions for the preparation of input data are explained in this manual.

This manual is designed for use with program number A526, and data-preparation form 9-1695, Stage-Discharge Relations at Culverts. The manual, program number, and data-preparation form displace, respectively, their counterparts of an older program used heretofore:

Somers, W. P., and Selner, G. I., 1965, Computation of stage-discharge relationships at culverts: Surface Water Techniques, book 1, chap. 8, U.S. Geol. Survey report.

Program number: A531 (also known as M0044).

Data-preparation form: Exp. form 4419 Rev., Stage-Discharge Relationships at Culverts.

COMPUTER PROGRAM

The program is written in Fortran IV for the IBM 360/65 computer. Discharge coefficients and adjustment factors to be selected for the computations are as defined in "Measurement of Peak Discharge at Culverts by Indirect Methods," by G. L. Bodhaine (1968). The program is adapted from one originally written by W. P. Somers and G. I. Selner in Balgol language for use on the Burroughs 220 computer. Subsequent translation to Fortran IV, revisions, and updating were provided by J. V. Tanida, O. G. Lara, and H. E. Stull.

Entries may be made on single computer input form for up to 12 selected discharges, up to 10 tailwater elevations, and up to 25 ground elevations in the approach cross section. The approach cross section can have up to four subareas with independent roughness coefficients. The computer can vary the roughness coefficients with depth by interpolation between assigned values at selected elevations. An approach section is required for every computation; therefore, if ponded approach conditions are anticipated and no cross section was obtained, a simple shape is assumed for which stationing and ground elevations are estimated in the field.

The program can accommodate single-barreled circular pipes, riveted or multi-plate pipe-arches, and rectangular box culverts having either no webs, or up to nine webs. It handles three entrance geometries directly: (a) flush setting in vertical headwall, (b) wingwall entrance, and (c) projecting entrance. The section and hydraulic properties of the three types of culvert barrels are computed and the type of flow is determined. Unusual conditions, such as mitered pipes set flush with sloping embankments, and culverts with 90° wingwalls, are discussed on page 14 in more detail.

Because almost all discharge coefficients and adjustment factors are independent of discharge or velocity, the user determines the appropriate net coefficient for several headwater elevations. The coefficient for type 3 flow in rectangular box culverts is dependent on the Froude number; this coeffi-

cient is therefore determined by the computer. The user has full freedom in selecting nearly all of the various discharge coefficients and adjustments.

Low-head flow is separated from high-head flow by the manner in which computation equations are balanced. Sometimes if criteria within the program are not satisfied in the transition range, there may be no computed results for certain discharges. Under such circumstances graphical interpolations can be made through the transition range to complete the entire rating.

When high-head conditions are computed, headwater elevations are generally given for both types 5 and 6 flow. The decision on the optimum figure is left to the analyst; guidelines are offered by Bodhaine (1968). Suggested procedures are given for smoothing the rating curve in the transition from low- to high-head conditions.

BASIC EQUATIONS AND COMPUTATION METHODS

The program consists of three major parts: (1) a precomputation edit program; (2) computation of section properties and the critical discharge for selected elevations at the approach section, and culvert-barrel section properties; and (3) computation of headwater elevations for selected discharges and tailwater elevations.

Part 1

A precomputation edit program examines all the input data for errors in logic, for improper symbols, or for lack of agreement with physical limits set on some of the input parameters. The error messages are explicit. Explanations of typical error messages are given on page 16.

If a given culvert problem has no input errors, computation commences at once before the next culvert problem is examined for errors.

When a fatal error is detected, a message identifying the particular culvert is first printed as follows, referring to the card 2 for that problem:

THE LAST NUMBER 2 CARD READ
WAS TITLED ----- (see site

identification as listed in columns 1-40 of card 2).

The next line will print out the entire card on which the error occurs, followed by a message describing the error. Prior cards on which no errors were detected in that culvert problem will not be printed out. However, all subsequent cards in that set, whether or not they contain errors, are printed out. They should be carefully examined because an earlier fatal error message for that culvert problem may preclude a thorough internal error check of the succeeding cards.

The last message for a culvert problem in which a fatal error has been detected will give an error count:

THERE ARE xx ERRORS IN THIS SET.

The edit program then examines the next culvert problem in the input deck.

Part 2

Approach-section properties are computed by standard procedures used by the U. S. Geological Survey. Up to four subareas can be used with individual roughness coefficients that can vary with stage between assigned values at selected elevations. Up to 25 points define the cross section, and properties can be computed for up to 25 selected elevations. The output is a tabulation of area, conveyance, velocity-head coefficient (alpha), and top width at each elevation. Also computed and tabulated is the critical discharge for each elevation at the approach section.

The next step is the computation of section properties of the culvert barrel in increments of $D/25$ from $d = 0$ to $d = D$, where d is the depth of flow measured from the lowest point in the cross section of the culvert, and D is the inside vertical dimension of the culvert barrel. The output for the culvert barrel is a tabulation of area, conveyance, and top width for each incremental depth.

This part of the program can be used independently of the culvert-flow computations. Thus, computations can be made only for approach-section properties, or for both approach and culvert-barrel section prop-

erties, by selecting options 1 and 2, respectively, on card 2, column 66. If, however, section properties are desired for cross sections having five to 20 subareas, or 26 to 200 ground elevations, the computer program C374 for slope-area measurements must be used (see Lara and Davidian, 1970).

Part 3

The first of 12 selected discharges is used to compute the headwater elevation associated with each tailwater elevation specified.

The critical depth of flow in the culvert barrel is determined from the general expression

$$\frac{Q^2}{g} = \frac{A_c^3}{T},$$

in which Q is discharge, A_c is cross-section area at critical depth, g is the gravitational constant, and T is top width. The conveyance at critical depth, K_c , is also computed, and the critical slope, S_c , is obtained from the equation

$$S_c = \left(\frac{Q}{K_c} \right)^2.$$

The culvert slope, S_o , is equal to z/L where z is the difference in invert elevations between the inlet and outlet, and L is the length of the culvert barrel. If $S_c \leq S_o$, type 1 flow is indicated; if $S_c > S_o$, type 2 flow is indicated.

The computations are made for h_1 , the piezometric head at the approach section (section 1), referred to the elevation of the invert at the culvert outlet. For each discharge the following computations are made in sequence:

1. Solve for h_1 by either type 1 or type 2 flow equations as indicated.
2. Solve for h_1 by the type 3 flow equation for each of the first nine or fewer tailwater elevations.
3. Solve for h_1 by the type 4 flow equation

for the highest tailwater elevation selected to submerge both the inlet and outlet.

If no results are obtained in step 1, the sequence is:

2. Solve for h_1 by both the type 5 and type 6 flow equations if the piezometric head at section 1 is greater than $1.5 D + z$, or solve for h_1 by the type 3 flow equation as indicated, if supercritical flow occurred in the section.

3. Solve for h_1 by the type 4 flow equation for the highest tailwater elevation, selected to submerge both the inlet and outlet.

An outline of the computer program steps for each type of flow is given below. For flow types 1-5, the sum of the potential and kinetic heads at the upstream section are equated to the sum of the potential and kinetic heads at the control section downstream plus the friction and entrance losses between the two sections.

Type 1 Flow

Critical depth occurs at the barrel entrance; therefore, the type 1 flow equation is:

$$h_1 + \frac{\alpha_1 Q^2}{2gA_1^2} = d_2 + z + \frac{Q^2}{2gA_2^2} + L_w \frac{Q^2}{K_1 K_2} + \left(\frac{1}{C^2} - 1 \right) \frac{Q^2}{2gA_2^2},$$

in which h_1 is the piezometric head at the approach section, section 1, referred to the elevation of the invert at the culvert outlet; α_1 (alpha) is the velocity-head coefficient at the approach section; A_1 is area of flow at the approach section; d_2 is the depth of flow at the barrel entrance, section 2; z is the difference in elevation between the entrance invert and the base (outlet invert) elevation; L_w is the length of the reach between the approach section and the barrel entrance; K_1 and K_2 are the conveyances at approach and entrance sections, respectively; C is the net discharge coefficient; and A_2 is the area

of flow at the barrel entrance.

The root of the equation is found by an iterative process between two extremes. The lower is the critical depth at the approach section for the selected discharge. The elevation is obtained by interpolation between critical discharges computed in Part 1 for the selected water-surface elevations at the approach section. The upper extreme is $1.5 D + z$. If no solution results because the piezometric head at section 1 is greater than $1.5 D + z$, solutions to flow equations for types 5, 6, and 4 are attempted.

If no solution results because of supercritical flow in the approach section, a message, "NO SOLUTION TYPE ONE FLOW-- SUPERCRITICAL FLOW AT APPROACH SECTION," is printed. Then solutions for successive type 3 conditions are tried and an attempt is made to solve the type 4 flow equation.

After a successful type 1 solution, flow equations for types 3 and 4 are solved if that option is chosen.

Type 2 Flow

Type 2 flow requires two equations for solution. Critical flow occurs at the barrel outlet, section 3; therefore, an equation for flow within the culvert is first solved for depth at the entrance, d_2 . This depth is then used in another equation to solve for the headwater elevation.

The first type 2 flow equation is

$$d_2 + z + \frac{Q^2}{2gA_2^2} = d_3 + \frac{Q^2}{2gA_3^2} + L \frac{Q^2}{K_2 K_3},$$

in which d_3 is depth of flow at the outlet corresponding to the critical discharge, L is the barrel length, and K_3 is the conveyance at the outlet section. The root of the equation is found by iteration between the two extremes, $d_2 = d_c$ and $d_2 = D$.

The second type 2 flow equation is

$$h_1 + \frac{\alpha_1 Q^2}{2gA_1^2} = d_c + \frac{Q^2}{2gA_3^2} + L_w \frac{Q^2}{K_1 K_2} + \left(\frac{1}{C^2} - 1 \right) \frac{Q^2}{2gA_3^2} + L \frac{Q^2}{K_2 K_3},$$

in which d_c is critical depth at the outlet.

The equation is solved by iteration between the two extremes, $h_1 = d_2 + z$, and $h_1 = 1.5 D + z$.

If no solution results because the piezometric head at section 1 is greater than $1.5 D + z$, solutions to flow equations for types 5, 6, and 4 are attempted.

If no solution results because of supercritical flow in the approach section, a message, "NO SOLUTION TYPE TWO FLOW--SUPERCRITICAL FLOW AT APPROACH SECTION," is printed. Then solutions for successive type 3 conditions and the type 4 flow equation are tried.

After a successful type 2 solution, flow equations for types 3 and 4 are solved if that option is chosen.

Type 3 Flow

Critical depth does not occur; therefore, d_3 is replaced by h_4 , the depth corresponding to the tailwater elevation. Equations and procedures are very similar to those used for type 2 flow. The depth at the entrance, d_2 , is obtained from the equation of flow between the entrance and the tailwater location, and then it is used to obtain the headwater elevation in the equation of flow between the approach cross section and the tailwater location.

The first type 3 flow equation is

$$d_2 + z + \frac{Q^2}{2gA_2^2} = h_4 + \frac{Q^2}{2gA_3^2} + L \frac{Q^2}{K_2 K_3},$$

in which h_4 is equal to the tailwater elevation minus the base elevation. The root between the extremes, $d_2 = d_c$ and $d_2 = D$, is obtained. The initial h_4 is computed from the first selected tailwater elevation (card 6) for which

h_4 is either greater than $d_c + z$ if type 1 flow occurred, or greater than d_c if type 2 flow occurred.

The second type 3 flow equation is

$$h_1 + \frac{\alpha_1 Q^2}{2gA_1^2} = h_4 + \frac{Q^2}{2gA_3^2} + L_w \frac{Q^2}{K_1 K_2} + \left(\frac{1}{C^2} - 1 \right) \frac{Q^2}{2gA_3^2} + L \frac{Q^2}{K_2 K_3},$$

and it is solved for the root between the extremes, $h_1 = d_2 + z$ and $h_1 = 1.5 D + z$.

If no solution results because of supercritical flow in either the approach section or the culvert barrel entrance, nothing is printed. Then computations for type 3 flow at successively higher tailwater elevations are tried.

Type 4 Flow

Type 4 flow occurs when the culvert is submerged, for which the flow equation is

$$h_1 = h_4 + \frac{Q^2}{2gA_o^2} + \left(\frac{1}{C^2} - 1 \right) \frac{Q^2}{2gA_o^2} + L \frac{Q^2}{K_o^2},$$

where A_o is the cross-section area and K_o is the conveyance for the full culvert barrel. The equation is solved directly. The value of h_4 is for the last tailwater elevation listed and should always be greater than D . For very steep culverts, the tailwater should be high enough to submerge the inlet also.

Type 5 Flow

Type 5 flow occurs when a culvert flows part full under a high head. The type 5 flow equation is

$$h_1 = z + \frac{Q^2}{2gA_o^2} + \left(\frac{1}{C^2} - 1 \right) \frac{Q^2}{2gA_o^2}.$$

The root is obtained between the limits $h_1 = 1.5 D + z$ and $h_1 = 5.0 D + z$, the latter of which is the maximum elevation given in card 8.

If no solution is possible, a message, "NO SOLUTION TYPE FIVE FLOW," is printed. A type 6 flow computation is attempted whether or not a type 5 flow solution is obtained.

Type 6 Flow

Type 6 flow occurs when a culvert flows full under a high head. Six steps are required to obtain the headwater elevation.

1. The term, $\frac{29 n^2 L}{R_o^{4/3}}$, is computed in

which n is the roughness coefficient of the barrel, and R_o is the hydraulic radius of the full barrel.

2. The value of C is taken from columns 62-65 of card 8.

3. A correction factor, k_f , is determined from polynomial equations within the program using values determined in steps 1 and 2. The equations approximate the curves of figure 17 in Bodhaine (1968).

4. The term, $\frac{Q}{A_o \sqrt{D}}$, is computed.

5. $\frac{Q}{A_o \sqrt{D}}$ is divided by k_f , and the result is used to obtain a value of h_1/D from the polynomial equation of the bottom curve in figure 17, Bodhaine (1968).

6. h_1 is computed by multiplying the value of h_1/D by D .

PROCEDURES

Field Data

A computer program for a complete stage-discharge relation imposes a few constraints not necessary when only one peak discharge is determined. Therefore, the field-party chief should be familiar with all the requirements for computation.

An approach section is necessary. If most of the flows will put the culvert under a high head with ponded approach conditions, a simple trapezoidal section approximating the approach channel can be defined in the field notes. However, the stage-discharge relation for low-head flows may not be very reliable.

Be certain to extend the approach section higher than the maximum headwater elevation required, which is about $2.0 D + z$. If field conditions make this impractical, assume vertical ends up to the required elevation.

Measure pertinent culvert geometry carefully. Note size and spacing of corrugations, and radius of rounding of corrugated-metal pipes, pipe-arches, and multiplate arches. Describe entrance and getaway conditions so that an appraisal can be made of the discharge coefficient and the possibility of tailwater control. Determine elevations along the roadway where overflow might occur. Use a survey datum low enough to avoid negative elevations, although the computer can handle them.

Roughness Coefficients

Roughness coefficients must be selected for the approach section below and above designated elevations. The elevations are to the nearest foot and must be 1 foot, or a multiple of 1 foot, apart. The value of n is constant below the lower elevation and above the higher elevation and varies linearly with depth between the two elevations. Roughness coefficients are selected in this manner for each subarea. If both n 's are the same, there is no variation with depth. Select roughness coefficients for the culvert barrel. Bodhaine (1968) furnishes guidelines on pages 10 and 11.

Coefficients of Discharge

Coefficients of discharge, C , for flow types 1-6 were defined by laboratory study and are discussed in detail by Bodhaine (1968), pages 37-45. The coefficients vary from 0.39 to 0.98, and they have been found to be a function of the degree of channel contraction and the geometry of the culvert entrance.

For certain entrance geometries the discharge coefficient is obtained by multiplying a base coefficient by an adjustment factor such as k_r or k_w . If this procedure results in a discharge coefficient greater than 0.98, a coefficient of 0.98 is used automatically by the computer as the limiting value.

The listing of discharge coefficients in Bodhaine (1968), has been put into categories

by types of flow and by entrance geometries. The six flow types are divided into three groups, each group having a discharge equation of the same general form. Thus, flow types 1, 2, and 3 form one group; types 4 and 6 another; and type 5 the third. The coefficient C is descriptive of the live-stream contraction at the inlet and its subsequent expansion in the barrel of the culvert. Hence, base coefficients for types 1, 2, and 3 flow should be identical for identical geometries, as should coefficients for types 4 and 6.

Entrance geometries have been classified in four general categories: (1) flush setting in vertical headwall, (2) wingwall entrance, (3) projecting entrance, and (4) mitered pipe set flush with sloping embankment. These four classes have been subdivided as necessary in Bodhaine (1968), but they are all common to the three flow-type groups.

Adjustment for Degree of Contraction

The degree of contraction may affect the value of the discharge coefficient if flow is type 1, 2, or 3. The ratio of channel contraction, m, is defined as $(1 - A/A_1)$ where A is the area of flow at the control section (section 2 for type 1 flow, and section 3 for types 2 and 3 flow). If m is less than 0.80, the term $(1/C^2 - 1)$ in the equations for flow types 1, 2, and 3 is replaced during the computation by

$$\left\{ \frac{0.64}{\left[0.784 - (0.98 - C)\left(1 - \frac{A}{A_1}\right)\right]^2} - 1 \right\}$$

Office Computations

Plot a plan of the site from the survey notes (Benson and Dalrymple, 1967, p. 25) and scale distances as needed. Select the discharges and tailwater elevations, and determine discharge coefficients for the range anticipated. See more detailed instructions in subsequent sections on the preparation of data for cards 5, 6, and 7. If the headwater elevation for a particular low-head computation is higher than the ground elevation at either end of the approach section, no result will be obtained.

Preparation of Data

The program requires a complete and

accurate set of data for a successful computation. If some bit of required information is lacking or incorrect, the computation will generally be aborted, though erroneous answers may be obtained depending upon the nature of the input error. Careful attention to instructions for completing the data sheet is essential. The reason for placing a digit or a symbol in a particular column may not be obvious, but these are instructions to the computer to direct the sequence of operations or to provide a reference identification.

Use Geological Survey form 9-1695, Stage-Discharge Relations at Culverts (fig. 2), for each culvert.

Only one form is needed for a culvert if up to 12 selected discharges and 10 tailwater elevations will define the rating. A second form with all data entered for all cards can be used if more discharges or tailwater elevations are needed.

The cards are numbered 2 to 9 (there is no card 1) in column 80 of the form; in the following instructions, "card 2," "card 3," etc., refer to these numbers. Each card has space for a sequence number of up to five digits. The sequence numbers simplify the arranging of punched cards in proper order and will insure no mixing of cards between decks for several culverts. For a given culvert problem, up to 12 cards are used, and these should be sequential within the set, starting the first card (a card 2) with any sequence number, and continuing for that particular culvert by increasing sequence numbers for subsequent cards by 1. A second culvert problem can start off with any new sequence number for its card 2, and this sequence number may be larger or smaller than those in the previous culvert problem.

In filling out the forms, care must be taken to leave designated blank spaces blank and to put no symbols in any space earmarked for a decimal. All minus signs must occupy a space alone, and may not be overpunched with any other symbol.

Make all entries easily readable -- large, clear, and dark. Use a dark pencil or ink. If erasures must be made, make the corrected entry legible. Do not cross out part of an entry. Cross out the entire figure and enter correct digits directly above those

STAGE-DISCHARGE RELATION AT CULVERTS

U. S. Department of the Interior
Geological Survey

STREAM HEADING CARD (2)

SITE IDENTIFICATION: 1-31

GAGING STA. NO. W_0 : 32-41, ΔW : 42-51, W_{max} : 52-59, NO. STA.: 60-61, NO. SA.: 62-63, C: 64-65, L_w : 66-71, SEQUENCE CARD: 72-78

APPROACH CROSS-SECTION DATA CARDS (3)

STATION SA GROUND ELEV. SEQUENCE CARD

1-4 5-8 9-12 13-16 17-20 21-24 25-28 29-32 33-36 37-40 41-44 45-48 49-52 53-56 57-60 61-64 65-68 69-72 73-76 77-78

SUB-AREA ROUGHNESS COEFFICIENTS CARD (4)

b a n_1 n_2 SEQUENCE CARD

1-2 3-4 5-6 7-8 9-10 11-12 13-14 15-16 17-18 19-20 21-22 23-24 25-26 27-28 29-30 31-32 33-34 35-36 37-38 39-40 41-42 43-44 45-46 47-48 49-50 51-52 53-54 55-56 57-58 59-60 61-62 63-64 65-66 67-68 69-70 71-72

DISCHARGES CARD (5)

1 2 3 4 5 6 7 8 9 10 11 12 SEQUENCE CARD

1-2 3-4 5-6 7-8 9-10 11-12 13-14 15-16 17-18 19-20 21-22 23-24 25-26 27-28 29-30 31-32 33-34 35-36 37-38 39-40 41-42 43-44 45-46 47-48 49-50 51-52 53-54 55-56 57-58 59-60 61-62 63-64 65-66 67-68 69-70 71-72

TAILWATER ELEVATIONS CARD (6)

1 2 3 4 5 6 7 8 9 10 SEQUENCE CARD

1-2 3-4 5-6 7-8 9-10 11-12 13-14 15-16 17-18 19-20 21-22 23-24 25-26 27-28 29-30 31-32 33-34 35-36 37-38 39-40 41-42 43-44 45-46 47-48 49-50 51-52 53-54 55-56 57-58 59-60 61-62 63-64 65-66 67-68 69-70 71-72

DISCHARGE COEFFICIENTS - TYPES 1, 2, 3 CARD (7)

HP 1 CP 1 HP 2 CP 2 HP 3 CP 3 HP 4 CP 4 CB 12 SEQUENCE CARD

1-2 3-4 5-6 7-8 9-10 11-12 13-14 15-16 17-18 19-20 21-22 23-24 25-26 27-28 29-30 31-32 33-34 35-36 37-38 39-40 41-42 43-44 45-46 47-48 49-50 51-52 53-54 55-56 57-58 59-60 61-62 63-64 65-66 67-68 69-70 71-72

DISCHARGE COEFFICIENTS - TYPES 4, 5, 6 CARD (8)

H5-1 C5-1 H5-2 C5-2 H5-3 C5-3 H5-4 C5-4 C 46 SEQUENCE CARD

1-2 3-4 5-6 7-8 9-10 11-12 13-14 15-16 17-18 19-20 21-22 23-24 25-26 27-28 29-30 31-32 33-34 35-36 37-38 39-40 41-42 43-44 45-46 47-48 49-50 51-52 53-54 55-56 57-58 59-60 61-62 63-64 65-66 67-68 69-70 71-72

CULVERT BARREL DATA CARD (9)

T_c BASE ELEV. z ELEV. D b n L k_f k_w k_B CAL WEB SEQUENCE CARD

1 2-4 5-8 9-12 13-16 17-20 21-24 25-28 29-32 33-36 37-40 41-44 45-48 49-52 53-54 55-56 57-58 59-60 61-62 63-64 65-66 67-68 69-70 71-72

LISTED BY _____ CHECKED BY _____

Figure 2. -- Data-input form 9-1695, stage-discharge relation at culverts.

crossed out -- not elsewhere. Clear, legible, neat copy for the keypunch operator will reduce punching errors and turn-around time.

Card 2 - Stream Heading Card

Columns 1-31. -- Identify the site using the letters or digits.

Columns 33-40. -- Enter gaging station number for all regular stations and crest-stage gage stations. Dash and decimal may be omitted if number has more than six numerals. Miscellaneous stations may be marked with MISC, or any other identification symbols, or these spaces can be left blank.

Columns 42-47. -- W_0 , fixed decimal in column 45, is the lowest water-surface elevation to be used in computing section properties of the approach section. Make W_0 any convenient elevation equal to or less than the elevation of the upstream invert of the culvert barrel, which is the "z Elev" on card 9. W_0 must also be chosen in relation to W_{max} and ΔW . See following instructions. If W_0 is lower than the minimum elevation at the approach section, zeros will be printed until W_0 plus one or more values of ΔW will give

positive section properties. In the flow computation procedure, the message, "DISCHARGE NOT IN THE RANGE OF CRITICAL DISCHARGES," is printed if any of the selected discharges are less than the critical discharge at W_0 . The next higher discharge is then used.

Columns 49-52. -- ΔW , fixed decimal in column 50, is the interval, in feet, between water-surface elevations for which approach-section properties are computed. Choose ΔW small enough so that the upper limit of 24 intervals is approximated; otherwise, the interpolation between critical discharges will not be reliable. Compute ΔW as

$$\Delta W = (W_{max} - W_0) / 24.$$

Then round upward until a whole number of intervals exists between W_0 and W_{max} . If a fractional number of intervals exists, the desired W_{max} will not be reached.

Columns 54-59. -- W_{max} , fixed decimal in column 57, is the highest water-surface elevation to be computed for the approach section. If W_{max} is less than 1.5 D + z elevation, the whole computation is aborted with the trial for the first headwater elevation for

types 1, 2, or 3 flow. Therefore, ground elevations at the ends of the approach section and the elevation, W_{\max} , should be at least as high as $2.0 D + z$ elevation to insure a computation. If necessary, bound the approach section by fictitious vertical lines to reach this elevation. W_{\max} is independent of the H5 values on card 8. W_{\max} is important only in types 1, 2, and 3 flow where the approach section properties are used. W_{\max} is not used in types 4, 5, and 6 flow because pooled approach conditions are assumed and the approach-section properties are not required. Therefore, H5-4 at 5.0 D on card 8 need not be covered by W_{\max} .

Columns 61-62. --NO. STA. is the number of stations used to define the approach section. It may not be less than three nor greater than 25.

Column 64. --NO. SA is the number of subareas in the approach section, and must be 1, 2, 3, or 4.

Column 66. --C is a choice of computation procedures. Use 0 if the stage-discharge computation is to be done; use 1 if only the approach cross-section properties are to be computed; or use 2 if approach and barrel cross-section properties are desired without the stage-discharge computations.

If 0 is used, complete cards 2 through 9; if 1 is used, complete cards 2 through 4; if 2 is used, complete cards 2, 3, 4, and 9. Number the completed cards sequentially.

Columns 68-72. -- L_w , fixed decimal in column 71, is the distance from the approach section to the culvert entrance. If an approach section is assumed, make L_w equal to the culvert width, b.

Columns 74-78. --SEQUENCE is the card sequence number, right justified. Each line used on the form is equivalent to one card. See instructions for sequence numbers under "Preparation of Data."

Column 80. --The card number is 2.

Card 3 - Approach Cross-Section Data

Data sets for five points defining the

approach section can be entered on each card 3. Up to five such cards can be used for a maximum of 25 points. The minimum number of points is three.

STATION is the distance, in feet, from the initial point. Standard Geological Survey practice is to locate the initial point on the left bank. List the data so that stationing increases in the positive direction. Negative stations can be handled. For example: A station sequence of -100, -50, -10, 20, 70, ... can be computed. A sequence of 100, 50, 10, -20, -70, ... cannot be computed because the stationing does not increase in the positive direction.

Stations are entered in columns 1-4, 15-18, 29-32, 43-46, and 57-60. The extremes are 9999 and -999 feet.

SA is the subarea number and must be 1, 2, 3, or 4 for each station. The first station is always in subarea 1, and a 1 is used for all subsequent stations in subarea 1 if the section is not subdivided. If the section is subdivided, the last station in subarea 1 is also the first one in subarea 2 and must have a 2 as its subarea number. Similarly, the first station in subarea 3 must have a 3 as its subarea number, and the first station in subarea 4 must have a 4 as its subarea number.

Subarea numbers are entered in columns 6, 20, 34, 48, and 62. The last subarea number entered must be the same as the number on card 2, column 64.

GROUND ELEV. is the ground elevation at each station. The dotted lines represent decimal points. Every ground elevation must be carried to tenths of a foot -- add a zero for the tenth if necessary.

Ground elevations are entered in columns 8-12, 22-26, 36-40, 50-54, and 64-68. Extremes are 9999.9 and -999.9 feet.

Minus signs, when used for STATION or GROUND ELEV., must be in any space within the appropriate field, to the left of the first digit. Thus, in a GROUND ELEV. field of 5 spaces, elevation -3.2 feet may be recorded as -bb32, b-b32, or bb-32, with b representing a blank space, and with the decimal between 3 and 2 implied.

SEQUENCE. Number the cards (lines) used sequentially starting with a number that is the card 2 sequence number, plus 1.

CARD. Card number, column 80, is 3.

Card 4 - Subarea Roughness Coefficients

The roughness coefficients for the approach-section subareas are entered in pairs along with two elevations. The program accommodates up to four subareas.

These data allow the computer to vary n linearly from n_1 at the lower elevation, b , to n_3 at the upper elevation, a . Therefore, below elevation b the roughness coefficient will equal n_1 ; between elevations b and a , the coefficient will vary linearly from n_1 to n_3 ; and above elevation a , the coefficient will equal n_3 .

Elevations b and a are to the nearest foot, and a must be 1 foot or a multiple of 1 foot higher than b . The values of n_1 and n_3 are the three digits to the right of the decimal in Manning's n . For example: An n of 0.035 would be entered as 035 with the decimal implied. The values of n_1 and n_3 can be the same or either can be higher than the other. A value must be entered for each n_1 , n_3 , a , and b space of each subarea.

If there are fewer than four subareas, leave the unused part of the card blank but add the sequence number, which is 1 greater than that on the last card 3.

The card number, column 80, is 4.

Card 5 - Discharges

List the selected discharges, in cfs (cubic feet per second), in ascending order. Do not select too low a discharge for wide box culverts or for wide, relatively flat approach sections. The program can distribute the flow only uniformly across a section, no matter how a small flow may entrench or channel itself; therefore a fallacious determination of supercritical flow is made.

Express the discharge as whole numbers, right justified, with no decimals or commas,

up to 99999 cfs. If less than 12 discharges are desired, leave the remaining columns blank and complete the sequence number (previous sequence number, plus 1). The discharges are entered in columns 1-5, 7-11, 13-17, 19-23, 25-29, 31-35, 37-41, 43-47, 49-53, 55-59, 61-65, and 67-71.

The card number, column 80, is 5.

Card 6 - Tailwater Elevations

List up to 10 selected tailwater elevations, in feet and hundredths, in ascending order. Make only the last one greater than the base elevation plus D for type 4 flow. For culverts on very steep slopes, this last tailwater elevation must be high enough to submerge the inlet also; therefore, it is best to choose it greater than the base elevation plus $D + z$. The smallest tailwater elevation should be greater than $0.04 D$ plus the base elevation. Only one type 4 computation is required for each discharge because the headwater elevation varies directly with the tailwater elevation. See Bodhaine (1968), figure 31.

If option 1 (card 9, column 68) is chosen, one headwater elevation is computed for each discharge without any influence from the tailwater. Provide one tailwater elevation, higher than the base elevation plus D , on card 6 so the computer will be able to follow the sequence of steps in the program.

If less than 10 tailwater elevations are needed, leave the remaining columns blank and complete the sequence number (previous sequence number, plus 1). The 10 elevations (maximum, 999.99 feet), are listed in columns 1-6, 8-13, 15-20, 22-27, 29-34, 36-41, 43-48, 50-55, 57-62, and 64-69. Fixed decimals are in every seventh column starting with column 4.

The card number, column 80, is 6.

Card 7 - Discharge Coefficients,
Types 1, 2, 3

There are curvilinear relations between the discharge coefficients, C , for flow types 1, 2, and 3, and the headwater elevation. The relations are approximated and the correct coefficient is computed from an input of discharge coefficients corresponding to four specific headwater elevations. List the net coefficients after adjustment for rounding,

beveling, wingwalls, or projecting entrance. Adjustment for degree of contraction is part of the computer program.

The HP and CP blocks on card 7 are for the headwater elevations and the discharge coefficients for pipes or pipe-arches. The CB12 block is for the constant-discharge coefficient for a rectangular box with types 1 or 2 flow. The discharge coefficient for type 3 flow in a rectangular box is a function of the Froude number and is computed in the program using data from card 9. Use either the blocks for pipes and pipe-arches, or that for a rectangular box.

List the four discharge coefficients and four headwater elevations corresponding to elevations at

- 0-times-D, plus the z elevation,
- 0.7 D + z elevation,
- 1.1 D + z elevation, and
- 1.5 D + z elevation.

The headwater elevations must be listed in ascending order. Be sure that HP4 is equal to or greater than 1.5 D + z elevation (not rounded off); if it is not, the computation halts.

The headwater elevations are listed in columns 1-6, 14-19, 27-32, and 40-45; and the coefficients in columns 8-11, 21-24, 34-37, and 47-50. Fixed decimals are in columns 4, 9, 17, 22, 30, 35, 43, and 48.

CB12 is in columns 62-65 with a fixed decimal in column 63.

Complete the card by adding the sequence number (previous sequence number, plus 1).

The card number, column 80, is 7.

Card 8 - Discharge Coefficients Types 4, 5, 6

The H5 and C5 blocks are for the headwater elevations and the discharge coefficients for type 5 flow at four specific headwater elevations. H5 values are independent of the W_{\max} value on card 2. List the net, or adjusted, coefficients and the headwater elevations corresponding to elevations at 1.5, 2.0, 3.0, and 5.0 times D, plus the z elevation, for all types of culvert barrels. The

headwater elevations must be listed in ascending order. Be sure H5-1 is equal to or less than 1.5 D + z elevation (not rounded off), and that H5-4 is equal to or greater than 5.0 D + z elevation; otherwise, the solution for type 5 flow between the extremes, (1.5 D + z) and (5.0 D + z), cannot be accomplished.

At and below the elevation of 1.5 D + z elevation, the discharge coefficient takes the value it is assigned at elevation 1.5 D + z elevation; at and above the elevation of 5.0 D + z elevation, the coefficient takes the value assigned at elevation 5.0 D + z elevation. Between the elevations of 1.5 D + z elevation and 5.0 D + z elevation, the correct discharge coefficient is computed in the program.

The headwater elevations are listed in columns 1-6, 14-19, 27-32, and 40-45; and the coefficients are listed in columns 8-11, 21-24, 34-37, and 47-50. Fixed decimals are in columns 4, 9, 17, 22, 30, 35, 43, and 48.

The block C46 is the constant-discharge coefficient for all conditions of type 4 and type 6 flow. The coefficient is listed in columns 62-65 with a fixed decimal in column 63.

Complete the card by adding the sequence number (previous sequence number, plus 1).

The card number, column 80, is 8.

Card 9 - Culvert Barrel Data

Eight items related to the description of the culvert barrel are entered on card 9. Also, adjustment factors k_r , k_w , and k_θ for the discharge coefficient are listed, but only if type 3 flow in a box culvert is to be computed. There is an option to include the influence from tailwater.

Column 1. -- T_c is the type of culvert barrel. Use the integer 1 for a circular pipe, 2 for a box, or 3 for a pipe-arch.

Columns 4-9. -- BASE ELEV. is the survey datum elevation of the culvert invert at the outlet. Heads are measured above this point as a base. The fixed decimal is in column 7.

Columns 11-16. -- z ELEV. is the survey

datum elevation of the culvert invert at the entrance. The fixed decimal is in column 14.

Columns 18-22. --D, fixed decimal in column 20, is the maximum inside vertical dimension, in feet, of the culvert barrel. For corrugated pipes, D is measured as the minimum inside diameter.

Columns 24-29. --b, fixed decimal in column 27, is the horizontal inside width, in feet, of a box or pipe culvert, or the sum of the inside widths of multibarrel culverts with webs. NOTE: If the culvert is a pipe-arch, b is the size of the culvert as coded in table 1 on page 13. Select the nominal dimensions that most nearly approximate the span and rise of the culvert barrel. Use the SIZE, including the decimal and both zeros, corresponding to the selected nominal dimensions. Do not interpolate.

Columns 32-36. --n is the roughness coefficient of the barrel. The fixed decimal is in column 33.

Columns 38-44. --L is the length, in feet, of the culvert barrel, with the fixed decimal in column 42.

Columns 51-54. -- k_r , fixed decimal in column 52, is the adjustment factor for entrance rounding of a box culvert, type 3 flow only; otherwise, use 0.0.

Columns 56-59. -- k_w , fixed decimal in column 57, is the adjustment factor for entrance beveling of a box culvert, type 3 flow only; otherwise use 0.0.

Columns 61-64. -- k_θ is the adjustment factor for wingwall angle of a box culvert, type 3 flow only; otherwise use 0.0. The fixed decimal is in column 62.

Column 68. --CAL is an option. To compute one headwater elevation for each discharge, with no influence from the tailwater--type 1, 2, or 5 flow--use integer 1. To compute all possible headwater elevations for each discharge, including those when the tailwater is partially controlling--types 3 and 4 flow--use integer 0.

Column 71. --WEB is an integer, 0 to 9, specifying the number of vertical webs in the barrel of a box culvert. The introduction of webs into the computation does not alter the area but changes the wetted perimeter, hydraulic radius, and conveyance.

Columns 74-78. --SEQUENCE is the card sequence number, right justified. (Use previous sequence number, plus 1.)

Column 80. --The card number is 9.

Checking Input Data

The checker has the responsibility to see that the data sheets have the correct figures, that numbers are in the right columns, that a figure is entered wherever one is required by the program, and that all entries are legible. If a correction is necessary, cross out the entire figure and enter correct digits directly above those crossed out.

A correct figure in the wrong column may mean that the decimal point was shifted or that one of the digits may not be read into the computer, which would change the figure by several orders of magnitude, or that a necessary bit of information was omitted, which would result either in no solution, or an incorrect solution.

Some specific entries to cross check are:

1. On card 2, columns 42-59, W_{\max} minus W_0 must equal ΔW times a whole number not greater than 24.
2. The number of stations, card 2, columns 61-62, must equal the sum of the stations listed on all cards 3.
3. The number of subareas, card 2, column 64, must equal subarea number for last station listed on card 3.
4. The first and last ground elevations on cards 3 should be equal to or greater than $2.0 D + z$ elevation.
5. The T_c value on card 9 should be compatible with the HP, CP, CB, k_r , k_w , and k_θ values.
6. The k_r , k_w , and k_θ values should be 0.0, 0.0, and 0.0 if T_c is 1 or 3, or if card 6 is blank, or if column 68 of card 9 is 1.

TRANSMITTAL

Send the completed data forms to the hydraulic specialist or computer consultant in the Regional Office until it is evident that

Table 1. -- Riveted and multiplate pipe-arch sizes to be used in culvert barrel description. See instructions for columns 24-29, card 9.

SIZE Riveted pipe-arches	Nominal dimensions	
	Span (inches)	Rise (inches)
1.00	18	11
2.00	22	13
3.00	25	16
4.00	29	18
5.00	36	22
6.00	43	27
7.00	50	31
8.00	58	36
9.00	65	40
10.00	72	44

Multiplate pipe-arches	Nominal dimensions			
	(ft - in)		(ft - in)	
11.00	6	1	4	7
12.00	6	4	4	9
13.00	6	9	4	11
14.00	7	0	5	1
15.00	7	3	5	3
16.00	7	8	5	5
17.00	7	11	5	7
18.00	8	2	5	9
19.00	8	7	5	11
20.00	8	10	6	1
21.00	9	4	6	3
22.00	9	6	6	5
23.00	9	9	6	7
24.00	10	3	6	9
25.00	10	8	6	11
26.00	10	11	7	1
27.00	11	5	7	3
28.00	11	7	7	5
29.00	11	10	7	7
30.00	12	4	7	9
31.00	12	6	7	11
32.00	12	8	8	1
33.00	12	10	8	4
34.00	13	5	8	5
35.00	13	11	8	7
36.00	14	1	8	9
37.00	14	3	8	11
38.00	14	10	9	1
39.00	15	4	9	3
40.00	15	6	9	5
41.00	15	8	9	7
42.00	15	10	9	10
43.00	16	5	9	11
44.00	16	7	10	1

forms are being completed properly. Then they may be sent directly to the most convenient Geological Survey computer center.

Request that cards be punched and verified. Verification will usually eliminate keypunch errors and will reduce the number of costly reruns and erroneous answers.

Specifications for job control cards have been frequently changed in the past and have varied among the Computer Center Division terminals. Therefore, information on job control cards should be obtained from the hydraulic specialist or from the nearest computer center.

All requests for processing of computations should include the following:

- (a) User registration code assigned by Computer Center Division.
- (b) Account number to be charged.
- (c) Estimated execution time in minutes. Estimate the time for 1-25 culverts as 2 minutes, 26-50 culverts as 3 minutes.
- (d) Estimated lines of printout, in thousands of lines. Estimate lines as 200 times the number of culverts.
- (e) User's name and mailing address.
- (f) Program number A526.

COMPUTATION

Card Deck

The data on form 9-1695 will be punched on cards just as they are entered on the form. The keypunch operator is in no position to decide whether or not the data submitted are correct.

Printout

There are four sections of printout: (1) the input data as punched on the cards, (2) approach-section properties, (3) barrel-section properties, and (4) output data associated with the stage-discharge relation. See the example on page 16 for details.

The values of C in the printout are those tabulated on the input form after adjustment for all pertinent conditions, such as by k_r , k_w , and k_θ , but not for the degree of

contraction. The discharge coefficient used in the computations is the net, or completely adjusted, coefficient listed as C ADJUSTED. It includes the adjustment for degree of contraction, as well as the reduction to a maximum value of 0.98 in the event that the various adjustments result in a combination giving a value for C in excess of 0.98, or impossible values greater than 1.00.

Results for both types 5 and 6 flow appear when high-head flow occurs. Criteria given in Bodhaine (1968, p. 30) will be helpful in deciding which result to use.

If supercritical flow occurs at the approach section, the culvert is no longer the control, and a valid computation is not possible.

APPLICATION OF RESULTS

The results in the printout enable the analyst to develop a graphical stage-discharge relation, or a family of curves if the tailwater elevation partially controls the relation.

Often, results for type 3 flow that is just submerging type 1 or 2 flow will give headwater elevations a few hundredths of a foot lower than that for type 1 or 2. Use the critical-depth condition (type 1 or 2 flow) or the high-head flows (type 5 or 6) as the limiting curve if such a slight anomaly exists.

The transition from low- to high-head flow is made, using recommendations of Bodhaine (1968, p. 47), as follows:

For transition from type 1 to type 5 flow, use low-head results below a headwater-diameter ratio, $(h_1 - z)/D$, of 1.2 and high-head results above a ratio of 1.5. Draw a straight-line transition between the two points.

For transition from type 2 to type 6 flow, use low-head results below a headwater-diameter ratio of 1.25, high-head results above a ratio of 1.75 and a straight line between.

For type 4 flow, the discharge is not related to stage, but is a function of the differential head between the approach section and the tailwater. Discharge is plotted against $(h_1 - h_4)$. See Bodhaine (1968, fig. 31).

Crest-stage gages are frequently installed upstream from a culvert so that the culvert acts as the control for the stage-discharge relation. At many sites, it is not practical to install the gage at the approach section, or the peak gage heights recorded are not directly representative of the average piezometric head in the approach section. Observations of peak gage heights and surveys to determine elevations of high-water marks at both ends of the approach section must be made to establish the relation between average elevations at the approach section and peak gage heights found in the crest-stage gage. THIS IS IMPORTANT.

SPECIAL CONDITIONS

Mitered Culverts

Headwater elevations for pipe or pipe-arch culverts with mitered or step-mitered entrances cannot be computed directly because lengths of the approach reach and culvert barrel vary with the headwater elevation.

For a culvert with a mitered entrance, prepare three or more sets of data, depending upon the size of culvert, using average values of L_w and L for several values of d_2/D , including a value of 1.0. Choose discharges that might be expected to flow within that part of the culvert. Screen the output from all sets of data and select the combination best suited to the conditions for the development of the stage-discharge relation.

If the culvert has a step-miter, prepare data sets for the top of the vertical part just above the culvert invert, for one or more elevations along the mitered part, and for the lower and upper elevations of the vertical part near the top of the culvert. Use average values of L_w and L , and select discharges expected in each range. Choose the combination of output from all data sets best suited to the conditions and develop the stage-discharge relation from it.

The above procedures are satisfactory because changes in L_w and L do not affect the discharge significantly.

Culverts with 90° Wingwalls

In culverts with 90° wingwalls, the proper

choice of culvert length may be a problem. A recommended solution is to run the entire problem with L measured along the invert to the toe of the wingwall, and again with L measured along the top of the culvert to the headwall. If the computed results are significantly different, there will be a basis provided for reasonable interpolation between the two stage-discharge relations, or a basis for selection of lengths for different ranges of discharge in future runs.

Unusual Culvert Entrances

The coefficient of discharge for the commercial flared opening described in figure 8 in Bodhaine (1968) is 0.95 for flow types 1, 2, and 3 for all diameters of pipe and all values of $(h_1 - z)/D$. The properties of these flared end sections are shown in figure 8 in Bodhaine (1968).

For culvert entrances of unusual shape, estimate the discharge coefficient on the basis of known values for the more common shapes (reentrant, sharp, 45-degree wingwalls). For the six types of flow discussed in this manual, this entrance coefficient can usually be estimated with sufficient accuracy. In high-head flow the entrance shape is very important because it may mean the difference between a culvert flowing full or partly full.

Remember that the effect of side contraction becomes negligible for flow types 4, 5, and 6 and that vertical contraction is very important.

Culverts with Fillets

Box culverts sometimes have corner fillets -- a condition for which no provision is made on the data-input form. There are no set criteria for handling this situation; therefore, trial solutions may be necessary.

As a first step, assume no fillets in the top corners. Compute an effective width (b in columns 24-29 of card 9) by dividing the cross-sectional area by D . The solution using this b will probably be most applicable for types 1, 2, and 3 flows involving small discharges.

Another trial solution can be performed using an effective b based on fillets in all corners. This solution would be more applicable for the larger discharges of types 4,

5, and 6 flows.

If the fillets are small relative to the cross-sectional area of the barrel, these two trials should not differ much. If they do differ, a probable stage-discharge relation can be interpolated between the two solutions obtained.

Multiple Culverts

Computations are sometimes required for two or more culverts that share a common approach cross section. The culverts might be identical, but located far enough apart so that the space between them cannot be considered to be a web, or they may be culverts of quite different geometry, slope, and roughness. The procedure recommended is to treat the culverts independently, assigning a part of the approach cross section to each.

If the approach cross section has a large, trapezoidal shape, it may be partitioned in proportion to the gross area of each culvert. See the method described by Matthai (1967, fig. 34 and p. 44).

If the approach cross section is irregular, with a main-channel section and overbank subsections, plot the cumulative area (for stage represented by W_{max}) as shown by Matthai (1967, fig. 30), and divide this in proportion to the gross culvert areas to determine the stationing of subdivision of the approach cross section.

Should these procedures result in individual approach sections that are so far displaced from their designated culverts that the flow pattern would seem to be unnaturally tortuous, the divisions should be readjusted somewhat to conform more with the natural geometry of the ponded regions upstream from the culverts. The stage-discharge relation is more affected by the approach section for the low-head flows than for the high-head flows. This fact should help influence the choice of appropriate boundaries.

If the culverts are relatively close together, or if the approach cross section is necessarily subdivided at points that do not coincide with natural geometric boundaries such as between a deep, natural channel and an adjacent flood plain of higher elevation, then it is recommended that the vertical division lines in the approach cross section not have

wetted perimeters. This is done by assigning a separate subarea to the vertical section when listing card 3, whether the vertical is on the left side, right side, or both sides of the subsection. Because a vertical line between two points has no area (no width) between the two points, the effect of this action is to eliminate conveyance for the subarea defined by the two points.

Nonstandard Conditions

The general computer program was not designed to compute headwater elevations for all conditions possible in the field. Do not use the computer program if the entrance is partly blocked by debris, ice, or snow, if there is a break in slope within the culvert barrel, or if the culvert has an alluvial natural bottom. Routing methods may be used or assumptions made that are peculiar to the site under study to determine the information necessary for a stage-discharge relation. For barrels that vary in size, use the minimum section dimensions.

EXAMPLE

The following example of input and output is for a 6-foot diameter corrugated-metal pipe, 76.6 feet long with the inlet 0.99 foot higher than the outlet, and an n of 0.025.

The input is the completed data form (fig. 3).

The output or computer printout consists of three parts. The first is a table of the approach cross-section properties (fig. 4). The second part is a table of the culvert barrel properties (fig. 5), and the third is a tabulation of discharges, headwater and tailwater elevations, depths, types of flow, and discharge coefficients (fig. 6).

The output is a combination of the computations for examples 1, 3, 5-8 in Bodhaine (1968). These data are used to derive the stage-discharge relation plotted in figure 7.

MESSAGES

The output sheets will occasionally have messages printed out. These will be of three types: (a) systems codes, (b) input-card errors, and (c) computational messages. Messages in each of these categories are described in detail below, along with explanations and remedies.

Systems Codes

Systems errors are those which result from job-control specifications or limitations involving the computer, and not the computer program or the input data cards.

One category of systems errors about which something can be done is that involving the physical limits chosen on the job control cards. The messages will appear in the job statistics part of the printout in the first part of the output, and give the reason for the job not being completed. The most frequently seen system completion codes are:

COMPLETION CODE-SYSTEM=222.....

Explanation: The operator at the Computer Center Division has cancelled the job. Check the estimated number of lines on the job card to be certain this number has not been exceeded, thus aborting the computation. Estimate the number of lines needed to be 200 times the number of culverts, rounded up to the next full thousand.

COMPLETION CODE-SYSTEM=322.....

Explanation: The time allotted to the job has been exceeded. Increase the estimated TIME parameter on the EXEC card. Use 2 minutes for 1-25 culverts, and 3 minutes for 25-50 culverts.

COMPLETION CODE-SYSTEM=80A.....

Explanation: An insufficient amount of core space necessary to run this program has been requested. Increase the REGION parameter on the EXEC card to 90K.

A second category of systems errors and messages shows up in the computational phase of the program. These have to do with underflow, overflow, divide checks, and standard fixups. The stringent precomputation edit checks are designed to avoid the occurrence of these conditions. If, however, such messages do appear in the output, the reason may be that a card has been misread or skipped. Check the alinement of punched holes on the cards, and be certain no cards are bent, scratched, dog-eared, or marred. Generally, messages of underflow, overflow, and divide checks should be referred to the Computer Center Division specialist of the terminal at which the job is submitted.

Input-Card Errors

Errors in this category will show up in the

AUTOMATIC COMPUTATION OF STAGE-DISCHARGE RELATIONS AT CULVERTS 17

Form 9-1995
(Dec. 1970)

STAGE-DISCHARGE RELATION AT CULVERTS

U. S. Department of the Interior
Geological Survey

STREAM HEADING CARD (2)

SITE IDENTIFICATION GAGING STA. NO. W_0 ΔW W_{max} NO. STA. NO. SA C L_w SEQUENCE CARD

RED	CREEK	WEAVER	ARMINTO	WYOMING		2190	050	1290	76	70	150	71	2
-----	-------	--------	---------	---------	--	------	-----	------	----	----	-----	----	---

APPROACH CROSS-SECTION DATA CARDS (3)

STATION	SA	GROUND ELEV.	SEQUENCE CARD												
9		150	9		130	9		114	9		94	9		77	2
37		140	45		137	50		132	55		127	60		120	3
66		139	69		135	73		131	80		126	90		120	3
90		130													3

SUB-AREA ROUGHNESS COEFFICIENTS CARD (4)

b	a	n_1	n_2	b	a	n_1	n_2	b	a	n_1	n_2	SEQUENCE CARD
6	6	030	030	6	6	030	030	6	6	030	030	76

DISCHARGES CARD (5)

1	2	3	4	5	6	7	8	9	10	11	12	SEQUENCE CARD
20	40	60	100	150	200	250	300	400	500			77

TAILWATER ELEVATIONS CARD (6)

1	2	3	4	5	6	7	8	9	10	SEQUENCE CARD
20	40	50	55	60	70	79	90			79

DISCHARGE COEFFICIENTS — TYPES 1, 2, 3 CARD (7)

HP 1	CP 1	HP 2	CP 2	HP 3	CP 3	HP 4	CP 4	CB 12	SEQUENCE CARD
290	195	710	196	750	197	790	198		79

DISCHARGE COEFFICIENTS — TYPES 4, 5, 6 CARD (8)

H5-1	C5-1	H5-2	C5-2	H5-3	C5-3	H5-4	C5-4	C 46	SEQUENCE CARD
290	194	790	197	2090	198	9290	198	179	80

CULVERT BARREL DATA CARD (9)

T_c	BASE ELEV.	a ELEV.	D	b	n	L	k_f	k_w	k_g	CAL	WEB	SEQUENCE CARD
1	297	290	600	600	025	7660	000	000	000	0	0	9

LISTED BY ABC CHECKED BY DEF

Figure 3. -- Completed data form.

RED CREEK NEAR ARMINTO, WYOMING BASE ELEVATION = 1.41 7 = 0.99

APPROACH ELEVATION	AREA	CONVEYANCE	ALPHA	TOP WIDTH	QC
2.90	0.0	0.0	0.0	0.0	0.0
3.40	0.0	0.0	0.0	0.0	0.0
3.90	3.8	70.7	1.000	16.0	10.30
4.40	18.2	635.2	1.000	30.8	79.66
4.90	34.1	1722.0	1.000	32.8	197.58
5.40	51.0	3222.6	1.000	34.8	350.70
5.90	70.4	4858.1	1.000	42.0	516.99
6.40	92.2	7743.7	1.000	45.2	746.94
6.90	115.5	10079.1	1.000	48.4	1013.37
7.40	140.5	13372.0	1.000	51.6	1316.44
7.90	167.0	17203.8	1.000	54.3	1662.02
8.40	194.8	21549.9	1.000	56.8	2047.19
8.90	223.9	26295.2	1.000	59.6	2462.73
9.40	254.4	31524.5	1.000	62.4	2915.08
9.90	286.4	37482.2	1.000	65.2	3404.74
10.40	319.7	43777.2	1.000	68.0	3932.25
10.90	354.4	50222.5	1.000	70.8	4498.14
11.40	390.5	57495.9	1.000	73.6	5103.03
11.90	428.1	65212.2	1.000	76.6	5740.71
12.40	467.0	73793.9	1.000	78.7	6452.72
12.90	506.8	82951.3	1.000	80.6	7210.61
13.40	547.3	93341.6	1.000	81.0	8072.78
13.90	587.8	104324.3	1.000	81.0	8985.23
14.40	628.3	115697.1	1.000	81.0	9929.69
14.90	668.8	127423.6	1.000	81.0	10905.09

Figure 4. -- Computer printout -- properties of approach cross section.

TECHNIQUES OF WATER-RESOURCES INVESTIGATIONS

RED CREEK NEAR ARMINTO, WYOMING BASE ELEVATION = 1.91 Z = 0.99

BARREL DEPTH	AREA	CONVEYANCE	TOP WIDTH	WETTED PERIMETER
0.0	0.0	0.0	0.0	0.0
0.240	0.39	6.6	2.35	2.42
0.480	1.06	28.7	3.26	3.44
0.720	1.92	67.4	3.90	4.24
0.960	2.92	127.3	4.40	4.94
1.200	4.03	192.9	4.80	5.56
1.440	5.22	278.2	5.12	6.14
1.680	6.48	377.1	5.39	6.69
1.920	7.80	488.4	5.60	7.22
2.160	9.16	610.5	5.76	7.72
2.400	10.56	742.1	5.88	8.22
2.640	11.98	881.5	5.96	8.70
2.880	13.42	1026.8	6.00	9.18
3.120	14.86	1176.2	6.00	9.66
3.360	16.29	1327.9	5.96	10.15
3.600	17.71	1479.6	5.88	10.63
3.840	19.11	1629.0	5.76	11.13
4.080	20.47	1771.9	5.60	11.63
4.320	21.79	1911.5	5.39	12.16
4.560	23.06	2034.9	5.13	12.71
4.800	24.25	2152.6	4.80	13.29
5.040	25.35	2248.6	4.40	13.91
5.280	26.35	2321.6	3.90	14.60
5.520	27.21	2363.6	3.26	15.41
5.760	27.89	2359.4	2.35	16.43
6.000	28.27	2202.8	0.01	18.84

Figure 5. --Computer printout -- properties of culvert barrel.

RED CREEK NEAR ARMINTO, WYOMING		BASE ELEVATION = 1.91		Z = 0.99			
D	ELEV H1	ELEV H4	D2	D3	TYPE	C	C ADJUSTED
20.0	4.58	*****	1.16	*****	1	0.91	0.91
20.0	5.08	5.00	2.09	3.09	3	0.90	0.90
20.0	5.55	5.50	2.40	3.59	3	0.89	0.89
20.0	6.03	6.00	3.10	4.09	3	0.88	0.88
20.0	7.02	7.00	4.10	5.09	3	0.86	0.86
20.0	7.92	7.90	5.00	5.99	3	0.84	0.84
20.0	9.02	9.00	6.00	6.00	4	0.78	0.78
40.0	5.33	*****	1.47	*****	1	0.90	0.90
40.0	5.33	5.00	2.07	3.09	3	0.90	0.90
40.0	5.70	5.50	2.40	3.59	3	0.89	0.89
40.0	6.13	6.00	3.10	4.09	3	0.88	0.88
40.0	7.08	7.00	4.11	5.09	3	0.86	0.86
40.0	7.97	7.90	5.02	5.99	3	0.84	0.84
40.0	9.08	9.00	6.00	6.00	4	0.78	0.78
60.0	5.94	*****	2.05	*****	1	0.88	0.88
60.0	NO SOLUTION TYPE THREE FLOW						
60.0	5.95	5.50	2.59	3.59	3	0.88	0.88
60.0	6.30	6.00	3.11	4.09	3	0.88	0.88
60.0	7.18	7.00	4.12	5.09	3	0.86	0.86
60.0	8.05	7.90	5.04	5.99	3	0.84	0.84
60.0	9.17	9.00	6.00	6.00	4	0.78	0.78
100.0	6.98	*****	2.69	*****	1	0.86	0.86
100.0	6.86	6.00	3.13	4.09	3	0.87	0.87
100.0	7.51	7.00	4.17	5.09	3	0.85	0.85
100.0	8.33	7.90	5.11	5.99	3	0.83	0.83
100.0	9.48	9.00	6.00	6.00	4	0.78	0.78
150.0	8.16	*****	3.35	3.32	2	0.84	0.84
150.0	NO SOLUTION TYPE THREE FLOW						
150.0	NO SOLUTION TYPE THREE FLOW						
150.0	8.16	7.00	4.29	5.09	3	0.84	0.84
150.0	8.88	7.90	5.27	5.99	3	0.82	0.82
150.0	10.07	9.00	6.00	6.00	4	0.78	0.78
200.0	9.34	*****	4.15	3.66	2	0.81	0.81
200.0	9.20	6.00	4.04	4.09	3	0.82	0.82
200.0	9.09	7.00	4.54	5.09	3	0.82	0.82
200.0	9.69	7.90	5.53	5.99	3	0.81	0.81
200.0	10.91	9.00	6.00	6.00	4	0.78	0.78
250.0	10.72	*****	4.94	4.33	2	0.78	0.78
250.0	10.33	7.00	5.00	5.09	3	0.79	0.79
250.0	10.90	7.90	5.97	5.99	3	0.77	0.77
250.0	11.98	9.00	6.00	6.00	4	0.78	0.78
300.0	11.92	*****	*****	*****	5	0.44	0.44
300.0	13.29	9.00	6.00	6.00	4	0.78	0.78
400.0	TYPE.. 2 ENERGY EQUATIONS NOT BALANCED						
400.0	15.61	*****	*****	*****	5	0.49	0.49
400.0	14.96	*****	*****	*****	6	0.78	0.78
400.0	16.63	9.00	6.00	6.00	4	0.78	0.78
500.0	TYPE.. 2 ENERGY EQUATIONS NOT BALANCED						
500.0	20.42	*****	*****	*****	5	0.53	0.53
500.0	19.26	*****	*****	*****	6	0.78	0.78
500.0	20.93	9.00	6.00	6.00	4	0.78	0.78

Figure 6. --Computer printout -- discharges, headwater and tailwater elevations, depths, types of flow, and discharge coefficients.

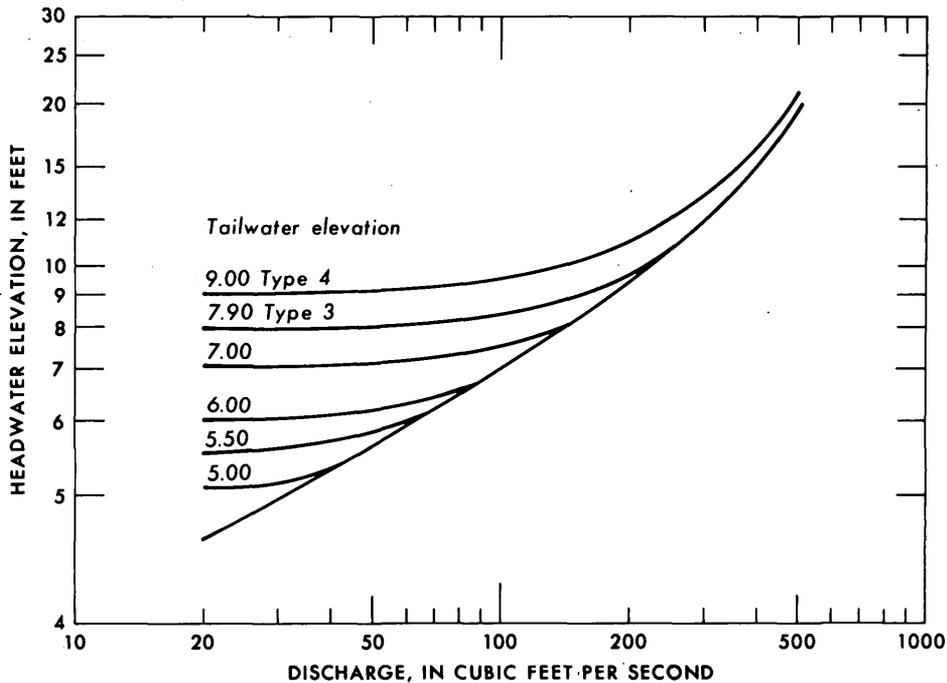


Figure 7. --Stage-discharge relation derived from computer printout (fig. 6).

precomputation edit phase of the culvert computation program. There are two types of these errors; edit-directed messages refer to general errors on the cards or in their sequence, whereas numeric-check messages refer to specific errors in the internal data on the cards.

Edit-Directed Messages

THE NEXT CARD SHOULD NOT BE PRESENT FOR THE OPTION (C) WHICH YOU HAVE CHOSEN.... Explanation: The C-option chosen in column 66 card 2, if it is 1 or 2, does not require all card types. Remove the unnecessary cards.

SEQUENCE NUMBER UNDEFINED.... Explanation: The sequence number on the last card image printed out contains an illegal character or is otherwise unreadable. Repunch the card.

SEQUENCE NUMBER NOT INCREASING.... User action: If cards are in correct card-type order, repunch the sequencing (columns 74-78).

SOME OR ALL OF THE INFORMATION ON THIS CARD IS NOT USABLE FOR AN INTERNAL CHECK.... Explanation: A warning that numerical checks will not be

performed upon the data on this card because of other errors. Correct the other errors, and check the values on this card.

CARD OUT OF ORDER OR C-OPTION INCORRECT.... Explanation: The card read was not the expected card type. Check the order of cards and the value of C option chosen in column 66 card 2.

IF THIS IS A 2 CARD WHICH IS OUT OF ORDER, THE FOLLOWING CARDS WILL BE TREATED AS A NEW SET.... Explanation: This message can appear only after the preceding one, and it arises if a new data set is examined unexpectedly.

ILLEGITIMATE CHARACTER IN COLUMN xx.... Explanation: A non-numeric character appears in a field reserved for numeric characters. Repunch column xx.

COLUMN xx SHOULD CONTAIN A BLANK.... Explanation: A field reserved for a blank has been punched. Eliminate the extra characters; check whether the block of figures for the parameter is positioned properly in its intended field.

VALUE(S) NOT RIGHT JUSTIFIED.... Explanation: The test for this condition is done by checking the column immediately to

left of a blank column to see if it contains a punch. If it does not, then it is assumed that if the same test is performed on the remainder of the fields, they will also be blank. This message is printed when they are not. Make sure all values in fields with an implied decimal point are padded with zeros to the right. Check to see if last digits are in proper columns. Check to see that groupings of similar parameters such as appear on cards 3, 4, 5, 6, 7, or 8, are listed successively in their proper fields from the left side of the card, with no skipping. Check for stray punches.

COLUMN xx SHOULD CONTAIN A DECIMAL..... Explanation: The check for decimal points in nonblank fields has found a non-decimal character. Place the decimal in the proper column.

A x HAS BEEN PUNCHED INSTEAD OF A y. THE DATA ON THIS CARD WILL BE TREATED AS IF IT WERE ON THE LATTER..... Explanation: Column 80 contains a mispunch (x), but through various tests the card is recognized as (y) and will be read as that type for internal checks. Correct the mispunch.

THE LAST NUMBER 2 CARD WAS TITLED xxx*****xxx..... Explanation: An aid in locating the card in error in the data deck.

THERE ARE xx ERRORS IN THIS SET..... Explanation: Gives total number of error messages printed. Note that some errors can generate several different messages.

Numeric-Check Messages

Most of these internal data-check messages are self-explanatory and require no further comment or suggested user action.

DELTA-W SHOULD BE GREATER THAN ZERO..... Explanation: DELTA-W is the printout form of ΔW .

WMAX SHOULD BE GREATER THAN W0..... Explanation: WMAX and W0 represent the printout forms of W_{max} and W_0 , respectively.

DELTA-W SHOULD BE GREATER THAN OR EQUAL TO (WMAX-W0)/24.

NO. STA SHOULD CONTAIN AN INTEGER BETWEEN 3 AND 25 INCLUSIVE.

NO. SA SHOULD CONTAIN AN INTEGER BETWEEN 1 AND 4 INCLUSIVE.

C SHOULD CONTAIN AN INTEGER BETWEEN 0 AND 2 INCLUSIVE.

LW SHOULD BE GREATER THAN ZERO FOR OPTIONS C = 0, OR C = 2.

THE FIRST SUBAREA IS NOT 1.

WMAX SHOULD BE LESS THAN OR EQUAL TO THE FIRST GROUND ELEVATION.

THE FINAL SUBAREA SHOULD BE EQUAL TO NO. SA.

SUBAREAS NOT IN INCREASING ORDER.

STATION DISTANCES ARE NOT INCREASING... Explanation: Appears if stations decrease, but not if they are the same, as in a vertical.

WMAX SHOULD BE LESS THAN OR EQUAL TO THE LAST GROUND ELEVATION.

N1 NOT GREATER THAN 0 IN SET x.

N3 NOT GREATER THAN 0 IN SET x.

UNLESS THERE WAS A PREVIOUS ERROR IN NO. SA, THE NUMBER OF SUBAREAS IS LESS THAN THE EXPECTED NUMBER.

B NOT LESS THAN A IN SET x..... Explanation: This refers to elevations b and a on card 4.

NO. SA IS NOT USABLE FOR INTERNAL CHECK, SO DATA ON THIS CARD CANNOT BE READ PROPERLY..... Explanation: Because an internal check of data cannot be made, spurious error messages may follow.

FIRST TAILWATER ELEVATION MUST BE GREATER THAN ZERO.

TAILWATER ELEVATION x IS NOT IN INCREASING ORDER.

TAILWATER ELEVATION x IS NOT GREATER THAN OR EQUAL TO $0.04 * D +$ BASE ELEVATION.

ONLY ONE TAILWATER ELEVATION SHOULD BE GREATER THAN OR EQUAL TO BASE ELEV. + D.

HP-x IS NOT IN INCREASING ORDER.

HP-4 SHOULD BE GREATER THAN OR EQUAL TO $1.5 * D + Z$ ELEV.

H5-x IS NOT IN ASCENDING ORDER.

H5-1 SHOULD BE LESS THAN OR EQUAL TO $1.5 * D + Z$ ELEV.

H5-4 SHOULD BE GREATER THAN OR EQUAL TO $5.0 * D + Z$ ELEV.

TC SHOULD BE 1, 2, or 3.

Z ELEV. SHOULD BE GREATER THAN OR EQUAL TO W0.

B SHOULD BE GREATER THAN 0.
Explanation: Refers to width b on card 9.

N SHOULD BE GREATER THAN 0.

L SHOULD BE GREATER THAN 0.

KT, KW, KR, AND CB12 SHOULD BE POSITIVE FOR TC=2.

KT, KW, KR, AND CB12 SHOULD BE ZERO FOR TC=1 OR TC=3.

CAL SHOULD BE 0 OR 1.

Computational Messages

The third category of messages is generated during the computational phase of the program, and usually describes why no solution is obtained for the stage-discharge relation.

DISCHARGE NOT IN THE RANGE OF CRITICAL DISCHARGES. . . Q = qqqqq. qq.
Explanation: The discharge shown is less than the critical discharge, Q_c , at the lowest water-surface elevation, W_o , at the approach section. The next discharge is then tried. If a solution is desired for the rejected Q, then W_o should be lowered.

qqqqq. q NO SOLUTION TYPE ONE FLOW. Explanation: Headwater elevation, H1, is greater than $1.5 D + z$ for the discharge shown.

qqqqq. q NO SOLUTION TYPE ONE FLOW--SUPERCRITICAL FLOW AT APPROACH SECTION. Explanation: Headwater elevation, H1, is less than the elevation for critical discharge, or neither type 1 nor type 5 flow can occur at the discharge shown.

qqqqq. q TYPE 2 ENERGY EQUATIONS NOT BALANCED. Explanation: Type 2 flow cannot occur at the discharge shown.

qqqqq. q NO SOLUTION TYPE TWO FLOW--SUPERCRITICAL FLOW AT APPROACH SECTION. Explanation: The area of the approach section at the elevation of $d_2 + z$ is zero, or the discharge shown is greater than critical discharge at the computed headwater elevation.

qqqqq. q NO SOLUTION TYPE FIVE FLOW. Explanation: Type 5 flow does not occur between headwater elevations at $1.5 D + z$ and $5.00 + z$, for the discharge shown.

qqqqq. q NO SOLUTION TYPE THREE FLOW. Explanation: Type 3 flow does not occur between headwater elevations at $d_2 + z$ and $1.5 D + z$ for the discharge shown. The tailwater elevation will be printed.

qqqqq. q TYPE 5 H NOT IN THE RANGE OF H5. H = hhh. hhhh. Explanation: This is a warning that for the discharge shown, the indicated trial headwater elevation is less than H5-1 or greater than H5-4, as they are listed on card 8. A type 5 solution is then printed using a discharge coefficient equal to C5-1 or C5-4.

TYPE X CANNOT INTERPOLATE COEFFICIENT--HEIGHT = hhhhh. hhhh.
Explanation: The trial headwater elevation shown is less than HP-1 or greater than HP-4 on card 7. No solution is possible, so the next discharge is tried.

TYPE X CANNOT INTERPOLATE CONVEYANCE--HEIGHT = hhhhh. hhhh.
Explanation: The trial headwater elevation shown is outside the range of elevations at the approach section. If flow is type 1, the next discharge is tried. For type 2 flow, the message, "NO SOLUTION TYPE TWO FLOW --SUPERCRITICAL FLOW AT APPROACH SECTION," is printed. If flow is type 3, the next tailwater elevation is tried.

TYPE X CULVERT AREA AND CONVEYANCE CANNOT BE INTERPOLATED-- HEIGHT = hhhhh.hhhh. . . . Explanation: The trial depth is outside the range of depth of the culvert barrel. The next discharge is tried. For type 3 flow, check tailwater elevations on card 6; elevations other than the last one should not be greater than $D + \text{base elevation}$.

REFERENCES

- Benson, M. A., and Dalrymple, Tate, 1967, General field and office procedures for indirect discharge measurements: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A1, 30 p.
- Bodhaine, G. L., 1968, Measurement of peak discharge at culverts by indirect methods: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A3, 60 p.
- Lara, O. G., and Davidian, Jacob, 1970, Preparation of input data for automatic computation of discharge by slope-area method: U.S. Geol. Survey Techniques Water-Resources Inv., book 7, chap. C2, 14 p.
- Matthai, H. F., 1967, Measurement of peak discharge at width contractions by indirect methods: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. A4, 44 p.

SYMBOLS AND UNITS

Symbol*	Definition	Unit
A	Area.	ft ²
A _o	Area of culvert barrel.	ft ²
A _c	Area of section of flow at critical depth.	ft ²
a; A	An elevation in the approach section, above which the roughness coefficient, n, is constant.	ft
BASE ELEV	Elevation of the culvert invert at the outlet.	ft
b; B	Horizontal inside width of barrel of a box or pipe culvert, or the sum of inside widths of multi-barrel culverts.	ft
b	Size of a pipe-arch culvert, as coded in table 1 (used on card 9).	
b; B	An elevation in the approach section, below which the roughness coefficient, n, is constant.	ft
C	Coefficient of discharge.	
C	Choice of computation procedures (on card 2).	
CAL	An option for computing for either one or more headwater elevations for each designated discharge (used on card 9).	
CB12	Constant-discharge coefficient for a rectangular box, used on card 7, for flow types 1 and 2.	
CP	Discharge coefficient for pipes or pipe-arches, used on card 7, for flow types 1, 2, and 3.	
C46	Constant-discharge coefficient for all types of culvert barrels, used on card 8, for all conditions of types 4 and 6 flow.	
C5	Net, or adjusted discharge coefficient for all types of culvert barrels, used on card 8, for type 5 flow.	
D	Maximum inside vertical dimension of culvert barrel, or the inside diameter of a circular section. (For corrugated pipes, D is measured as the minimum inside diameter.)	ft
D _m	Maximum inside diameter of pipe culvert at entrance.	ft
d	Depth of flow measured from the lowest point in the cross section for culverts.	ft
d _c	Maximum depth in critical-flow section.	ft
d _m	Mean depth.	ft
F	Froude number.	
g	Gravitational constant (acceleration).	ft/sec ²
HP	Headwater elevation for pipes or pipe-arches, used on card 7, for flow types 1, 2, and 3.	ft

SYMBOLS AND UNITS--Continued

Symbol*	Definition	Unit
H5	Headwater elevation for all types of culvert barrels, used on card 8, for type 5 flow.	ft
h; H	Static or piezometric head above an arbitrary datum.	ft
h_c	$d_c + z$ for type 1 culvert flow.	ft
h_e	Head loss due to entrance contraction.	ft
h_f	Head loss due to friction.	ft
h_v	Velocity head at a section	ft
K	Conveyance of a section.	ft ³ /sec
K_c	Conveyance of critical-depth section.	ft ³ /sec
K_o	Conveyance of full culvert barrel.	ft ³ /sec
k_r ; KR	Adjustment factor for entrance rounding of a box culvert, used on card 9, and applied only to type 3 flow.	
k_w ; KW	Adjustment factor for entrance beveling of a box culvert, used on card 9, and applied only to type 3 flow.	
k_θ ; KT	Adjustment factor for wingwall angle of a box culvert, used on card 9, and applied only to type 3 flow.	
L	Length of culvert barrel.	ft
L_p	Distance a culvert barrel projects beyond a headwall or embankment.	ft
L_w	Distance from approach section to entrance of culvert.	ft
m	Channel-contraction ratio.	
NO. STA.	The number of stations used to define the approach cross section.	
NO. SA	The number of subareas in the approach section.	
n; N	Manning roughness coefficient.	ft ^{1/6}
P	Wetted perimeter of cross section of flow.	ft
P_v	Wetted perimeter of the paved invert of a culvert.	ft
Q	Total discharge.	ft ³ /sec
Q_c ; QC	The critical discharge for designated elevations in the approach section.	ft ³ /sec
R	Hydraulic radius.	ft
R_v	Hydraulic radius of a culvert barrel.	ft
r; R	Radius of entrance rounding.	ft
S	Friction slope	
S_c	Bed slope of culvert for which the normal depth and the critical depth are equal.	

SYMBOLS AND UNITS--Continued

Symbol*	Definition	Units
S_o	Bed slope of culvert barrel.	
SA	Subarea (used on card 3).	
T	Width of a section at the water surface.	ft
T_c ; TC	Type of culvert barrel (used on card 9): use integer 1 for a circular pipe, 2 for a box, or 3 for a pipe-arch.	
V	Mean velocity of flow in a section.	ft/sec
V_o	Full culvert velocity.	ft/sec
ΔW ; DELTA-W	Interval between water-surface elevations for which approach section properties are computed.	ft
W_{max} ; WMAX	Highest water-surface elevation to be computed for the approach section.	ft
W_o ; W0	Lowest water-surface elevation to be used in computing section properties of the approach section.	ft
WEB	An integer, 0 to 9, specifying the number of vertical webs in the barrel of a box culvert (used on card 9).	
w	Measure of the length of a wingwall or chamfer.	ft
x	Length of part-full flow.	ft
z; Z	Difference in invert elevations between inlet and outlet of culvert.	ft
z elevation; Z ELEV	Elevation of the upstream invert of the culvert barrel.	ft
1, 2	Subscripts which denote the location of cross sections or section properties in downstream order.	
α ; ALPHA	Velocity-head coefficient.	
θ	Acute angle between a wingwall and plane of contraction or headwall; and the bevel angle.	
<	Less than.	
≤	Equal to or less than.	
>	Greater than.	
≥	Equal to or greater than.	

*Text symbol precedes printout symbol if both are shown.