DRE 216

PROGRAM DOCUMENTATION

A GENERAL PROGRAM TO COMPUTE FLOW THROUGH GATED CULVERTS

BY

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS

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INTRODUCTION

This report documents a computer program used to calculate flow through gated culverts. The program was developed in 1980 for the Upland Demonstration Project (Kissimmee) to calculate flow through eleven culvert sites. A review of the computation procedures available at that time indicated that existing procedures were suitable for design use , but were inadequate to meet the specific requirements of the project. It was therefore decided to develop a general culvert flow computation program with the criteria that: (a) the program uses rigorous hydraulic principles with minimum use of simplifying approximations, (b) the program can handle all flow conditions, (c) the program can handle circular and box culverts with different inlet control gates, and (d) the program is general enough to be used for all District culvert structures.

The program has been used to process flow for the above project for the last five years. The program was later used to process flow for five additional sites in the Taylor Creek Nubbin Slough Project. Recently a production version was implemented to routinely process flow through all District culvert structures. Based on experience gained from applying the program to a wide range of culverts and conditions, it was possible to refine the program many times to improve its efficiency and accuracy. Program verification and debugging are essentially complete.

The next section presents an overview of program capability and methodology. A detailed explanation on the flow computation procedures follows. Hydraulic principles will be presented without derivation, since they can be found in many hydraulic textbooks. The program was written in FORTRAN and for the convenience of reading the computer program, the same FORTRAN symbols and mathematical operators will be used in the explanation. The final section illustrates the usage of the program and verifies the results with experimental and field data. A listing of the program is included in the appendix.

PROGRAM OVERVIEW

This report documents a general program used to calculate flow through gated culverts. The program is capable of handling circular or box culverts with a rectangular or circular slide gate or a flashboard weir at the inlet. Inputs to the program are culvert physical parameters, headwater stage, tailwater stage, and gate opening or weir elevation; outputs are discharge and coding of the flow type.

The program can be used to process flow data or to design culvert structures. There are two versions of the program. A production version is suitable for processing a large amount of data when only the discharge data are needed. An interactive version is useful in design application, parameter calibration, trouble shooting, flow rating, or in gaining an understanding of the flow hydraulics. The interactive version provides a detailed output on the hydraulic computation.

The program is intended to compute flow to an accuracy of one percent mathematical error by applying exact hydraulic principles. Iteration procedures are used when needed to satisfy some complex hydraulic relationships. The use of simplifying approximations commonly used in handbook procedures is kept to the minimum.

A culvert can flow under many different hydraulic conditions. The program classifies the flow into three major types: Full Flow, Orifice Flow, and Open Channel Flow. There are two subtypes under Full Flow conditions depending on whether the inlet is submerged or unsubmerged. Orifice Flow consists of two subtypes depending on whether the barrel is partially filled or completely free. Three subtypes are considered in Open Channel Flow conditions depending on whether critical flow occurs at inlet or at outlet, or whether subcritical flow occurs throughout the barrel under tailwater control. Iteration procedures are used to compute flow under Open Channel Flow conditions, since both the depth of flow and the flow itself are related implicitly. A one percent tolerance criterion is used to terminate all iterations

The program uses explicit mathematical criteria to differentiate the major type of flow. The subtypes under each major flow, however, cannot always be differentiated by simple explicit criteria. Wherever possible, the program uses simple explicit criteria to differentiate the subtype, otherwise, the flows under different subtypes are computed. The controlling subtype is indicated by the one with the lowest flow.

The existence of an inlet gate may shift the type of flow if the restriction is significant. Otherwise, if the restriction is small, the effect is to increase the entrance loss coefficient and the flow can be computed as if the gate did not exist except that the entrance loss coefficient is modified. Based on numerical experimentation, the two conditions are differentiated by simple mathematical criteria. Under the second condition, the entrance loss coefficient is modified by the ratio of the gate opening to the flow area according to a formula which expresses loss due to sudden contraction.

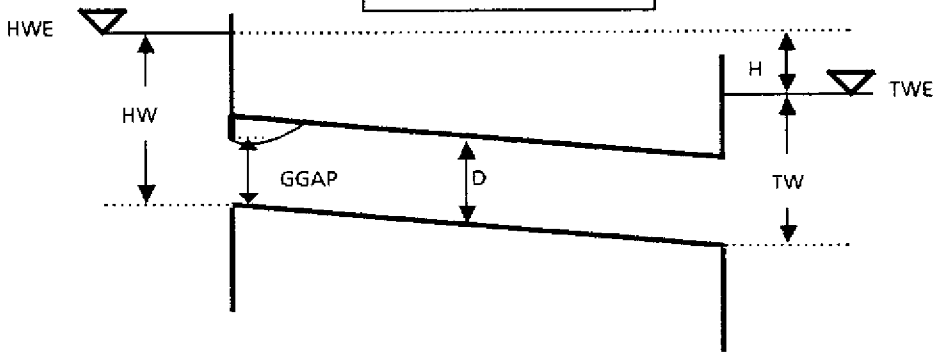
Entrance loss coefficients given in hydraulic handbooks are generally applicable to full flow conditions. The coefficients are considerably smaller under open channel flow conditions due to a smoother transition. The program currently uses a 0.36 factor to adjust the coefficient under all unsubmerged inlet conditions.

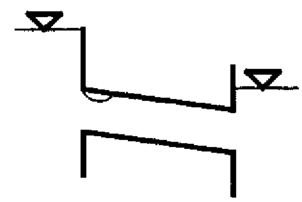
Constant coefficients are used throughout the program (friction loss, entrance loss, orifice flow, and weir flow coefficients, etc.) because there are insufficient experimental data to generalize a more sophisticated approach using variable coefficients. Since these coefficients are input parameters, the user may elect to calibrate them with field data or vary them according to user selected criteria.

The District is currently establishing a laboratory model to test the flow hydraulics in gated culverts. The test results will be used to better define the flow coefficients, and to evaluate the assumptions in the program. The test results will be published separately as a supplement to this documentation.

The interactive version consists of a main program and seven subroutines. The main program controls the input and output of data, differentiates the major type of flow, and branches the computation to the appropriate subroutine. Subroutine PIPE, ORIFICE, DITCH, and WEIR compute flow under full flow, orifice flow, open channel flow, and weir flow conditions, respectively. Subroutine GATE determines the gate opening area and adjusts the entrance loss coefficient caused by the reduced opening area. Subroutine CIRCLE and RECT determine the hydraulic properties of the barrel (flow area, hydraulic depth, radius, etc) needed for other subroutines. The production version is similar to the interactive version except that the main program is in subroutine form suitable for inclusion in another program. The user must write his own main program to control the input and output of data to suit his specific format requirements.

FULL PIPE FLOW
Criteria: TW > D





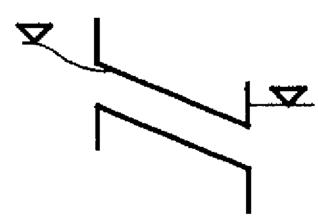
Subtype I: Submerged Inlet. Code: "F"

Criteria: HW > 1.3*D or HW>2*GGAP

Comment: Full flow throughout the barrel

Equation: Q = A*SQRT{64.4*H/(1 + KE + KF)} where

- A = Area of barrel
- KE = Adjusted entrance loss coefficient
- KF = Friction loss coefficient
  = 29.1*N**2*L/R**1.3333
- N = Manning coefficient
- L = Length of barrel
- R = Hydraulic radius
- H = HWE - TWE
- HWE = Headwater elevation
- TWE = Tailwater elevation
- GGAP = Gate opening in feet
- D = Depth of culvert



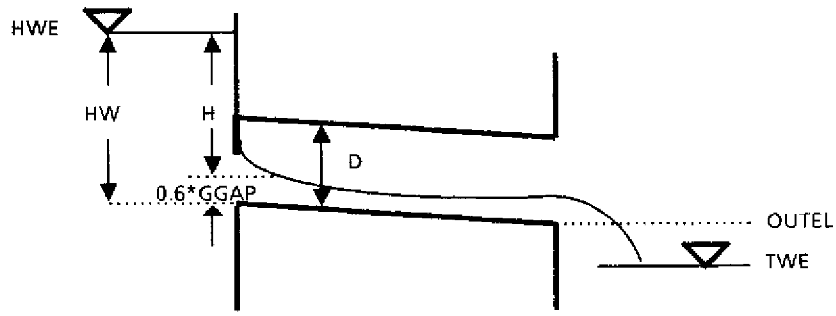
Subtype II: Unsubmerged inlet. Code: "F"

Criteria: HW < 1.3*D or HW<2*GGAP

Comment: Entrance loss coefficients given in textbooks are applicable to full flow only and are too large when the inlet is unsubmerged. Assuming the entrance contraction coefficient of a submerged inlet to be 0.6 and applying the continuity equation, the equivalent entrance loss coefficient of an unsubmerged inlet can be shown to be 0.36 the coefficient for a similar submerged inlet.

Equation: Same as in subtype I except that the entrance loss coefficient K is adjusted by a factor of 0.36.

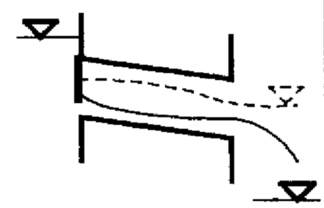
ORIFICE FLOW
Criteria: TW < D and {HW>1.3*D or HW>2*GGAP}



Subtype I: Free Orifice Flow. Code: "O"

Criteria: Subtype I flow < Subtype II flow

Comment: Inlet control. Barrel is never filled and flow is unaffected by barrel friction. The gate can be submerged if the tailwater is higher than the gate opening.

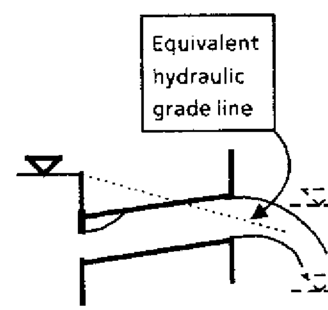


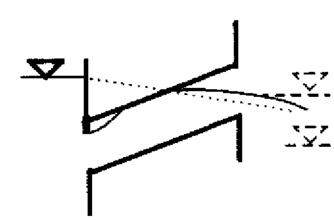
Equation: Q = C*AG*SQRT(64.4*H) where
- C = Orifice flow coefficient (average 0.6)
- AG = Area of gate opening in ft^2
- H = Hydraulic head
  - = HW-0.6*GGAP or HW - 0.6*(TWE-INEL) whichever is smaller
- GGAP = Gate opening in ft
- HWE = Headwater elevation
- TWE = Tailwater elevation

Subtype II: Part full pipe flow. Code: "P"

Criteria: Subtype II flow < Subtype I flow

Comment: May occur when the barrel is on an adverse slope or under high tailwater conditions. Flow is affected by barrel friction and evaluated as full pipe flow with equivalent hydraulic grade line.

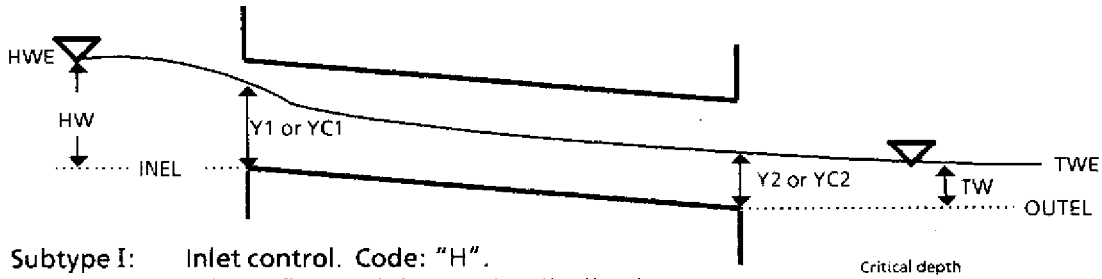


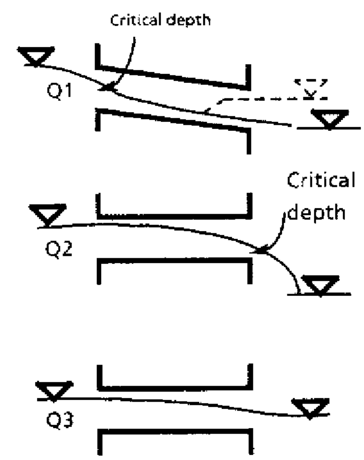


Equation: Q = A*SQRT{64.4*H/(1 + KE + KF)} where
- A = Area of barrel
- H = Equivalent hydraulic head
  - = The smaller of HWE-(OUTEL + 0.5*D) or HWE-TWE for HWE>OUTEL + D. Otherwise the smaller of 0.5*(HWE-OUTEL) or HWE-TWE for HW<OUTEL + D.
- OUTEL = Invert elevation at outlet
- D = Depth of barrel
- KE = Adjusted entrance loss coefficient
- KF = Friction loss coefficient
  - = 29.1*N**2*L/R**1.3333
- L = Length of culvert
- R = Hydraulic radius

OPEN CHANNEL FLOW

Criteria: TW<D and {HW<1.3*D or HW<2*GGAP}





Subtype I: Inlet control. Code: "H".
Comment: Critical flow at inlet. Hydraulically, the barrel is on a steep slope. A hydraulic jump may occur inside the barrel (Q1).

Subtype II: Outlet control. Code: "T".
Comment: Critical flow or free fall at outlet. The barrel is hydraulically on a mild slope (Q2).

Subtype III: Tailwater control. Code "T"
Comment: Subcritical flow throughout the barrel. High tailwater condition (Q3).

Note: Entrance loss coefficient is adjusted by a factor of 0.36 because the inlet is unsubmerged (see explanation in page 4)

Criteria: The subtypes cannot be differentiated by simple explicit relationships because the criteria themselves depend on the unknown depth of flow which is related implicitly to the discharge to be estimated. The following algorithm is used to differentiate the subtypes:

Step 1: Compute the flow Q1 as inlet control and determine the inlet critical depth YC1.

Step 2: Check if the tailwater elevation TWE is above the inlet critical depth YC1. If so compute the flow Q3 by proceeding to step 5 as tailwater control and compare Q1 with Q3. The lower of the two is the controlling one, and end further computation. Otherwise, if TWE is below YC1, proceed to step 3.

Step 3: Compute critical slope SC from Q1. Compare the bottom slope SB of the culvert with SC. If SB is greater than SC the flow is under inlet control and end further computation. Otherwise proceed to step 4.

Step 4: Compute the flow Q2 as outlet control and determine the outlet critical depth YC2. Compare tailwater elevation TWE with YC2. If TWE is below YC2, compare Q1 with Q2. The lower of the two is the controlling one and end further computation. Otherwise proceed to step 5 to compute Q3 as tailwater control.

Step 5: Compute flow Q3 as tailwater control and compare Q1 with Q3. The lower of the two is the controlling one.

OPEN CHANNEL FLOW
(Continue)

Iteration Procedures

Under open channel flow conditions, the unknown flow and depth of flow are related implicitly. It is necessary to use iteration to determine the flow and the depth. The iteration is started by first estimating an initial depth. The flow and the depth are then computed with the estimated depth. The deviation between the computed and estimated depth is used to revise the estimated depth until a 0.01 ft tolerance level is achieved. Constraints are set in the iteration to assure that critical flow and entrance drawdown conditions are satisfied, and the flow depth is within the limits of the barrel diameter. An adjustment factor, IADJ, is used to modify the iteration:

Y1 = Y11 + DEV*0.1 / IADJ

Where Y1 = Estimated depth
Y11 = Computed depth
DEV = Y11-Y1
IADJ = Iteration adjustment factor (1 to 11)

Numerical experiment indicates that the choice of IADJ affects the iteration significantly. A large IADJ will assure convergency and stability, but will prolong the iteration. A small IADJ will speed up the iteration, but may lead to infinite oscillation and nonconvergency. For optimum conditions the program initializes IADJ at 1 and gradually increases IADJ as the iteration proceeds.

Inlet Control (See diagrams in page 6)

For a box culvert the inlet critical depth YC1 and discharge Q can be determined explicitly from:

YC1 = 2*HW/(3 + KE) and
Q = SQRT(32.2*HD1)*A1

where KE = Entrance loss coefficient
HD1 = Hydraulic depth at inlet.
= YC1 for box culvert.
A1 = Flow area at inlet

For a circular culvert, YC1 and Q are related implicitly. It is required to iterate YC1 until it satisfies the entrance drawdown and critical flow conditions. The iteration procedure is as follows:

- Step 1 Estimate YC1 initially as 0.75*HW.
- Step 2 Estimate HW as HW1 = YC1 + (1 + KE)*HD1/2, where YC1 and HD1 are the critical and hydraulic depths, respectively, at the entrance.
- Step 3 If deviation DEV = HW-HW1 is less than 0.01, the entrance drawdown and critical flow conditions are satisfied and terminate the iteration. Otherwise revise YC1 by YC1 + DEV*0.1 and return to Step 2.
- Step 4 Compute Q as SQRT(32.2*HD1)*A1, where A1 is the flow area at the inlet.

OPEN CHANNEL FLOW
(Continue)

Tailwater Control (See diagrams in page 6):

Under tailwater control, Y2 is known (same as TW), and it is required to iterate Y1 until the entrance drawdown condition is satisfied. The iteration is as follows:

Step 1 Estimate Y1 initially as 1.01*(TWE-INEL), where INEL is the invert elevation at the inlet.

Step 2 Compute geometric mean conveyance as:
CONVEY = 1.49/N*SQRT(A1*R1**0.6667*A2*R2**0.6667),
where A1, R1, A2, R2 are the flow areas and hydraulic radii at the inlet and outlet, respectively (from subroutine CIRCLE or RECT).

Step 3 Compute energy slope from S = F/L
where L = Length of culvert
F = Fall in water surface elevation
= (Y1 + INEL) - (Y2 + OUTEL)
INEL = Invert elevation at inlet
OUTEL = Invert elevation at outlet

Step 4 Compute Q = CONVEY*SQRT(S) and V1 = Q/A1, where V1 is the flow velocity at the inlet.

Step 5 Estimate Y1 as Y11 = HW - (1 + KE)*V1**2/64.4

Step 6 If deviation DEV = Y11 - Y1 is less than 0.01, the entrance drawdown condition is satisfied and the iteration will be terminated. Otherwise, revise Y1 by Y1 + DEV*0.1 / IADJ and return to Step 2, where IADJ is the adjustment factor (see page 6).

Outlet Control (See diagrams in page 6):

Under outlet control, both Y1 and Y2 are unknown. Y2 must satisfy the critical flow condition and be designated as YC2. Y1 must satisfy the entrance drawdown condition . Two loops of iteration are needed. First, iterate YC2 until exit critical flow condition is satisfied. Second, iterate Y1 until entrance drawdown condition is satisfied. The iteration is as follows:

Step 1 Estimate Y1 and YC2 initially as:
Y1 = YC1 + OUTEL - INEL and YC2 = 0.8*YC1
where YC1 = Inlet critical depth from Inlet Control calculation.

Step 2 Compute geometric mean conveyance CONVEY, energy slope S and discharge Q as in Step 2 through Step 4 under Tailwater Control.

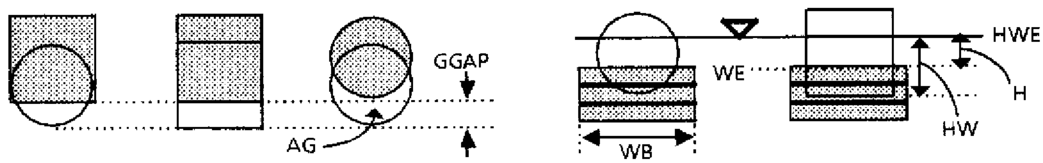
Step 3 Given estimated YC2, compute hydraulic depth HD2 from channel properties (Subroutine CIRCLE or RECT). Compute hydraulic depth HD22 alternatively from critical flow relationship :
HD22 = V2**2/32.2 where V2 = Q/A2

Step 4 If deviation DEV2 = HD22 - HD2 is less than 0.01, outlet critical flow condition is satisfied and proceed to Step 5. Otherwise revise YC2 as YC2 + DEV*0.1 / IADJ and return to Step 2.

Step 5 Estimate Y1 as Y11 = HW - (1 + KE)*V1**2/64.4.

Step 6 If deviation DEV = Y11-Y1 is less than 0.01, the entrance drawdown condition is satisfied and iteration will be terminated. Otherwise, revise Y1 by Y1 + DEV*0.1 / IADJ and return to Step 2

INLET CONTROL GATE



Three types of inlet control gates are considered: rectangular slide gate, circular slide gate, and flashboard weir. The existence of an inlet gate may affect the flow in two ways: (1) If the restriction is significant, the flow regime will be shifted. For example, open channel flow will be shifted to orifice flow if the gate opening is small; or full pipe flow will be shifted to weir flow if the weir crest is high. (2) If the restriction is minor, the flow regime will remain the same but the entrance loss will be increased. The two conditions can be distinguished by computing the flows under both conditions. The controlling condition is indicated by the one with the lower flow. Numerical experimentation based on the above criteria, however, was used to establish coefficients whereby the first condition is distinguished by:

Orifice control: HW > 2*GGAP
Weir control: AW < 2*A
where HW = Head above the inlet invert
GGAP = Gate opening height
AW = Flow area above weir crest
A = Flow area in the barrel

The flow under the second condition can be computed as if the gate did not exist except that the entrance loss coefficient is adjusted by:

For slide gate: KE = {[SQRT(K) + 1]*A/AG-1}**2
For weir: KE = 0.1*(A/AW)**2 + K
where K = Entrance loss coefficient (input parameter, 0.1 to 0.9)
AG = Gate opening area (from Subroutine GATE)
KE = Adjusted entrance loss coefficient due to gate restriction

The above adjustment is based on the application of the continuity equation and the assumption that entrance loss is equivalent to sudden contraction loss which can be expressed by $(1/C_c-1)^2 V^2/2g$, where C_c is the contraction coefficient (Reference 7, p.6-22).

Under weir control conditions, the flow is computed by:

Free weir flow: QW = CW*WB*H**1.5
Submerged flow: Free flow multiplied by {1-[(TWE-WE)/(HWE-WE)]**1.5}**0.385
(Villemonte formula, reference 7)
where QW = Weir flow
CW = Weir flow coefficient (average 3.3)
WB = Weir length
WE = Weir elevation
H = Head above the weir crest (HWE-WE)

For some weir structures, overflow may occur along the wingwall or riser, which can be treated as a side weir with total length SWB and crest elevation SWE. The same equations are used to compute the overflow by substituting WB with SWB and WE with SWE.

PROGRAM USAGE AND VERIFICATION

There are two versions of the program. A production version is suitable for processing a large amount of data when detailed output is not needed. An interactive version is suitable for design applications, parameter calibration, trouble shooting, flow rating, or for learning how to use the program. The interactive version provides a detailed printout of the hydraulic computation.

This section illustrates the use of the interactive version with three examples, and verifies the results with laboratory or field data. The use of the production version will not be illustrated because it is almost identical with the interactive version except that the main program is in a subroutine form suitable for inclusion in another program. The user must write his main program to control the input and output of the data to suit his specific format requirements.

Example I demonstrates open channel and orifice flow under inlet control. The example culvert is a square-edged entrance concrete pipe taken from a laboratory model from reference 5. The inlet has no control gate and the outlet is under free discharge condition. The length and slope of the culvert are unknown; however, neither parameter affects the computation because the flow is under inlet control. Laboratory measurements from reference 5 are available for comparison with the computed results.

Examples II and III demonstrate full pipe and orifice flow under gated conditions. The example culverts are corrugated metal pipes with circular slide gates, which are taken from District Structures 150 and 151. Both culverts are on a horizontal slope and flow is affected by high tailwater. Field measurement data are available for comparison with the computed results.

The computer interactive section is shown in page 12 through 20. The results of the computation and their comparisons with actual measurements are shown on the next page. The results in Example I compare favorably with the laboratory measurements. The results in Examples II and III are between 1 to 15 % different from the field measurements. The lower accuracy in Examples II and III can be attributed to less than ideal conditions in the field. For example, the pipe could be partially silted, vegetation might have collected at the entrance, the flow measurements could be in error by 5 to 10 %, the shape and elevations of corrugated metal pipes could be distorted by the weight of the fill, etc.

Example I

Square-edged entrance concrete pipe (Laboratory model from reference 5)

Diameter D = 1 ft

Inlet invert elevation INEL = 0 msl

Outlet invert elevation OUTEL = -2 msl (unknown, assumed)

Length L = 20 ft (Unknown, assumed)

Manning n = 0.012

Entrance loss coefficient k = 0.5

Gate opening GGAP = 999 (No gate, assumed large value)

Orifice coefficient = 0.6

Flow condition: The flow is under inlet control. Pipe length L, Manning n, and slope do not affect the flow.

HWE (ft)	0.25	0.50	0.75	0.90	1.25	1.50	1.90	2.60	3.00	3.50
Measured# (cfs)	0.20	0.65	1.50	2.00	3.00	3.60	4.50	5.50	6.00	6.50
Computed (cfs)	0.20	0.72	1.49	2.02	3.37	3.59	4.31	5.35	5.86	6.44
Flow type	H	H	H	H	H	O	O	O	O	O

Laboratory measurements taken from Figure 9 of reference 5.

Example II

Corrugated metal pipe with circular slide gate (S-150)

Diameter D = 7 ft

Inlet invert elevation INEL = 3 msl

Outlet invert elevation OUTEL = 3 msl

Length L = 94 ft

Manning n = 0.024

Entrance loss coefficient k = 0.7

Orifice coefficient C = 0.47 (Calibrated, circular gate opening appears to have lower C)

Flow condition: The flow is under gate control and tailwater influence.

HWE (ft)	12.15	11.76	11.76	11.71	11.62	11.60	11.49	12.40	12.02	12.02
TWE (ft)	11.09	11.23	9.80	9.10	8.73	10.54	10.00	10.35	10.89	11.68
Gate (ft)	7.0	7.0	7.0	3.5	2.5	7/1.67*	5.0	3.5	7.0	6.0
Measured# (cfs)	201	156	288	201	135	264	246	172	202	100
Computed (cfs)	203	159	309	199	147	285	209	183	232	110
Flow type	F	F	T	O	O	F	F	F	F	F

Field measurements by SFWMD. * Total flow from two culverts with different gate openings.

Example III

Corrugated metal pipe with circular slide gate (S-151)

Diameter D = 7 ft

Inlet invert elevation INEL = -1.5 msl

Outlet invert elevation OUTEL = -1.5 msl

Length L = 98 ft

Manning n = 0.024

Entrance loss coefficient k = 0.7

Orifice coefficient C = 0.47 (Calibrated)

Flow condition: The flow is under gate control and tailwater influence.

HWE (ft)	7.40	7.10	10.98	8.69	6.96	6.46
TWE (ft)	5.58	5.86	9.10	8.16	4.08	5.37
Gate (ft)	3.09	4.5	7.0	7.0	1.68	4.33
Measured# (cfs)	150	181	247	145	83	190
Computed (cfs)	152	176	269	143	99	201
Flow type	F	F	F	F	O	T

Original field measurements by SFWMD were for three culverts with equal gate openings. Data shown have been adjusted for one culvert.

COMPUTER INTERACTIVE SECTION

(For Examples I,II and III in Page 11)

```
/get,culvert/un=afan
/ftn5,i=culvert,l=0
     2.149 CP SECONDS COMPILATION TIME.
/lgo
 NAME OF CULVERT ?
? example I
 CULVERT SHAPE 0=CIRCLE 1=BOX (DEFAULT=CIRCLE) ?
? 0
 GATE TYPE 0=CIRCLE 1=RECTANGLE 2=WEIR ?               {Culvert has no gate
? 1                                                    enter any number}
 INEL, OUTEL, LENGTH, DIAM/DEPTH, WIDTH ?
? 0,-2,20,1,1
 MANNING N, INLET K, ORIFICE C ?
? .012,.5,.6                                           {Enter any low TWE
 HWE, TWE, WEIR EL/GATE OPEN ?                         for free outfall.
? 0.25,-20,999                                         No gate, enter any
                                                       large gate opening}
 -----EXAMPLE I
  INPUT DATA:
  HWE=    .25  INEL=    .00  GTYPE=      1  GGAP=   1.00
  TWE= -20.00  OUTEL=  -2.00  BARREL=     0  D=   1.00   {See Dictionary of
  W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60  Program Symbols
 RESULTS:                                              on page 23}
 UNSUBMERGED INLET---UNSUBMERGED OUTLET
      INLET CONTROL  : CRITICAL FLOW AT INLET  Q= .201 CFS
 YC1=    .18 DEV=  -.009 HW1=    .26 A1=    .10 KE=   .180
 V1=   2.03 FROUDE  1.000
 #   1       .201 H CFS
 NAME OF CULVERT ?
? <RETURN>                                             {Enter <RETURN> for
 HWE, TWE, WEIR EL/GATE OPEN ?                         same culvert}
? .5,,,                                                {Enter HWE only, no
                                                       change in other data}
 -----EXAMPLE I
```

```
 INPUT DATA:
 HWE=    .50  INEL=    .00  GTYPE=      1  GGAP=   1.00
 TWE= -20.00  OUTEL=  -2.00  BARREL=      0  D=   1.00
 W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
RESULTS:
UNSUBMERGED INLET---UNSUBMERGED OUTLET
     INLET CONTROL  : CRITICAL FLOW AT INLET   Q=       .724 CFS
YC1=    .36 DEV=  -.009 HW1=    .51 A1=    .25 KE=   .180
V1=   2.90 FROUDE  1.000
#   2        .724 H CFS
NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? .75,,,

-----EXAMPLE I
 INPUT DATA:
 HWE=    .75  INEL=    .00  GTYPE=      1  GGAP=   1.00
 TWE= -20.00  OUTEL=  -2.00  BARREL=      0  D=   1.00
 W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
RESULTS:
UNSUBMERGED INLET---UNSUBMERGED OUTLET
     INLET CONTROL  : CRITICAL FLOW AT INLET   Q=      1.492 CFS
YC1=    .52 DEV=  -.010 HW1=    .76 A1=    .41 KE=   .180
V1=   3.64 FROUDE  1.000
#   3      1.492 H CFS
NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? .9,,,

-----EXAMPLE I
 INPUT DATA:
 HWE=    .90  INEL=    .00  GTYPE=      1  GGAP=   1.00
 TWE= -20.00  OUTEL=  -2.00  BARREL=      0  D=   1.00
 W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
RESULTS:
UNSUBMERGED INLET---UNSUBMERGED OUTLET
     INLET CONTROL  : CRITICAL FLOW AT INLET   Q=      2.024 CFS
YC1=    .61 DEV=  -.009 HW1=    .91 A1=    .50 KE=   .180
V1=   4.06 FROUDE  1.000
#   4      2.024 H CFS
NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? 1.25,,,

-----EXAMPLE I
 INPUT DATA:
 HWE=   1.25  INEL=    .00  GTYPE=      1  GGAP=   1.00
 TWE= -20.00  OUTEL=  -2.00  BARREL=      0  D=   1.00
 W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
RESULTS:
UNSUBMERGED INLET---UNSUBMERGED OUTLET
```

```
     INLET CONTROL  : CRITICAL FLOW AT INLET   Q=      3.365 CFS
 YC1=    .78 DEV=  -.009 HW1=   1.28 A1=    .66 KE=   .180
 V1=   5.09 FROUDE  1.000
 #   5       3.365 H CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 1.5,,,

 -----EXAMPLE I
  INPUT DATA:
  HWE=   1.50  INEL=    .00  GTYPE=      1  GGAP=   1.00
  TWE= -20.00  OUTEL=  -2.00  BARREL=     0  D=   1.00
  W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
 RESULTS:
 SUBMERGED INLET---UNSUBMERGED OUTLET
     ORIFICE CONTROL  Q=      3.588 CFS
 KE=   .500 A=    .79 AG=    .79 H=    .90
     PART FULL PIPE FLOW  Q=      7.658 CFS
 A=    .79 H=   3.00 KE=   .500 KF=   .532 R=    .25
 #   6       3.588 O CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 1.9,,,

 -----EXAMPLE I
  INPUT DATA:
  HWE=   1.90  INEL=    .00  GTYPE=      1  GGAP=   1.00
  TWE= -20.00  OUTEL=  -2.00  BARREL=     0  D=   1.00
  W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
 RESULTS:
 SUBMERGED INLET---UNSUBMERGED OUTLET
     ORIFICE CONTROL  Q=      4.312 CFS
 KE=   .500 A=    .79 AG=    .79 H=   1.30
     PART FULL PIPE FLOW  Q=      8.153 CFS
 A=    .79 H=   3.40 KE=   .500 KF=   .532 R=    .25
 #   8       4.312 O CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 2.6,,,

 -----EXAMPLE I
  INPUT DATA:
  HWE=   2.60  INEL=    .00  GTYPE=      1  GGAP=   1.00
  TWE= -20.00  OUTEL=  -2.00  BARREL=     0  D=   1.00
  W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
 RESULTS:
 SUBMERGED INLET---UNSUBMERGED OUTLET
     ORIFICE CONTROL  Q=      5.348 CFS
 KE=   .500 A=    .79 AG=    .79 H=   2.00
     PART FULL PIPE FLOW  Q=      8.953 CFS
 A=    .79 H=   4.10 KE=   .500 KF=   .532 R=    .25
```

```
#  9      5.348 O CFS
NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? 3.0,,,

-----EXAMPLE I
 INPUT DATA:
 HWE=   3.00  INEL=    .00  GTYPE=      1  GGAP=   1.00
 TWE= -20.00  OUTEL=  -2.00  BARREL=      0  D=   1.00
 W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
RESULTS:
SUBMERGED INLET---UNSUBMERGED OUTLET
     ORIFICE CONTROL  Q=      5.859 CFS
KE=   .500 A=    .79 AG=    .79 H=   2.40
     PART FULL PIPE FLOW  Q=      9.379 CFS
A=    .79 H=   4.50 KE=   .500 KF=   .532 R=    .25
#  10      5.859 O CFS
NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? 3.5,,,

-----EXAMPLE I
 INPUT DATA:
 HWE=   3.50  INEL=    .00  GTYPE=      1  GGAP=   1.00
 TWE= -20.00  OUTEL=  -2.00  BARREL=      0  D=   1.00
 W=   1.00  L=  20.00  N=   .012  K=    .50  C=    .60
RESULTS:
SUBMERGED INLET---UNSUBMERGED OUTLET
     ORIFICE CONTROL  Q=      6.440 CFS
KE=   .500 A=    .79 AG=    .79 H=   2.90
     PART FULL PIPE FLOW  Q=      9.886 CFS
A=    .79 H=   5.00 KE=   .500 KF=   .532 R=    .25
#  11      6.440 O CFS
NAME OF CULVERT ?
? example II                                          {Enter new culvert
CULVERT SHAPE 0=CIRCLE 1=BOX (DEFAULT=CIRCLE) ?       name}
? 0
GATE TYPE 0=CIRCLE 1=RECTANGLE 2=WEIR ?
? 0
INEL, OUTEL, LENGTH, DIAM/DEPTH, WIDTH ?
? 3,3,94,7,7
MANNING N, INLET K, ORIFICE C ?
? .024,.7,.47
HWE, TWE, WEIR EL/GATE OPEN ?
? 12.15,11.09,7

-----EXAMPLE II
 INPUT DATA:
 HWE=  12.15  INEL=   3.00  GTYPE=      0  GGAP=   7.00
 TWE=  11.09  OUTEL=   3.00  BARREL=      0  D=   7.00
 W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
RESULTS:
```

```
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=    203.260 CFS
 H=   1.06 KE=   .700 KF=   .747 A=  38.48 AG=  38.48
 #  12    203.260 F CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 11.76,11.23,7

 -----EXAMPLE II
  INPUT DATA:
  HWE=  11.76  INEL=   3.00  GTYPE=      0  GGAP=   7.00
  TWE=  11.23  OUTEL=   3.00  BARREL=      0  D=   7.00
  W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=    159.017 CFS
 H=    .53 KE=   .252 KF=   .747 A=  38.48 AG=  38.48
 #  13    159.017 F CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 11.76,9.8,7

 -----EXAMPLE II
  INPUT DATA:
  HWE=  11.76  INEL=   3.00  GTYPE=      0  GGAP=   7.00
  TWE=   9.80  OUTEL=   3.00  BARREL=      0  D=   7.00
  W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 UNSUBMERGED INLET---UNSUBMERGED OUTLET
      INLET CONTROL  : CRITICAL FLOW AT INLET   Q=    419.141 CFS
 YC1=   5.39 DEV=  -.008 HW1=   8.77 A1=  31.80 KE=   .252
 V1=  13.18 FROUDE  1.000
      OUTLET CONTROL : TAILWATER EFFECT  Q=    309.011 CFS
 S=   .007 Y1=   7.50 DEV=    .01 Y2=   6.80 V1=    8.0 V2=    8.1
 #  14    309.011 T CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 11.71,9.1,3.5

 -----EXAMPLE II
  INPUT DATA:
  HWE=  11.71  INEL=   3.00  GTYPE=      0  GGAP=   3.50
  TWE=   9.10  OUTEL=   3.00  BARREL=      0  D=   7.00
  W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---UNSUBMERGED OUTLET
      ORIFICE CONTROL  Q=    198.650 CFS
 KE=  4.064 A=  38.48 AG=  23.44 H=   5.05
 #  15    198.650 O CFS
 NAME OF CULVERT ?
? <RETURN>
```

```
 HWE, TWE, WEIR EL/GATE OPEN ?
? 11.62,8.73,2.5

 -----EXAMPLE II
  INPUT DATA:
  HWE=  11.62  INEL=   3.00  GTYPE=      0  GGAP=   2.50
  TWE=   8.73  OUTEL=   3.00  BARREL=      0  D=   7.00
  W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---UNSUBMERGED OUTLET
      ORIFICE CONTROL  Q=    146.997 CFS
 KE=  9.788 A=  38.48 AG=  17.12 H=   5.18
 #  16     146.997 O CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 11.,10.54,7

 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 11.6,10.54,7

 -----EXAMPLE II
  INPUT DATA:
  HWE=  11.60  INEL=   3.00  GTYPE=      0  GGAP=   7.00
  TWE=  10.54  OUTEL=   3.00  BARREL=      0  D=   7.00
  W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=    224.885 CFS
 H=   1.06 KE=   .252 KF=   .747 A=  38.48 AG=  38.48
 #  17     224.885 F CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? ,,1.67

 -----EXAMPLE II
  INPUT DATA:
  HWE=  11.60  INEL=   3.00  GTYPE=      0  GGAP=   1.67
  TWE=  10.54  OUTEL=   3.00  BARREL=      0  D=   7.00
  W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=     60.299 CFS
 H=   1.06 KE= 26.059 KF=   .747 A=  38.48 AG=  11.58
 #  18     60.299 F CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 11.49,10,5

 -----EXAMPLE II
```

```
 INPUT DATA:
 HWE=  11.49  INEL=   3.00  GTYPE=       0  GGAP=   5.00
 TWE=  10.00  OUTEL=   3.00  BARREL=      0  D=   7.00
 W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
RESULTS:
SUBMERGED INLET---SUBMERGED OUTLET
     FULL PIPE FLOW     Q=    209.031 CFS
H=   1.49 KE=  1.505 KF=   .747 A=  38.48 AG=  31.74
#  19    209.031 F CFS

NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? 12.4,10.35,3.5

-----EXAMPLE II
 INPUT DATA:
 HWE=  12.40  INEL=   3.00  GTYPE=       0  GGAP=   3.50
 TWE=  10.35  OUTEL=   3.00  BARREL=      0  D=   7.00
 W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
RESULTS:
SUBMERGED INLET---SUBMERGED OUTLET
     FULL PIPE FLOW     Q=    183.437 CFS
H=   2.05 KE=  4.064 KF=   .747 A=  38.48 AG=  23.44
#  20    183.437 F CFS
NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? 12.02,10.89,7

-----EXAMPLE II
 INPUT DATA:
 HWE=  12.02  INEL=   3.00  GTYPE=       0  GGAP=   7.00
 TWE=  10.89  OUTEL=   3.00  BARREL=      0  D=   7.00
 W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
RESULTS:
SUBMERGED INLET---SUBMERGED OUTLET
     FULL PIPE FLOW     Q=    232.191 CFS
H=   1.13 KE=   .252 KF=   .747 A=  38.48 AG=  38.48
#  21    232.191 F CFS
NAME OF CULVERT ?
? <RETURN>
HWE, TWE, WEIR EL/GATE OPEN ?
? 12.02,11.68,6

-----EXAMPLE II
 INPUT DATA:
 HWE=  12.02  INEL=   3.00  GTYPE=       0  GGAP=   6.00
 TWE=  11.68  OUTEL=   3.00  BARREL=      0  D=   7.00
 W=   7.00  L=  94.00  N=   .024  K=    .70  C=    .47
RESULTS:
SUBMERGED INLET---SUBMERGED OUTLET
     FULL PIPE FLOW     Q=    110.194 CFS
H=    .34 KE=   .924 KF=   .747 A=  38.48 AG=  36.04
```

```
 #  22    110.194 F CFS
 NAME OF CULVERT ?
? example III                                           {Enter new culvert
 CULVERT SHAPE 0=CIRCLE 1=BOX (DEFAULT=CIRCLE) ?        name}
? 0
 GATE TYPE 0=CIRCLE 1=RECTANGLE 2=WEIR ?
? 0
 INEL, OUTEL, LENGTH, DIAM/DEPTH, WIDTH ?
? -1.5,-1.5,98,7,7
 MANNING N, INLET K, ORIFICE C ?
? .024,.7,.47
 HWE, TWE, WEIR EL/GATE OPEN ?
? 7.4,5.58? ,3.09

 -----EXAMPLE III
  INPUT DATA:
  HWE=   7.40  INEL=  -1.50  GTYPE=      0  GGAP=   3.09
  TWE=   5.58  OUTEL=  -1.50  BARREL=      0  D=   7.00
  W=   7.00  L=  98.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=    152.662 CFS
 H=   1.82 KE=  5.669 KF=   .779 A=  38.48 AG=  20.91
 #  23    152.662 F CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 7.1,5.86,4.5

 -----EXAMPLE III
  INPUT DATA:
  HWE=   7.10  INEL=  -1.50  GTYPE=      0  GGAP=   4.50
  TWE=   5.86  OUTEL=  -1.50  BARREL=      0  D=   7.00
  W=   7.00  L=  98.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=    176.326 CFS
 H=   1.24 KE=  2.025 KF=   .779 A=  38.48 AG=  29.17
 #  24    176.326 F CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 10.975,9.1,7

 -----EXAMPLE III
  INPUT DATA:
  HWE=  10.98  INEL=  -1.50  GTYPE=      0  GGAP=   7.00
  TWE=   9.10  OUTEL=  -1.50  BARREL=      0  D=   7.00
  W=   7.00  L=  98.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=    268.594 CFS
 H=   1.88 KE=   .700 KF=   .779 A=  38.48 AG=  38.48
 #  25    268.594 F CFS
```

```
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 8.69,8.16,7

 -----EXAMPLE III
  INPUT DATA:
  HWE=   8.69  INEL=  -1.50  GTYPE=      0  GGAP=   7.00
  TWE=   8.16  OUTEL=  -1.50  BARREL=      0  D=   7.00
  W=   7.00  L=  98.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---SUBMERGED OUTLET
      FULL PIPE FLOW     Q=    142.802 CFS
 H=     .53 KE=   .700 KF=   .779 A=  38.48 AG=  38.48
 #  26    142.802 F CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 6.96,4.08,1.68

 -----EXAMPLE III
  INPUT DATA:
  HWE=   6.96  INEL=  -1.50  GTYPE=      0  GGAP=   1.68
  TWE=   4.08  OUTEL=  -1.50  BARREL=      0  D=   7.00
  W=   7.00  L=  98.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 SUBMERGED INLET---UNSUBMERGED OUTLET
      ORIFICE CONTROL  Q=     99.316 CFS
 KE= 25.697 A=  38.48 AG=  11.65 H=   5.11
 #  27     99.316 O CFS
 NAME OF CULVERT ?
? <RETURN>
 HWE, TWE, WEIR EL/GATE OPEN ?
? 6.455,5.365,4.33

 -----EXAMPLE III
  INPUT DATA:
  HWE=   6.46  INEL=  -1.50  GTYPE=      0  GGAP=   4.33
  TWE=   5.37  OUTEL=  -1.50  BARREL=      0  D=   7.00
  W=   7.00  L=  98.00  N=   .024  K=    .70  C=    .47
 RESULTS:
 UNSUBMERGED INLET---UNSUBMERGED OUTLET
      INLET CONTROL  : CRITICAL FLOW AT INLET   Q=    289.008 CFS
 YC1=   4.47 DEV=  -.008 HW1=   7.96 A1=  25.94 KE=   .812
 V1=  11.14 FROUDE  1.000
      OUTLET CONTROL : TAILWATER EFFECT  Q=    201.403 CFS
 S=   .003 Y1=   7.18 DEV=    .01 Y2=   6.87 V1=    5.2 V2=    5.3
 #  28    201.403 T CFS
 NAME OF CULVERT ?
? <RETURN>                                             {End program by two
 HWE, TWE, WEIR EL/GATE OPEN ?                         <RETURN>s }
? <RETURN>
    0.754 CP SECONDS EXECUTION TIME.
/bye
```

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LIST OF APPENDIX

DICTIONARY OF PROGRAM SYMBOLS
(Partial listing)

A	Flow area
A1	Flow area at inlet section
A2	Flow area at outlet section
AG	Gate opening area
BARREL	Barrel shape coding, "0" = circle, "1" = box
BOARD	Weir board elevation or gate opening height (input parameter)
C	Orifice flow coefficient
CW	Weir flow coefficient
D	Diameter of pipe culvert or depth of box culvert
DEV	Deviation of computed and estimated values in iteration
FROUDE	Froude number
GGAP	Gate opening height
GTYPE	Gate type coding, "0" = circular, "1" = rectangular, "2" = weir
H	Hydraulic head difference
HD1	Hydraulic depth at inlet section
HD2	Hydraulic depth at outlet section
HW	Headwater depth
HWE	Headwater elevation
INEL	Inlet invert elevation
K	Entrance loss coefficient (input parameter)
KE	Adjusted entrance loss coefficient (due to gate restriction)
KF	Friction loss coefficient
L	Length of culvert
N	Manning n
OUTEL	Outlet invert elevation
Q	Flow
Q1	Critical flow at inlet
Q2	Critical flow at outlet
Q3	Subcritical flow
QA	Actual flow (final output)
QW	Weir flow
R	Hydraulic radius
R1	Hydraulic radius at inlet section
R2	Hydraulic radius at outlet section
S	Energy slope
SWB	Total side weir length
SWE	Side weir crest elevation (riser or wingwall)
TW	Tailwater depth
TWE	Tailwater elevation
V	Flow velocity
V1	Flow velocity at inlet section
V2	Flow velocity at outlet section
VC1	Critical flow velocity at inlet section
VC2	Critical flow velocity at outlet section
W	Width of box culvert
Y	Flow depth in barrel
Y1	Flow depth at inlet section
Y2	Flow depth at outlet section
WB	Weir length
WE	Weir crest elevation

```
      PROGRAM CULVERT(INPUT,OUTPUT,ERRORF,TAPE5=INPUT,TAPE6=OUTPUT,
     2TAPE9=ERRORF)
C**************************************************************
C*                   <INTERACTIVE VERSION>
C* THIS PROGRAM COMPUTES THE DISCHARGE THROUGH GATED CULVERTS
C*
C*  Note: Interactive version "culvert" or production version "QCUL"
c*         can be obtained from user group "AFAN".
C*
C* CODE: W=WEIR CONTROL; F=FULL PIPE FLOW; O=ORIFICE CONTROL;
C*       P=PARTIAL PIPE FLOW; H=HEAD WATER CONTROL;
C*       T=TAILWATER CONTROL; ?=CHECK "ERRORF"
C*
C*
C*                    A. FAN  10/8/82
C**************************************************************
      COMMON /A/ HWE,TWE,GGAP,BARREL,GTYPE,INEL,OUTEL,L,D,W,N,K,C,
     2           HW,TW,KE,ICOUNT
      COMMON /B/ WB,WE,SWB,SWE,CW,A,AW
      INTEGER BARREL,GTYPE
      REAL INEL,L,N,K,KE
      CHARACTER NAME*50,CODE*1
      ICOUNT=0
   10 ICOUNT=ICOUNT+1
      WRITE(6,*) 'NAME OF CULVERT ?'
      READ (5,20,END=30) NAME
   20 FORMAT(A)
C ***** DEFAULT VALUES FOR EACH NEW CULVERT
      PRESET=999.
      OUTEL=PRESET
      GTYPE=1
      BOARD=PRESET
      BARREL=0
      N=0.012
      K=0.5
      C=0.6
      SWB=0.
      SWE=PRESET
      CW=3.3
C *****  READ INPUT PHYSICAL DATA
      WRITE(6,*) 'CULVERT SHAPE 0=CIRCLE 1=BOX (DEFAULT=CIRCLE) ?'
      READ(5,*) BARREL
      WRITE(6,*) 'GATE TYPE 0=CIRCLE 1=RECTANGLE 2=WEIR ?'
      READ(5,*) GTYPE
      WRITE(6,*)'INEL, OUTEL, LENGTH, DIAM/DEPTH, WIDTH ?'
      READ(5,*)INEL,OUTEL,L,D,W
      WRITE(6,*)'MANNING N, INLET K, ORIFICE C ? '
      READ(5,*)N,K,C
      IF(GTYPE.EQ.2)THEN
         WRITE(6,*)'WEIR WIDTH, WEIR COEF, RISER LENGTH, RISER EL ?'
         READ(5,*)WB,CW,SWB,SWE
      ENDIF
C ***** INITIALIZATION FOR EACH NEW COMPUTATION
```

```
   30 QW=PRESET
      QC=PRESET
      QA=PRESET
      REVERSE=PRESET
      CODE=' '
C ***** READ INPUT OPERATION DATA
      WRITE(6,*)'HWE, TWE, WEIR EL/GATE OPEN ?'
      REWIND 5
      READ(5,*,END=130)HWE,TWE,BOARD
      IF(GTYPE.EQ.2)THEN
         WE=BOARD
         IF(WE.EQ.PRESET)WE=INEL
         GGAP=D
      ELSE
         GGAP=MIN(BOARD,D)
      ENDIF
      IF(OUTEL.GE.PRESET)OUTEL=INEL
C ***** WRITE INPUT DATA
      WRITE(6,40) NAME,HWE,INEL,GTYPE,GGAP,TWE,OUTEL,BARREL,D,W,L,N,K,C
   40 FORMAT(/1X,'-----',A/'  INPUT DATA:'/
     2'  HWE=',F7.2,'  INEL=',F7.2,'  GTYPE=',I7,
     3'  GGAP=',F7.2/'  TWE=',F7.2,'  OUTEL=',F7.2,'  BARREL='
     4,I7,'  D=',F7.2/'  W=',F7.2,'  L=',F7.2,'  N=',F7.3,
     5'  K=',F7.2,'  C=',F7.2)
      IF(GTYPE.EQ.2)WRITE(6,50)WB,WE,CW,SWE,SWB
   50 FORMAT('  WB=',F7.2,'  WE=',F7.2,'  CW=',F7.2,
     2'  SWE=',F7.2,'  SWB=',F7.2)
C *****
      HW=HWE-INEL
      TW=TWE-OUTEL
      ELMAX=MAX(INEL,OUTEL)
      IF(GGAP.EQ.0.)GOTO 60
      IF(GTYPE.EQ.2 .AND. HWE.LE.WE .AND. TWE.LE.WE)GOTO 60
      IF(HWE.LE.ELMAX .AND. TWE.LE.ELMAX)GOTO 60
      IF(HWE-TWE)70,60,80
   60 WRITE(6,*) '     ***** ZERO FLOW OCCURED *****'
      QA=0.
      GO TO 110
   70 WRITE(6,*) '     ***** REVERSE FLOW OCCURED *****'
      CODE='R'
      REVERSE=HWE
      HWE=TWE
      TWE=REVERSE
   80 WRITE(6,90)
   90 FORMAT(1X,'RESULTS:')
      IF(GTYPE.EQ.2)THEN
         CALL WEIR(QW,CODE)
         IF(AW/A .LT. 0.2)GOTO 100
      ENDIF
      IF(TW.GE.D)THEN
         CALL PIPE(QC,CODE)
      ELSE IF(HW.GE.1.3*D .OR. HW.GE.2.0*GGAP)THEN
         CALL ORIFICE(QC,CODE)
      ELSE
```

```
         CALL DITCH(QC,CODE)
      ENDIF
  100 IF(GTYPE.EQ.2.AND.QW.LE.QC)THEN
         QA=QW
         CODE='W'
      ELSE
         QA=QC
      ENDIF
      IF(REVERSE.NE.PRESET)QA=-QA
  110 WRITE(6,120)ICOUNT,QA,CODE
  120 FORMAT(1X,'#',I4,F11.3,1X,A1,' CFS')
      GO TO 10
  130 STOP
      END
C *
C *
      SUBROUTINE WEIR(QW,CODE)
      COMMON /A/ HWE,TWE,GGAP,BARREL,GTYPE,INEL,OUTEL,L,D,W,N,K,C,
     2           HW,TW,KE,ICOUNT
      COMMON /B/ WB,WE,SWB,SWE,CW,A,AW
      INTEGER BARREL,GTYPE
      REAL INEL,L,N,K,KE,KWE
      CHARACTER CODE*1
      H=HWE-WE
      QW=CW*WB*H**1.5
      IF(TWE.GT.WE)QW=QW*(1.-((TWE-WE)/(HWE-WE))**1.5)**0.385
      IF(HWE.GT.SWE)THEN
         QSW=CW*SWB*(HWE-SWE)**1.5
         IF(TWE.GT.SWE)QSW=QSW*(1.-((TWE-SWE)/(HWE-SWE))**1.5)**0.385
         QW=QW+QSW
      ENDIF
      WRITE(6,10)QW
   10 FORMAT(6X,'WEIR CONTROL    Q=',F11.3,' CFS'/)
C *****  MODIFY ENTRANCE LOSS COEFFICIENT FOR CULVERT FLOW COMPUTATION
C *****       ASSUME ENTRANCE LOSS COEFFICIENT OVER WEIR TO BE 0.10
      KWE=0.10
      AW=WB*H
      IF(HWE.GT.SWE)AW=AW+(HWE-SWE)*SWB
      IF(BARREL.EQ.0)CALL CIRCLE(HW,D,A,R,HD)
      IF(BARREL.EQ.1)CALL RECT(HW,D,W,A,R,HD)
      KE=KWE*(A/AW)**2+K
      RETURN
      END
C *
C *
      SUBROUTINE PIPE(QC,CODE)
      COMMON /A/ HWE,TWE,GGAP,BARREL,GTYPE,INEL,OUTEL,L,D,W,N,K,C,
     2           HW,TW,KE,ICOUNT
      INTEGER BARREL,GTYPE
      REAL INEL,L,N,K,KE,KF
      CHARACTER CODE*1
      CALL GATE(GTYPE,BARREL,HW,GGAP,D,W,K,KE,A,AG)
      H=HWE-TWE
      IF(HW.LE.(1.3*GGAP))KE=0.36*KE
```

```
      IF(BARREL.EQ.0)R=D/4.
      IF(BARREL.EQ.1)R=(D*W)/(2*D+W)
      KF=29.1*N**2*L/R**1.3333
      Q=A*SQRT(64.4*H/(1.+KE+KF))
      QC=Q
      CODE='F'
      WRITE(6,10) Q
   10 FORMAT(1X,'SUBMERGED INLET---SUBMERGED OUTLET'
     2/6X,'FULL PIPE FLOW    Q=',F11.3,' CFS')
      WRITE(6,20) H,KE,KF,A,AG
   20 FORMAT(1X,'H=',F7.2,' KE=',F7.3,' KF=',F7.3,' A=',F7.2,
     2' AG=',F7.2)
      RETURN
      END
C *
C *
      SUBROUTINE ORIFICE(QC,CODE)
      COMMON /A/ HWE,TWE,GGAP,BARREL,GTYPE,INEL,OUTEL,L,D,W,N,K,C,
     2           HW,TW,KE,ICOUNT
      INTEGER BARREL,GTYPE
      REAL INEL,L,N,K,KE,KF
      CHARACTER CODE*1
      CALL GATE(GTYPE,BARREL,HW,GGAP,D,W,K,KE,A,AG)
      H=MIN(HW-0.6*GGAP, HW-0.6*(TWE-INEL))
      Q=C*AG*SQRT(64.4*H)
      Q1=Q
      WRITE(6,10) Q1
   10 FORMAT(1X,'SUBMERGED INLET---UNSUBMERGED OUTLET'
     2/6X,'ORIFICE CONTROL  Q=',F11.3,' CFS')
      WRITE(6,20) KE,A,AG,H
   20 FORMAT(1X,'KE=',F7.3,' A=',F7.2,' AG=',F7.2,' H=',F7.2)
      IF(HW .LT. 1.3*D)THEN
         QC=Q1
         CODE='O'
         RETURN
      ENDIF
C *****   PART FULL PIPE FLOW
      H=MIN( HWE-(OUTEL+0.5*D), HWE-TWE)
      IF(HWE.LE.(OUTEL+D)) H=MIN(0.5*(HWE-OUTEL),HWE-TWE)
      IF(BARREL.EQ.0)R=D/4.
      IF(BARREL.EQ.1)R=(D*W)/(2*D+W)
      KF=29.1*N**2*L/R**1.3333
      Q=A*SQRT(64.4*H/(1.+KE+KF))
      Q2=Q
      WRITE(6,30) Q2
   30 FORMAT(6X,'PART FULL PIPE FLOW  Q=',F11.3,' CFS')
      WRITE(6,40) A,H,KE,KF,R
   40 FORMAT(1X,'A=',F7.2,' H=',F7.2,' KE=',F7.3,' KF=',F7.3,
     2' R=',F7.2)
      IF(Q2.LE.Q1)THEN
         QC=Q2
         CODE='P'
      ELSE
         QC=Q1
```

```
         CODE='0'
      ENDIF
      RETURN
      END
C *
C *
      SUBROUTINE DITCH(QC,CODE)
      COMMON /A/ HWE,TWE,GGAP,BARREL,GTYPE,INEL,OUTEL,L,D,W,N,K,C,
     2           HW,TW,KE,ICOUNT
      INTEGER BARREL,GTYPE
      REAL INEL,L,N,K,KE,FROUDE
      CHARACTER CODE*1
      Q1=Q2=Q3=9999.
      IF(GTYPE.EQ.2)THEN
         KE=0.36*KE
      ELSE IF(HW .LT. 1.3*GGAP)THEN
         KE=0.36*K
      ELSE
         CALL GATE(GTYPE,BARREL,HW,GGAP,D,W,K,KE,A,AG)
         KE=0.36*KE
      ENDIF
C *****
C *****   INLET CONTROL
C *****
      IF (BARREL.EQ.1) GO TO 30
      YC1=0.75*HW
C *****  ITERATION FOR INLET CRITICAL DEPTH YC1
      DO 10 I = 1,250
         CALL CIRCLE(YC1,D,A1,R1,HD1)
         HW1=YC1+(1.+KE)*HD1/2.
         DEV=HW-HW1
         IF (ABS(DEV).LE.0.01) GO TO 20
         YC1=YC1+DEV*0.1
   10 CONTINUE
C *****
   20 Q=SQRT(32.2*HD1)*A1
      GO TO 40
   30 YC1=2.*HW/(3.+KE)
      CALL RECT(YC1,D,W,A1,R1,HD1)
      Q=SQRT(32.2*YC1)*A1
   40 Q1=Q
      V1=Q1/A1
      FROUDE=V1/SQRT(32.2*HD1)
      WRITE(6,50) Q1
   50 FORMAT(1X,'UNSUBMERGED INLET---UNSUBMERGED OUTLET'
     2/6X,'INLET CONTROL  : CRITICAL FLOW AT INLET   Q=',
     3F11.3,' CFS')
      WRITE(6,60) YC1,DEV,HW1,A1,KE,V1,FROUDE
   60 FORMAT(1X,'YC1=',F7.2,' DEV=',F7.3,' HW1=',F7.2,' A1=',F7.2
     2,' KE=',F7.3/' V1=',F7.2,' FROUDE',F7.3)
      IF(TWE .GT. YC1+INEL)GOTO 120
      SC=(Q*N/(1.49*A1*R1**.6667))**2
      SB=(INEL-OUTEL)/L
      IF(SB.GE.SC)THEN
```

```
         QC=Q1
         CODE='H'
         RETURN
      ENDIF
C *****
C *****  FREE FALL AT OUTLET
C *****
      YC2=0.8*YC1
      Y1=YC1+OUTEL-INEL
      V1=1E-20
      V2=1E-20
C *****  ITERATION FOR OUTLET CRITICAL DEPTH YC2
      DO 80 I = 1,1000
         IADJ=I/100+1
         IF(Y1.GE.HW)Y1=0.999*HW
         IF(YC2.GE.(Y1+INEL-OUTEL))YC2=(Y1+INEL-OUTEL)*0.999
         IF(YC2.LE.0.)YC2=0.001
         IF(Y1 .LE. YC2+OUTEL-INEL)Y1=(YC2+OUTEL-INEL)*1.001
         IF(BARREL.EQ.0)THEN
            CALL CIRCLE(Y1,D,A1,R1,HD1)
            CALL CIRCLE(YC2,D,A2,R2,HD2)
         ELSE
            CALL RECT(Y1,D,W,A1,R1,HD1)
            CALL RECT(YC2,D,W,A2,R2,HD2)
         ENDIF
         CONVEY=1.49/N*SQRT(A1*R1**.6667 * A2*R2**.6667)
         F=(Y1+INEL)-(YC2+OUTEL)
         S=F/L
         IF(S.LE.0.)S=0.0001
         Q=CONVEY*SQRT(S)
         V1=Q/A1
         V2=Q/A2
         FROUDE=V2/SQRT(32.2*HD2)
         HD22=V2**2/32.2
         DEV2=HD22-HD2
         IF (ABS(DEV2).LE.0.01) GO TO 70
         YC2=YC2+DEV2*0.1/IADJ
         GO TO 80
C *****  ITERATION FOR Y1
   70    Y11=HW-(1+KE)*V1**2/64.4
         DEV1=Y11-Y1
         IF (ABS(DEV1).LE.0.01) GO TO 90
         Y1=Y1+DEV1*0.1/IADJ
   80 CONTINUE
C *****
   90 Q2=Q
      WRITE(6,100) Q2
  100 FORMAT(6X,'OUTLET CONTROL : FREE FALL AT OUTLET     Q=',
     2F11.3,' CFS')
      WRITE(6,110) S,Y1,DEV1,YC2,FROUDE,V1,V2,HD2,A2
  110 FORMAT(1X,'S=',F7.3,' Y1=',F7.2,' DEV1=',F7.3,' YC2=',F7.2,
     2' FROUDE=',F7.3,' V1=',F7.2/' V2=',F7.2,' HD2=',F7.2,' A2=',F7.2)

      IF(I.GE.1000)GOTO 170
```

```
      IF (TW.GT.YC2) GO TO 120
      IF(Q2.LE.Q1)THEN
         QC=Q2
         CODE='T'
      ELSE
         QC=Q1
         CODE='H'
      ENDIF
      RETURN
C *****
C *****   TAILWATER EFFECT
C *****
  120 Y1=1.01*(TWE-INEL)
      Y2=TW
      V1=1E-20
      V2=1E-20
C *****  ITERATION FOR Y1
      DO 130 I = 1,250
         IADJ=I/50+1
         IF(Y1.GE.HW)Y1=0.999*HW
         IF(Y1.LE.(TWE-INEL))Y1=(TWE-INEL)*1.001
         IF(BARREL.EQ.0)THEN
            CALL CIRCLE(Y1,D,A1,R1,HD1)
            CALL CIRCLE(Y2,D,A2,R2,HD2)
         ELSE
            CALL RECT(Y1,D,W,A1,R1,HD1)
            CALL RECT(Y2,D,W,A2,R2,HD2)
         ENDIF
         CONVEY=1.49/N*SQRT(A1*R1**.6667 * A2*R2**.6667)
         F=(Y1+INEL)-(Y2+OUTEL)
         S=F/L
         IF(S.LE.0.)S=0.0001
         Q=CONVEY*SQRT(S)
         V1=Q/A1
         V2=Q/A2
         Y11=HW-(1+KE)*V1**2/64.4
         DEV=Y11-Y1
         IF (ABS(DEV).LE.0.01) GO TO 140
         Y1=Y1+DEV*0.1/IADJ
  130 CONTINUE
C *****
  140 Q3=Q
      WRITE(6,150) Q3
  150 FORMAT(6X,'OUTLET CONTROL : TAILWATER EFFECT  Q='
     2,F11.3,' CFS')
      WRITE(6,160) S,Y1,DEV,Y2,V1,V2
  160 FORMAT(1X,'S=',F7.3,' Y1=',F7.2,' DEV=',F7.2,' Y2=',F7.2,
     2' V1=',F7.1,' V2=',F7.1)
      IF(I.GE.250)GOTO 170
      IF(Q3.LE.Q1)THEN
         QC=Q3
         CODE='T'
      ELSE
         QC=Q1
```

```
         CODE='H'
      ENDIF
      RETURN
C *****  ERROR DETECTION
  170 WRITE(9,180)ICOUNT
  180 FORMAT(' #',I4,' TOO MANY ITERATION,POSSIBILY A JUMP OCCURED')
      QC=MIN(Q1,Q2,Q3)
      CODE='?'
      RETURN
      END
C *
C *
      SUBROUTINE GATE(GTYPE,BARREL,HW,GGAP,D,W,K,KE,A,AG)
      REAL K,KE
      INTEGER BARREL,GTYPE
      IF (GTYPE.EQ.0.AND.BARREL.EQ.0) GO TO 30
      IF (GTYPE.GE.1.AND.BARREL.EQ.0) GO TO 20
      IF (GTYPE.GE.1.AND.BARREL.EQ.1) GO TO 10
   10 AG=GGAP*W
      CALL RECT(HW,D,W,A,R,HD)
      IF(GTYPE.NE.2)KE=((SQRT(K)+1)*A/AG-1)**2
      RETURN
   20 CALL CIRCLE(GGAP,D,AG,R,HD)
      CALL CIRCLE(HW,D,A,R,HD)
      IF(GTYPE.NE.2)KE=((SQRT(K)+1)*A/AG-1)**2
      RETURN
   30 Z=D/2.
      GGAP1=Z-GGAP/2.
      CALL CIRCLE(GGAP1,D,AG1,R,HD)
      A1=3.1416*Z**2
      AG=A1-2.*AG1
      CALL CIRCLE(HW,D,A,R,HD)
      KE=((SQRT(K)+1)*A/AG-1)**2
      RETURN
      END
C *
C *
      SUBROUTINE CIRCLE(YX,D,A,R,HD)
      Z=D/2.
      DEP=YX
      IF(DEP.GE.D)DEP=0.9999*D
      IF(DEP.LE.0.)DEP=0.0001*D
      DAB=DEP-Z
      Y=DAB/Z
      Y1=ABS(Y)
C *****  ARCSIN APPROXIMATION
      PHIY=1.570796+(-0.214512+(0.0878763+(-0.0449589+(
     20.0193499-0.00433777*Y1)*Y1)*Y1)*Y1)*Y1
      ANGLE=1.570796-(1.0-Y1)**0.5*PHIY
      IF (Y) 10,20,20
   10 ANGLE=-ANGLE
   20 DAC=ANGLE+1.570796
      A=(DAB*(D*DEP-DEP*DEP)**0.5)+(Z*Z*DAC)
      IF(A.LE.0.)A=0.000001
```

```
      T=2.*(Z*Z-DAB*DAB)**0.5
      WP=D*DAC
      HD=A/T
      R=A/WP
      RETURN
      END
C *
C :*
      SUBROUTINE RECT(Y,D,W,A,R,HD)
      DEP=Y
      IF(DEP.GE.D)DEP=0.9999*D
      IF(DEP.LE.0.)DEP=0.0001*D
      A=W*DEP
      R=W*DEP/(W+2.*DEP)
      HD=DEP
      RETURN
      END
```