# APPENDIX 9

## Recommended Guidance for Riser and Barrel Spillway Discharge Characteristics and Flood Routing

Riser and Barrel type of spillway is widely used as the principal spillway in stormwater pond and wetland facilities. In the flood routing computations for ponds or wetlands using this type of spillway, the outflow discharge characteristics of the spillway is provided as input or is included in the computations. The computations for the design of ponds (or wetlands) submitted to the City for its technical review should include the details of the discharge characteristics (Outflow Discharge versus Pond Elevation or Stage) of the spillways, including the dimensions, elevations, and materials of the riser and barrel and the roughness coefficient (Manning's coefficient n or Darcy-Weisbach friction factor f) of the barrel (and riser if it is of small cross-sectional area relative to the barrel). The discharge characteristics of the Riser and Barrel Spillway, in terms of the outflow discharge varying with the pond water surface elevation (or "stage" above the crest of the riser), is somewhat complex since the flow is subject to varying hydraulic controls as the pond level rises above the crest of the riser. The following explanation and computation methodology is provided to serve as an acceptable general basis in either manual or computer-assisted computations submitted by Engineers to the City. Other methodologies and/or computer application software packages may be used if the formulas and discharge coefficients used in them are consistent with those recommended herein or enough justification is provided in support of those used.

A schematic sketch of a typical configuration of the Riser and Barrel Spillway, including notations used in the formulas in the following paragraphs, is shown in the following Figure.
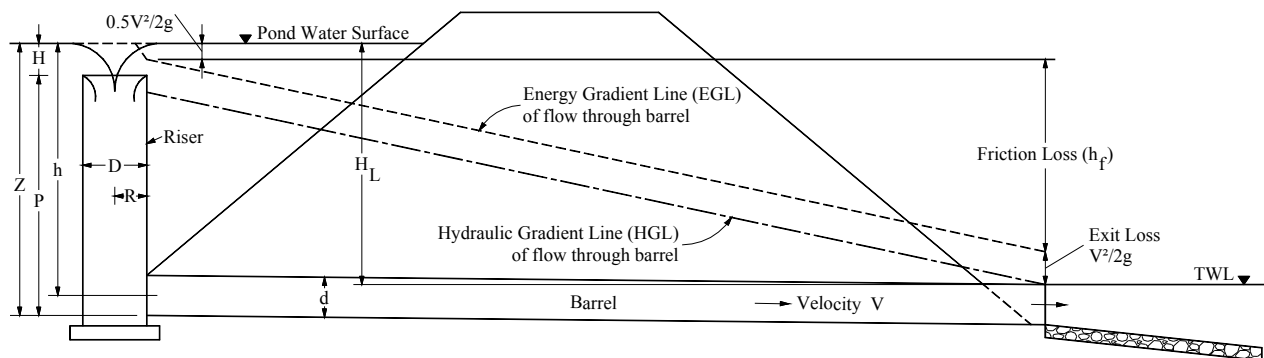


RISER AND BARREL SPILLWAY - SCHEMATIC

As the pond water level rises above the crest of the riser with the incoming flood, water first flows over the rim of the riser as flow over a weir. The flow in this mode is controlled by the weir. The weir will be a sharp-crested weir if the crest is thin (as in a corrugated aluminum pipe and the bell end of a concrete pipe) and a broad-crested weir if the crest is of substantial thickness relative to the head over the weir as in a riser structure built of concrete or brick masonry. As the head on the riser crest increases, the control of flow into the riser will transition

from weir-controlled flow to orifice-controlled flow, with the open top of the riser functioning as an orifice. Based on observations in tests performed by the U.S. Bureau of Reclamation (USBR), the flow into the riser will be weir flow with free discharge (no downstream submergence) up to a H/R ratio of approximately 0.5 changing to submerged weir discharge for H/R ratios of 0.5 to 1.0, wherein H = head of pond water above the (riser) weir crest and R = D/2 = Radius of the circular (diameter D in feet) weir crest. USBR tests also show that as H/R ratio approaches 1.0, transition from (submerged weir) control to orifice control occurs and orifice control is established at an H/R ratio of approximately 1.0,. For H/R ratios higher than 1.0, orifice control (at the top of the riser) may be assumed to govern the flow into the riser. Independent of the flow control at the top of the riser, the barrel of the spillway will act as a culvert with head-water rising inside the riser with increasing flow passing through the culvert/barrel system. The water surface elevation in the riser may be governed either by "inlet control" at the entrance to the barrel acting as an orifice or by "outlet control" resulting from the tail water level and the head losses through the barrel, similar to flows through culverts. Initially (for small flows falling into the riser), with water depth in the riser above the barrel invert less than the height of the barrel, the flow in the barrel will be governed by inlet control with weir type of flow. This mode of flow in the barrel is not of practical significance in this context since the head water elevation under inlet weir control is typically below the crest of the riser and consequently does not affect the pond water surface elevation. With increasingly higher flows, however, the culvert flow shifts to either inlet control (acting as an orifice) or outlet (downstream) control. The head water depth and elevation inside the riser increase as a function of the orifice discharge characteristics if inlet control governs or tail-water elevation (downstream of barrel outlet) and the head losses due to (pipe) friction in the barrel and inlet and exit head losses if outlet control governs. For higher discharges during the passage of a flood, the outlet control of the flow in the barrel (rather than the inlet to the riser) could potentially govern the discharges of the spillway, especially if the barrel is long and is constructed of corrugated metal pipes with high friction factor. The hydraulic control of the discharge of the spillway during the complete passage of larger floods is typically a composite of the above modes of flow control. The computational approach is to calculate the discharge characteristics in the four modes of control separately and to determine the composite discharge characteristic relationship as the one that gives the minimum of the flows in the four control modes for a given pond water surface elevation or the maximum pond water surface elevation among the four modes for a given discharge. The following formulas may be used for computing the flows in the different hydraulic control modes.

## Weir Control of Riser

$$Q = C_wLH^{3/2}$$

$C_w$ = Discharge coefficient of weir.
L = Length (along perimeter) of weir crest
H = Head of water above riser crest = Elevation of water surface in pond – Elevation of riser crest = (Z – P)

The value of $C_w$ for **sharp-crested circular weirs** (as distinguished from sharp-crested weirs in straight alignment for which $C_w$ = 3.3) is given by the following approximate relationships (derived from the results of model tests on circular weirs reported in the "Spillways" chapter of

the publication "Design of Small Dams by the U.S. Bureau of Reclamation). Risers built of plain or corrugated sheet metal and manufactured concrete pipe with grooved (bell) end at the riser crest may be considered as sharp-crested circular weirs.

**$C_w = 3.4 – 0.5(H/R)$ for $H/R < 0.5$; $C_w = 3.15 – 2.3(H/R – 0.5)$ for $H/R > 0.5$**
L = 3.14 D for circular weir crest.

It may be noted that if riser crest weir control is confined to relatively low heads, with H/R ratio less than 0.5 (un-submerged outflow jet), the average value of $C_w$ from the above formula (for H/R < 0.5) is 3.275, which is almost equal to the theoretical value of 3.3 that is generally used for straight sharp-crested weirs. Hence, **using a constant value of $C_w$ = 3.3 (in lieu of the variable values in using the formulas above) is acceptable if the following combinations of riser and barrel diameters, that generally result in the weir control to occur in the range of heads with H/R below 0.5, are used in the design:**

**12 inch Barrel: Minimum 30 inch Riser**
**15 inch Barrel: Minimum 36 inch Riser**
**18 inch Barrel: Minimum 42 inch Riser**
**24 inch and larger Barrel: Minimum 2 x Barrel Dia. for Riser**

The value of $C_w$ for **broad-crested straight weirs** (risers rectangular in plan form, built of straight walls of concrete or brick masonry) is given by the following approximate formulas, based on Plate No. 13 in the Army Corps of Engineers' Engineering Manual EM 1110-2-1602, App. III, 1993, and the values given in Table 5.3 in "Handbook of Hydraulics" by King & Brater.

Cw = 2.65 for H/B<0.5; Cw = 2.65 + 0.5 (H/B – 0.5) for <H/B<1.8; Cw = 3.3 for H/B>1.8, where B = breadth of the weir crest (thickness of the weir wall at its top) in the direction of flow.

The above formulas are applicable for free discharging (into atmosphere) weirs, without submergence (with curtailed aeration) on the downstream side. Although published test data are not available, it is reasonable to assume that the flow over a broad-crested weir riser (with relatively short side lengths), with increasing head, will also be affected by the transition to downstream submergence as in a sharp-crested weir riser described above, with a gradual reduction in the discharge coefficient. The increase in Cw with increase in H/B (for H/B > 0.5) will thus be offset by a decrease in Cw due to downstream submergence effects with increasing head. In view of these considerations, **use a constant value of Cw = 2.65 for the full range of head.**

For **broad-crested circular weirs** (risers circular in plan form, built of concrete or brick masonry walls), use a modified value of Cw based on an approximately 10% reduction in the values of $C_w$ used for broad-crested straight weirs, to account for the effects of converging radial flow toward and over circular weirs (lacking published data on circular broad-crested weirs). **Use a constant value of $C_w$ = 2.4 for the full range of head.**

## Orifice Control of Riser

This mode of flow control occurs typically for H/R values above 1.0.

$Q = C_d \, A \, (2gH)^{0.5}$ for orifices

$C_d$ = Coefficient of discharge of submerged orifice = 0.5

This is based on the theoretical value 0.5 for "Reentrant or Borda's mouthpiece" (an experimental average value of 0.51 is reported on page 4-19 in "Handbook of Hydraulics" by King & Brater). Reentrant or Borda's mouthpiece is a short cylindrical tube projecting inward into a body of water, as distinguished from an orifice in the plane of the wall of the containing tank. The configuration and hydraulics of a riser projecting upward into a pool of water is similar to a Borda's mouthpiece. **Use Cd = 0.5**

For cylindrical risers, $\mathbf{Q = 3.15 \, D^2 \, H^{0.5}}$

H = Head of water above the crest of riser in feet
A = Area of orifice opening at riser crest in sq. ft.
D = Diameter of crest of cylindrical riser in feet

## Transition from Weir Control to Orifice Control of Riser

It has been stated above that weir control of circular riser crest governs up to an H/R value of approximately 1.0, and orifice control of riser (top opening) governs for H/R values above 1.0. It is instructional to note that the same observations (based on tests by the U.S. Bureau of Reclamation) can also be deduced from the above stated formulae for the two modes of flow. To identify the transition, which is the point of intersection of the characteristic curves of the weir discharge relationship valid for H/R above 0.5 and the orifice discharge relationship, equate the discharge (Q) values from the two formulas.

$3.14 \, D \, (3.15 - 2.3(H/R - 0.5)) \, H^{1.5} = 0.5 \, (3.14 \, D^2 / 4) \, (2gH)^{0.5}$

Substituting 2R for D in the above equation and performing some algebraic steps, the equation reduces to the following.

$1.15 \, (H/R)^2 - 2.15 \, (H/R) + 1.003 = 0$

The solution of the above quadratic equation yields H/R = 0.98 (approximately 1.0)

## Barrel Inlet Control

Use the following formula for the flow conditions with the water surface elevation in the riser above the top of barrel at its entrance (submerged orifice condition). The flow condition in the barrel with the head water below the top of the barrel is not of practical significance since it is below the crest of the riser and does not affect the pond water elevation. For submerged orifice

flow with water surface in riser above the top of barrel at its entrance, the following formula is applicable

$Q = C_d \, a \, (2gh)^{0.5}$; For circular pipe barrel, $Q = 6.3 \, C_d \, d^2 \, h^{0.5}$

$C_d$ = Coefficient of discharge of submerged orifice, whose values are as listed in the following table.

Values of Coefficient of Discharge, $C_d$, of Orifices

| Entrance Condition | $C_d$ |
|---|---|
| Typical default value | 0.60 |
| Square-edged entrance | 0.59 |
| Concrete pipe, grooved end | 0.65 |
| Concrete pipe, mitred to slope | 0.52 |
| Corrugated metal pipe, projecting from fill | 0.51 |

h = head of water above the center-line of the barrel entrance = $(Z - d/2)$ in feet
d = diameter of (circular pipe) barrel entrance in feet
a = Area of cross-section of barrel at entrance in sq. ft.

## Barrel Outlet Control

Barrel outlet control occurs when the water level in the riser required to drive a given flow through the barrel (differential head relative to the tail water at the downstream end of barrel) is higher than that under inlet (submerged orifice) control. The differential head relative to the tail water level is equal to the sum of head loss at entrance to the barrel, head loss due to friction in the barrel, and the head loss at the exit due to dissipation of the kinetic energy of flow. If the tail water levels for different flows are lower than the crown of the barrel outlet, assume the tail water elevation as equal to the top of the barrel at the outlet in considering the differential head. The formula for the differential head (total head loss, $H_L$) above the tail water level is as follows:

$H_L = (K_e + fL/d + 1.0) \, V^2/2g = (K_e + 185 \, n^2 \, L/d^{4/3} + 1.0) \, (Q^2/64.4 \, a^2)$
$Q = 8.02 \, a \, H_L^{0.5}/(Ke + 185 \, n^2 \, L/d^{1.333} + 1.0)^{0.5}$
$Q = 6.3 \, d^2 \, H_L^{0.5}/(Ke + 185 \, n^2 \, L/d^{1.333} + 1.0)^{0.5}$
$K_e$ = Entrance loss coefficient, whose values are as follows:

| Type of Entrance to Barrel | $K_e$ |
|---|---|
| Square-cornered entrance flush with wall | 0.5 |
| Rounded-cornered entrance | 0.25 |
| Inward-projecting, square-cornered entrance | 0.9 |

f = Darcy-Weisbach "friction factor" = $185 \, n^2/d^{1/3}$
n = Manning roughness coefficient, whose values are as follows. Use the higher value in the range for head loss computations to conservatively account for aging of the barrel material.

| Type of Pipe | Range of n |
|---|---|
| Ductile Iron Pipe | 0.011 – 0.015 |
| Concrete Pipe | 0.011 – 0.015 |
| Corrugated Metal (including Aluminum Pipe), including helical corrugated metal pipes shorter than 20 diameters or with annular corrugations at ends | 0.022 – 0.026 |
| Plastic Pipe (smooth interior) | 0.011 – 0.015 |

L   =   Length of barrel in feet
d   =   Diameter of barrel in feet
a   =   Area of cross-section of barrel in sq. ft.
Q   =   Discharge through barrel in cfs.

The computations for inlet and outlet control of barrel may also be performed using the inlet and outlet control charts published by the Federal Highway Administration's Manual FHWA HDS-5, which are reproduced in the City of Greensboro's "Storm Drainage Design Manual" in the culvert design section. This method may be used only if manual (instead of computerized) calculations are performed for stage-discharge characteristics of the riser-barrel spillway. If spreadsheet computations are performed, the formulae given above can be used. The following example illustrates the computations using an Excel spreadsheet.

**Example: Stage – Discharge For Riser/Barrel Spillway and Flood Routing**

Data
Riser of Corrugated Aluminum Pipe (CAP) with annular corrugations; Barrel of Helically Corrugated Aluminum Pipe (CAP) segments with ("recorrugated") annular corrugations at ends (for joints).
Diameter of Riser, $D = 4.0$ ft; Radius, $R = 2.0$ ft
Diameter of Barrel, $d = 2.0$ ft
Elevation of Riser crest $= 700.00$ ft
Elevation of Invert of Barrel at Entrance $= 690.00$ ft
Elevation of Invert of Barrel at Outlet $= 689.00$ ft
Length of Barrel, $L = 80$ ft

Computations
Head over Riser Crest as Weir $= H =$ Stage (elevation) of Pond Water Surface –
     Elevation of riser crest $=$ (Stage $- 700.00$)
Riser (weir) $C_w = 3.4 - 0.25 H$ for $H < 1.0$; $C_w = 3.15 - 1.15 (H - 1.0)$ for $H > 1.0$
Riser (weir) Discharge $= C_w 12.56 H^{1.5}$
Riser (orifice) $C_d = 0.5$; Riser (orifice) Discharge $= 50.4 H^{0.5}$
Barrel (orifice inlet control) $C_d = 0.6$; Barrel (orifice) Discharge $= 15.12 (9.0 + H)^{0.5}$
Barrel (outlet control) $K_e = 0.5$; Manning $n = 0.024$
Barrel (outlet control) $Q = 6.3 d^2 H_L^{0.5}/(K_e + 185 n^2 L/d^{1.333} + 1.0)^{0.5} = 11.4 H_L^{0.5}$
$H_L =$ Pond Water Elevation – Elevation of Top of Barrel $=$ Pond Water Elevation $- 691.0$

Computations for the Stage-Discharge characteristics of the spillway, using the data and formulae listed above, are presented in the Excel spreadsheet in Table 1 on the next page. A plot of the four potential controlling discharges and the actual composite controlling discharge of the spillway is also presented in Figure 1 on the page following the spreadsheet.

In this example of a riser-barrel spillway, it may be seen that the discharge is initially controlled by the riser crest acting as a sharp-crested weir for heads up to about 0.9 ft. The control shifts to Barrel outlet control at 0.9 ft head and continues for all heads above that value.

Summary of Results of Stage-Discharge Characteristics

Based on the results of computations in the spreadsheet in Table 1 on the next page and the curves in Figure 1, the stage-discharge characteristics for the spillway in this example are:

**For Stage (Head on riser crest), H < 0.9 ft, $Q = 12.56 (3.4 – 0.25 H) H^{1.5}$**
**For Stage (Head above riser crest), H > 0.9 ft, $Q = 11.4 H_L^{0.5} = 11.4 (9.0 + H)^{0.5}$**
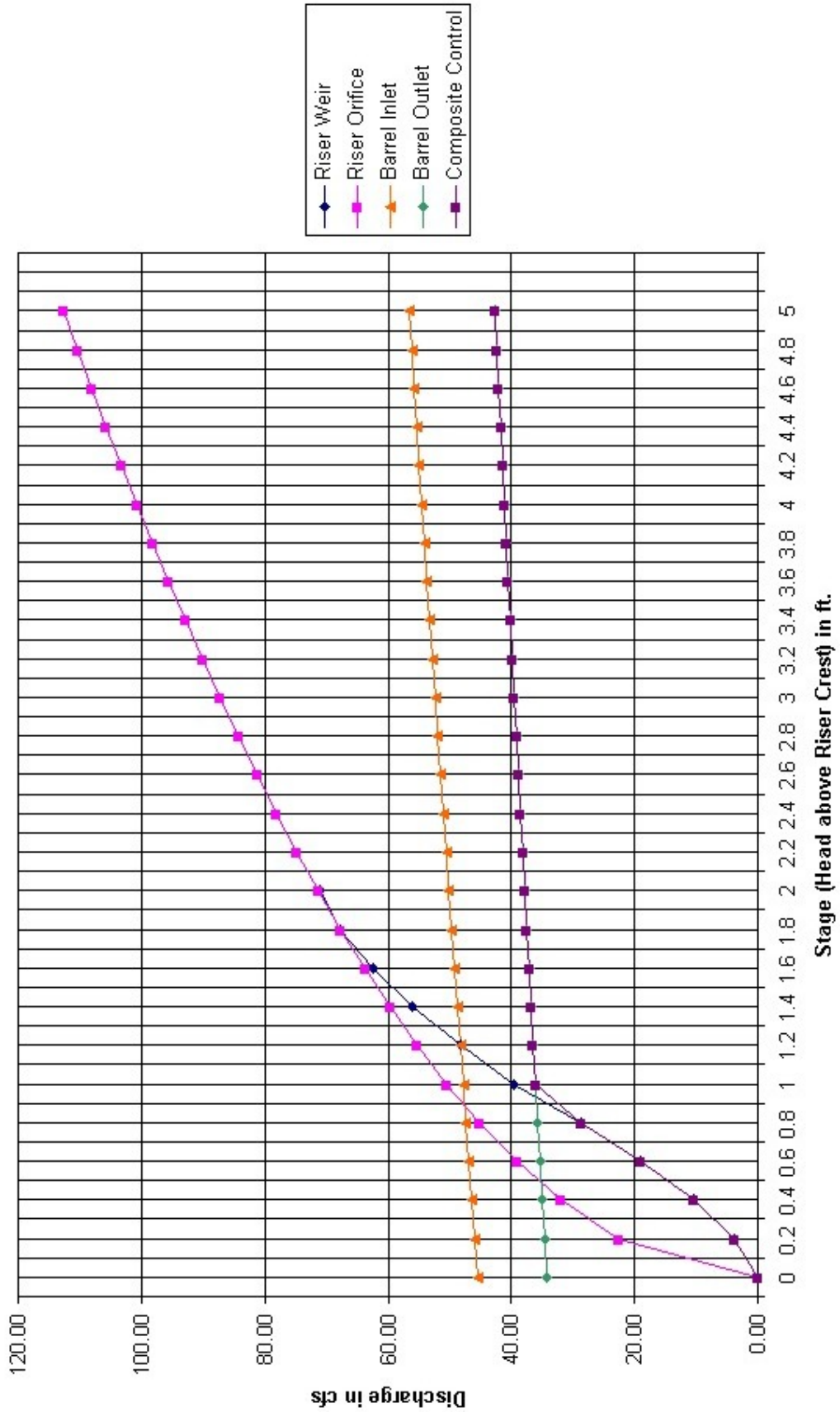
The above formulas can be entered as input to the cells in the column of Principal Spillway in the spreadsheet computations for flood routing, similar to the one included in Appendix 2, as detailed below.

# TABLE 1

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | STAGE-DISCHARGE CHARACTERISTICS OF RISER-BARREL SPILLWAY | | | | | | | | | | |
| 2 | | | | | | | | | | | |
| 3 | Riser (CAP) Diameter = 4 ft; Riser Crest El = 700.0 ft; | | | | | | | | | | |
| 4 | Barrel (CAP) Diameter = 2 ft; Barrel Invert El: Inlet 690.0 ft, Outlet 689.0 ft; Barrel Length = 80 ft | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | Elev. of Pond | Barrel Tailwater Elevation | Riser Weir Head, H | Barrel Total Head Loss, HL | Riser Weir Cw | Riser Weir Discharge | Riser Orifice Discharge | Barrel Orifice (Inlet) Outlet Discharge | Barrel Outlet Control Discharges | Composite Discharge | Comments |
| 8 | | | | | | | | | | | |
| 9 | (ft) | (ft) | (ft) | (ft) | | (cfs) | (cfs) | (cfs) | (cfs) | (cfs) | |
| 10 | | | | | | | | | | | |
| 11 | 700 | 691 | 0 | 9 | 3.4 | **0.00** | 0.00 | 45.36 | 34.20 | **0.00** | Riser Weir Control |
| 12 | 700.2 | 691 | 0.2 | 9.2 | 3.35 | **3.76** | 22.54 | 45.86 | 34.58 | **3.76** | |
| 13 | 700.4 | 691 | 0.4 | 9.4 | 3.3 | **10.49** | 31.88 | 46.36 | 34.95 | **10.49** | |
| 14 | 700.6 | 691 | 0.6 | 9.6 | 3.25 | **18.97** | 39.04 | 46.85 | 35.32 | **18.97** | |
| 15 | 700.8 | 691 | 0.8 | 9.8 | 3.2 | **28.76** | 45.08 | 47.33 | 35.69 | **28.76** | |
| 16 | 701 | 691 | 1 | 10 | 3.15 | 39.56 | 50.40 | 47.81 | **36.05** | 36.05 | Barrel Outlet Control |
| 17 | 701.2 | 691 | 1.2 | 10.2 | 2.92 | 48.21 | 55.21 | 48.29 | **36.41** | 36.41 | |
| 18 | 701.4 | 691 | 1.4 | 10.4 | 2.69 | 55.97 | 59.63 | 48.76 | **36.76** | 36.76 | |
| 19 | 701.6 | 691 | 1.6 | 10.6 | 2.46 | 62.53 | 63.75 | 49.23 | **37.12** | 37.12 | |
| 20 | 701.8 | 691 | 1.8 | 10.8 | 2.23 | 67.64 | 67.62 | 49.69 | **37.46** | 37.46 | |
| 21 | 702 | 691 | 2 | 11 | 2 | 71.05 | 71.28 | 50.15 | **37.81** | 37.81 | |
| 22 | 702.2 | 691 | 2.2 | 11.2 | | | 74.76 | 50.60 | **38.15** | 38.15 | |
| 23 | 702.4 | 691 | 2.4 | 11.4 | | | 78.08 | 51.05 | **38.49** | 38.49 | |
| 24 | 702.6 | 691 | 2.6 | 11.6 | | | 81.27 | 51.50 | **38.83** | 38.83 | |
| 25 | 702.8 | 691 | 2.8 | 11.8 | | | 84.34 | 51.94 | **39.16** | 39.16 | |
| 26 | 703 | 691 | 3 | 12 | | | 87.30 | 52.38 | **39.49** | 39.49 | |
| 27 | 703.2 | 691 | 3.2 | 12.2 | | | 90.16 | 52.81 | **39.82** | 39.82 | |
| 28 | 703.4 | 691 | 3.4 | 12.4 | | | 92.93 | 53.24 | **40.14** | 40.14 | |
| 29 | 703.6 | 691 | 3.6 | 12.6 | | | 95.63 | 53.67 | **40.47** | 40.47 | |
| 30 | 703.8 | 691 | 3.8 | 12.8 | | | 98.25 | 54.09 | **40.79** | 40.79 | |
| 31 | 704 | 691 | 4 | 13 | | | 100.80 | 54.52 | **41.10** | 41.10 | |
| 32 | 704.2 | 691 | 4.2 | 13.2 | | | 103.29 | 54.93 | **41.42** | 41.42 | |
| 33 | 704.4 | 691 | 4.4 | 13.4 | | | 105.72 | 55.35 | **41.73** | 41.73 | |
| 34 | 704.6 | 691 | 4.6 | 13.6 | | | 108.10 | 55.76 | **42.04** | 42.04 | |
| 35 | 704.8 | 691 | 4.8 | 13.8 | | | 110.42 | 56.17 | **42.35** | 42.35 | |
| 36 | 705 | 691 | 5 | 14 | | | 112.70 | 56.57 | **42.65** | 42.65 | |

## FIGURE 1

### STAGE-DISCHARGE CURVE OF RISER-BARREL SPILLWAY



Legend:
- Riser Weir
- Riser Orifice
- Barrel Inlet
- Barrel Outlet
- Composite Control

Y-axis: Discharge in cfs

X-axis: Stage (Head above Riser Crest) in ft.

# Flood Routing

Perform the flood routing in the pond using the "Chain Saw" method that facilitates the computations using any commercial spreadsheet software (such as Excel).

The basic continuity equation applicable to the flood routing process is

$$\Delta S = (I\text{-}O).\Delta T$$

where,   AS = Change in storage during a time interval,
         AT = Time interval,
         I = Average inflow during the time interval,
         0 =Average outflow during the time interval

To enable computations using a spreadsheet, the Inflow and Outflow values at the beginning of a time interval, instead of the average values for the time interval, are used in the procedure for computing incremental storage. The governing equation thus becomes:

$$\Delta S_{ij} = (I_i\text{—}O_i).\ \Delta T_{ij}$$

This equation is used in the spreadsheet to compute incremental storage during various time intervals and the cumulative storage at the corresponding times.

Table 2 illustrates a typical spreadsheet used for storage routing computations for a 20 acre site, with pre-project CN=70 and post-project CN=90. The pond at normal pool (orifice level) is assumed to be 160 ft. X 80 ft. (0.3 acre) in size, with side slopes of 3H:1V. The principal spillway is assumed to be a riser and barrel spillway of Corrugated Aluminum Pipe (CAP), riser of 4 ft diameter and barrel of 2 ft diameter, with crest at an elevation of 700.00 ft. A 3-inch diameter drain, located 1 foot below the principal spillway crest level is assumed to function as an orifice with a discharge coefficient of 0.6. The spreadsheet shows the computations for the 10-year recurrence rain.  The inflow hydrograph values computed and shown in Table 3 of Appendix 2 are used in this example spreadsheet.  The Figure 2 on the following page shows the graph of the inflow and outflow hydrographs. The proposed spillway was found (as discussed in step 10 below) to match the post-project flood peak with the pre-project value of 42 cfs. The storage required, as may be seen in Table 2 (cell D20), is 75,200 cubic feet (1.73 acre- feet). The corresponding maximum stage (depth) above the riser crest is seen (in cell G20) as 3.7 feet.

Following are the steps in using the spreadsheet.

  (1) Initialize the first row in the computations, say row #10 (assuming rows 1 through 9 are used for title, descriptive text, and column headings), by entering 0 (zero) in all the cells. In the first cell for time (A10), you may alternatively enter the time corresponding to one time interval before the start of the inflow (say, 10.5 hours if inflow values in Table 2 start at 11.0 hours).

(2) Enter the data for time and the corresponding inflow hydrograph unit discharges read from Table 2 in columns A and B respectively, starting with the second row (row # 11; cells A11 and B11).

(3) In the second row of computations, enter 0 or a small (nominal) value in the cell for outflow (H11), since outflow at the start is unknown.

(4) In cell C11, enter the formula for the Inflow (q) as given in step 5 under "Inflow Flood Hydrograph" above: =(value of A.Q/640)*(B11). Copy the formula from cell C11 and paste into all the cells below that in column C.

(5) In cell D11, enter: =(D1O+(A11-A10)*36OO*(C10-H10)). Copy the formula from cell D11 and paste into all the cells below that in column D.

(6) In cell E11, enter: =(D11-D10). Copy the formula from cell E11 and paste into all the cells below that in column E.

(7) In cell F11, enter the formula for the stage in terms of storage. For convenience, consider the zero value for stage as the elevation of the orifice, which in most cases would be the normal pool elevation in a pond. Develop data for the area (a) of the pond at the principal spillway (normal pool: zero stage) elevation and various stages (h) above the principal spillway elevation from the contour map or proposed grading plan. Calculate the storage volumes (V) for different stages (h) using prismoidal formula: $V = (d/3).((a_1 + (a_1.a_2)^{.05} +a_2))$, where $a_1$ and $a_2$ are the areas of the pond at two stages and d is the vertical distance between the two stages.

The storage volume (V) versus stage (h) relationship for the pond above the normal pool (principal spillway crest elevation) can generally be approximated by an equation of the form:

$V = kh^n$

$\log V = \log k + n \log h$; For $h = h_1 = 1$, $\log h_1 = 0$; hence $k = V_1$, where $V_1 = $ volume of storage at $h = 1.0$ ft. stage. Hence, $V = V_1.h$. Determine the values of n from the known pairs of values of V and h. Use the average of the values of n for computations. Alternatively, determine the value of n by plotting the V versus h pairs of values on a log-log paper. With the values of $k = V_1$ and n determined as above, the formula for the stage (h) can be written in terms of storage volume (V) as:

$h = (V/V_1)^{1/n}$
In this example, $h = (V/13531)^{0.9}$

Enter the above formula for the stage in cell F11 of the spreadsheet: $(D11/13531)^{0.9}$. Copy the formula from cell F11 and paste into all the cells below that in column F. In cell G11, enter the function: If(F11 > 1.0, (F11 − 1.0), 0) and copy and paste it in the cells below G11 to enter the values of "stage" or head above the crest of the riser.

(8) In cell H12, enter the formula for the total outflow as equivalent to the sum of the outflows through the various outflow facilities: =(I12+J12+K12)). Copy the formula from cell H12 and paste into all the cells below that in column H. Note that either 0 or a small value was entered in cell H11 in step 3 above.

(9) In cell I12, enter the formula for orifice discharge: =4.8*(value of orifice area)*(F12)^0.5. Copy the formula from cell I12 and paste into all the cells below that in column I.

(10) In cell J11, enter the formulas for the principal spillway discharge stated in the Summary of Results of the analysis of Riser and Barrel Spillway, using the "IF" function as follows: IF(G11<0.9, (12.56(3.4 – 0.25 * G11)* G11^1.5), (11.4 * (9 + G11)^0.5)). In most cases, the stage of the spillway crest would be zero. Copy the formula from cell J11 and paste into all the cells below that in column J. Since the spillway dimensions required are unknown, a few trial values for the spillway riser and barrel diameters may have to be tried, each resulting in a unique flood routing and peak outflow value (in column H). The final design to be accepted should be the one that results in the peak outflow value that closely matches or is less than the target value (such as the pre-project runoff peak discharge).

(11) In cell K11, enter 0. Copy the 0 from cell K11 and paste into all the cells below that in column K. Revise the values in column K only for routing floods larger than a 10-year flood, as given in the following steps.

(12) After performing the routing computations for detention storage required for the 10-year recurrence rain (no emergency spillway flows up to 10-year flood), the 10 year flood pool elevation would be known. Then, establish the crest elevation of the emergency spillway at or above the 10-year flood pool elevation.

(13) Revise the values in columns C and K to perform flood routing computations for the 100-year inflow flood, which would provide design information regarding the 100-year flood pool elevation and the discharges through the different outflow facilities. In column C, revise the formula in cell C11 and the ones below that to reflect the revised value of runoff (Q) for the 100-year rainfall. If the emergency spillway crest is set at the elevation of the maximum pool (highest stage) in a 10-year flood event, enter the formula for the emergency spillway discharge in the cell in column K and row corresponding to the highest value for the stage (column F) in the 10-year flood routing computation described in steps up to #11 above. If the emergency spillway crest elevation is set above the 10-year flood pool elevation, enter the formula in the cell in (column K) in the row below that having the highest value for stage in column F or G. Assuming that the emergency spillway would function as a broad-crested weir, enter the formula in cell K20 for the discharge as:

=2.65*(length of spillway)*(F20 minus stage (relative to the orifice) of the crest of emergency spillway)^1.5. If the hydraulic characteristics of the spillway are different from that of a broad-crested weir, change the formula accordingly. Copy the formula from the cell in which the formula is entered and paste into all the cells below that in column K. The

computations should be complete with this step. Obtain the design parameters from the values in the row in which the maximum stage and storage occurs.

# TABLE 2

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FLOOD ROUTING COMPUTATIONS (CHAIN SAW METHOD) | | | | | | | | | | |
| 2 | For 10-year, 24-hour Rain Event;  Project:  Typical Development | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | Site area = 20 acres; Post-develop. CN = 90; $T_c$ = 20 Min.; 10-year Rain = 5.1 in.; Runoff = 4.0 in. | | | | | | | | | | |
| 5 | Pond area t normal pool – 0.3 acre; Stage-Volume: h=(V/13531)^0.9; Target Peak Outflow = 42 cfs | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | Time | Tab. Hydr. Value | Inflow | Storage | Change in Storage | Head on Orifice | Head on Riser | Outflow | Outflow Facilities (Spillway sand Orifices) | | |
| 8 | (hours) | (csm/in) | (cfs) | (cu.ft.) | (cu.ft.) | (ft.) | (cfs) | (cfs) | Orifice | Prin. Spillway | Emerg. Spillway |
| 9 | | | | | | | | | | | |
| 10 | 10.7 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| 11 | 11 | 20 | 2.5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| 12 | 11.3 | 28 | 3.5 | 2700.00 | 2700.00 | 0.23 | 0.00 | 0.11 | 0.11 | 0.00 | 0 |
| 13 | 11.6 | 41 | 5.125 | 6356.59 | 3656.59 | 0.51 | 0.00 | 0.17 | 0.17 | 0.00 | 0 |
| 14 | 11.9 | 118 | 14.75 | 11710.17 | 5353.58 | 0.88 | 0.00 | 0.22 | 0.22 | 0.00 | 0 |
| 15 | 12 | 235 | 29.375 | 16940.56 | 5230.39 | 1.22 | 0.22 | 4.72 | 0.26 | 4.46 | 0 |
| 16 | 12.1 | 447 | 55.875 | 25816.87 | 8876.32 | 1.79 | 0.79 | 28.49 | 0.32 | 28.17 | 0 |
| 17 | 12.2 | 676 | 84.5 | 35676.24 | 9859.36 | 2.39 | 1.39 | 37.12 | 0.37 | 36.75 | 0 |
| 18 | 12.3 | 676 | 84.5 | 52734.25 | 17058.02 | 3.40 | 2.40 | 38.93 | 0.44 | 38.49 | 0 |
| 19 | 12.4 | 459 | 57.375 | 69139.87 | 16405.62 | 4.34 | 3.34 | 40.54 | 0.49 | 40.05 | 0 |
| 20 | 12.5 | 283 | 35.375 | 75200.79 | 6060.92 | 4.68 | 3.68 | 41.11 | 0.51 | 40.60 | 0 |
| 21 | 12.6 | 196 | 24.5 | 73137.05 | -2063.74 | 4.57 | 3.57 | 40.92 | 0.50 | 40.41 | 0 |
| 22 | 12.7 | 146 | 18.25 | 67227.48 | -5909.57 | 4.23 | 3.23 | 40.36 | 0.49 | 39.87 | 0 |
| 23 | 12.8 | 114 | 14.25 | 59268.97 | -7958.51 | 3.78 | 2.78 | 39.58 | 0.46 | 39.13 | 0 |
| 24 | 13 | 80 | 10 | 41028.66 | -18240.31 | 2.71 | 1.71 | 37.70 | 0.39 | 37.31 | 0 |
| 25 | 13.2 | 66 | 8.25 | 21082.33 | -19946.33 | 1.49 | 0.49 | 14.43 | 0.29 | 14.14 | 0 |
| 26 | 13.4 | 57 | 7.125 | 16633.72 | -4448.61 | 1.20 | 0.20 | 4.14 | 0.26 | 3.88 | 0 |
| 27 | 13.6 | 51 | 6.375 | 18782.98 | 2149.25 | 1.34 | 0.34 | 8.65 | 0.27 | 8.37 | 0 |
| 28 | 13.8 | 46 | 5.75 | 17146.10 | -1636.87 | 1.24 | 0.24 | 5.12 | 0.26 | 4.86 | 0 |
| 29 | 14 | 42 | 5.25 | 17600.06 | 453.96 | 1.27 | 0.27 | 6.04 | 0.27 | 5.77 | 0 |
| 30 | 14.3 | 37 | 4.625 | 16746.21 | -853.85 | 1.21 | 0.21 | 4.35 | 0.26 | 4.09 | 0 |
| 31 | 14.6 | 33 | 4.125 | 17044.05 | 297.84 | 1.23 | 0.23 | 4.92 | 0.26 | 4.66 | 0 |
| 32 | 15 | 31 | 3.875 | 15900.49 | -1143.55 | 1.16 | 0.16 | 2.86 | 0.25 | 2.61 | 0 |
| 33 | 15.5 | 28 | 3.5 | 17723.19 | 1822.69 | 1.27 | 0.27 | 6.30 | 0.27 | 6.03 | 0 |
| 34 | 16 | 24 | 3 | 12685.90 | -5037.29 | 0.94 | 0.00 | 0.23 | 0.23 | 0.00 | 0 |
| 35 | 16.5 | 22 | 2.75 | 17673.25 | 4987.35 | 1.27 | 0.27 | 6.19 | 0.27 | 5.93 | 0 |
| 36 | 17 | 20 | 2.5 | 11474.96 | -6198.29 | 0.86 | 0.00 | 0.22 | 0.22 | 0.00 | 0 |
| 37 | 17.5 | 19 | 2.375 | 15580.52 | 4105.57 | 1.14 | 0.14 | 2.36 | 0.25 | 2.11 | 0 |
| 38 | 18 | 18 | 2.25 | 15613.67 | 33.15 | 1.14 | 0.14 | 2.41 | 0.25 | 2.16 | 0 |
| 39 | 19 | 16 | 2 | 15047.05 | -566.62 | 1.10 | 0.10 | 1.59 | 0.25 | 1.35 | 0 |
| 40 | 20 | 13 | 1.625 | 16508.81 | 1461.76 | 1.20 | 0.20 | 3.91 | 0.26 | 3.65 | 0 |
| 41 | 22 | 12 | 1.5 | 46.22 | -16462.59 | 0.01 | 0.00 | 0.02 | 0.02 | 0.00 | 0 |
| 42 | 26 | 0 | 0 | 21382.37 | 21336.15 | 1.51 | 0.51 | 15.24 | 0.29 | 14.95 | 0 |
| 43 | | | | | | | | | | | |
| 44 | *Note: Principal Spillway: Riser and Barrel Spillway: Corrugated Aluminum Pipe (CAP) Riser and Barrel; | | | | | | | | | | |
| 45 | Riser Dia. = 4.0 ft, Barrel Dia. = 2.0 ft, Barrel Length = 80 ft, Riser Crest El = 700 ft, Water Quality | | | | | | | | | | |
| 46 | Orifice El = 699.0 Barrel Invert El = 690.0 at inlet and 689.0 at outlet; Tail Water below crown of barrel outlet. | | | | | | | | | | |

FIGURE 2

FLOOD ROUTING: 10-YEAR RAIN EVENT