APPENDIX E BASIN OUTLET SIZING EXAMPLES

Perforated Risers Outlet Sizing Methodology (Figure 2-2)

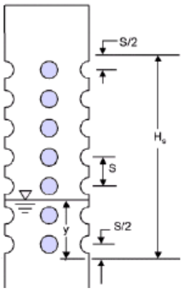
The following attributes influence the perforated riser outlet sizing calculations**:**

- Shape of the basin (e.g. trapezoidal)
- Depth and volume of the basin
- Elevation / depth of first row of holes
- Elevation / depth of last row of holes
- Size of perforations
- Number of rows or perforations and number of perforations per row
- Desired draw down time (e.g. 16 hour and 32 hour draw down for top half and bottom half respectively, 48 hour total draw down time)

The governing rate of discharge from a perforated riser structure can be calculated using Equation E-1 below:

$$Q = C_p \frac{2A_p}{3H_s} \sqrt{2g} H^{3/2} \qquad \text{(Equation E-1)}$$

Where:



Q = riser flow discharge (cfs)
C_p = discharge coefficient for perforations (use 0.61)
A_p = cross-sectional area of all the holes (ft^2)
s = center to center vertical spacing between perforations (ft)
H_s = distance from s/2 below the lowest row of holes to s/2 above the top row of holes (McEnroe 1988)
H = effective head on the orifice (measured from center of orifice to water surface)

For the iterative computations needed to size the perforations in the riser and determine the riser height a simplified version of Equation E-1 may be used, as shown below in Equation E-2:

$$Q = kH^{3/2} \qquad \text{(Equation E-2)}$$

Where:

$$k = C_p \frac{2A_p}{3H_s} \sqrt{2g} \qquad \text{(Equation E-3)}$$

Uniformly perforated riser designs are defined by the depth or elevation of the first row of perforations, the length of the perforated section of pipe, and the size or diameter of each perforation. The steps needed to size a perforated riser outlet are outlined below.

Step 1: Determine riser elevation or depth in the basin

Set the riser elevation at 6" above the basin bottom to provide for sediment storage. Select a riser height such that the last row of perforations is in-line with the top of the water quality pool elevation.

Step 2: Determine basin and riser attributes and constants for computations

Parameters examined at this step include basin geometry such as basin shape, basin bottom length and width, and basin side slopes. Organize the attributes obtained in this step in a table such as Table E-1.

Step 3: Determine constant *k*

Determine the value of the constant *k* (Equations E-2 and E-3) that provides the desired draw down time.

Set up a computation table such as Table E-3. Note that the table must have at least 19 height slices or the bottom 5% of the basin shall be combined in the computations. The formulas for each column of the computation table are provided in Table E-2.

Using the basin depth, partition the basin into equal height horizontal slices to be stored as entries in Table E-3. At each elevation E_n (or table entry), complete the following:

Determine the change in elevation H_n (ft) [$H_n = (E_o - E_{n+1})$]
Calculate the average discharge Q_n (cfs) [$Q_n = k(H_n)^{3/2}$] *Eqn E-2*
Calculate the basin surface area A_n (ft^2) [$A_n = L_n \times W_n$ for
rectangular basins]
Compute the available storage V_n (ft^3) [$V_n = A_n \times H_n$]
Determine the average drain time T_n (hrs) [$T_n = (V_n / Q_n) \times 3600$]

Sum up the drain times at each height slice to determine the total drain time for the basin. If the value obtained is smaller or greater than the desired value, increase or decrease the *k* value and repeat the computations in step b until the desired drain time is achieved.

Step 4: Determine the size and number of rows of perforations

Determine the size and number of rows of perforations that yield a *k* value equal to the *k* value used in the previous step. Follow the steps below to obtain riser attributes:

Select an initial number of rows, number or holes per row and an initial hole diameter.

Obtain flow area per row values from Table E-4 or compute flow area.

Select a value for H_s and C_p and compute *k*.

Repeat the above steps varying the number of rows, hole diameter, number of holes per row and H_s until the desired value of *k* is obtained or it is determined that *k* is too small to be matched by any realistic combination of inputs. Hole diameter shall not be less than 1/4" to minimize the potential for clogging.

Step 5: Verify the design

The design is completed by verifying that the drain time for both the top half and the bottom half are acceptable and the total drain time is equivalent to the desired value. Note that the drain time for the top half can be obtained by summing the drain times for the top half of the entries in the computation Table E-3. The drain time for the bottom half can similarly be obtained by summing values for the drain times for the bottom half of the entries in the computation Table E-3.

Table E-1: Constants Used in Example Computations

Constant	Values	Units
Orifice coefficient (C_p)	0.6	-
Perforation diameter (d)	0.0468	ft
Combined area of holes (A_p)	0.0399	ft^2
Acceleration due to gravity (g)	32.2	ft/s^2
Basin bottom length (L)	40	ft
Basin bottom width (W)	20	ft
Side slopes (z)	3	-
Basin bottom surface area (A)	800	ft^2
k	0.02791	$ft^{3/2}/s$

Table E-2: Basin Draw Down Time Calculation

Line No.	Elev. (ft)	Change in Elevation (ft)	Average Discharge (cfs)	*Basin Surface Area (ft^2)	Storage Volume (ft^3)	Average Drain Time (hrs)
1	E_o	$H_o = (E_o – E_1)$	$Q_0 = k(H_o)^{3/2}$	$A_0 = L_0 \times W_0$	$V_o = A_o \times H_o$	$T_0 = V_0 / Q_0$
2	E_1	$H_1 = (E_1 – E_2)$	$Q_1 = k(H_1)^{3/2}$	$A_1 = L_1 \times W_1$	$V_1 = A_1 \times H_1$	$T_1 = V_1 / Q_1$
3	E_2	$H_2 = (E_2 – E_1)$	$Q_2 = k(H_2)^{3/2}$	$A_2 = L_2 \times W_2$	$V_2 = A_2 \times H_2$	$T_2 = V_2 / Q_2$
...	...	...	...	...	...	...

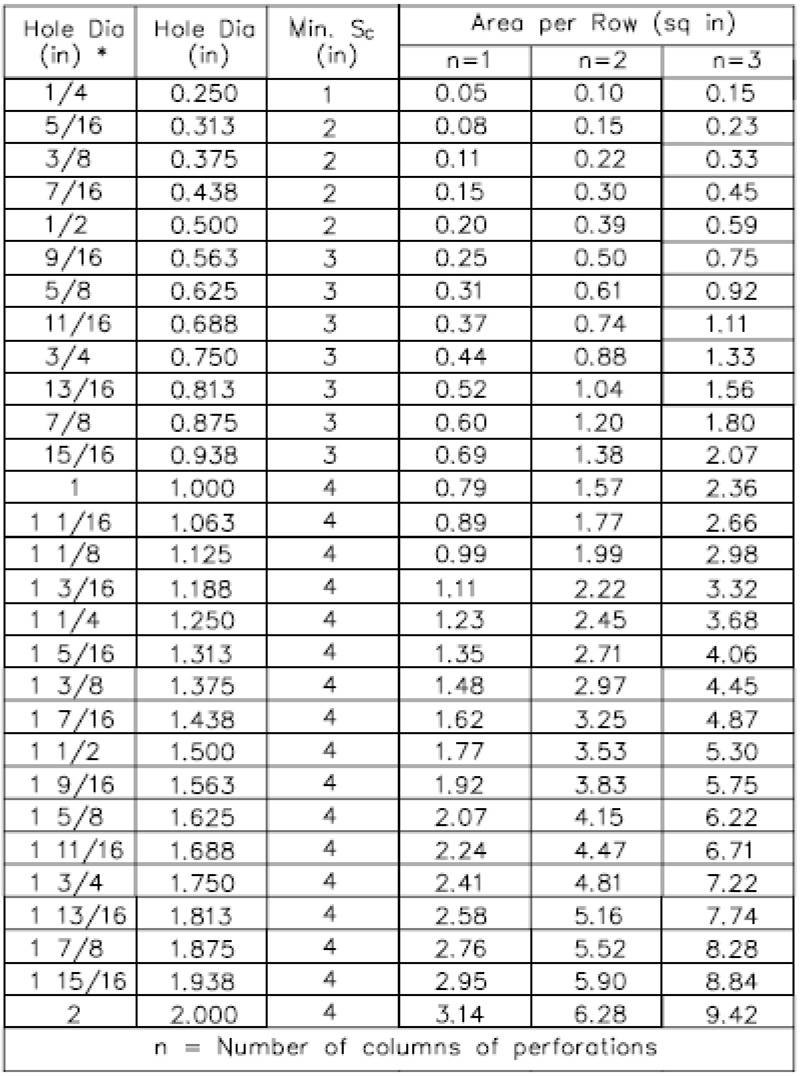
* Basin surface area can be calculated or measured. Non rectangular cross sections must use the appropriate formulas for calculating cross-sectional areas.

Table E-3: Sample Spread Sheet for Perforated Riser Outlet Sizing Calculations

Line No.	Elevation	Change in height	Average Flow at Elev. (top orifice only)	Basin Surface Area	Storage Volume	Time to Drain Unit at Current

						Flow
	[E_n] (ft)	[E_n - E_{n+1}] H_n (ft)	[See Eqn E-2] Q_n (cfs)	A_n (ft^2)	[A_n x H_n] V_n (ft^3)	[V_n / Q_n] T_n (hrs)
1	6	0.3	0.4102	4256	1419	1.0
2	5.7	0.3	0.3765	3996	1332	1.0
3	5.3	0.3	0.3438	3744	1248	1.0
4	5.0	0.3	0.3120	3500	1167	1.0
5	4.7	0.3	0.2814	3264	1088	1.1
6	4.3	0.3	0.2518	3036	1012	1.1
7	4.0	0.3	0.2233	2816	939	1.2
8	3.7	0.3	0.1960	2604	868	1.2
9	3.3	0.3	0.1699	2400	800	1.3
10	3.0	0.3	0.1450	2204	735	1.4
11	2.7	0.3	0.1215	2016	672	1.5
12	2.3	0.3	0.0995	1836	612	1.7
13	2.0	0.3	0.0789	1664	555	2.0
14	1.7	0.3	0.0601	1500	500	2.3
15	1.3	0.3	0.0430	1344	448	2.9
16	1.0	0.3	0.0279	1196	399	4.0
17	0.7	0.3	0.0152	1056	352	6.4
18	0.3	0.3	0.0054	924	308	15.9
19	0.0	0.0	0.0000	800	0	0.0
				Total Draw Down Time		48

Table E-4: Circular Perforation Sizing for Perforated Riser.



Hole Dia (in) *	Hole Dia (in)	Min. S_c (in)	Area per Row (sq in)		
			n=1	n=2	n=3
1/4	0.250	1	0.05	0.10	0.15
5/16	0.313	2	0.08	0.15	0.23
3/8	0.375	2	0.11	0.22	0.33
7/16	0.438	2	0.15	0.30	0.45
1/2	0.500	2	0.20	0.39	0.59
9/16	0.563	3	0.25	0.50	0.75
5/8	0.625	3	0.31	0.61	0.92
11/16	0.688	3	0.37	0.74	1.11
3/4	0.750	3	0.44	0.88	1.33
13/16	0.813	3	0.52	1.04	1.56
7/8	0.875	3	0.60	1.20	1.80
15/16	0.938	3	0.69	1.38	2.07
1	1.000	4	0.79	1.57	2.36
1 1/16	1.063	4	0.89	1.77	2.66
1 1/8	1.125	4	0.99	1.99	2.98
1 3/16	1.188	4	1.11	2.22	3.32
1 1/4	1.250	4	1.23	2.45	3.68
1 5/16	1.313	4	1.35	2.71	4.06
1 3/8	1.375	4	1.48	2.97	4.45
1 7/16	1.438	4	1.62	3.25	4.87
1 1/2	1.500	4	1.77	3.53	5.30
1 9/16	1.563	4	1.92	3.83	5.75
1 5/8	1.625	4	2.07	4.15	6.22
1 11/16	1.688	4	2.24	4.47	6.71
1 3/4	1.750	4	2.41	4.81	7.22
1 13/16	1.813	4	2.58	5.16	7.74
1 7/8	1.875	4	2.76	5.52	8.28
1 15/16	1.938	4	2.95	5.90	8.84
2	2.000	4	3.14	6.28	9.42

n = Number of columns of perforations

Source: UDFCD, 1999

Multiple Orifice Outlet Sizing Methodology

The following attributes influence multiple orifice outlet sizing calculations**:**

- Shape of the basin (e.g. trapezoidal)
- Depth and volume of the basin
- Elevation of each orifice
- Desired draw-down time (e.g., 16 hour and 32 hour draw down times for top half and bottom half, respectively, 48 hour draw down time for whole basin)

The rate of discharge from a single orifice can be calculated using Equation E-4 below:

$$Q = CA(2gH)^{0.5} \qquad \text{(Equation E-4)}$$

Where:

Q = orifice flow discharge
C = discharge coefficient
A = cross-sectional area of orifice or pipe (ft^2)
g = acceleration due to gravity (32.2 ft/s^2)
H = effective head on the orifice (measured from center of orifice to water surface)

Multiple orifice designs are defined by the depth (or elevation) and the size (or diameter) of each orifice (Figure 2-1). The steps needed to size a dual orifice outlet are outlined below; multiple orifices may be provided and sized using a similar approach.

Step 1: Determine orifice elevations

For the bottom orifice, set the orifice elevation (H_b) at a maximum of 6” above the basin bottom. If the bottom orifice is below the invert of the outlet pipe, then use the outlet pipe invert elevation for orifice calculations.

For the top orifice, set the orifice elevation (H_t) at half way to the top of the water quality pool.

Step 2: Determine basin and orifice attributes and constants for computations

Parameters examined at this step include basin geometry such as basin shape, basin bottom length and bottom width and basin side slopes. Organize the attributes obtained in this step in a table such as Table E-5.

Step 3: Determine the required size of the bottom orifice

Set up a computation table such as Table E-6. The formulas for each column of the computation table are provided in Table E-7.

Using the basin depth, partition the basin into equal height horizontal slices to be stored as entries in Table E-6. At each elevation E_n (or table entry), complete the following:

Determine the change in elevation H_n (ft) [$H_n = (E_o - E_{n+1})$]
Calculate the average discharge Q_n (cfs) [$Q_n = CA(2gH_n)^{0.5}$] *Eqn E-4*
Calculate the basin surface area A_n (ft2) [$A_n = L_n \times W_n$ for rectangular basins]
Compute the available storage V_n (ft3). [$V_n = A_n \times H_n$]
Determine the average drain time T_n (hrs) [$T_n = (V_n / Q_n) \times 3600$]

Sum up the drain times at each height slice to determine the total drain time for the bottom half of the basin. If the value obtained is smaller or greater than the desired value, increase or decrease the orifice diameter and repeat the computations in step b above until the desired drain time is achieved

Step 4: Determine the required size of the top orifice

Set up a Table such as Table E-8. The formulas for each column of the computation tables are provided in Table E-7.

At each elevation E_n complete the following:

Determine the change in elevation H_n (ft) [$H_n = (E_n - E_{n+1})$]
Calculate the average discharge Q_n (cfs) [$Q_n = CA(2gH_n)^{0.5}$] *Eqn E-4*
Calculate the combine average discharge Q_{TOT-n} [$Q_{TOT-n} = Q_n + Q_b$]
Calculate the basin surface area A_n (ft^2) [$A_n = L_n \times W_n$ for rectangular basins]
Compute the available storage V_n (ft^3) [$V_n = A_n \times H_n$]
Determine the average drain time T_n (hrs) [$T_n = V_n / Q_t$]
Note that Q_b is the maximum discharge from the bottom orifice.

Sum up the drain times at each height slice to determine the total drain time for the top half of the basin. If the value obtained is smaller than the desired value, increase or decrease the orifice diameter and repeat the computations in step 4b until the desired drain time is achieved.

Step 5: Verify the design

The design is completed by verifying that the sum of the detention times for the top half of the basin and the bottom half of the basin add up to the total desired detention time (36 to 48 hours).

Table E-5: Constants Used in Example Computations

Constant	Lower Orifice Values	Upper Orifice Values	Units
Orifice coefficient (C_p)	0.6	0.6	-
Orifice diameter (d)	0.0633	0.0675	ft
Orifice cross-sectional area (a)	0.003	0.004	ft^2
Acceleration due to gravity (g)	32.2	32.2	ft/s^2
Basin bottom length (L)	40	40	ft
Basin bottom width (W)	20	20	ft
Side slopes (z)	3	3	-
Basin bottom surface area (A)	800	800	ft^2

Table E-6: Sample Spreadsheet for Dual Orifice Basin Outlet Sizing Calculations: Bottom Half of Basin

Line Number	Elevation [E]	Change in height	Average Discharge at Elevation, E (bottom orifice only)	Basin Surface Area	Available Storage Volume	Average Drawdown Time at Current Flow Rate
		$[E_n-E_{n+1}]$	[See Eqn E-4]	A_n	$[A_n \times H_n]$	$[V_n / Q_n]$
	(ft)	H_n (ft)	Q_n (cfs)	(ft^2)	V_n (ft^3)	T_n (hrs)
1	3.0	3.0	0.0567	2204	735	3.6
2	2.7	2.7	0.0534	2016	672	3.5
3	2.3	2.3	0.0500	1836	612	3.4
4	2.0	2.0	0.0463	1664	555	3.3
5	1.7	1.7	0.0422	1500	500	3.3
6	1.3	1.3	0.0378	1344	448	3.3
7	1.0	1.0	0.0327	1196	399	3.4
8	0.7	0.7	0.0267	1056	352	3.7
9	0.3	0.3	0.0189	924	308	4.5
10	0.0	0.0	0.0000	800	0	0.0
				Subtotal Draw Down Time		32.0

Table E-7: Basin Draw Down Time Calculation

Line No.	Elev (ft)	Change in Elevation (ft)	Average Discharge at Elevation, E (top orifice only) (cfs)	*Combined Average Discharge (cfs)	**Basin Surface Area (ft^2)	Storage Volume (ft^3)	Average Drain Time (hrs)
1	E_o	$H_o =(E_o - E_1)$	$Q_o = CA(2gH_o)^{0.5}$	$Q_{TOT-o} = Q_o + Q_b$	$A_0 = L_0 \times W_0$	$V_o = A_o \times H_o$	$T_0 = V_0 / Q_0$
2	E_1	$H_1 =(E_1 - E_2)$	$Q_1 = CA(2gH_1)^{0.5}$	$Q_{TOT-1} = Q_1 + Q_b$	$A_1 = L_1 \times W_1$	$V_1 = A_1 \times H_1$	$T_1 = V_1 / Q_1$
3	E_2	$H_2 =(E_2 - E_1)$	$Q_2 = CA(2gH_2)^{0.5}$	$Q_{TOT-2} = Q_2 + Q_b$	$A_2 = L_2 \times W_2$	$V_2 = A_2 \times H_2$	$T_2 = V_2 / Q_2$
...	...	...	...	...	...	...	...

* Q_b is the maximum discharge from the bottom orifice.

** Basin surface area can be calculated or measured. Non-rectangular cross sections must use the appropriate formulas for calculating cross-sectional areas.

Table E-H-8: Sample Spreadsheet for Dual Orifice Basin Outlet Sizing Calculations: Top Half of Basin

Line Number	Elevation	Change in height	Average Flow at Elevation, E (top orifice only)	Combined Average Discharge	Basin Surface Area	Storage Volume	Time to Drain Unit at Current Flow
	[E]	[E_n - E_{n+1}]	[See Eqn E-4]	[Q_n + Q_b]	A_n	[A_n x H_n]	[V_n / Q_n]
	(ft)	H (ft)	Q_n (cfs)	Q_{TOT-n} (cfs)	(ft^2)	V_n (ft^3)	T_n (hrs)
1	6.0	3.0	0.1615	0.2181	4256	1419	1.8
2	5.7	2.7	0.1522	0.2089	3996	1332	1.8
3	5.3	2.3	0.1424	0.1990	3744	1248	1.7
4	5.0	2.0	0.1318	0.1885	3500	1167	1.7
5	4.7	1.7	0.1203	0.1770	3264	1088	1.7
6	4.3	1.3	0.1076	0.1643	3036	1012	1.7
7	4.0	1.0	0.0932	0.1499	2816	939	1.7
8	3.7	0.7	0.0761	0.1328	2604	868	1.8
9	3.3	0.3	0.0538	0.1105	2400	800	2.0
10	3.0	0.0	0.0000	0.0567	2204	0	0.0
						Subtotal Draw Down Time	16.0
						Total Draw Down Time	48.0