URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

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TECHNICAL MEMORANDUM

FROM: Ken MacKenzie

SUBJECT: Water quality orifice sizing equation for EURV and WQCV detention basins

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The purpose of this memorandum is to document the derivation of the orifice sizing equation developed to drain the urban excess runoff volume (EURV) from full spectrum detention basins and to drain the water quality capture volume (WQCV) from extended detention basins, constructed wetland basins, and water quality retention ponds. It is important to drain these facilities over the proper length of time in order to assure the optimum level of sediment and pollutant removal. This equation is applicable when the individual orifices are spaced four inches on center vertically (for example, a two foot storage depth would have orifices at of 0, 4, 8, 12, 16, and 20 inches from the bottom of the storage volume). To develop this equation, storage volumes were modeled using the USEPA Storm Water Management Model (SWMM) Version 5.0.018. One hundred forty storage volume cases were modeled as 2:1 rectangular basins at five different trickle channel slopes and seven different depths. Side slopes of 4:1 were assumed for the storage above the sloped floor of the basin. The result of the modeling was the development of an equation to size each orifice in the orifice plate column such that the runoff storage volume would drain in roughly the prescribed drain time (±10%). All of the modeling was done using a 72-hour drain time, and the final equation was adapted to allow other drainage times.

This simplified method can serve as a substitute for a more detailed reservoir routing design approach when UDFCD standards regarding the detention basin parameters described above have been met.

The design parameters that influence the area of the individual orifices in the orifice plate are:

- The storage volume to be drained,
- The prescribed drain time,
- The design depth of the storage volume,
- The slope of the bottom of the detention basin (i.e., the trickle channel slope).

The drain time is particularly sensitive to the slope parameter as it has a strong effect on the stage-storage relationship. For each slope, the calculated orifice areas for each of the eight volumes were plotted vs. the design depth, as shown in Figure 1.

A power regression was applied to the data. The equation for this regression takes the form:

$$A_O = \alpha Vol^{\beta}$$ *Equation 1*

Where A_O is the required orifice area per row in the orifice column (in square inches), Vol is the storage volume (in acre-feet), α is the leading coefficient, and β is the exponent of the power regression function.

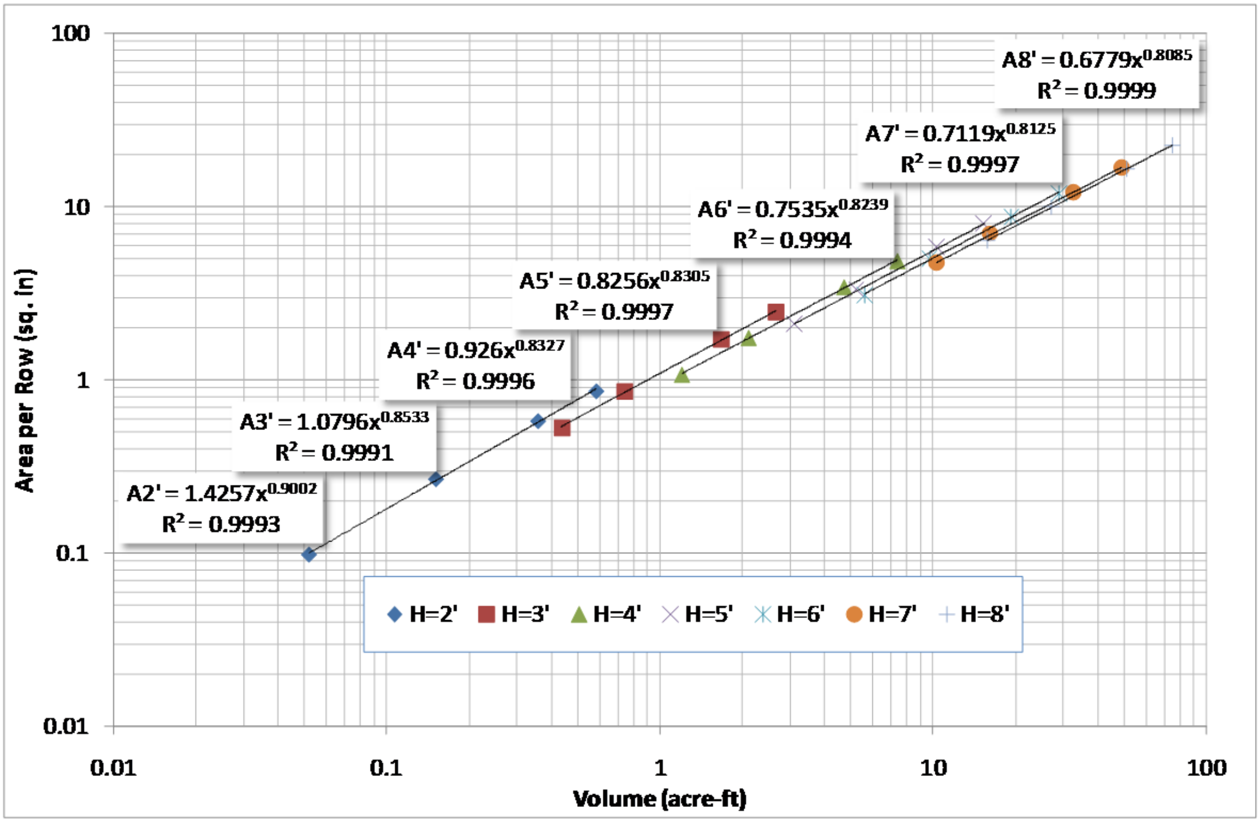
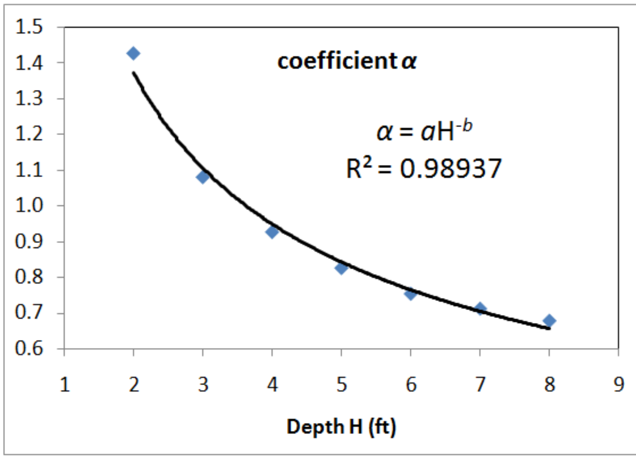


Figure 1: Orifice area vs. storage volume was plotted for each of the storage depths and each of the five trickle channel slopes. This figure shows the equations for the 0.5% slope.

For each storage depth, the leading coefficient α and the exponent β from Equation 1 were plotted as a function of that depth, as shown in Figures 2 and 3.



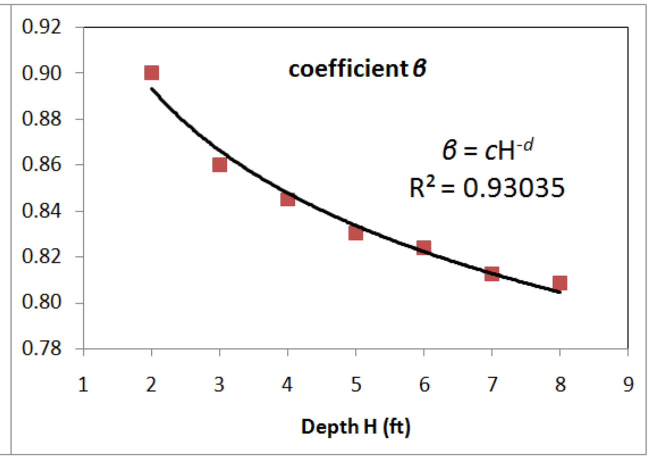


Figure 2: Orifice area sizing power regression coefficient α vs. storage depth

Figure 3: Orifice area sizing power regression exponent β vs. storage depth

A power regression fits the data for both α and β. By substitution, the general equation becomes:

$$A_O = aH^{-b} Vol^{c\left(H^{-d}\right)} \qquad \textit{Equation 2}$$

Where *Vol* is the storage volume to be drained (in acre-ft), *a* and *b* are the coefficient and exponent (respectively) of the power regression of coefficient α from Equation 1, and *c* and *d* are the coefficient and exponent (respectively) of the power regression of exponent β, also from Equation 1.

Because all modeling was performed using a 72-hour drain time, coefficient *a* was multiplied by 72 in order to normalize the final equation so that it could be used with other drain times. The general orifice sizing equation was then rearranged as:

$$A_O = \frac{72 a Vol^{\left(c/H^{d}\right)}}{T_D H^{b}} \qquad \textit{Equation 3}$$

Where T_D is the prescribed drain time (in hours). The coefficients *a, b, c,* and *d* are all dependent on the trickle channel slope. These coefficients were plotted vs. trickle channel slope and power regression expressions were developed for each, as shown in Figure 4.

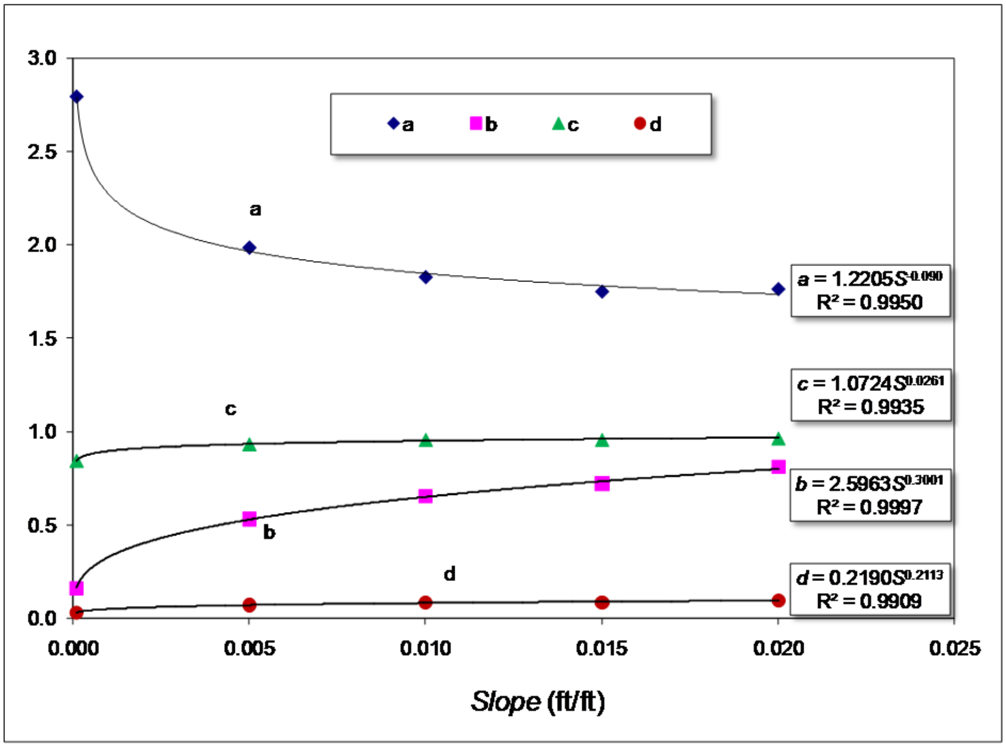


Figure 4: Sizing coefficients a, b, c, and d plotted vs. trickle channel slope.

The regression equations for the coefficients *a*, *b*, *c* and *d* are power functions, expressed as:

$$a = 1.22(S^{-0.09}) \qquad \textit{Equation 4}$$

$$b = 2.6(S^{0.3}) \qquad \textit{Equation 5}$$

$$c = 1.07(S^{0.026}),\text{ or } 0.95 \qquad \textit{Equation 6}$$

$$d = 0.219(S^{0.211}),\text{ or } 0.085 \qquad \textit{Equation 7}$$

It was determined through sensitivity testing on these coefficients that coefficient *c* could be substituted with the constant 0.95 and coefficient *d* could be substituted with the constant 0.085 without noticeably affecting the result. The orifice sizing equation therefore becomes:

$$A_O = \frac{72a\left[Vol^{\left(0.95/H^{0.085}\right)}\right]}{T_D\left(H^b\right)} \qquad \textit{Equation 8}$$

A minimum trickle channel slope of 0.0001 feet vertical / feet horizontal was selected to represent the flat bottomed basin, the retention pond, and the constructed wetland pond as a best fit to match the prescribed drain time since a zero percent slope would result in A_O being undefined. The equations presented here were developed by modeling storage volumes from 0.0082 acre-feet to 75.5 acre-feet, slopes from 0.0001 to 0.02 feet vertical / feet horizontal, depths from two feet to eight feet, and an orifice coefficient of 0.60. These equations are valid for this range of input parameters but have not been tested outside this range.

Combining Equations 4, 5, and 8 gives the final form of the orifice sizing equation:

$$A_O = \frac{88Vol^{\left(0.95/H^{0.085}\right)}}{T_D S^{0.09} H^{2.6\left(S^{0.3}\right)}} \qquad \textit{Equation 9}$$

Where:

- A_O is the required orifice area per row in square inches,
- S is slope in feet vertical / feet horizontal (substitute 0.0001 for zero),
- Vol is the storage volume in acre-feet,
- T_D is the prescribed drain time in hours, and
- H is the storage depth at the outlet above the lowest orifice, in feet.

For a storage volume with a flat bottom (e.g. retention pond or constructed wetland pond), this equation can be simplified to:

$$A_O = \frac{201Vol^{\left(0.95/H^{0.085}\right)}}{T_D H^{0.164}} \qquad \textit{Equation 10}$$

Example 1: A full spectrum detention basin is designed to drain a runoff volume of 0.25 acre-feet of stormwater in 72 hours. The design depth of the storage volume is 3 feet and the basin has a trickle channel slope of 1%. Find the total orifice area for each row of orifices in the orifice plate.

Analysis: The orifice plate will have orifices at 0, 4, 8, 12, 16, 20, 24, 28, and 32 inches from the bottom of the storage volume. The values for *a*, *b*, *c* and *d* are:

$$a = 1.22(0.01^{-0.09}) = 1.85$$

$$b = 2.6(0.01^{0.3}) = 0.65$$

$$c = 0.95$$

$$d = 0.085$$

Substituting these values into Equation 3 gives:

$$A_O = \frac{72a\left[Vol^{\left(c/H^d\right)}\right]}{T_D\left(H^b\right)} = \frac{72(1.85)\left(0.25^{\left(0.95/3^{0.085}\right)}\right)}{72(3^{0.65})} = 0.27 \text{ inch}^2$$

Solution: Each of the nine orifices must have an area of 0.27 inch^2, or a diameter of 0.6 inch (5/8”).

Example 2: A water quality retention pond is designed to drain the volume from the previous example in 12 hours. This volume has the same depth as the previous example and is stored above the permanent pool. Find the correct orifice area for each orifice in the orifice plate vertical column.

Analysis: The bottom of the surcharge volume is the permanent pool water surface which has a slope of zero toward the outlet. A zero slope will result in A_O being undefined. Through modeling, we know that substituting a slope of 0.0001 will produce acceptable drain time results. The values for coefficients *a*, *b*, *c* and *d* are:

$$a = 1.22(0.0001^{-0.09}) = 2.8$$

$$b = 2.6(0.0001^{0.3}) = 0.1633$$

$$c = 0.95$$

$$d = 0.085$$

Substituting these values into Equation 3 gives:

$$A_O = \frac{72a\left[Vol^{\left(c/H^d\right)}\right]}{T_D\left(H^b\right)} = \frac{72(2.8)\left(0.25^{\left(0.95/3^{0.085}\right)}\right)}{12\left(3^{0.1633}\right)} = 4.2 \text{ inch}^2$$

Solution: Each of the nine orifices must have an area of 4.2 inch^2, or 2” high rectangular orifices having a width of 2.1 inch.