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TECHNICAL MEMORANDUM

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SUBJECT: Storm Inflow Hydrograph Shaping for Detention Design

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The purpose of this memorandum is to document the development of the storm hydrograph shaping method built into the UD-Detention workbook. When the UD-Detention workbook was first developed to calculate full spectrum detention sizing needs and outflow configuration requirements, the workbook included an embedded library of 16,000 storm hydrographs of incrementally-increasing runoff volumes from 28 cubic feet (0.0006 acre-feet) to 665 acre-feet.

The CUHP output is a synthetic storm hydrograph, where the runoff volume is sensitive to watershed area, soil type, and imperviousness. The runoff volume is not sensitive to watershed slope or to watershed shape (characterized the ratio of length-to-area and expressed as $L^2/A$). The shape of the storm hydrograph is primarily a function of the watershed slope and watershed shape, with long, flat watersheds producing long, drawn-out storm hydrographs with lower flow rates at each time step and short, steep watersheds producing short, “flashy” storm hydrographs with higher flow rates at each time step.

The storm hydrographs for the UD-Detention workbook were created using CUHP v2.0.0 for watersheds that held the slope constant at 2% and the $L^2$/Area ratio constant at 2:1. A standard two-hour temporal distribution was applied to the NOAA Atlas 14 one-hour rainfall input in accordance with standard CUHP protocol. It was initially thought that for the purposes of detention sizing this would be adequate. Further testing of these standard inflow hydrographs compared to hydrographs created in CUHP for watersheds with slopes and shape factors ($L^2/A$ ratio) that differed from the default values indicated that an effort to shape the hydrograph for the watershed is appropriate.

For the analysis, watersheds with the following parameters were evaluated:

- Watershed area = 20, 40, 80, 160, 320, 640, and 2,000 acres.
- Watershed shape factor ($L^2/A$ ratio) = 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5 and 6.0
- Watershed slope = 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, 3.0%, 3.5% and 4.0%
- Watershed imperviousness = 50%
- Watershed depression storage and infiltration characteristics used were the default values for Type C/D soils from the CUHP user manual.

The peak flow rate from each of the watersheds was compared to that of its default counterpart, that is the watershed having a slope of 2% and a shape factor of 2. For each of the seven watershed areas and eight slopes, the ratio of peak flow rate to default peak flow rate was plotted vs. the shape factor as shown in Figure 1.

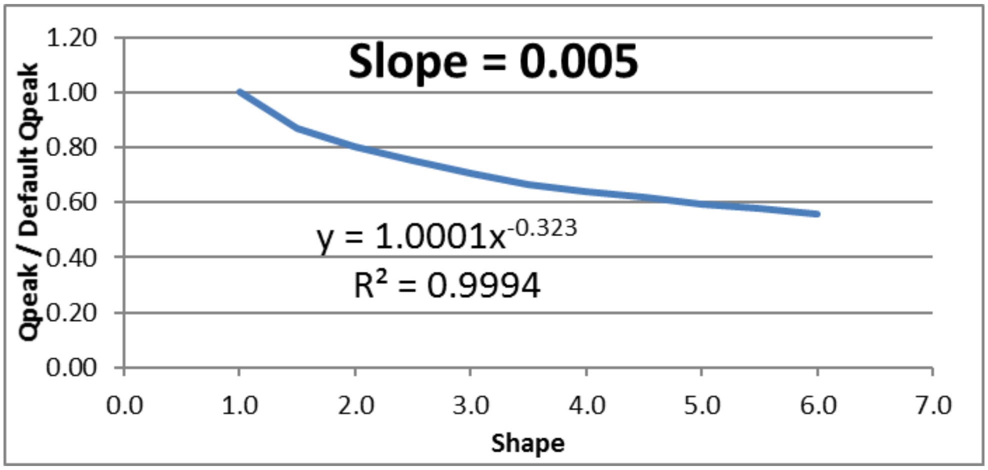


*Figure 1: Ratio of peak flow rate to default peak flow rate vs. watershed shape factor. This analysis was repeated for each of the 8 slopes and for each of the 7 watershed areas.*

For each of the 56 combinations of area and slope, a trend line that closely matched the data was found in the form of a power function as shown in Equation 1. All 56 power equations had an $R^2$ fit greater than 0.99.

$$\frac{Q_{Peak}}{Q_{DefaultPeak}} = \alpha * Shape^{\beta} \qquad \text{Equation 1}$$

Next, for each of the seven watershed areas, the constant (α) and exponent (β) values were plotted against slope and new trendlines were fit to the data points as shown in Figure 2 (values shown in Figure are for 20-acre watershed).

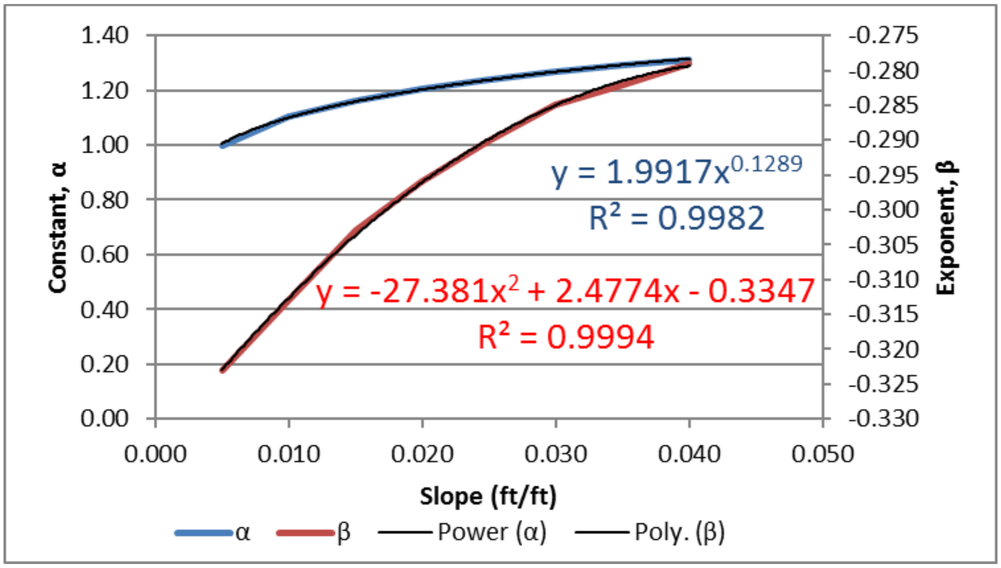


*Figure 2: Constant (α) and Exponent (β) vs. watershed slope for area of 20 acres. This analysis was repeated for each of the 7 watershed areas.*

A power function was fit to the constants (α) as shown in Equation 2. A second order polynomial was fit the exponents (β) as shown in Equation 3.

$$\alpha = x * Slope^{y} \qquad \text{Equation 2}$$

$$\beta = a * Slope^{2} + b * Slope + c \qquad \text{Equation 3}$$

Combining equations 1 through 3 results in a single equation to calculate the ratio of peak flow rate to default peak flow rate as shown in Equation 4. A separate equation 4 was developed for each of the seven watershed areas evaluated. The resulting equations produced peak flows that were within +/- 2.5% of the peak flows produced by CUHP.

$$\frac{Q_{Peak}}{Q_{DefaultPeak}} = (x * Slope^{y}) * Shape^{(a*Slope^{2}+b*Slope+c)} \qquad \text{Equation 4}$$

In order to generate a single equation to represent all watershed areas, Excel's Solver was used to generate a single set of coefficients (x, y, a, b, and c) for Equation 4 by minimizing the sum of squared errors between CUHP peak flows and the equation peak flows. The coefficients were constrained to ensure that equation results at the default condition (shape = 2.0 and slope = 0.02) were identical to the CUHP results. The resulting coefficients are shown in Equation 5. The final equation produces peak flows that are on average within 0.6% of the peak flows produced by CUHP (+6.6% and -2.6%).

$$\frac{Q_{Peak}}{Q_{DefaultPeak}} = (2.183\ Slope^{0.145}) * Shape^{(-34.524\ Slope^{2}+2.07\ Slope-0.336)} \qquad \text{Equation 5}$$

**<u>Example Problem:</u>** A 50-acre Denver watershed is found to have the following characteristics: 50% impervious, HSG C/D soils (default infiltration parameters), 4% slope and a length of 2,950 feet. The 100-year one-hour rainfall depth is 2.31 inches.

Determine the ratio of peak flow to default peak flow for the given watershed.

Analysis:

$$Shape = \frac{L^2}{A} = \frac{(2{,}950\ ft)^2}{50\ ac * 43{,}560} = 4.0$$

$$\frac{Q_{Peak}}{Q_{DefaultPeak}} = (2.183\ (0.04)^{0.145}) * 4.0^{(-34.524\ (0.04)^2 + 2.07\ (0.04) - 0.336)}$$

$$\frac{Q_{Peak}}{Q_{DefaultPeak}} = 1.369 * 4.0^{-0.308} = \mathbf{0.893}$$

The actual peak discharge calculated by CUHP for the given watershed described above is 109.3 cfs. UD-Detention calculates a peak discharge of 122.9 cfs using the default slope (2%) and shape factor (2.0). It then multiplies the calculated peak flow by the ratio determined above which results in an adjusted peak flow of 109.7 cfs. The calculated peak flow in UD-Detention is within 0.4% of the actual CUHP peak flow.