URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

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TECHNICAL MEMORANDUM

FROM: Ken MacKenzie and Ryan Taylor

SUBJECT: Determination of watershed historic peak flow rates as the basis for detention basin design

DATE: June 7, 2012

The purpose of this memorandum is to document the development of the 2012 revision to the historic peak unit flow rates (hereinafter referred to as "historic q", in cfs per acre) and associated equations used as a basis for the allowable peak unit discharges from detention basins for flood control; and particularly for full spectrum detention basins (those basins sized to detain the excess urban runoff volume (EURV) as well as the 100-year volume).

All of the equations developed in this memorandum were based on CUHP modeling and one-hour rainfall depths from Figures RA-1 through RA-12 of the *Urban Storm Drainage Criteria Manual Rainfall Chapter* (USDCM 2001), and are valid only for one-hour rainfall depths of 0.94 – 2.72 inches.

The Colorado Urban Hydrograph Procedure (CUHP 2005, v1.3.3) was used to evaluate 570 subcatchments from recent UDFCD master planning studies. Subcatchments having a width/length ratio, slope, or size outside one standard deviation of the mean of the initial data set were discarded in order to limit data scatter, leaving a data set of 293 subcatchments for further evaluation.

The one-hour rainfall depth corresponding to probability of occurrence for the Denver region can be approximated by those values in Table 1, also shown graphically in Figure 1.

Table 1: Average one-hour rainfall depth in the Denver region, as a function of probability of occurrence.

Recurrence Interval (Years)	Probability of Occurrence	Rainfall Depth (Inch)
WQCV	N/A	0.53
2	0.50	0.95
EURV	0.38	1.07
5	0.20	1.34
10	0.10	1.64
25	0.04	2.02
50	0.02	2.32
100	0.01	2.61

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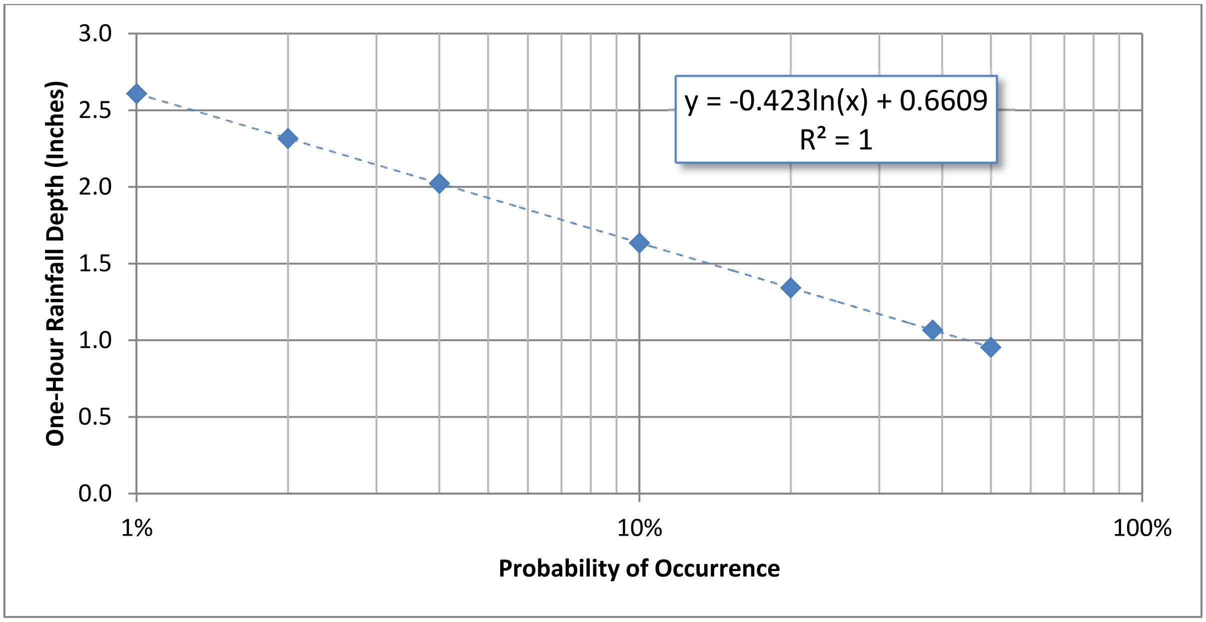

Figure 1: Natural log plot of one-hour rainfall depth vs. probability of occurrence for the Denver region.

These one-hour rainfall depths were temporally distributed over a two-hour period to create design storms consistent with CUHP protocol, and the CUHP model was run for all 293 subcatchments and return periods consisting of the 2-, 5-, 10-, 25-, 50-, and 100-year, with the hydrologic parameters listed in Table 2. Watershed characteristics (e.g., size, shape, slope, location of centroid) were taken directly from the master planning studies. The results of the CUHP modeling are shown in Figures 2 through 4.

Table 2: hydrologic parameters used in the CUHP modeling.

Soil Group	Historic Impervious Percentage	Pervious Depression Storage (inch)	Impervious Depression Storage (inch)	Initial Infiltration Rate (in/hr)	Horton's Decay Coefficient ($second^{-1}$)	Final Infiltration Rate (in/hr)
HSG A	2	0.35	0.1	5.0	0.0070	1.0
HSG B	2	0.35	0.1	4.5	0.0018	0.6
HSG C	2	0.35	0.1	3.0	0.0018	0.5

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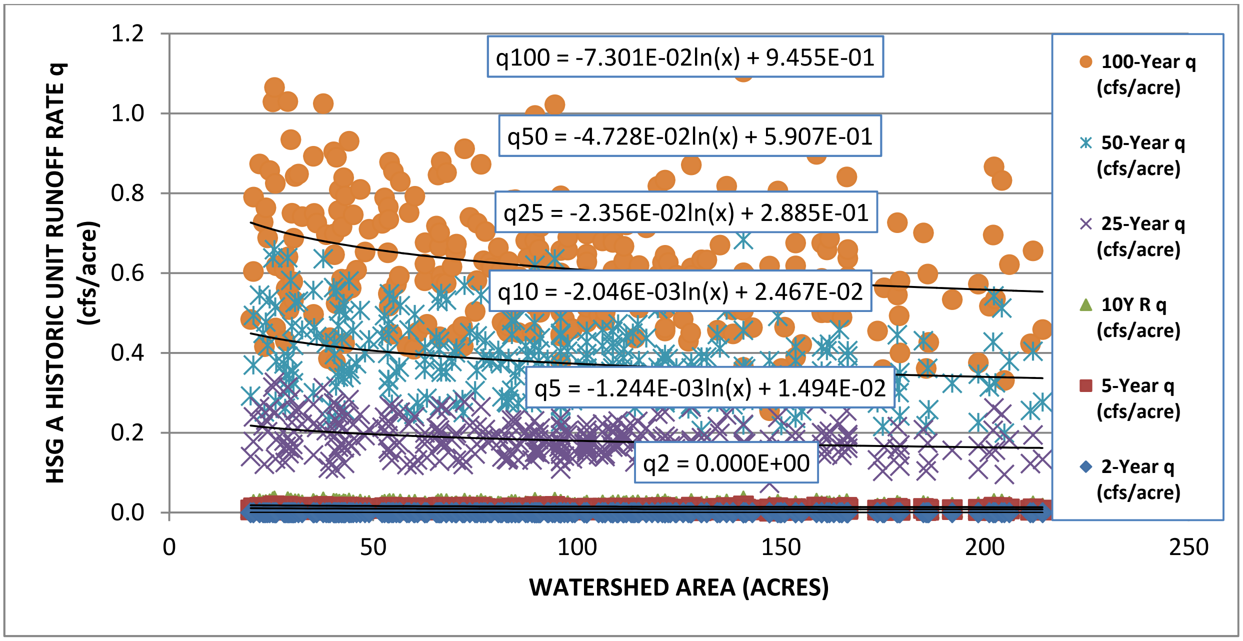

Figure 2: Natural log regression plot of historic q from CUHP modeling for Hydrologic Soil Group A.

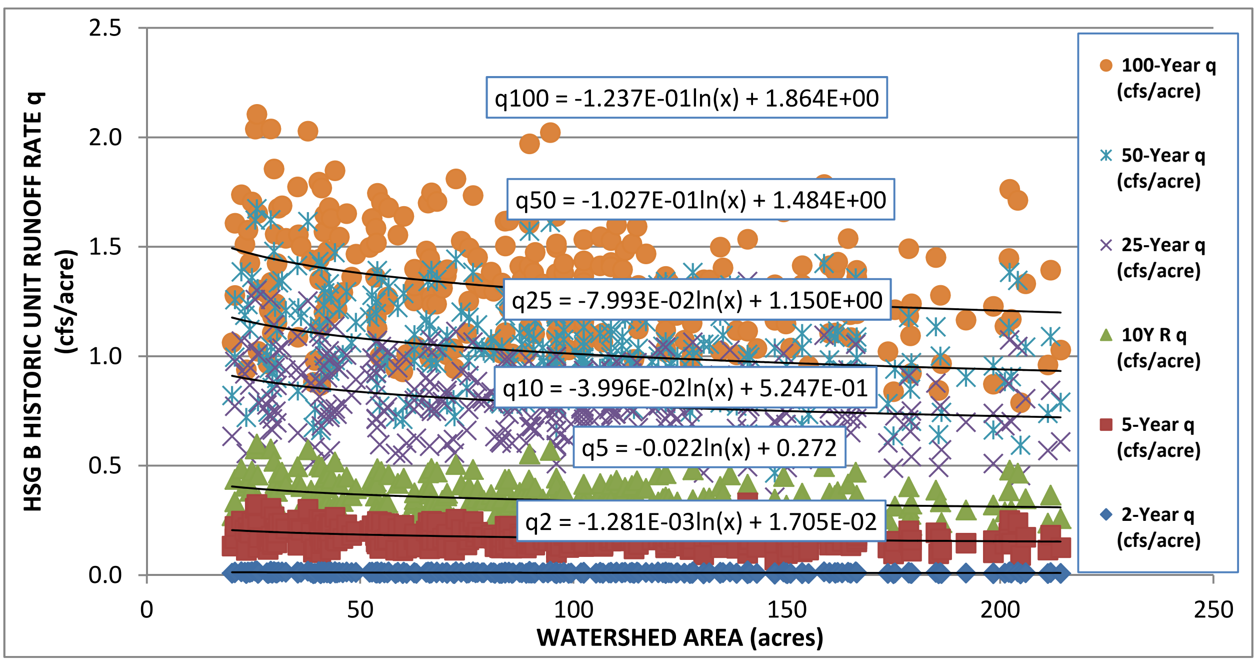

Figure 3: Natural log regression plot of historic q from CUHP modeling for Hydrologic Soil Group B.

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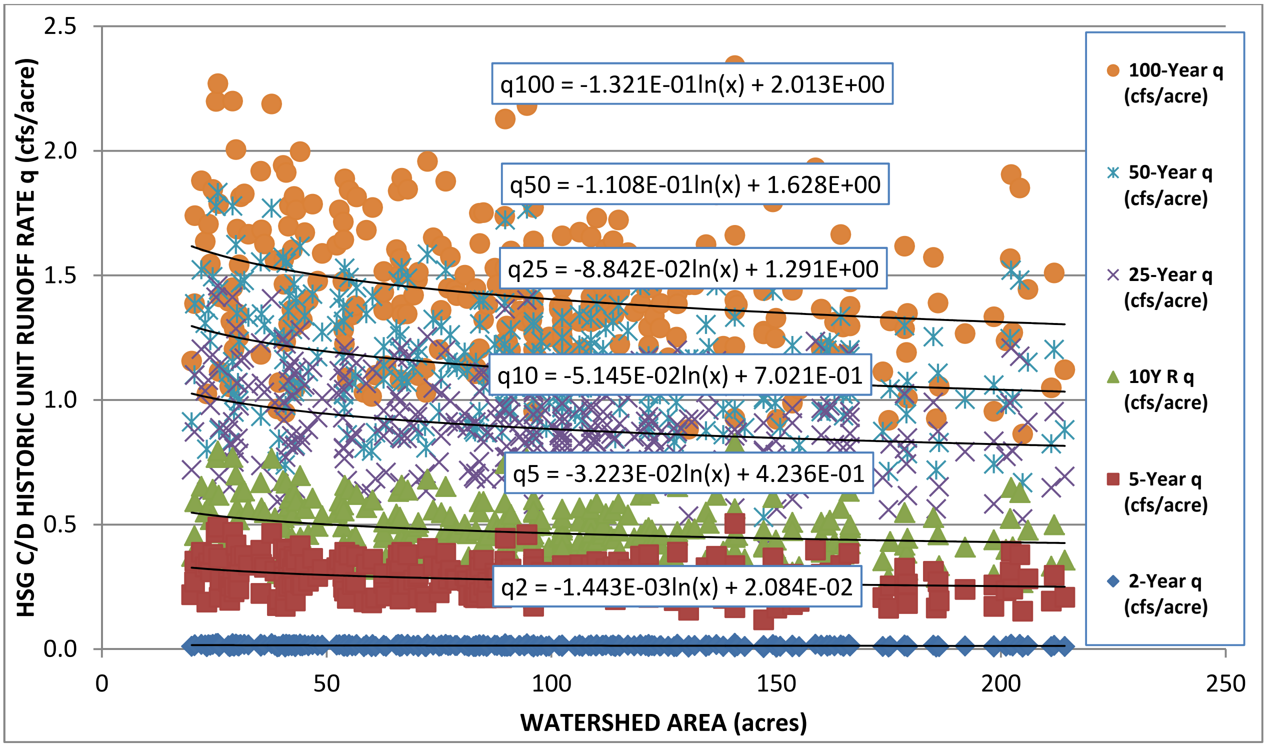

Figure 4: Natural log regression plot of historic q from CUHP modeling for Hydrologic Soil Groups C & D.

The historic peak unit runoff rates based on the equations in Figures 2 through 4 are shown graphically in Figures 5 through 7. Note that the maximum historic q for watersheds smaller than 20 acres is held at the rate corresponding to 20 acres, while the minimum historic q for watersheds larger than 2,000 acres is held at the rate corresponding to 2,000 acres. These limits are based on consideration of the limitations of the CUHP method with regard to very small and very large watersheds.

CUHP/SWMM modeling of large watersheds containing several spatially distributed full spectrum detention basins demonstrated that the cumulative effect of these spatially distributed detention basins each releasing at almost exactly the historic 100-year flow rate results in the flow rate at the downstream outlet of the watershed increasing to approximately 107% - 108% of the historic rate. The watersheds were modeled with fairly smooth (low n-value) conveyance elements to minimize the effects of channel storage. In reality, the impact of channel storage in vegetated channels is substantial, but to be conservative, it is recommended that the full spectrum detention basin be designed to have a 100-year release rate that is no greater than 90% of the historic value. This CUHP/SWMM research is documented in another technical memorandum available at www.udfcd.org.

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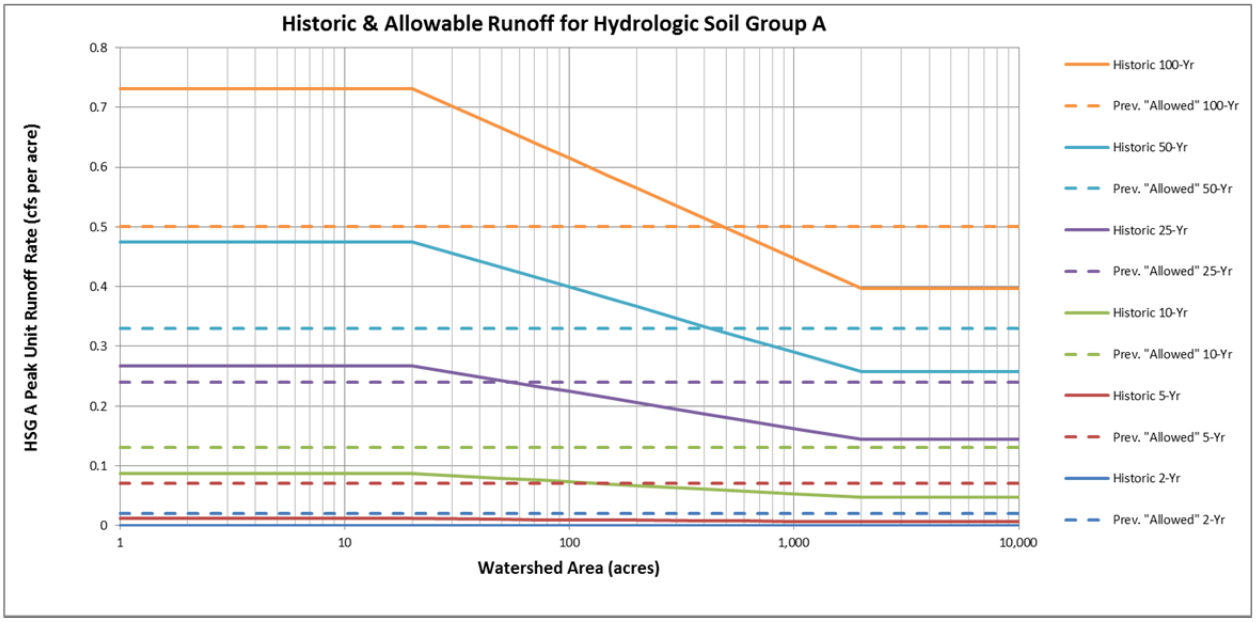

Figure 5: Historic q based on the equations in Figure 2 for Hydrologic Soil Group A and on Denver area rainfall from Table 1. Previous "Allowable q" from USDCM 2001 shown for comparison only.

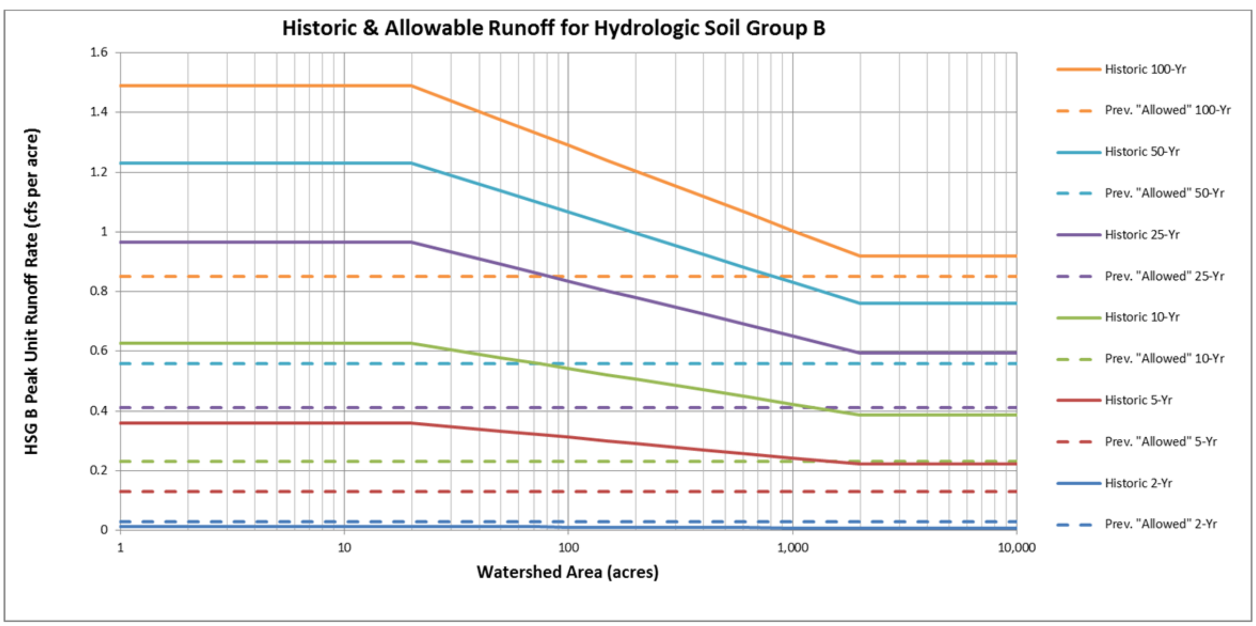

Figure 6: Historic q based on the equations in Figure 3 for Hydrologic Soil Group B and on Denver area rainfall from Table 1. Previous "Allowable q" from USDCM 2001 shown for comparison only.

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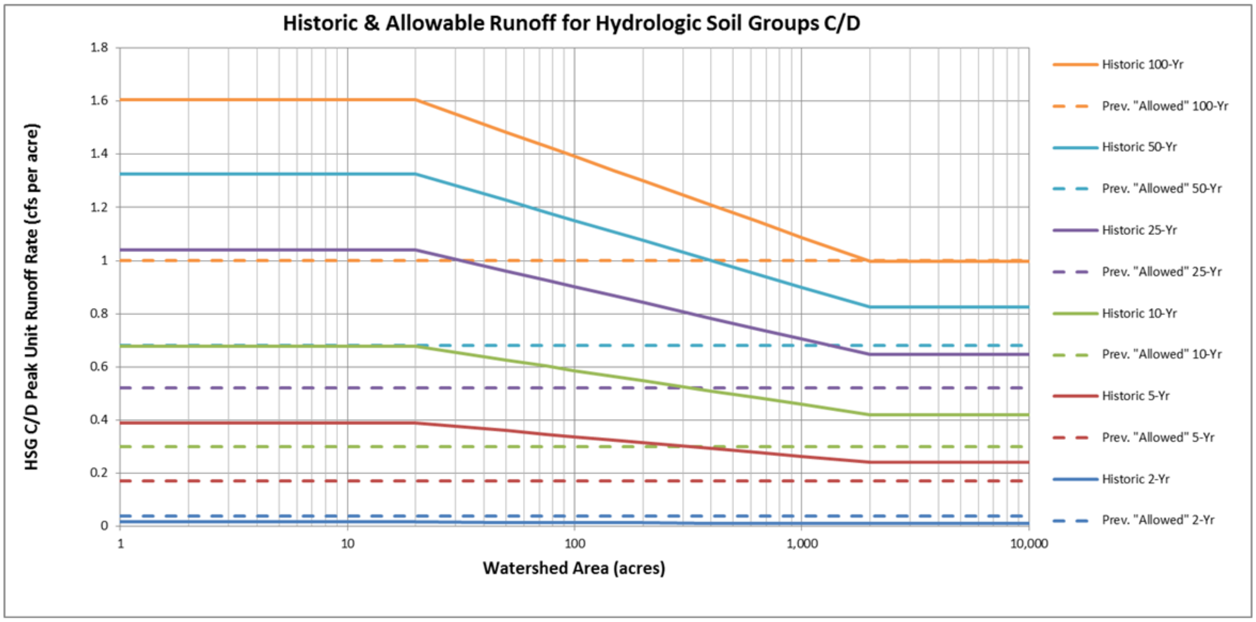

Figure 7: Historic q based on the equations in Figure 4 for Hydrologic Soil Groups C and D, and on Denver area rainfall from Table 1. Previous "Allowable q" from USDCM 2001 shown for comparison only.

Table 3 provides a complete list of historic q equations as revised by this work for hydrologic soil groups A, B, and C/D for the 2-, 5-, 10-, 25-, 50-, and 100-year return period, while Table 4 provides extreme limits imposed upon those calculated values.

Table 3: Equations to determine the peak historic q (in cfs per acre) for a given watershed area (in acres) and six return periods, based on Denver area rainfall from Table 1. Note that the values calculated by these equations must fall within the limits shown in Table 4 and Figures 5 through 7.

Return Period	Hydrologic Soil Group A	Hydrologic Soil Group B	Hydrologic Soil Groups C and D
2-Year	$q_2 = 0$	$q_2 = -0.00128 * LN(A) + 0.017$	$q_2 = -0.00144 * LN(A) + 0.021$
5-Year	$q_5 = -0.00124 * LN(A) + 0.015$	$q_5 = -0.0221 * LN(A) + 0.27$	$q_5 = -0.032 * LN(A) + 0.42$
10-Year	$q_{10} = -0.002 * LN(A) + 0.025$	$q_{10} = -0.04 * LN(A) + 0.52$	$q_{10} = -0.051 * LN(A) + 0.7$
25-Year	$q_{25} = -0.0236 * LN(A) + 0.29$	$q_{25} = -0.08 * LN(A) + 1.15$	$q_{25} = -0.088 * LN(A) + 1.29$
50-Year	$q_{50} = -0.047 * LN(A) + 0.59$	$q_{50} = -0.103 * LN(A) + 1.48$	$q_{50} = -0.11 * LN(A) + 1.63$
100-Year	$q_{100} = -0.073 * LN(A) + 0.95$	$q_{100} = -0.124 * LN(A) + 1.86$	$q_{100} = -0.132 * LN(A) + 2$

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Table 4: High and low limits imposed upon historic unit discharge rate (q, cfs per acre) for watersheds smaller than 20 acres and for watersheds larger than 2,000 acres.

	Hydrologic Soil Group A		**Hydrologic Soil Group B**		**Hydrologic Soil Groups C/D**	
Return Period	Max q (cfs/acre) for watersheds < 20 acres	Min q (cfs/acre) for watersheds > 2,000 acres	Max q (cfs/acre) for watersheds < 20 acres	Min q (cfs/acre) for watersheds > 2,000 acres	Max q (cfs/acre) for watersheds < 20 acres	Min q (cfs/acre) for watersheds > 2,000 acres
2-Year	0.00072	0.00034	0.013	0.008	0.017	0.010
5-Year	0.014	0.005	0.360	0.222	0.390	0.242
10-Year	0.091	0.046	0.627	0.386	0.677	0.420
25-Year	0.270	0.143	0.964	0.595	1.040	0.645
50-Year	0.477	0.257	1.231	0.759	1.327	0.824
100-Year	0.732	0.397	1.489	0.918	1.604	0.996

The work up to this point was based on Denver area rainfall from Table 1. In order to implement this method outside the Denver area, historic q equations based on a one-hour point precipitation value were developed. For the general form of the equation $q = \alpha LN(A)+\beta$, the coefficients α and β from Table 3 were consolidated into Table 5 in order to perform the regression analysis needed to develop the historic q equations.

Table 5: Equation coefficients taken from Table 3.
Note: Coefficient α is represented as the absolute value to avoid negative values during analysis.

Return Period	Hydrologic Soil Group A		Hydrologic Soil Group B		Hydrologic Soil Group C/D	
	α	β	α	β	α	β
2-Year	0.0001	0.001	0.00128	0.017	0.00144	0.021
5-Year	0.00124	0.015	0.0221	0.27	0.032	0.42
10-Year	0.002	0.025	0.04	0.52	0.051	0.7
25-Year	0.0236	0.29	0.08	1.15	0.088	1.29
50-Year	0.047	0.59	0.103	1.48	0.11	1.63
100-Year	0.073	0.95	0.124	1.86	0.132	2

From the regression analysis, the historic q based on one-hour point precipitation can be estimated with Equations 1 through 3.

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Hydrologic Soil Group A:

$$q_A = (-0.0307 * P^2 + 0.0655 * P - 0.0346) * LN(A) + (0.4118 * P^2 - 0.8943 * P + 0.4789) \quad (1)$$

$0.00034 \le q_A$

Hydrologic Soil Group B:

$$q_B = (-0.0739 * P + 0.069) * LN(A) + (1.1102 * P - 1.0377) \quad (2)$$

$0.008 \le q_B$

Hydrologic Soil Groups C & D:

$$q_{C/D} = (-0.0787 * P + 0.0733) * LN(A) + (1.1922 * P - 1.1116) \quad (3)$$

$0.010 \le q_{C/D}$

In which:

$q_{A,B,C/D}$ = peak unit flow rate, in cfs/acre

P = one-hour point precipitation, in inches

A = watershed area, in acres

Equations 1 through 3 will produce negative results if the one-hour point precipitation is less than 0.94 inches – the low limit shown beneath each equation represents the limit of the validity of the CUHP modeling and should therefore be substituted for the calculated results in cases where the one-hour point precipitation is less than 0.94 inches.

Figures 8 through 10 are based on a watershed area of 2.718 acres (Euler's number "*e*", for which the natural log is unity), in order to produce results independent of watershed size. These figures compare the historic q equations based on one-hour point precipitation values to the CUHP-based historic peak unit flow rate, by hydrologic soil group. The point precipitation equations tend to overestimate q for the intermediate return periods, especially the 5- through 25-year return period; this is considered acceptable and necessary in order to accurately estimate the more critical end points (i.e., the 2- and 100-year return periods) without creating unwieldy high order regression equations.

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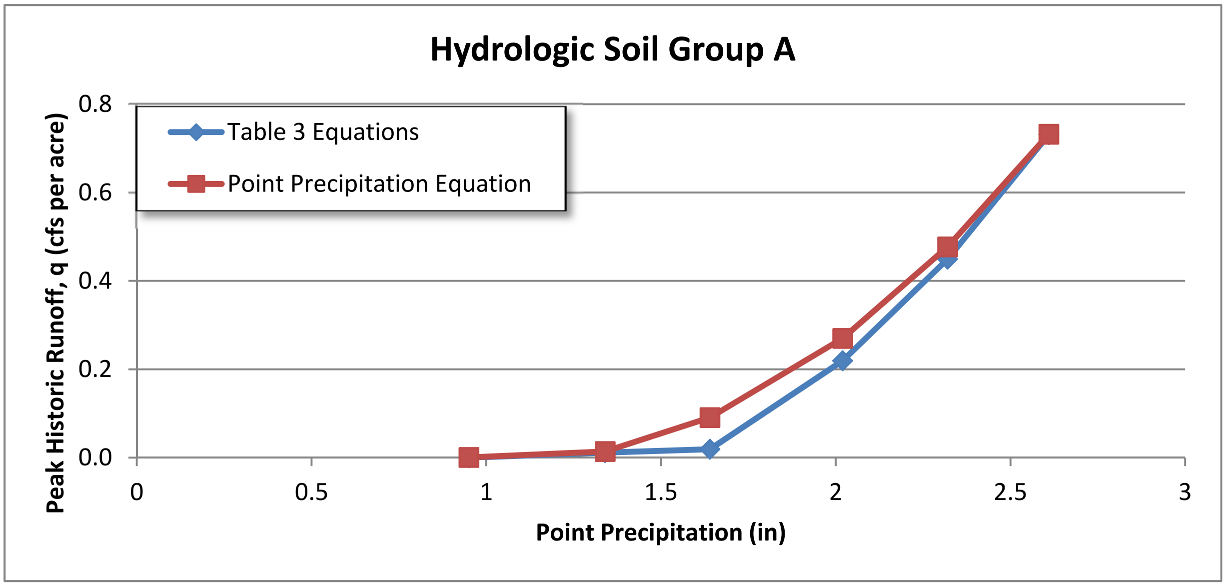

Figure 8: Comparison between CUHP results and the point precipitation equation for the Hydrologic Soil Group A

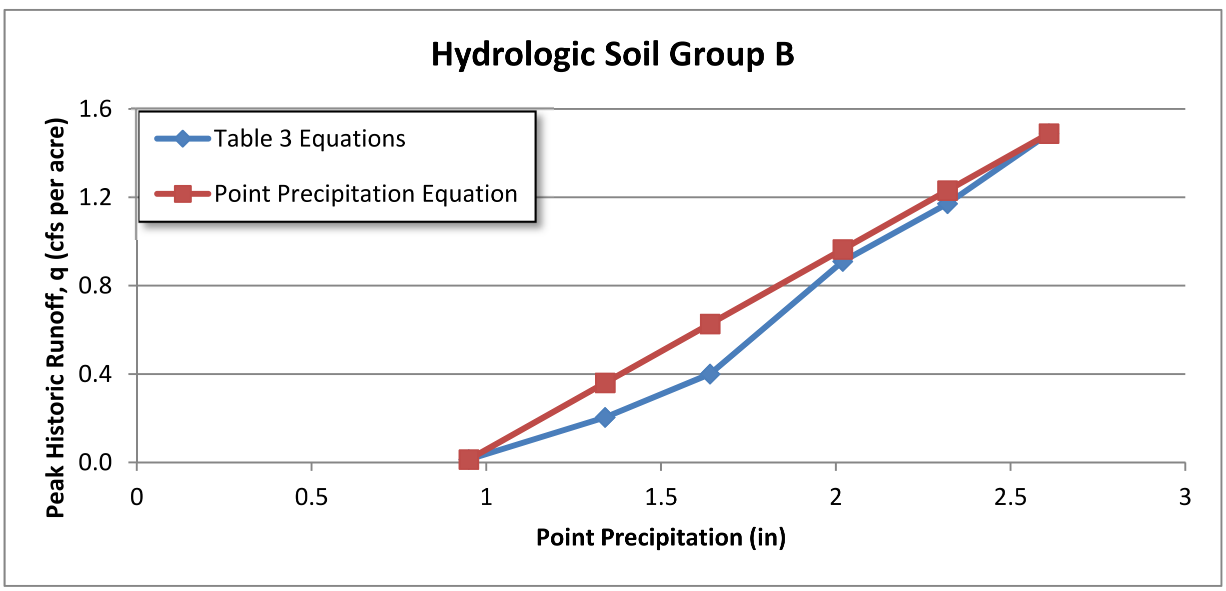

Figure 9: Comparison between CUHP results and the point precipitation equation for the Hydrologic Soil Group B

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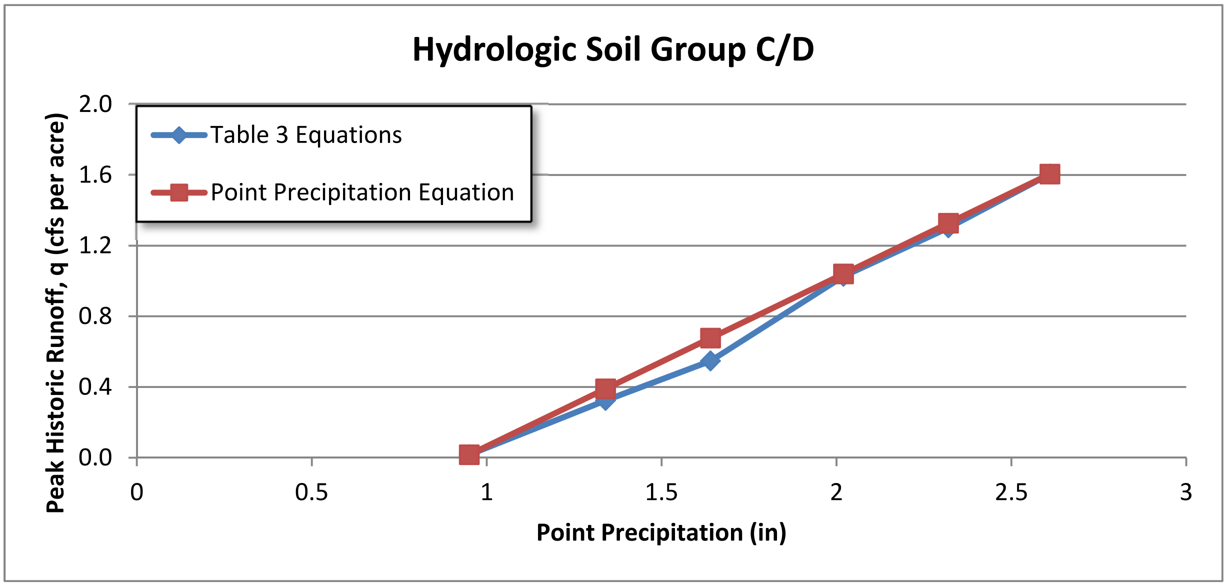

Figure 10: Comparison between CUHP results and the point precipitation equation for the Hydrologic Soil Group C/D.

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Example Problem: A 17-acre Denver area watershed is situated on 43% HSG B and 57% HSG C.

Determine:

1. The historic 100-year flow rate from this watershed using the equations from Table 3 and the point precipitation equations, and

2. The historic 100-year flow to be used as the basis for a full spectrum detention basin at the downstream end of the watershed (the detention basin release rate will be 10% less than this value).

Analysis:

1. From Table 3, the historic 100-year peak unit flow rate from this watershed is:

   $q_{100} = 0.43 * [-0.124 * LN(20) + 1.86] + 0.57 * [-0.132 * LN(20) + 2]$

   $q_{100} = 0.43 * 1.493 + 0.57 * 1.615 = 1.56$ cfs per acre.

   The total historic flow rate is Q_{100} = (1.56 cfs per acre) * 17 acres = **26.6 cfs.**

   - Note that LN(20) was used in the unit-discharge equations, even though the watershed is only 17 acres. This limits the calculated historic unit discharge rate to the maximum allowable value.

2. From the point precipitation equation, the historic 100-year unit flow rate from this watershed is:

   Hydrologic Soil Group B (Equation 2):

   $q_{100} = 0.43 * [(-0.0739 * 2.61 + 0.069) * LN(20) + (1.1102 * 2.61 – 1.0377)]$

   $q_{100} = 0.43 * [-0.371 + 1.86] = 0.64$ cfs per acre.

   Hydrologic Soil Group C (Equation 3):

   $q_{100} = 0.57 * [(-0.0787 * 2.61 + 0.0733) * LN(20) + (1.1922 * 2.61 – 1.1116)]$

   $q_{100} = 0.57 * [-0.3957 + 2] = 0.914$ cfs per acre.

   The total historic flow rate is Q_{100} = (0.64 + 0.914) * 17 acres = **26.4 cfs.**

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3. To find the historic flow rates to be used as the basis for a full spectrum detention basin at the downstream end of the watershed (the detention basin release rate will be 10% less than this value), use the values from the "Max q (cfs/acre) for watersheds ≤ 20 acres" row in Table 4:

Return Period	≤ 20 Acres HSG B	≤ 20 Acres HSG C	≤ 20 Acres Composite Unit Flow Rate (cfs per acre)	≤ 20 Acres Peak Historic Flow Rate (cfs)
2-Year	0.013	0.017	0.43 * 0.013 + 0.57 * 0.017 = 0.015	0.015 * 17 = 0.26
5-Year	0.360	0.390	0.43 * 0.360 + 0.57 * 0.390 = 0.377	0.377 * 17 = 6.05
10-Year	0.627	0.677	0.43 * 0.627 + 0.57 * 0.677 = 0.655	0.655 * 17 = 11.14
25-Year	0.964	1.040	0.43 * 0.964 + 0.57 * 1.040 = 1.007	1.007 * 17 = 17.12
50-Year	1.231	1.327	0.43 * 1.231 + 0.57 * 1.327 = 1.285	1.285 * 17 = 21.85
100-Year	1.489	1.604	0.43 * 1.489 + 0.57 * 1.604 = 1.555	1.555 * 17 = **26.44**

If the given watershed in this exercise had been larger than 20 acres, steps 1 (Denver area) or 2 (one-hour point precipitation outside Denver area) would be repeated for each return period.