URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

Ken MacKenzie, Executive Director
2480 W. 26th Avenue, Suite 156B
Denver, CO 80211-5304

Telephone 303-455-6277
Fax 303-455-7880
www.udfcd.org

TECHNICAL MEMORANDUM

FROM: Ken MacKenzie, P.E., UDFCD Master Planning Program Manager
Derek N. Rapp, P.E., CFM, Peak Stormwater Engineering

SUBJECT: Determination of Watershed Predeveloped Peak Unit Flow Rates as the Basis for Detention Basin Design

DATE: Revised December 21, 2016 (November 26, 2015)

The purpose of this memorandum is to document the development of the 2016 revision to the predeveloped (previously referred to as "historic") peak unit flow rates 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).

The predeveloped peak unit flow rate equations developed in this memorandum were based on Colorado Urban Hydrograph Procedure (CUHP 2005, v2.0.0) modeling and one-hour rainfall depths from NOAA Atlas 14 at the Capitol Building in Denver.

The equations are valid for one-hour rainfall depths between 0.83 and 3.14 inches as shown in Table 1. These one-hour rainfall depths were temporally distributed over a two-hour period to create design storms consistent with CUHP protocol for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods.

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)
2	0.50	0.83
5	0.20	1.09
10	0.10	1.33
25	0.04	1.69
50	0.02	1.99
100	0.01	2.31
500	0.002	3.14

CUHP was used to evaluate 2,020 subcatchments from recent UDFCD master planning studies. Subcatchments having a width/length ratio, slope, or centroid length outside one standard deviation of the mean of the data set were discarded in order to limit data scatter, leaving 1,203 subcatchments for further evaluation. The CUHP model was run for all 1,203 subcatchments and return periods with the hydrologic parameters listed in Table 2. Watershed characteristics (e.g., size, shape, slope, location of centroid, and imperviousness) were taken directly from the master planning studies. Various combinations of Soil Type (A, B, and C/D) were evaluated for each subcatchment.

Table 2: hydrologic parameters used in the CUHP modeling.

Soil Group	Predeveloped 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	0.0007	1.0
HSG B	2	0.35	0.1	4.5	0.0018	0.6
HSG C/D	2	0.35	0.1	3.0	0.0018	0.5

By performing regression analysis on the resultant peak unit flow rate (q) for those remaining CUHP subcatchments, it became evident that the predeveloped peak unit flow rate was primarily a function of the following three parameters:

- Watershed flow path slope
- Watershed shape factor (L^2/A)
- Watershed flow length

It was determined that of the three parameters, watershed flow length had the least effect on q and since it is indirectly accounted for in the shape factor it was omitted while performing the final analyses, leading to a general multiple regression equation in the form:

$$q = P1 * C_1(Slope^{C_2})(Shape^{C_3}) \quad (1)$$

Where *q* is the watershed peak unit flow rate for the given return period (cfs/acre),
P1 is the 1-hour precipitation depth (in) from NOAA Atlas 14,
Slope is the length-weighted average watershed flow path slope (ft/ft),
Shape is the watershed flow length^2 to area ratio (ft^2/ft^2), and
C_1, C_2, and C_3 are coefficients derived from multiple regression analyses.

These coefficients are presented in Table 3.

Due to limitations inherent to the CUHP model and confounded by the multiple regression analyses, an unknown degree of uncertainty exists. For this reason, it is recommended to apply the following limits to *Slope* and *Shape* within Equation 1:

$0.01 \leq Slope \leq 0.04$, and

$1 \leq Shape \leq 6$

Table 3: Coefficients to be used with Equation 1.

Peak Unit Discharge (cfs/acre): NRCS Hydrologic Soil Group A, Imperviousness = 2%								
Return Period →		2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Leading Coeff.	C_1	0.0014	0.0104	0.0208	0.0478	0.2652	0.5622	0.9318
Slope Exp.	C_2	0.1684	0.2065	0.2070	0.2491	0.2056	0.2021	0.1853
Shape Exp.	C_3	-0.3533	-0.4430	-0.4453	-0.4406	-0.4385	-0.4286	-0.3933

Peak Unit Discharge (cfs/acre): NRCS Hydrologic Soil Group B, Imperviousness = 2%								
Return Period →		2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Leading Coeff.	C_1	0.0285	0.0377	0.3509	0.8566	1.0437	1.2088	1.4061
Slope Exp.	C_2	0.1911	0.1855	0.2069	0.1761	0.1743	0.1677	0.1640
Shape Exp.	C_3	-0.4045	-0.3950	-0.4446	-0.3729	-0.3696	-0.3542	-0.3470

Peak Unit Discharge (cfs/acre): NRCS Hydrologic Soil Group C&D, Imperviousness = 2%								
Return Period →		2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
Leading Coeff.	C_1	0.0338	0.2418	0.5375	0.9920	1.1614	1.3053	1.4949
Slope Exp.	C_2	0.1869	0.2005	0.1901	0.1720	0.1715	0.1651	0.1623
Shape Exp.	C_3	-0.3946	-0.4280	-0.4055	-0.3641	-0.3637	-0.3490	-0.3438

Example Problem: An 18-acre watershed in the UDFCD region is found to have the following characteristics: A 100-year, 1-hour rainfall depth of 2.31 inches and a soil composition consisting of 15% HSG A, 25% HSG B, and 60% HSG C&D. The watershed flow path length is 2,320 feet and the average flow path slope is 0.8%.

Determine the allowable peak 100-year release rate for a detention basin serving this entire watershed (where the allowable Q is 90% of the predeveloped peak runoff rate).

Analysis:

The minimum recommended slope for analysis is 0.01 ft/ft so substitute that value for the given 0.008 ft/ft. *Slope* = 0.01 ft/ft.

The shape factor is $2{,}320^2$ / (18 * 43560) = 6.86. This is greater than 6 so use *Shape* = 6.

Now apply Equation 1 for each NRCS hydrologic soil group:

$$q_{HSG\ A} = 2.31 * 0.5622(0.01^{0.2021})(6^{-0.4286}) = 0.24 \text{ cfs/acre}$$

$$q_{HSG\ B} = 2.31 * 1.2088(0.01^{0.1677})(6^{-0.3542}) = 0.68 \text{ cfs/acre}$$

$$q_{HSG\ C\&D} = 2.31 * 1.3053(0.01^{0.1651})(6^{-0.3490}) = 0.75 \text{ cfs/acre}$$

$$q_{AGGREGATE} = 0.15(0.24) + 0.25(0.68) + 0.60(0.75) = 0.66 \text{ cfs/acre}$$

Solution:

For the watershed:

$Q_{predeveloped}$ = 18 acres * 0.66 cfs/acre = 11.9 cfs, and

$Q_{allowable}$ = 0.9(11.9) or 10.7 cfs