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Technical Memorandum

TO: Ken MacKenzie / Urban Drainage and Flood Control District

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SUBJECT: Analysis of Watershed-Scale Release Rates from Spatially Distributed Full-Spectrum Detention

DATE: September 5, 2012

This memorandum documents an analysis of multiple full-spectrum detention facilities to confirm the release rates necessary to reduce developed condition peak flows to levels at or below pre-development, or historic, conditions on a watershed-wide basis (the terms "pre-development" and "historic" are used interchangeably in this memo). The results of this analysis provide the basis for recommendations for new Storage Chapter criteria as part of the 2012 update.

Ten 10-acre and ten 100-acre sub-watersheds were examined for pre-development conditions (using an imperviousness of 2 percent) and developed conditions (using impervious values of 45 percent and 75 percent). Further discussion regarding the specific steps completed as part of this analysis and the specific sub-watershed parameters used is discussed below.

Historic Flow Rates

The first step in the analysis was to create two example sub-watersheds of varying size that would produce historic peak 100-year flow rates in CUHP which match the results of the equations developed in the 2010 thesis completed by Ken MacKenzie entitled *Full-Spectrum Detention for Stormwater Quality Improvement and Mitigation of the Hydrologic Impact of Development: A Regionally Calibrated Empirical Design Approach* (herein referred to as the "Full-Spectrum Thesis"). CUHP (2005, v1.3.3) was used to model a 10-acre and 100-acre sub-watershed. Table 1 summarizes the hydrologic parameters used to obtain pre-developed flowrates matching the thesis.

Table 1: CUHP Hydrologic Parameters and Resulting Pre-development Flowrate

Sub-watershed Area (Ac)	Sub-watershed Area (mi^2)	Distance to Centroid (mi)	Length (mi)	Slope (ft/ft)	Percent Imperviousness	Pervious Depression Storage (inch)	Impervious Depression Storage (inch)	Initial Infiltration Rate (in/hr)	Horton's Decay Coefficient (1/second)	Final Infiltration Rate (in/hr)	CUHP Results - 100-Year Q (cfs)
10	0.0156	0.08	0.13	0.035	2	0.35	0.1	3.0	0.0018	0.5	**20**
100	0.156	0.40	0.63	0.035	2	0.35	0.1	3.0	0.0018	0.5	**147**

Once the 100-year historic peak flow rates were determined, the second step in the analysis was to run CUHP to determine pre-development peak discharges for more frequent storm events including the 2- and 10-year events (these peak flows were generally similar to the pre-development flows calculated from equations in the Full-Spectrum Thesis, but were not adjusted to actually match the thesis values).

The next step of the analysis included expanding the CUHP models to create ten identical 10-acre and ten identical 100-acre sub-watersheds. Then two Storm Water Management Models (EPA SWMM, v5.0) were prepared that combined and routed the 10-acre and 100-acre sub-watersheds. The conveyance elements between each sub-watershed were trapezoidal channels. The parameters used for the SWMM input are summarized in Table 2.

Table 2: SWMM Routing Parameters and Resulting Historic Flowrate

Sub-Watershed Area (Ac)	Total Number of Sub-Watersheds	Properties of Conduit Between Sub-Watersheds (Trapezoidal Channel)					CUHP Results – 100-Year Q (cfs)
		Bottom Width (ft)	Left and Right Sideslope	Longitudinal Slope (%)	Length (ft)	Roughness	
10	10	10	10:1	0.8%	400	0.05	**183**
100	10	25	10:1	0.4%	700	0.05	**1338**

Developed, Undetained Flow Rates

Once the historic flow rates were established, the next step was to evaluate the sub-watersheds under developed conditions. CUHP models were run for both the 10-acre and 100-acre sub-watersheds for impervious values of 45% and 75%. Other than the change in impervious values, all of the CUHP parameters provided in Table 1 remained the same for the developed, undetained conditions model. In addition to the 100-year event, more frequent storm events were also evaluated in CUHP.

Once the 45% and 75% sub-watersheds were established in CUHP, 10 identical sub-watersheds were routed in SWMM. The SWMM routing parameters summarized in Table 2 remained the same for the developed, undetained SWMM model. Table 3 summarizes the results from CUHP and SWMM for the developed, undetained sub-watersheds.

Table 3: CUHP and SWMM Output for Developed, Undetained Sub-Watersheds

Sub-Watershed Area (Ac)	Impervious Value (%)	100-Year Q for Single Sub-Watershed (cfs)	100-Year Q for 10 Routed Sub-Watersheds (cfs)
10	45	43	356
10	75	66	494
100	45	339	2764
100	75	481	3494

Developed Flow Rates with Full Spectrum Detention

After the historic and developed (undetained) flow rates for the sub-watersheds were determined, the final step was to incorporate full spectrum detention basins into each sub-watershed. The goal of this exercise was to determine the cumulative effect at the downstream end of the watershed from releasing the historic 100-year flow rate through 10 sub-watersheds containing full spectrum detention basins.

In order to model full spectrum detention in SWMM with geometries that mimic "real world" scenarios, Muller based the stage storage curves on actual full spectrum detention basins that had undergone a detailed design and had been constructed (herein referred to as baseline detention). A ratio of the EURV storage requirements between the baseline detention and the detention modeled for this analysis was generated. This ratio was then used to create a stage-storage relationship for the detention basins analyzed in this study. Several iterations were necessary in order to identify the appropriate pond geometry and outlet structure that resulted in the desired release rates.

The scenario with ten 100-acre sub-watersheds and 45% imperviousness was analyzed with a variety of outlet structure configurations and release rates. This was done in order to trace the effects that altering these parameters has at the downstream end of the 10 sub-watersheds. Table 4 summarizes the multiple scenarios analyzed and the SWMM results.

Table 4: Summary of Parameters and Output for Full-Spectrum Detention Basins Modeled for Ten 100-Acre Watershed Scenario at I=45%

	Condition 1 Peak Q_{100} Controlled by Outlet Pipe with Orifice Plate	**Condition 2** Peak Q_{100} Controlled by Outlet Box Weir	**Condition 3** Peak Q_{100} Controlled by Outlet Pipe with Orifice Plate	**Condition 4** Peak Q_{100} Controlled by Outlet Box Weir
100-Year Peak Q at Each Sub-Watershed (cfs) **Q_{100} Historic = 147 cfs**	147 (100% of Historic)	147 (100% of Historic)	132 (90% of Historic)	100 (1 cfs per acre/ 68% of Historic)
100-Year Q Downstream of 10 Sub-Watersheds (cfs) **Q_{100} Historic = 1338 cfs**	1417 (106% of Historic)	1318 (99% of Historic)	1294 (97% of Historic)	898 (67% of Historic)
100-yr Pond Volume (AF)	9.5	10.2	10.0	12.2

Figures 1-4 below provide graphical representation of the data presented in Tables 2, 3 and 4 and include the 2 and 10 year storm events.

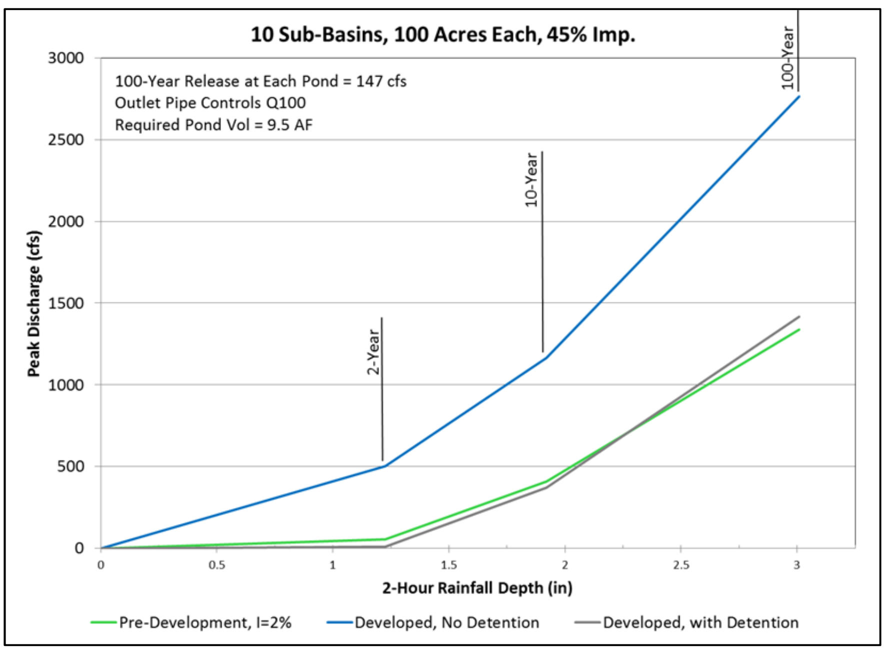

*Figure 1: Peak Discharge Plot for **Condition 1**. Ten 100-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Pipe.*

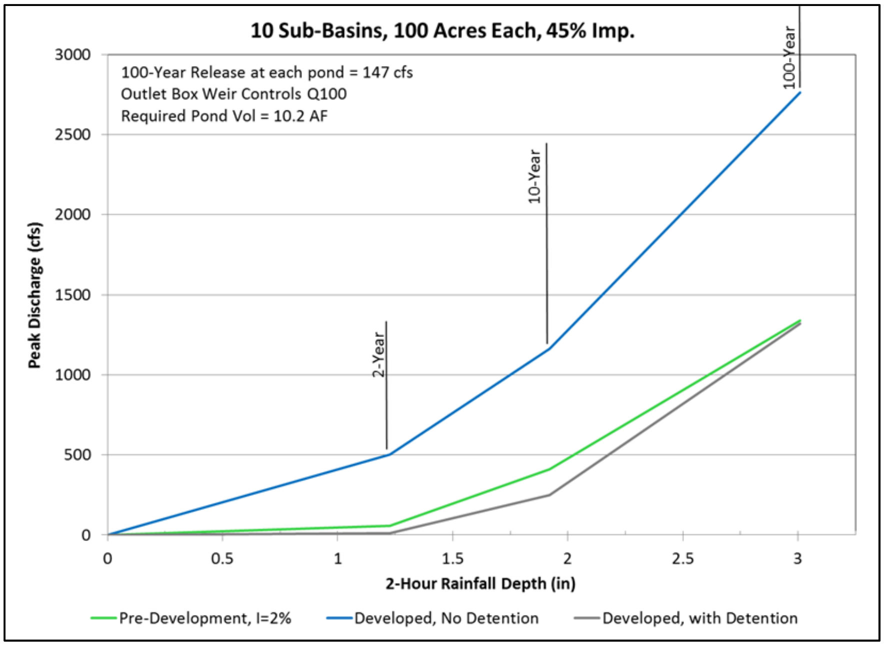

*Figure 2: Peak Discharge Plot for **Condition 2**. Ten 100-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Box Weir*

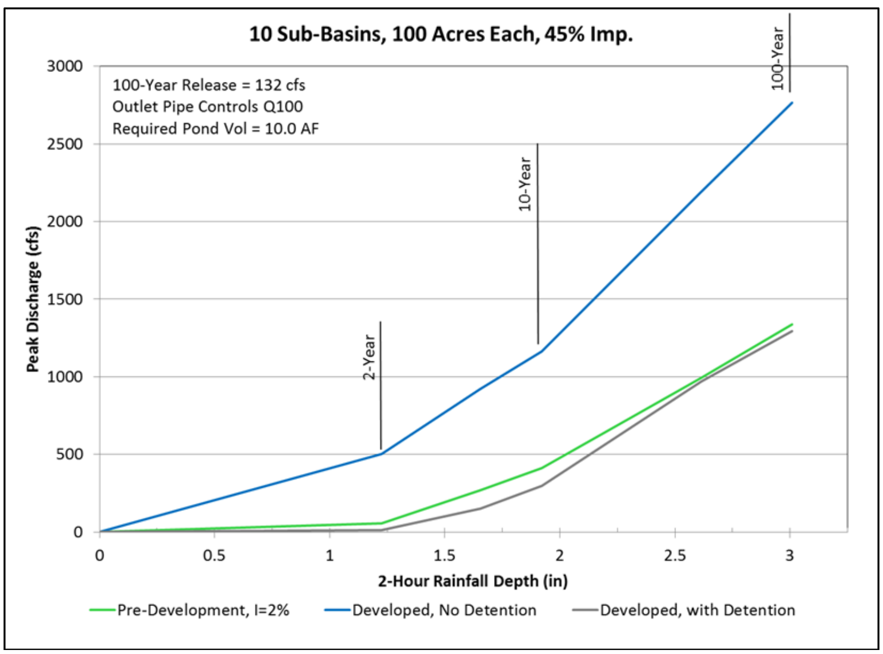

*Figure 3: Peak Discharge Plot for **Condition 3**. Ten 100-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Pipe*

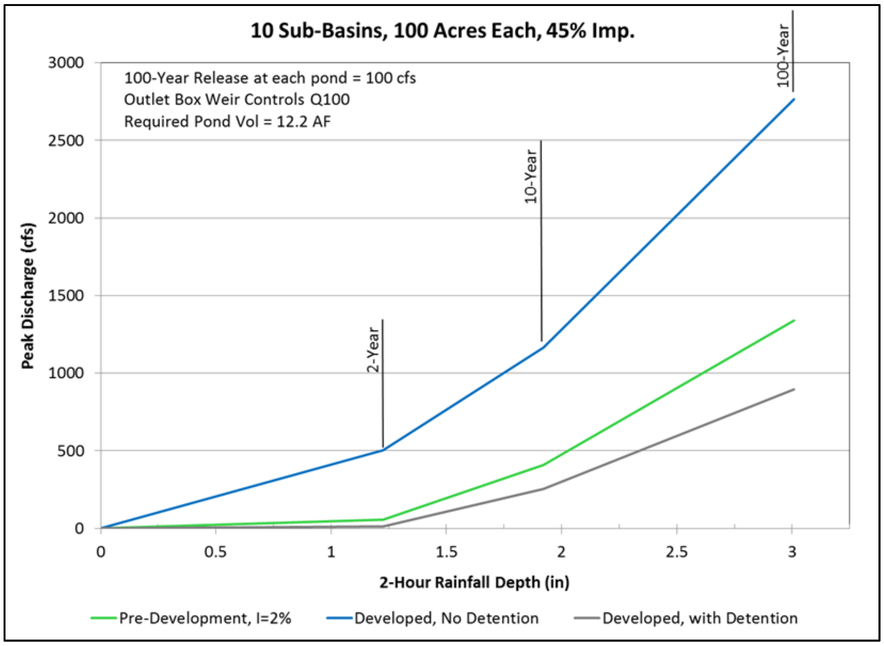

Figure 4: Peak Discharge Plot for ***Condition 4****. Ten 100-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Box Weir.*

In addition to the SWMM model of ten 100-acre sub-watersheds at 45% imperviousness with full spectrum detention, ten 100-acre sub-watersheds at 75% were also modeled. These sub-watersheds were modeled with the 100-year peak flow rate from each pond controlled by the outlet box weir and matching the historic 100-year release rate. Figure 5 below summarizes the results of modeling the ten sub-watersheds. The historic flow rates for this alternative match those presented in Table 4 above. The required pond volume to reduce the 75% sub-watershed to the historic runoff rate is 12.5 acre-feet.

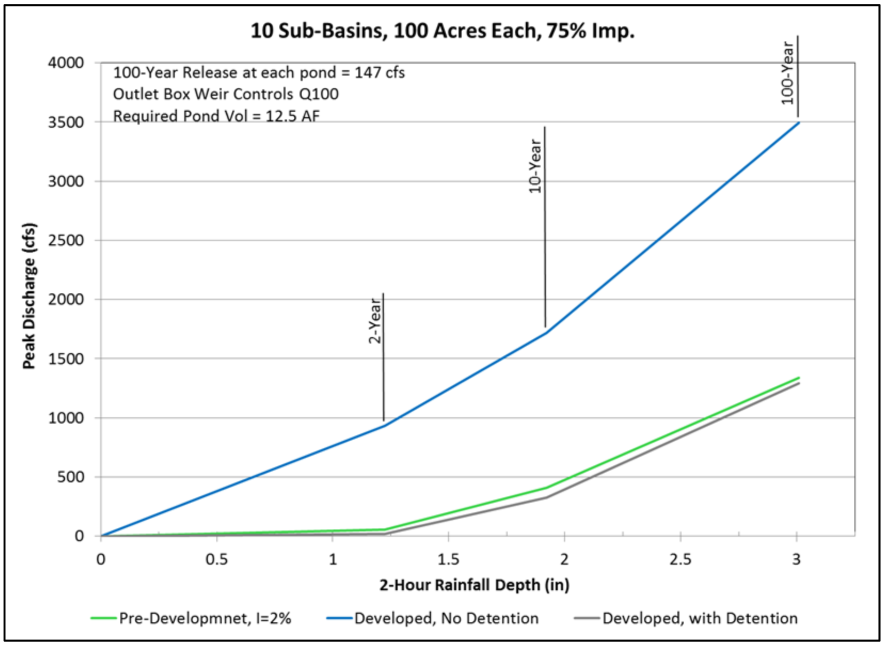

Figure 5: Peak Discharge Plot for Ten 100-Acre Sub-Watersheds with I=75%, Peak Q_{100} Controlled by Outlet Box Weir.

After completing the modeling of various 100-acre sub-watersheds, the evaluation was repeated for 10-acre sub-watersheds. The 10-acre sub-watersheds were evaluated by determining developed condition runoff rates for impervious values of 45% and 75% and routing the runoff through full spectrum detention in SWMM to determine the cumulative effect at the downstream end of the watershed. Table 5 summarizes the results from the 10-acre sub-watersheds for I=45% and 75%.

Table 5: Summary of Output for Full-Spectrum Detention Modeled for 10-10 Ac Watershed Scenario

	Condition 5 **I = 45%, Peak Q_{100} Controlled by Outlet Box Weir**	**Condition 6** **I = 75%, Peak Q_{100} Controlled by Outlet Box Weir**
100-Year Peak Q at Each Sub-Watershed (cfs) **Q_{100} Historic = 20 cfs**	20 (100% of Historic)	20 (100% of Historic)
100-Year Q Downstream of 10 Sub-Watersheds (cfs) **Q_{100} Historic = 183 cfs**	184 (101% of Historic)	180 (98% of Historic)
100-yr Pond Volume (AF)	0.9	1.4

Figures 6-7 below provide graphical representation of the data presented in Tables 2, 3 and 5 including the 2 and 10 year storm events.

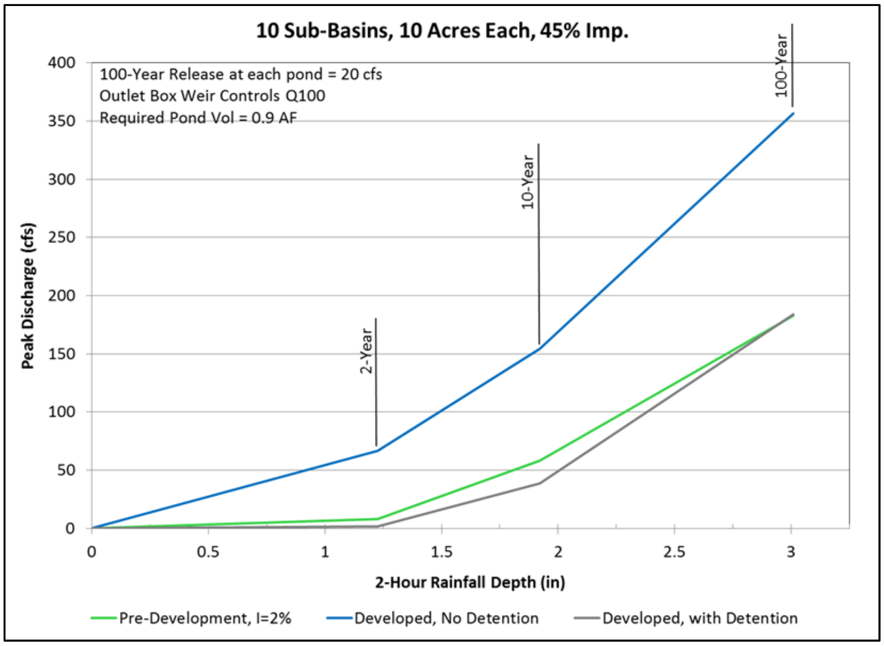

Figure 6: Peak Discharge Plot for ***Condition 5****. Ten 10-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Box Weir*

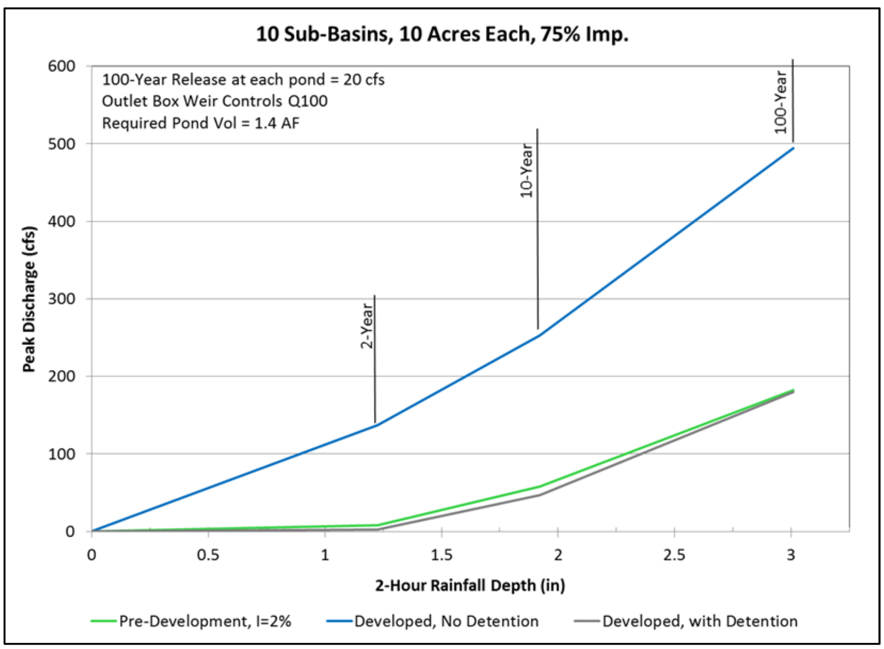

Figure 7: Peak Discharge Plot for ***Condition 6****. Ten 10-Acre Sub-Watersheds with I=75%, Peak Q_{100} Controlled by Outlet Box Weir*

Evaluation of Additional Storm Events for Conditions 2 and 3

An additional step in the evaluation of the full spectrum detention for the ten 100-acre watershed was to model additional storm events to verify that the developed sub-watersheds with full spectrum detention maintain a peak discharge at or below pre-development conditions for the "full spectrum" of storm events. This evaluation was completed for Condition 2 and Condition 3 of the 45% impervious sub-watershed scenarios. Table 6 summarizes the results of the storm events evaluated. Figures 8 and 9 present the data in Table 6 in graphical form. Refer to Table 4 for additional information (including required pond volume) for Conditions 2 and 3.

Table 6: Summary of Peak Flowrates for Pre-Developed, Developed, and Developed with Full-Spectrum Detention for Multiple Storm Events

	Peak Q_{100} from 1-100 Ac Sub-Watershed (cfs)	**Peak Q from Ten 100-Acre Watershed (cfs)**				
		2-year	**5-year**	**10-year**	**50-year**	**100-year**
Pre-Development Peak Q (I=2%)	147	56	270	411	994	1338
Developed without Detention (I=45%)	339	504	922	1164	2193	2764
Condition 2 Developed with Full Spectrum Detention (I=45%), Outlet Box Weir Controls Q_{100}	147	11	121	250	862	1318
Condition 3 Developed with Full Spectrum Detention (I=45%), Outlet Pipe Controls Q_{100}	132	11	151	297	970	1294

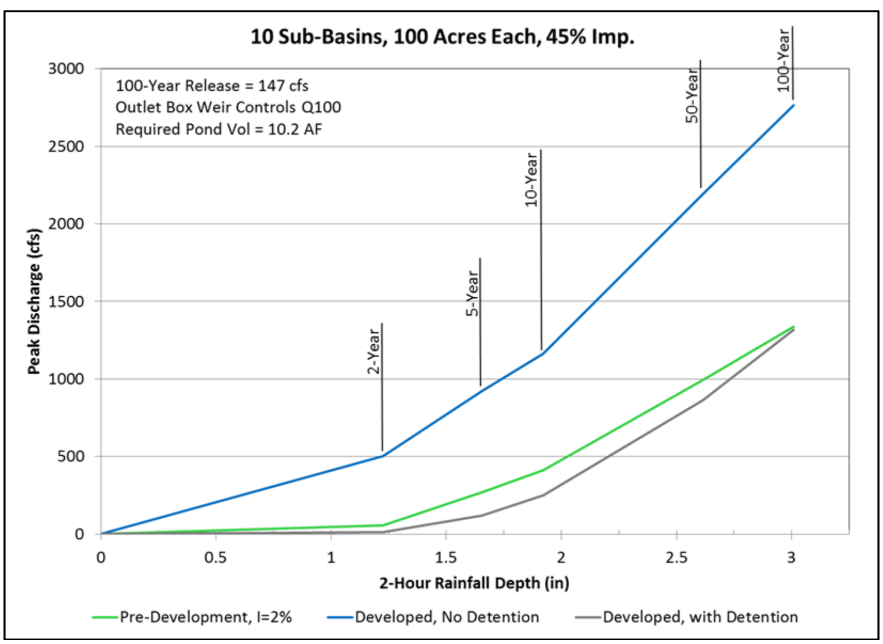

*Figure 8: Peak Discharge Plot for **Condition 2**. Ten 100-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Box Weir*

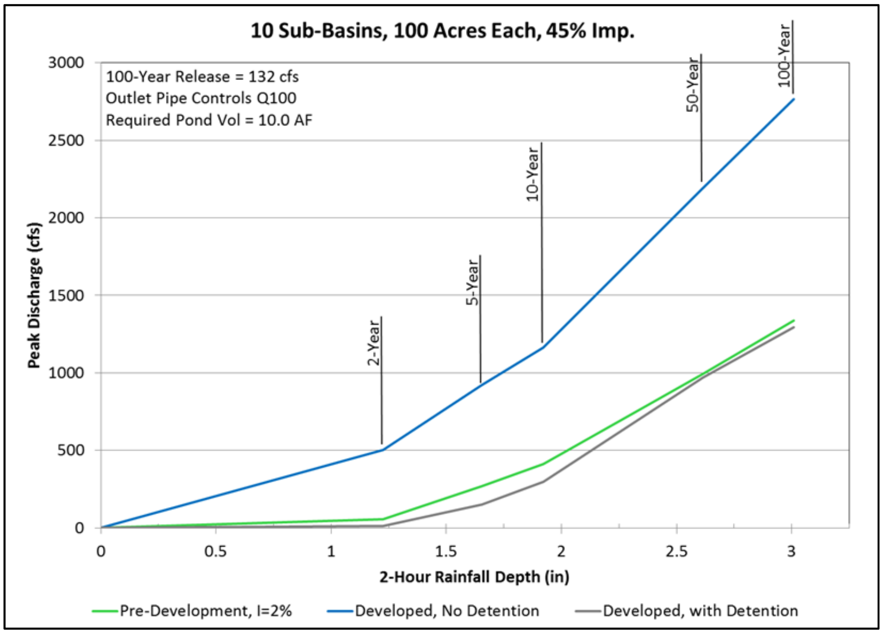

*Figure 9: Peak Discharge Plot for **Condition 3**. Ten 100-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Pipe*

Proposed New Release Rate Criteria

The results of the analyses described to this point in this memorandum were reviewed with UDFCD. It was concluded that of the four full-spectrum pond configurations represented by in Table 4, Condition 1 – controlling outflows with the 100-year pipe orifice – resulted in a 100-year flow rate slightly greater than historic conditions at the downstream end of the ten sub-watersheds. Condition 2 – controlling outflows with the weir of the drop box – did keep the 100-year peak flow at or below historic at the downstream end of the watershed; however, using the weir to control flows is less desirable due to the likelihood that debris accumulation could affect the release rate. Condition 3 – controlling outflows at the 100-year pipe orifice to 90 percent of the historic rate at each individual full-spectrum detention basin – resulted in peak flows less than historic at the downstream end of the watershed and also resulted in a smaller required pond volume than Condition 2. Condition 4 -- controlling outflows at the 100-year pipe orifice to a rate of 1.0 cfs per acre (representing the release rates of the former criteria) -- resulted in peak flows considerably less than historic at the downstream end of the watershed and resulted in a significantly greater required detention volume.

Of the pond outflow configurations modeled, it was determined that Condition 3 provides the desired results. It was decided to further analyze proposed criteria that would control release rates to 90 percent of the historic 100-year peak discharge at individual full-spectrum detention facilities with the intent of increasing the likelihood that historic peak flows would not be exceeded on a watershed-wide basis.

On June 7, 2012 UDFCD released a Technical Memorandum entitled *Determination of Watershed Historic Peak Flow Rates for Detention Sizing* (referred to as the Historic Q Technical Memo). The memo provided a recommendation for sizing full-spectrum detention facilities for 90 percent of the historic 100-year peak discharges. The memo also provided equations for historic peak discharges; these were slightly different from the peak discharges shown in the Full Spectrum Thesis.

Modification to Historic Peak Flow Rate Determination

Using Equation 3 on page 8 of the Historic Q Technical Memo, the resulting 100-year historic peak flow rate for one 100-acre sub-watershed is 139 cfs. This flowrate is approximately 5% smaller than the historic flowrate determined using the Full Spectrum Thesis of 147 cfs.

A comparison was completed to evaluate the results from the Full-Spectrum Thesis and the Historic Q Technical Memo for a range of storm events. A CUHP model was then generated that produced a 100-year historic flowrate identical to the Historic Q Technical Memo. This model was then run for the full range of storm events to trace the results and compare them to the results from the 2 aforementioned documents. The results of this comparison are summarized in Figure 10 below.

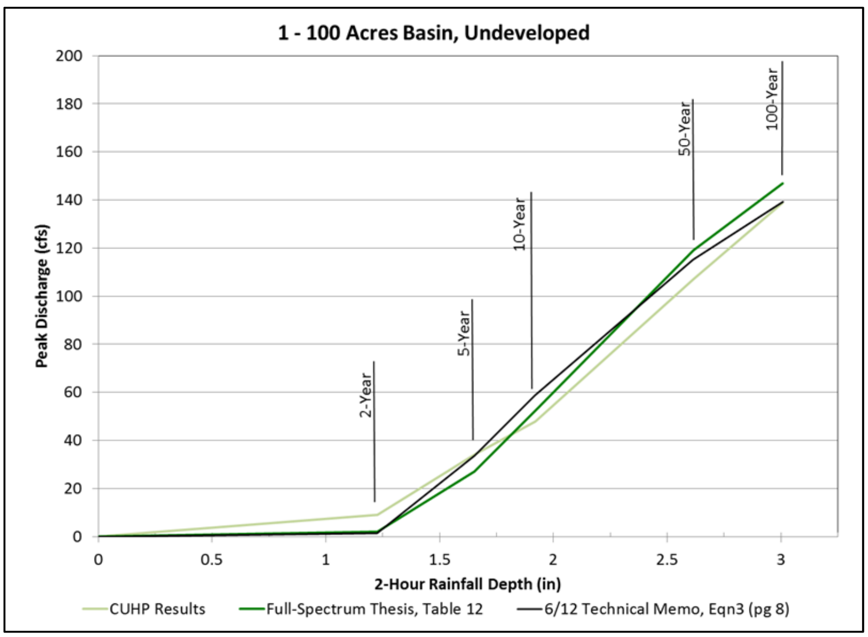

Figure 10: Comparison of Undeveloped Flowrates Resulting from the Full Spectrum Thesis, the Historic Q Technical Memorandum, and CUHP.

UDFCD determined that it would be appropriate to complete any further CUHP analyses by matching the revised 100-year historic flowrate of 139 cfs. Table 7 summarizes the CUHP parameters used to generate a 100-year historic peak flowrate that matches the results of the Historic Q Technical Memo.

Table 7: CUHP Hydrologic Parameters and Resulting Historic Flowrate (Match Historic Q Technical Memo)

Sub-Watershed Area (Ac)	Sub-Watershed Area (mi^2)	Distance to Centroid (mi)	Length (mi)	Slope (ft/ft)	Percent Imperviousness	Pervious Depression Storage (inch)	Impervious Depression Storage (inch)	Initial Infiltration Rate (in/hr)	Horton's Decay Coefficient (1/second)	Final Infiltration Rate (in/hr)	CUHP Results – 100-Year Q (cfs)
100	0.156	0.46	0.64	0.035	2	0.35	0.1	3.0	0.0018	0.5	**139**

CUHP was then run for a 100-acre sub-watershed with an imperviousness of 45%. The CUHP results were evaluated in SWMM incorporating full-spectrum detention. The properties for the conduit between sub-watersheds (trapezoidal channel) in the SWMM analysis were the same as the previous analysis, shown in Table 2.

Test of Proposed New Release Rate Criteria

The Historic Q Technical Memo recommends that all full spectrum detention basins have a 100-year release rate no greater than 90% of the historic flowrate from the basin. Taking this recommendation into consideration, the release rate for the full spectrum detention basin was reduced to 90% of historic, from 139 cfs to 125 cfs. The required pond volume to meet this 90% release rate is 10.1 acre-feet. The results of this additional analysis are summarized in Table 8 below and Figure 10 presents the data in graphical form.

Table 8: Summary of Peak Flowrates for Pre-Developed, Developed, and Developed with Full-Spectrum Detention for Modified Historic Peak Q

	Peak Q_{100} from 1-100 Ac Sub-Watershed (cfs)	Peak Q from Ten 100-Acre Watershed (cfs)				
		2-year	5-year	10-year	50-year	100-year
Pre-Development Peak Q (I=2%)	139	54	258	393	948	1277
Developed without Detention (I=45%)	325	491	895	1128	2118	2669
Developed with Full Spectrum Detention (I=45%), Outlet Pipe Controls Q_{100}	125	11	141	280	920	1231

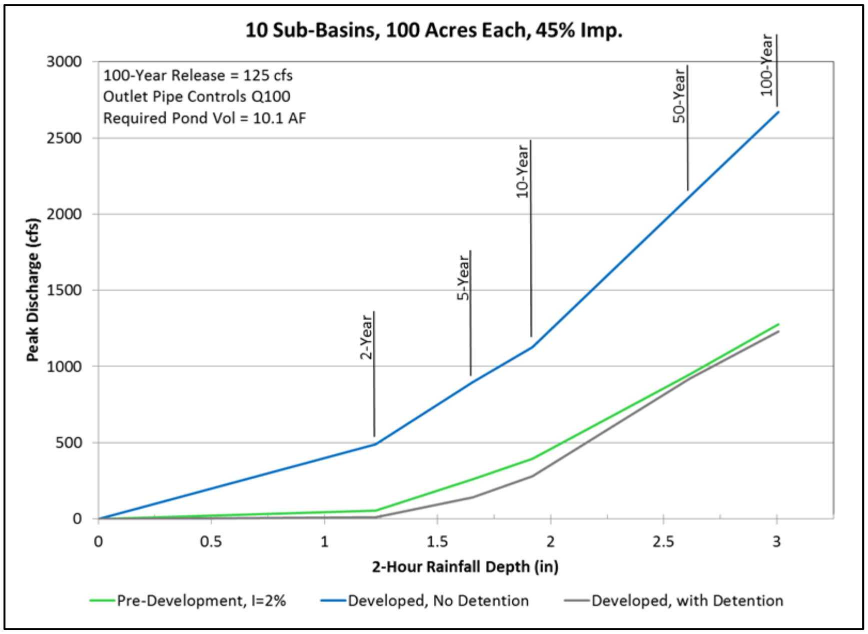

Figure 11: Peak Discharge Plot (Modified Historic Peak Q) for Ten 100-Acre Sub-Watersheds with I=45%, Peak Q_{100} Controlled by Outlet Pipe

Conclusions

The results of these analyses support the recommendation that individual full spectrum detention facilities be designed with a release rate no greater than 90% of the 100-year historic peak flowrate determined based on the equations in the Historic Q Technical Memo. The analyses show that for the sub-watersheds modeled, the cumulative effect of multiple full spectrum detention facilities result in developed condition flow rates being controlled to levels at or below historic rates for the 2- through 100-year storm events at the downstream end of the watershed.