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Full Spectrum Detention to Control Stormwater Runoff

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INTRODUCTION

Background

The effects of multiple on-site stormwater detention basins on receiving water peak flows were studied by McCuen, 1974; Hardt and Burges, 1976; Glidden, 1981; Urbonas and Glidden, 1983 and others. Urbonas and Glidden (1983) found that it was possible to reasonably control peak post-development flows in receiving waters with multiple on-site detention basins within larger urban watersheds for bigger design storms. This was not the case for the 2-year and smaller storms. As the tributary area increased, the numbers of on-site basins also increased and the peak flows in the receiving waters far exceeded the pre-developed flow rates. They concluded time that this was the result of increases in post-urbanization runoff volumes and the summation of many small, flat, and long-duration hydrographs.

Recent Developments in within the Urban Drainage and Flood Control District Area

The Urban Drainage and Flood Control District (UDFCD) in 1992 published Volume 3 of the Urban Storm Drainage Criteria Manual; completely updated in 1999 (UDFCD, 1992 & 1999). This manual recommends practices to reduce stormwater surface runoff volumes and the flow rates for the large numbers of storms equal to and smaller than the 2-year design storm. As a result, USDCM recommended Best Management Practices (BMPs) that include a *Water Quality Capture Volume* (*WQCV*) equal to the 80th percentile runoff event, released over an extended period of time (12 to 40 hours depending on the type of BMP used). These criteria significantly reduced the impacts of urban runoff on receiving waterways. The residual effects of increases in runoff volumes still resulted in sufficient numbers of periods when critical shear stress in the receiving waterways were exceeded. Although the rates and extent of geomorphic changes observed in local ephemeral, intermittent and perennial receiving gulches and streams were reduced, there is still a clear indication that better control over a broader spectrum of runoff events to reduce the rates of geomorphic changes in these waterways even more is needed.

CONTROL USING FULL-SPECTRUM DETENTION

New design protocols for on-site stormwater detention facilities were developed and initially investigated using UDFCD computer modeling tools with design storms (Wulliman and Urbonas, 2005). The concept was then tested by UDFCD and refined using US EPA's SWMM 5.0 calibrated against recorded rainfall and runoff data collected over a 15-year period at a 3.1 square mile urban watershed. This test watershed had 5 tipping bucket rain gages and two flow gaging sites, one at a point where it had 0.4 square miles and the other 3.1 square miles of tributary area. The final design concept was effective in controlling stormwater peak flow rates along the modeled stream from the smallest event, namely the *mean storm*, up to the 100-year major flood. The findings are most applicable for the Denver region and other locations having similar precipitation patterns; however, the underlying principles used to develop this concept can, however, be used to develop design protocols for other hydrologic regions of USA and in other countries.

This new design approach, is called *full-spectrum detention* (*FSD*). It is based on the following:

1. The difference between urban and pre-development runoff volume, the *excess urban runoff volume* (*EURV*) per impervious unit area, was found to be fairly constant for a wide range of design storm sizes and watershed imperviousness for given NRCS hydrologic soil groups.

2. When *EURV* (this was later modified to add 10% of the original EURV) is captured and released over an extended period of time, the runoff volume exceeding *EURV* approximates pre-development runoff volume.

3. The *EURV's* outlet was designed originally to drain this volume fully in 70-hours and, after further testing was modified to drain it in 72-hours. This is an extrapolation of the 40-hour drain time used in the Denver area for the release of the *WQCV*.

4. The upper stage of a *FSD* basin is sized to control the 100-year peak flow rate from the tributary sub-watershed to the pre-development peak flow rate recommended by UDFCD.

The suggested *FSD* sizing protocols were developed using site characteristics with various NRCS Hydrologic Soil Types while recognizing the variations in pre-development runoff rates and *EURV* for each soil type. The total basin volume for the *FSD* concept that also controls the 100-year peak flow appears to require approximately same volume as the volume required for 100-year on-site detention basins using simplified empirical equations recommended by UDFCD for NRDC Type B, C and D soils; however, it requires more volume for Type A soils.

ANALYSIS PERFORMED

Testing of the Concept

To test the efficacy of the *FSD* sizing protocols, an example 5,000 acre watershed was created using 50 identical 100-acre sub-watersheds (Figure 1). Imperviousness of 2% was used to represent the typical pre-development conditions found in the Denver region. UDFCD's regional runoff model was used to simulate to yield 100-year peak discharges of 0.5, 0.85, and 1.00 cfs/acre for NRCS Hydrologic Soil Groups A, B, and C/D, respectively, which are the recommended unit flow release rates for on-site detention facilities in the Denver region.

Excess Urban Runoff Volume

The CUHP model was then run using two small design storms that had total rainfall depths of 0.50- and 0.60-inches and six standard design storms with return periods of 2-, 5-, 10-, 25-, 50- and 100-years, ten different impervious values (i.e., 2%, 5%, 15%, 25%, 30%, 35%, 40%, 50%, 75% and 100%), and three different NRCS Hydrologic Soil Groups (A, B, C/D). The *EURV* was found by subtracting pre-developed from the post-developed runoff volumes. It was observed that

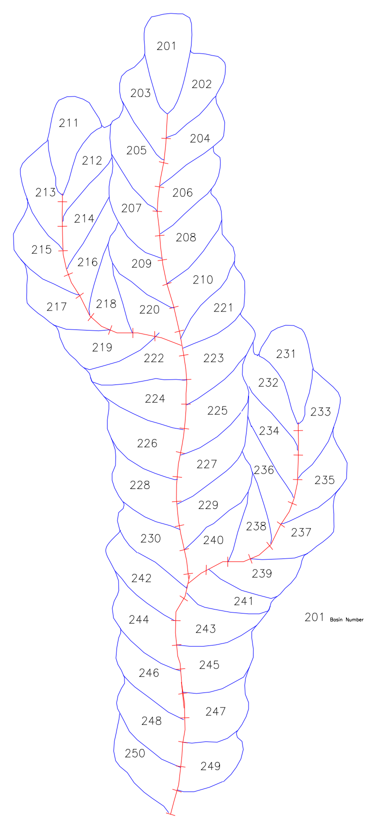

Figure 1. Example 5,000-acre watershed.

the *EURV* became almost a constant value once 20% imperviousness was reached and there was very little difference between the various design storms, with the exception of very small storms. Based on these findings, an average *EURV* was found for the 2-, 5-, 10-, and 100-year design storms for each soils group. The results for Soil Group C/D are illustrated in Figure 2. The UDFCD's UD-SWMM model was used to combine and route the flows when more than one sub-watershed was involved.

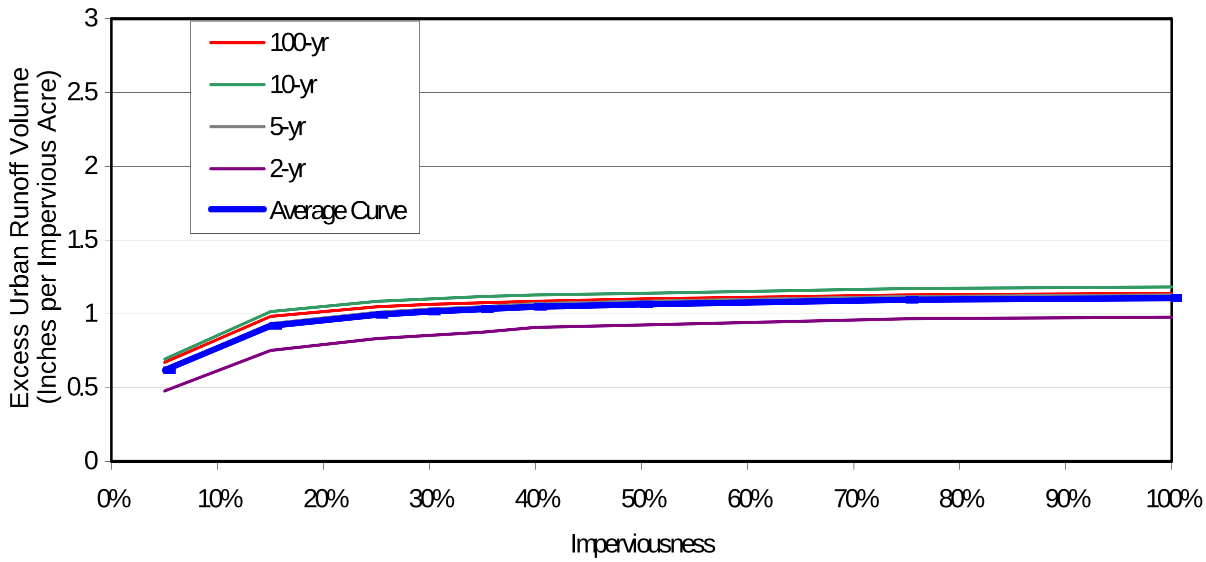

Figure 2. *Excess Urban Runoff Volume* for Hydrologic Soil Group C/D.

Controlling the Detention Release Rates

A single representative sub-watershed of 50 acres was used to modeling each of the scenarios mentioned earlier. A single detention basin was designed to capture the *EURV* and the 100-year volume and then drain the *excess* volume in 70 hours and control the release of the 100-year runoff volume to a rate to limit peak discharge to the unit release rate described earlier, depending on soil type. This detention control was replicated for all 100 sub-catchments illustrated in Figure 1. A typical profile for this outlet arrangement is illustrated in Figure 3.

<u>EFFECTIVENESS OF FULL-SPECTRUM DETENTION</u>

Testing with Design Storms

Figure 4 summarizes the calculated peak flows for one sub-watershed and Figure 5 does the same for the cumulative peak flows along the major waterway for 50 sub-watersheds when all of them have 50% total impervious cover. The effectiveness of *FSD* is illustrated when compared to the pre-developed condition and the fully developed condition with no detention, especially for the 50 sub-watershed scenario. Note that the peak flows with *full-spectrum detention* closely match pre-development flows for the smaller, more frequently occurring, storms, not only downstream of one detention basin but also when large numbers of detention facilities operate simultaneously. Similar results were seen for other levels of development imperviousness.

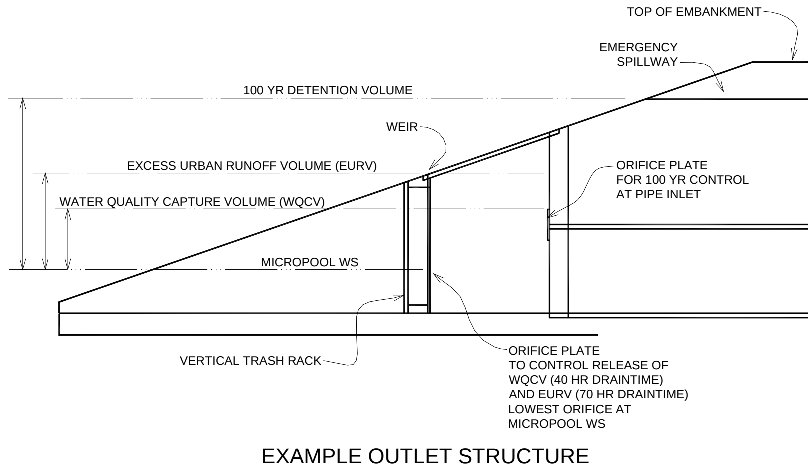

Figure 3. Typical outlet structure's profile for modeling *FSD*.

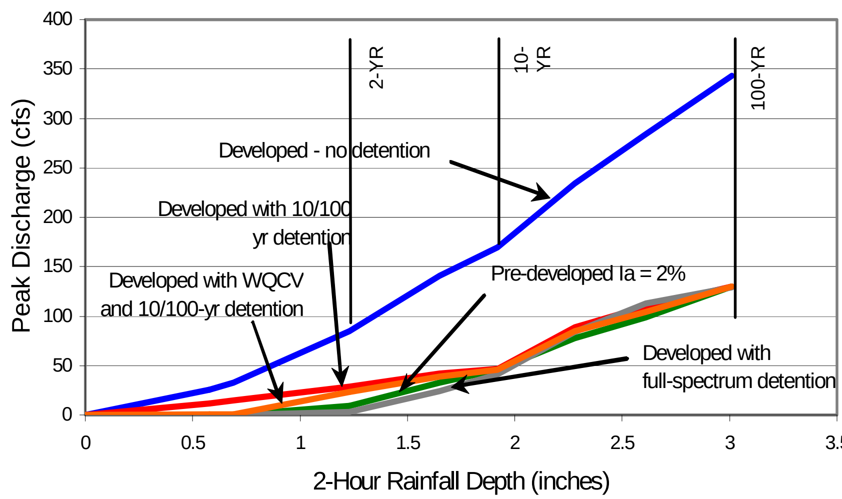

Figure 4. Peak flow rates from a **single** 100-acre tract (Developed Ia = 50%, C/D Soils).

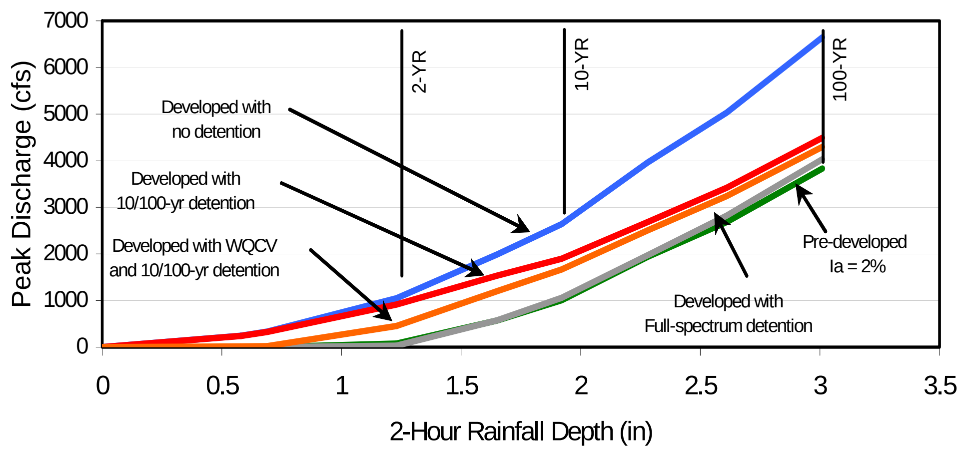

Figure 5. Peak flow rates from **fifty** 100-acre tracts (Ia = 50%, C/D Soils).

Testing with Continuous Simulation

Figure 6 compares the effects on peak flows at the downstream end of the 3.1 square mile test watershed controlled by 59 individual detention basins sized using the final version of the *FSD* simplified design protocols developed for the Denver region. These results were developed using Log-Pearson distribution analysis of the simulated peaks for a partial duration series. Because of the short (15-yr) period of rainfall data record, extrapolations beyond 20-year return period were considered unreliable and are not shown. It is this analysis that prompted a minor adjustment to the final *FSD* protocol, namely a 10% increase in the *EURV* and use of 72-hour drain time instead of the original 70-hour drain time for the *EURV*. Once these adjustments were made the final protocols virtually duplicated the peak flow distribution for the pre-developed land use condition for this range of return periods.

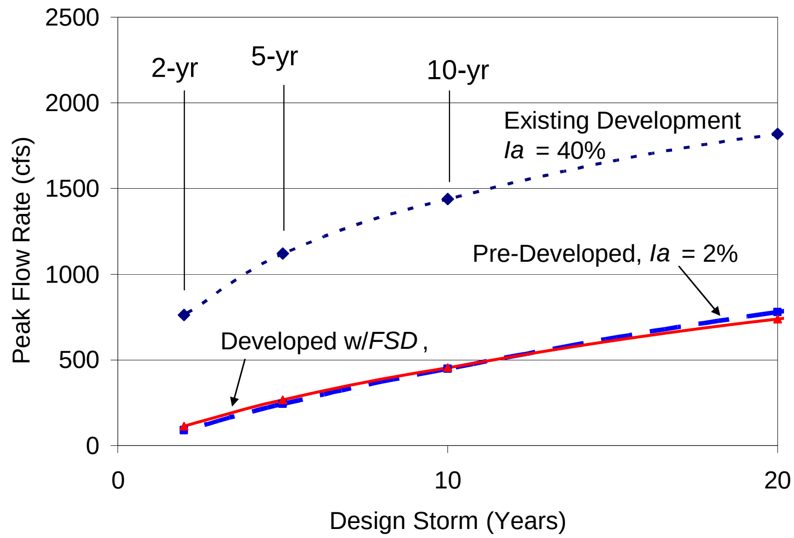

Figure 6. Peak Flow Comparisons for Larger Events Using Continuous Simulation for a 3.1 sq. mi. Watershed with 59 Detention Basins intercepting 100% of All Runoff.

Figures 7 and 8 compare the probability of occurrence distributions for all the simulated runoff peaks for the 15-year rainfall record using the calibrated SWMM model at a single detention basin with 0.4 square miles of tributary area and with 59 detention basins in the total watershed of 3.1 square miles. When the results are plotted using log scale, differences in the peak flow distributions become apparent for the small rainstorms in the record. Although the differences are apparent and appear quite large on this scale, the peak flow distribution seen for the *FSD* control scenario mostly fall below the estimated critical shear stress of the receiving waterway. Although not a perfect match, the total geomorphic effect may be minimal if the urban watershed is controlled using this concept and stream degradation can be reduced significantly.

As the numbers of detention basins increases with the size of the watershed and all of the basins operate simultaneously, the excess volume of runoff has a residual effect that cannot be fully controlled using detention. Rohrer and Roesner (2005) arrived at a similar conclusion while studying one detention basin scenario designed to capture a Water Quality Capture Volume and then control the peaks from 10- and 100-year storms. What they concluded and this study further confirms is that there may be a need to provide in-stream grade controls to limit any residual stream degradation that may result from urbanization. In the Denver region urbanization results in the conversion of many ephemeral streams and gulches into perennial ones as urbanization occurs. Thus, controlling stream degradation with the use of grade controls, in combination with newly established perennial flows, creates new reaches for aquatic life and its habitat.

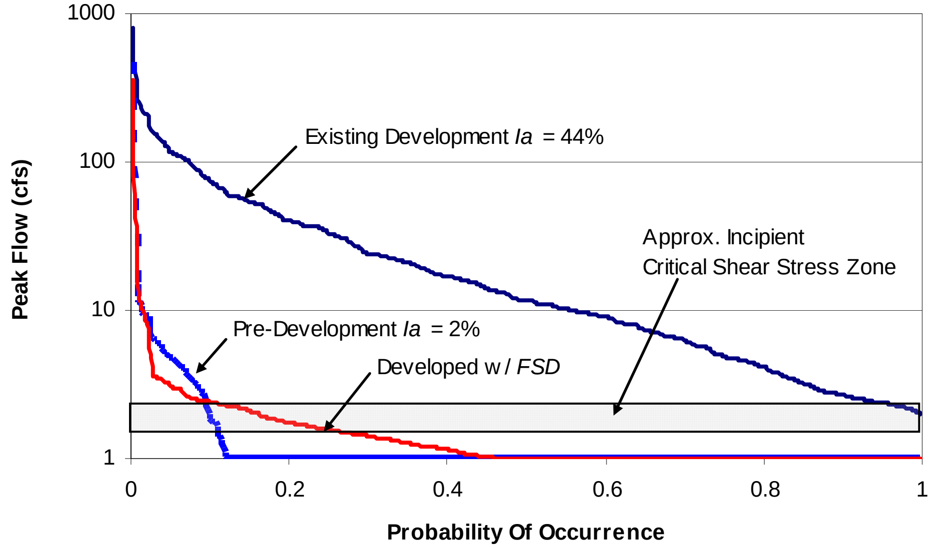

Figure 7. Continuous Simulation Peak Flow Comparison for 0.4 sq. mi. Catchment.

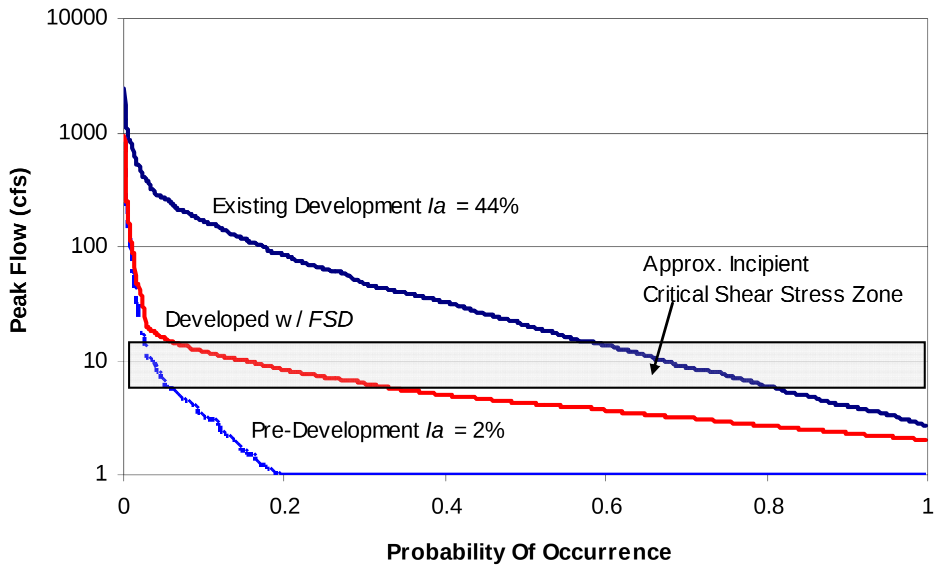

Figure 8. Continuous Simulation Peak Flow Comparison for 3.1 sq. mi. watershed.

CONCLUSIONS

A new detention sizing concept is presented that appears to control the peak flows along the headland receiving waterways in a manner that closely matches the pre-development peak flows for a wide array of design storms in the Denver region and was incorporated into the USDCM, 2001 (http://udfcd.org/downloads/down_critmanual.htm#vol2). This approach was developed using the design storms and runoff models used by UDFCD and refined using continuous simulation of a small urban watershed with a calibrated EPA SWMM 5.0 model. The findings and the details of the design protocols developed are probably applicable to areas that have similar hydrology. However, the concept of capturing the EURV and releasing it over extended periods of time appears to have merit and may be another tool for engineers to minimize the hydrologic modification effect of urbanization on receiving streams. It, like any other set of runoff controls, has a chance of working only if it is uniformly implemented over 100% of the watershed and only if all facilities are designed, built and maintained in perpetuity for watersheds of up to a moderate size. In other word any stormwater management concept is only as good as its implementation and continued to functioning over time (i.e., are sustainable).

To assist with the design of *FSD* basins for the Denver region, an Excel™ spreadsheet (UD-Detention) is available at http://udfcd.org/downloads/down_technical.htm. It assists with the calculation of the needed *EURV* and the 100-year design volume as well as the 100-year release rates. All that the spreadsheet needs to do these calculations is the user to enter the tributary watershed size, imperviousness, soil types and their distribution.

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