Peak flow control for a full spectrum of design storms

Le maîtrise des débits de pointe pour un spectre complet de pluies de project

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RÉSUMÉ

Les effets engendrés par plusieurs bassins de rétention, fonctionnant en même temps, sur les cours d'eau récepteurs dans les zones en cours d'urbanisation ne sont pas encore bien compris. Il a déjà été prouvé que la géométrie des cours d'eau et l'habitat aquatique se dégradent si l'on opère de la rétention d'eau ou non. Aussi le principe qui consiste à capturer le volume de ruissellement en excès, dû à l'urbanisation et de le relarguer après un certain temps est connu. Le rapport suivant détaille comment l'application de ce principe permet d'atténuer les effets de l'urbanisation, à savoir l'augmentation du pic de ruissellement, dans le cas où sont installés plusieurs équipements répartis aléatoirement et utilisant la rétention du spectre complet.

ABSTRACT

The effects of multiple detention basins, when operating at the same time, on receiving streams in urbanizing areas are not well understood. Evidence exist that stream geometries and aquatic habitat degrade whether stormwater detention is used or not. The concept of capturing the *excess urban runoff volume* that results from urbanization and releasing it over extended periods of time was investigated. This paper report how the application of this concept helps to mitigate the effects of urbanization, namely the increases in surface runoff peaks, when multiples of randomly distributed *full spectrum detention* facilities are operating during storm events.

KEY WORDS

Detention systems, Effects in receiving streams, Full spectrum detention, Mitigation of urbanization effects.

1 INTRODUCTION

1.1 Background

The topic of the effects of multiple on-side stormwater detention basins on receiving water peak flows was studied in the past by various investigators (e.g., McCuen, 1974; Hardt and Burges, 1976; Glidden, 1981; Urbonas and Glidden, 1983). The findings by Urbonas and Glidden (1983) revealed that it was possible to reasonably achieve pre-development peak flows in the downstream receiving waters for the larger design storms, but for the 2-year storm the peak flows in the receiving waters were not being controlled as the watershed increased in size and the numbers of on-site basins also increased. They concluded that this was the result of increases in post-urbanization runoff volumes.

1.2 Recent Technical Developments in Denver Area

The Urban Drainage and Flood Control District (UDFCD) in 1992 published Volume 3 of the Urban Storm Drainage Criteria Manual, which was completely updated in 1999 (UDFCD, 1992 & 1999). This manual officially recognized the need to reduce, to the maximum extent practicable, the stormwater surface runoff volumes and the flow rates that occur during the large number of small storms. Volume 3 of the USDCM recommended Best Management Practices (BMPs) that include a Water Quality Capture Volume (*WQCV*) and a requirement that this volume be released over an extended period of time ranging from 12- to 40-hours depending on the BMP used. Thus, the technical criteria in Volume 3 have improved the attenuation of the wet-weather peak flows resulting from small, frequently occurring events. However, some of the shortcomings discussed above still remained, namely, increases in runoff volumes, numbers of runoff events and flow rates along receiving waters.

1.3 Need for Improved Detention Sizing Practices

The profound geomorphic changes, namely bank erosion and bottom degradation, observed in local ephemeral, intermittent and smaller perennial receiving gulches and streams clearly indicated the need to better control the frequently occurring smaller runoff events. It is postulated that stream degradation and erosion will occur at reduced rates and, possibly, to lesser levels if runoff volumes and peak rates are kept closer to predevelopment conditions for the full spectrum of runoff events. To do this, better design guidance for on-site stormwater detention is needed. The goal of such guidance would be to achieve peak flows close to pre-development conditions for the full spectrum of runoff events with greater confidence. While such designs may slow down and reduce the rates and extent of geomorphic changes along receiving waters, they will probably not totally eliminate them. Stream stabilization measures will probably still be needed to reduce excessive degradation and loss aquatic habitat or ecological function.

2 FULL SPECTRUM DETENTION

A different approach toward design of on-site stormwater detention was investigated using the design storm concepts employed by the UDFCD for the Denver region of Colorado, USA. Although specific results may vary based on local hydrologic methods, the underlying principles may provide guidance for developing similar design protocols in other hydrologic regimes. The detention design concept that best achieved the intent of controlling flow rates to pre-developed conditions for the full spectrum of design storms is presented next. It appears promise in control of stormwater peak flow rates along receiving waters for the full spectrum of runoff events, from the smallest such as one generated by the *mean storm*, up to the 100 year event. This design approach is termed *full-spectrum detention* and was developed based on the following points and concepts:

1. The difference between urban runoff volume and predevelopment volume, called *excess urban runoff volume* per impervious unit area was found to be fairly consistent for a wide range of design storm sizes and levels of watershed imperviousness.
2. When this *excess urban runoff volume* is captured and released over an extended period of time, the remaining runoff from a site approximates the runoff volume under predevelopment conditions.
3. The first stage of a two-stage *full-spectrum detention* basin is sized to capture the *excess urban runoff volume*.
    - For NRCS Type C/D soils (i.e., mostly silt or clay) the *excess urban runoff volume* is about twice the *WQCV* recommended in the USDCM.
    - A 70-hour drain time was selected for the release of the *excess urban runoff volume*; longer than the 40-hour drain time for the WQCV used in Denver.
4. The upper stage of a *full-spectrum detention* basin is sized to control the 100-year peak flow rate from the tributary sub-watershed to the pre-development rate. When using the design guidance for the Denver area, the total *full-spectrum detention* volume approximates the volume required to control the 100-year peak plus the *WQCV* with the recommended 20-percent of WQCV sediment storage. *Full-spectrum detention* sizing appears to require less total basin volume than the current sizing methods require for sites with imperviousness exceeding 50-percent.

The suggested *full-spectrum detention* sizing protocols were developed using modeled results using sites with various NRCS Hydrologic Soil Types to recognize the variations in pre-development runoff rates and *excess urban runoff volumes* for different soil types. In addition to meeting the goal of matching pre-development peak flow rates of runoff, UDFCD recommends reducing the runoff volumes from urban areas to the maximum extent practicable through the use of practices that minimize directly connected impervious area (MDCIA) and other practices such as porous landscape detention (i.e., rain gardens), porous pavement, etc.

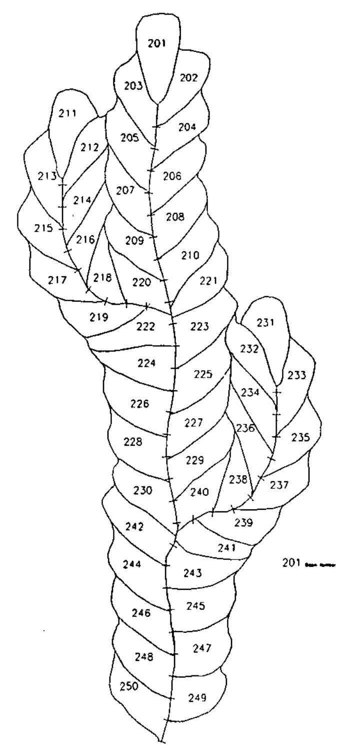

Figure 1. Example 2,000-Ha watershed.

3 ANALYSIS METHODOLOGY

3.1 Testing of the Concept

To test the efficacy of *full-spectrum detention* sizing protocols, an example 2.000 Ha watershed was created using 50 identical 40 Ha sub-watersheds (Figure 1). Imperviousness of 2% was used to represent the typical pre-development conditions found in the Denver region. The Colorado Urban Hydrograph Procedure (CUHP) runoff model was used to simulate to yield 100-year peak discharges of 0.035, 0.060, and 0.070 m^3/Ha for NRCS Hydrologic Soil Groups A, B, and C/D, respectively, which are the recommended unit flow release rates by the UDFCDM for on-site detention facilities.

3.2 Excess Urban Runoff Volume

The CUHP model was then run using two small design storms that had total rainfall depths of 13 and 15 millimeters and six standard design storms used by UDFCD 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 *excess urban runoff volume* was estimated by subtracting pre-development runoff volume from the runoff volume estimated for all simulation conditions described above. It was observed that the *excess urban runoff volume* per unit area of impervious surface became almost a constant value once 20% imperviousness was reached and there was very little difference between the various design storms. The exception was very small storms, where the volume became mostly a function of rainfall volume. Based on these findings, an average *excess urban runoff volume* was found for all design storms for each of the soils groups. The results for Soil Group C/D are illustrated in Figure 2. The SWMM model was used to combine and route the flows when more than one sub-watershed was involved.

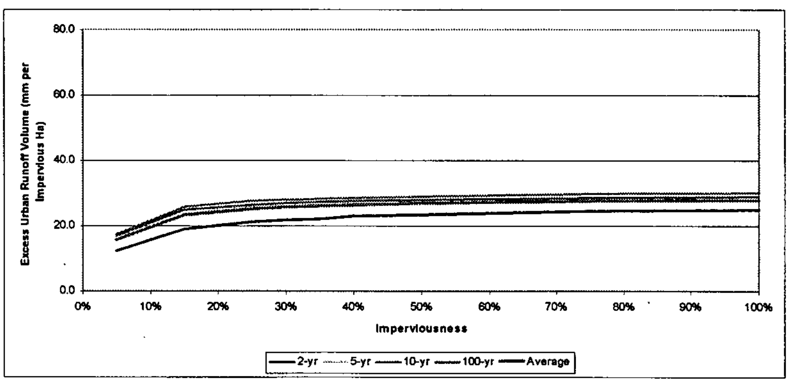

Figure 2. *Excess Urban Runoff Volume* for Hydrologic Soil Group C/D.

3.3 Controlling the Detention Release Rates

A single detention basin was designed to capture the *excess urban runoff volume* and the 100-year volume. The outlet was designed to then drain the *excess* volume completely in 70 hours and to control the release of the 100-year runoff volume to a rate that limited its peak discharge to the unit release rate described earlier. This design was varied by the soil type in the sub-watershed being studied. Each sub-watershed scenario and its detention facility was then replicated and arranged in a system 50 illustrated in Figure 1. A typical profile for an outlet that accomplishes this is illustrated in Figure 3.

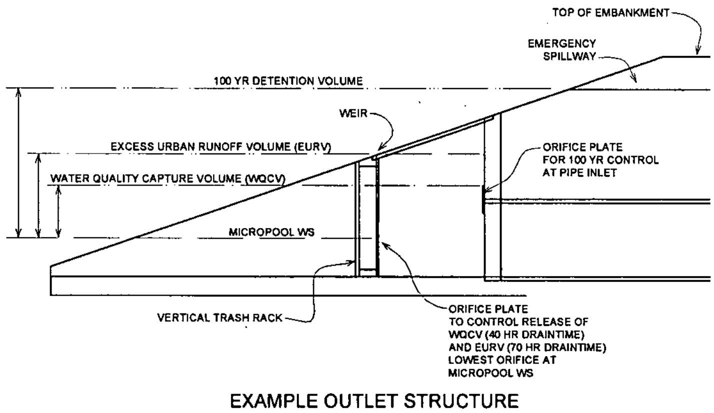

Figure 3. Typical outlet structure conceptual profile for modeling *full-spectrum detention.*

4 EFFECTIVENESS OF FULL-SPECTRUM DETENTION

Figure 4 illustrates the calculated peak flows for one sub-watershed and Figure 5 does the same for the cumulative peak flows along the major waterway downstream of the 50 sub-watersheds when all of them have 50% total impervious cover. The effectiveness of *full-spectrum detention* is clearly illustrated when compared to the pre-developed condition and the fully developed condition with no detention. Additional comparisons can be seen on this figure for the "10/100-year detention" control and the "10/100-year detention plus Water Quality Capture Volume (WQCV)" control scenarios, which further illustrate the much greater effectiveness of the *full-spectrum detention* in controlling the peak flows over the entire range of design storm.

While all the other detention scenarios do reasonably well at controlling peak flow rates at individual sites for a range of design storms, the *full-spectrum detention* scenario does well at an individual site and for controlling peaks after many on-site detention facilities are used in larger watersheds. What is of particular interest is the way that the peak flows with *full-spectrum detention* closely match pre-development flows for the smaller, more frequently occurring, storms. Similar results were observed for sub-watersheds having greater and lesser impervious cover over the land surfaces.

Another attractive feature of this design is its simplicity. Instead of attempting to size detention basins to match a variety of design storm sizes, this design has two simple volumes, the *excess urban runoff volume* and the total volume needed to control the 100-year peak rate of runoff. This means that the designer needs to design outlets for the two control situations only, one to drain the *excess urban runoff volume* in about 70 hours and the other to control the maximum release rate specified for the 100-year runoff event. In cases where the local jurisdiction has a flood detention policy other than the control of the 100-year peak flow, say a 10-year peak flow, similar volume sizing protocols, including the spreadsheet, can be developed.

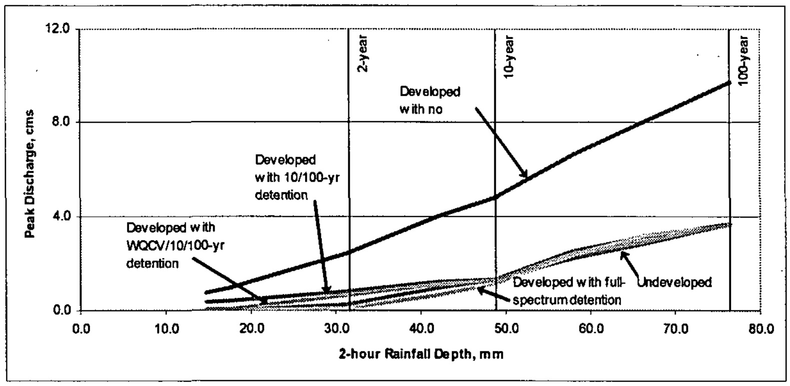

Figure 4. Peak flow rates from a single 40-hectare tract (Developed Ia = 48%, C/D Soils).

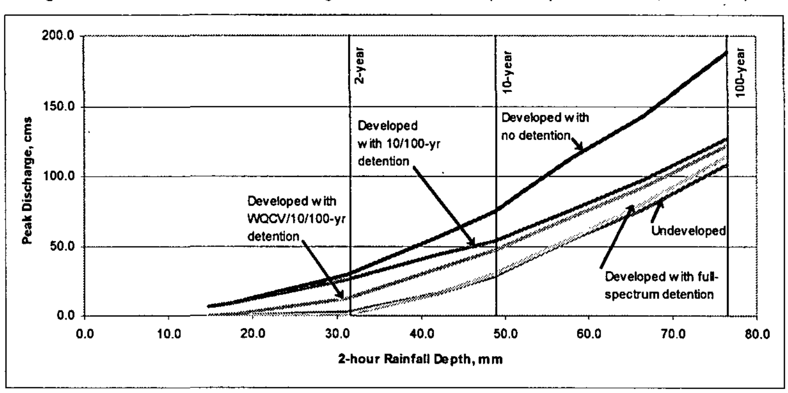

Figure 5. Peak flow rates from fifty 40-hectare tracts (Ia = 48%, C/D Soils).

5 CONCLUSIONS

A new detention sizing concept, termed *full spectrum detention*, 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. This approach was developed using the design storms and runoff models used in the Denver metropolitan area. As a result, the comparisons made in this paper are based on the use of these hydrologic tools and analysis protocols and may or may not be the same for other regions and when other hydrologic and detention sizing protocols are used.

This design concept is based on "capturing" the *excess urban runoff volume* and releasing it slowly. In addition, the cases analyzed also included a control of the 100-year outflows to match allowable unit area release rates recommended in the USDCM for any mix of NRCS Hydrologic Soil Groups. This approach provides a relatively simple protocol for the actual sizing of detention volumes and outlets. To assist with the design of *full-spectrum detention*, an Excel™ spreadsheet (UD-Detention) has been prepared and is available on the www.udfcd.org (under Downloads -> Technical Downloads) web site that calculates the needed design volumes and the 100-year release rates based on tributary watershed size, imperviousness, and distribution of soil types. However, this spreadsheet was designed using the protocols and hydrologic conditions for this region and is not intended for use in other regions with different policies, sizing protocols and hydrology. It does, however, illustrate the simplicity of the sizing protocols that can be implemented by any community to achieve receiving water protections and simplicity and consistency of implementation of such a goal.

Although excellent matching of pre-development peak flow rates using the design storms used in the Denver region was achieved, it is recommended that future studies of this concept be done for other regions of United States and in other countries to see if this concept has broader applicability. It is recommended that such studies also employ continuous simulation with locally calibrated rainfall-runoff-routing models; something that would answer many other remaining uncertainties about this concept's broader applicability.

The authors do not claim that this concept will mitigate all of the stormwater-related impacts on receiving waters due to expansion of urban areas. It does appear, however, to be more robust in mitigating the effects of hydrologic modifications than many other methods that are currently used.

Full spectrum detention is yet another "simplified" sizing and design methodology that appears to provide very robust control of stormwater peak flows over a large array of design storms. As a result, it appears to address at least one of the hydrologic modification issues of urbanization (i.e., increased flow rates) better than other detention sizing procedures for the Denver area. However, this control has a chance of working only if this concept is uniformly implemented over 100 percent 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 words, this and other stormwater management concepts are only as good as their implementation and if they continue to function over time (i.e., are sustainable). Until such assurances can be made, it is unwise to suggest that any detention or best management practices alone will safeguard receiving waters from impacts of urban growth. This method should also be viewed as a add-on to runoff volume reduction practices that are implemented during urbanization or retrofitted into existing urban areas. Stormwater runoff volume reduction practices can reduce the size of full-spectrum detention facilities by reducing the watersheds effective imperviousness.

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