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SIZING A CAPTURE VOLUME FOR STORMWATER QUALITY ENHANCEMENT

by

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INTRODUCTION

Urban stormwater management is rapidly changing from a focus only on the control of damages resulting from storm runoff to now include water quality. Two basic issues are influencing this change. First is a fundamental heightening of environmental awareness and concern by the public. It is documented that urban stormwater, along with non-point runoff from non-urban sources, contributes pollutants to the receiving waters and efforts to do something about it are slowly picking up support and momentum.

The second factor causing a shift toward urban stormwater quality is the Water Quality Act of 1987 (WQA), which amended the Federal Water Pollution Control Act. How this WQA may impact the citizens, communities, local governments, industry, consultants and the water quality across the United States is yet to be seen. Nevertheless, local governments and industries are mandated by Congress to control pollutants in urban runoff to the "maximum extent practicable" (MEP). This hopefully means that Congress expects solutions to be practical, pragmatic, and economical.

In order to be practical and effective it is important that technologies for dealing with urban stormwater runoff be available. Several simple technologies are emerging (Urbonas and Roesner, 1986), (Roesner, Urbonas and Sonnen, 1989), which include detention and retention basins, infiltration and percolation at the source of runoff, wetlands, sand filters, and combinations of these techniques. It is clear from the references cited above that stormwater quality facilities first need to capture a certain volume of runoff in order to treat it. As a result, the size of runoff event to be captured is critical in the design of stormwater quality facilities. For example, if the design runoff event is too small, the effectiveness will be reduced because too many storms will exceed the capacity of the facility. On the other hand, if the design event is too large, the smaller runoff events will tend to empty faster than desired for adequate treatment to take place. We know that large detention basins designed to control peaks from larger storms will not provide the needed retention time for the smaller events, which are much more numerous than the larger storms.

A balance between the storage size and water quality treatment effectiveness is needed. Grizzard et. al. (1986) reported results from a field study of basins with extended detention times in the Washington, D. C. area. Based on their observations they suggested that these basins provide good levels of treatment when they are sized to have an average drain time for all runoff events of 24 hours. This equates to a 40 hour drain time for a brim-full basin. Beyond that, there remains little rationale for the sizing of the capture volume that results in reasonable pollutant load removal while providing reasonably sized facilities.

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This paper will discuss one possible method to find a point of diminishing returns for the sizing of water quality capture volume. It utilizes rainstorm records as its base instead of synthesized design storms. An example based on the National Weather Service long term precipitation record in Denver will illustrate this methodology.

FINDING A POINT OF DIMINISHING RETURNS

In 1976 Von den Herik (1976) suggested in Holland a rainfall-databased method for estimating runoff volumes which he called Rain Point Diagram (RPD). This was later modified to a Runoff Volume Point Diagram (RVPD) method, which approximates continuous modeling without setting up a continuous model. The method requires combining individual recorded hourly or 15-minute rainfall increments in a given period of record into separate storm depths. Individual storms are defined by the time during which no rainfall occurs. Very small storms are purged from the record. Storm totals are converted to runoff volumes by multiplying each storm's depth by the watershed's runoff coefficient (C).

The use of the RVPD is illustrated in Figure 1, where the individual storm runoff depth is plotted against storm duration. The runoff capture envelope consists of the "brim-full" volume of the detention facility, plus the average release rate times its emptying time. In this figure the runoff capture envelope is based on a detention basin that has a brim-full capacity of 0.3 watershed inches which can be emptied in 12 hours. All the points above the capture envelope line represent individual storms that have sufficient runoff to exceed the available storage volume (i.e., brim-full volume) of the detention facility. A software package was developed to perform this analysis and to report the results after testing a variety of capture volumes.

For the storm events in a given record there is a capture volume that will intercept all runoff within the record. For practical reasons this maximum pond volume, P_m, was defined to be equal to the 99.5 percent probability runoff event volume for the period of record. For the Denver rain gauge period of record studied (1944-1984), P_m is equal to the runoff from 3.04 inches of precipitation, or 6.9 times the precipitation of an average runoff producing storm for this same period of record. This value of P_m was then used to normalize all pond sizes being tested using the following equation:

$$P_r = P / P_m \qquad (1)$$

in which, P_r = relative pond size normalized to P_m

P = pond size being tested

P_m = maximum runoff volume (i.e., 99.5% probability).

The search for the point of diminishing returns, sometimes called "maximized point," incrementally increases the relative (i.e., normalized) pond size and calculates runoff volume and the number of events. Figure 2 illustrates an example of the results of such an analysis for the following conditions: storm separation criteria is 6-hours, emptying time for the brim-full basin is 12-hours, and the runoff coefficient for the watershed is C = 0.5.

The maximized pond size occurs where the 1:1 slope is tangent to the runoff capture rate function. Before this point is reached the capture rate increases faster than the relative capture volume size. After this point is reached the increases in the capture rate become less than corresponding increases in relative capture volume size. In other words, when the point of maximization is passed, diminishing returns are experienced if the capture volume is increased any further. Or the example illustrated in Figure 2, the maximized point occurs when the relative capture volume is equal to 0.18, which converts to 0.27 watershed inches.

A statistical summary of rainfall characteristics for all storms that exceeded a total of 0.1 inch at the Denver Rain Gauge is given in Table 1. A 0.1-inch "filter" was used to eliminate from the record the very small storms, which are not likely to produce runoff (see "Incipient Runoff Value of Rainfall in the Denver Region" in this issue of *Flood Hazard News* concerning the point of incipient runoff in the Denver area).

You can see from this summary that the rainfall exhibits a skewed statistical distribution. More than two-thirds of the storms have less precipitation than the average storm. Apparently in the Denver area the average runoff producing rainstorm depth is a relatively large event.

Once the precipitation and runoff probabilities were understood, an attempt was made to find a simple yet reasonably accurate relationship for approximating the maximized capture volume for water quality facilities. The final result for the Denver rain gauge data is illustrated in Figure 3. This figure relates the maximized capture volume to the watershed's runoff coefficient. Separate relationships are shown for the brim-full storage volume emptying time of 12-, 24- and 40-hours.

The capture volume found using these curves will result in 86 percent of all runoff events being totally captured and processed by the facility. It is the frequency of the shock loads that has the greatest negative effect on the aquatic life in the receiving streams. On the other hand, the very few large storms in the record are responsible for all of the flooding damages. Even during these larger events some degree of capture and treatment occurs, even though it may be at somewhat reduced efficiency.

SENSITIVITY OF PROCEDURE

An attempt was made to test the sensitivity of the capture volume as a surcharge above a permanent pool level on the removal rates of total suspended solids. For lack of local data on sediment settling velocities, the data given by EPA (1986) were use for several capture volume sizes. Estimates were made of the dynamic removals that occur while the runoff event is occurring and for the quiescent removals in the pond that occur between runoff events.

When theses estimates were made using a capture volume equal to 70% of the maximized volume, the annual removal of TSS was estimated at 86%. This compares to an estimated rate of 88% for the maximized capture volume and 90% for a volume that is twice as large as the maximized volume. In other words, the removal efficiencies appear to be very insensitive to an increasing the capture volume beyond the capture of the runoff from the 70th percentile event.

It thus appears possible to use a lesser capture volume above the wet detention pond water surface than the maximized volume and have virtually no effect on the TSS removal efficiency. Currently we suggest that the design volume could be based on the capture of an 80th percentile runoff event instead of the maximized volume. Obviously this suggestion needs further testing. In the meantime, Figure 4 may be used to size the surcharge capture volume for ponds with permanent pools of water and Figure 5 may be used to size a capture volume for a detention facility that drains completely.

On the other hand, if the removal of dissolved nutrients, such as phosphorous or nitrates, is desired, the designer has to consider using wet ponds or a marsh. Biologic activity is responsible for the removal of dissolved constituents. The effectiveness of these processes is primarily the function of residence time within the permanent water pool. Increasing the capture volume above this pool will have little effect on the removal efficiencies of dissolved compounds. On the other hand, dry ponds have little effect on the removal of dissolved materials, since their primary removal mechanism is sedimentation (Grizzard, et. al., 1986; Schueler, 1987; Roesner, et. al., 1988; Stahre and Urbonas, 1988) the quiescent removals in the pond at 86 percent. This compares to an between storms estimated rate of 88 percent annual. Using a capture volume equal to 70 removal of TSS when using the percent of the maximized volume, the maximized capture volume, and to a annual removal of TSS was estimated 90 percent removal rate when using

DETERMINATION OF RUNOFF COEFFICIENT

In 1982 EPA published data as part of the NURP study on rainfall depth vs. runoff volume. Although EPA did acknowledge some regional differences, much of the United States was found to be well represented by the data plotted in Figure 6. The curve in this figure is a third order regressed polynomial with the regression coefficient R^2 = 0.79. This value of R^2 implies a reasonably strong correlation between the watershed imperviousness, I, in percent and the runoff coefficient, *C*, for the range of data collected by EPA. Since the NURP study covered only two-year period, in our opinion this relationship is justified for 2-year recurrence probability and smaller storms.

CONCLUSIONS

An investigation of sizing stormwater quality facilities for maximized capture of stormwater runoff events and their performance in removing settleable pollutants revealed that simplified design guidelines arc possible. These guidelines can be developed using local or regional rain gauge records. Preliminary suggestions for such guidelines are illustrated in Figures 4 and 5 for the Denver area and areas having similar rain and snowstorm patterns.

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TABLE 1. Denver Rain Gauge Hourly Data Summary For Storms Larger Than 0.1 Inches In Depth

Separation Basis For New Storm (Hours)	Number of Storms	Average *Depth* (Inches)	Average Storm Duration (Hours)	Average Time Between Storms (Hours)	Percent of Storms Smaller Than Average
1	1131	0.39	7	267	70.9
3	1091	0.42	9	275	71.7
6	1084	0.44	11	275	70.7
12	1056	0.46	14	280	70.8
24	983	0.51	23	293	69.8
48	876	0.58	43	310	70.0

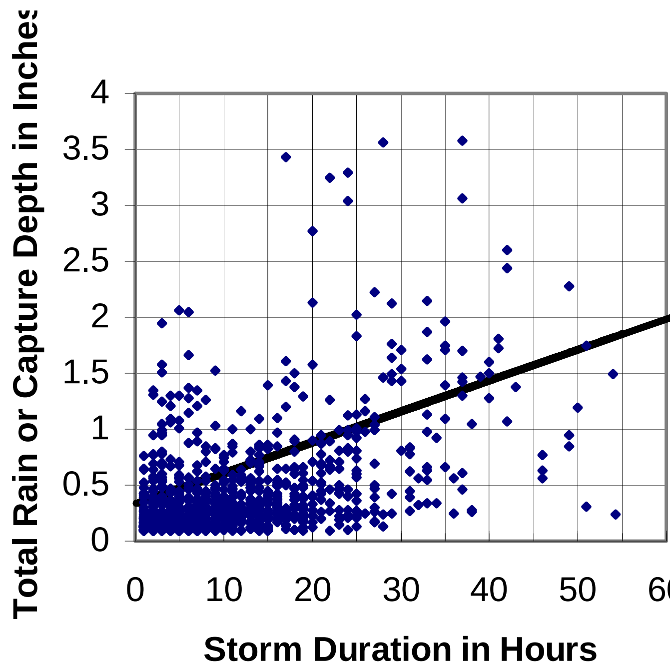

Figure 1. Example of a Capture Volume Envelope for a 0.33-inch Basin Volume and an Outlet Sized to Drain This Volume in 12-hours.

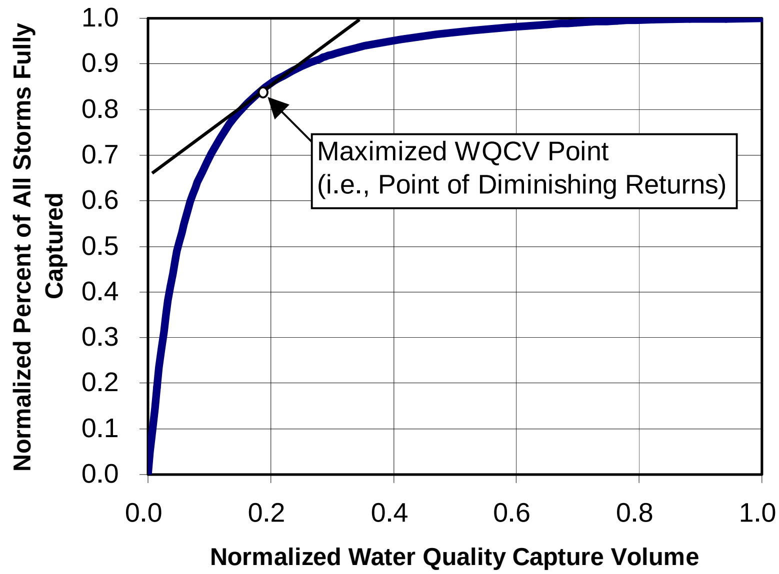

Figure 2. Point of Maximization of WQCV - Denver Example

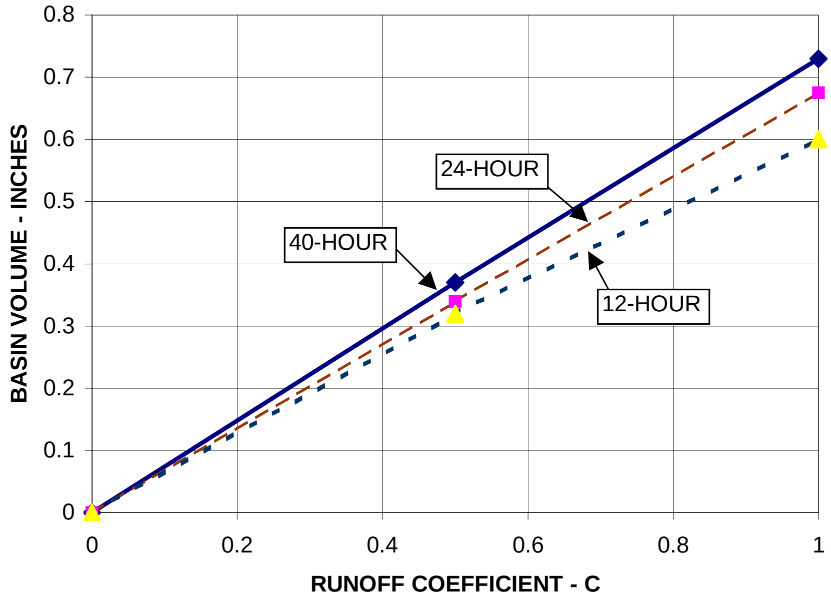

Figure 3. Maximized Capture Volume, Denver Raingage 1944-84 Period

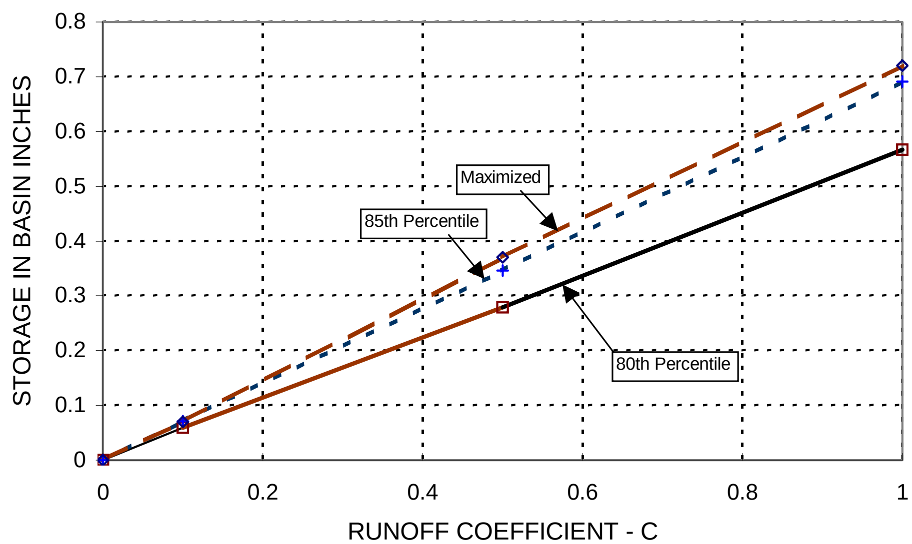

Figure 4. Capture Volume Using Denver Raingage for 40-Hour Emptying Time

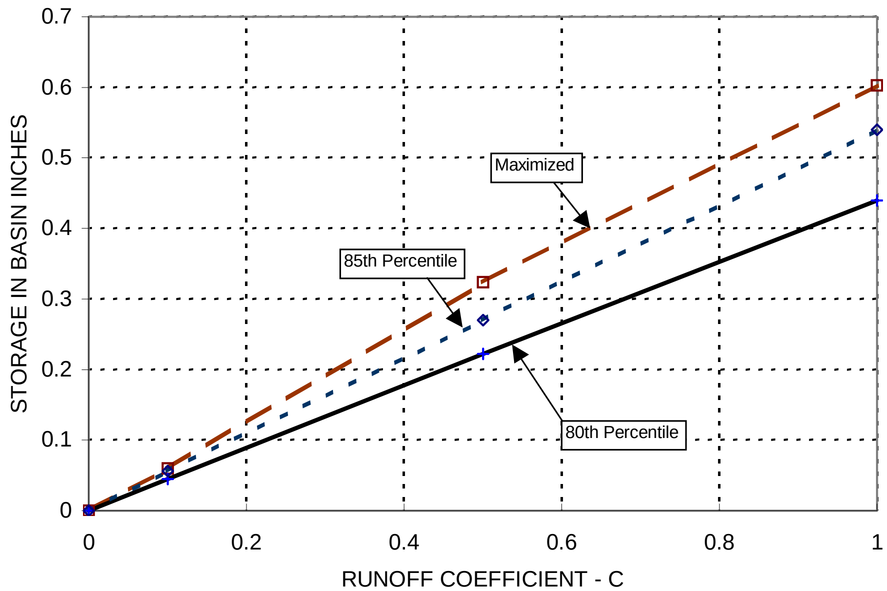

Figure 5. Capture Volume Using Denver Raingage for 12-Hour Emptying Time

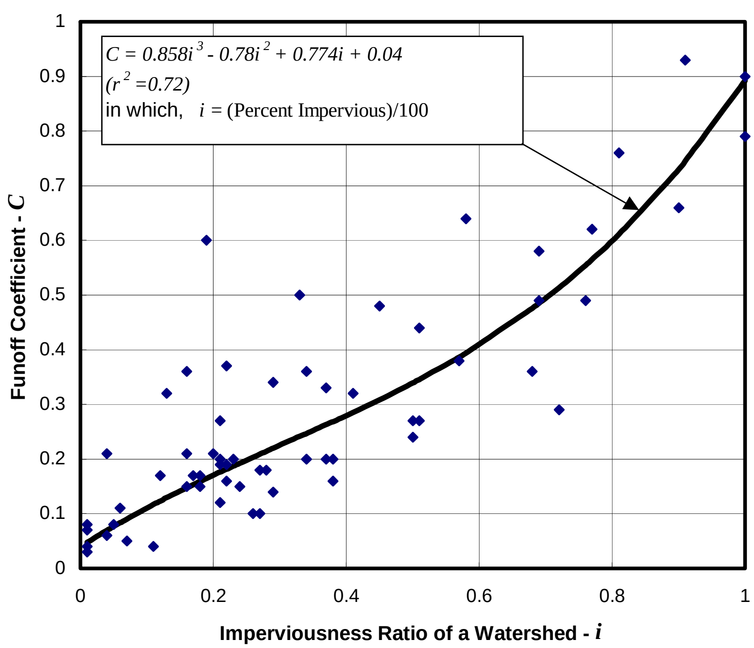

Figure 6. Runoff Coefficient Relationship Based on NURP Data. Applicable to 2-year and Smaller Design Storms.