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RATIONAL VOLUMETRIC METHOD (MODIFIED FAA) FOR STORM WATER DETENTION DESIGN

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INTRODUCTION

Storm water management is one of the major tasks for preserving urban water environment (ASCE, 1994). A storm water drainage system consists of conveyance and storage facilities. Detention and retention basins are the major storage facilities designed for storm water quantity and quality controls. Storage facilities in a drainage network should be placed at strategic locations in order to effectively attenuate peak flood flows. In order to achieve an overall optimization of costs and benefits, it is necessary to evaluate all feasible combinations of basin locations, storage volumes, and allowable release rates (McCuen in 1998, Guo and Urbonas in 1996). Decision making relies on the impact assessments by numerical simulations for the entire watershed with and without the proposed drainage facilities. A detention basin may operate as an on-line facility if the inflow channel directly flows through it or an off-line facility if storm water is diverted into the basin from the channel. A diversion device is designed to divert water when the inflow exceeds the channel capacity. In this study, the runoff volume method using the Federal Aviation Administration approach (FAA, 1970) is revised to extend its application from on-line to off-line storm water detention basin designs. In general, an off-line detention basin is more economic in cost than on-line basins. The revised method is a very useful when dealing with urban catchments.

RUNOFF VOLUME METHOD

The volumetric method has been recommended for small detention basin designs. For the design event, the average rainfall intensity for a specified duration can be depicted as:

$$I = \frac{C_1}{(C_2 + T_d)^{C_3}} \tag{1}$$

in which I = rainfall intensity, T_d= rainfall duration, and C_1, C_2, and C_3 are local empirical constants. Using the Rational method, the detention storage volume can be directly calculated as the difference between the inflow and outflow volumes through the detention basin. For simplicity, the inflow hydrograph to the basin is approximated by a trapezoidal shape as shown in Figure 1 (Guo 2001). The inflow hydrograph has a linear rising limb over the time of concentration of the tributary watershed, and the peaking portion of the inflow hydrograph is a plateau from the time of concentration, T_c, to the end of the rainfall event at T_d. Runoff water is diverted into the off-line basin at a pre-set flow rate, Q_b. The detention volume is the area of *bcde* in Figure 1 and can be calculated as:

$$S_o = \frac{Q_a}{2}(T_d + T_c - 2T_b) + \frac{Q_b}{2}[(T_d + T_c - 2T_1) + (T_d + T_c)] \quad (2)$$

in which S_o = outflow volume, T_c = time of concentration of the tributary watershed, T_d = rainfall duration, and T_b = time to begin the diversion.

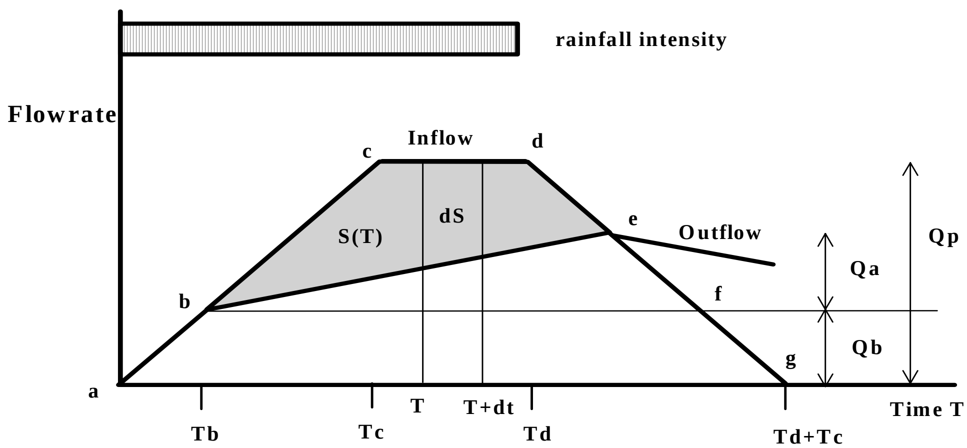

Figure 1 Illustration of Detention Volume in Relation to Hydrographs

Using a linear approach, the peak inflow occurs at T_c, and the time to start flow diversion can be approximated by:

$$T_b = \frac{Q_b}{Q_p} T_c \quad (3)$$

in which Q_p= peak inflow determined by the Rational method for the selected T_d as

$$Q_p = \alpha CIA \quad (4)$$

in which α= unit conversion factor equal to 1 for acre and feet or 1/360 for hectare and mm, C = runoff coefficient, and A = watershed area. For mathematical convenience, the outflow volume, S_o, is expressed by the average release over the rainfall duration, T_d, as:

$$S_o = mQ_aT_d \quad (5)$$

Equating Eq 2 to Eq 5 yields the value of m to be:

$$m = \frac{1}{2}[1 + \frac{(T_c - 2T_b)}{T_d}] + \frac{Q_b}{Q_a}[1 + \frac{(T_c - T_b)}{T_d}] \quad \text{for } T_d > T_c \quad (6)$$

For an on-line detention basin, Q_b =0 and T_b=0. As a result, Eq 6 is reduced to

$$m = \frac{1}{2}(1 + \frac{T_c}{T_d}) \quad \text{for } T_d > T_c \quad (7)$$

Eq 7 agrees with previous studies (Aron and Kibler in 1990 and Guo in 1999). According to the Rational method, the inflow volume, S_i, to the basin is equal to:

$$S_i = \alpha CIAT_d = Q_p T_a \quad (8)$$

Aided by Eq's 5 and 8, the detention volume, S_d, for the selected T_d is:

$$S_d = S_i - S_o = (Q_p - mQ_a)T_d \quad (9)$$

The basic concept used in the volumetric method is to find the maximum volume difference by Eq 9 in terms of rainfall duration. The method begins with T_d=T_c, and then uses an increment of 5 or 10 minutes for storm duration to compute the detention volume until the maximum storage volume is identified (Urbonas and Stahre in 1992, Guo 1999). The design storage volume, S_s, for a basin is determined by:

$$S_s = \max(S_i - S_o) \quad (10)$$

The aforementioned maximization procedure identifies the design storm and the maximal detention volume.

DESIGN EXAMPLE FOR OFF-LINE BASIN

The example catchment is located next to a road side ditch that carries the storm water generated from a tributary area of 62 acres. The runoff coefficient for the tributary area is 0.68. The time of concentration of the catchment is 20 minutes. The total allowable storm water release from the watershed is set to be 62 cfs. The drainage system illustrated in Figure 2 is designed to pass no more than 15 cfs into the roadside ditch. A flow diversion is installed to transfer excess storm water into the detention basin. The maximum release from the detention basin for this case is 47 cfs) which is the difference between the total allowable release of 62 and the on-line release of 15 cfs. The Denver's rainfall intensity curve is prescribed with C_1 = 74.1, C_2 = 10.0, and C_3 = 0.786 for the 100-year event. The task is to determine the off-line detention storage volume.

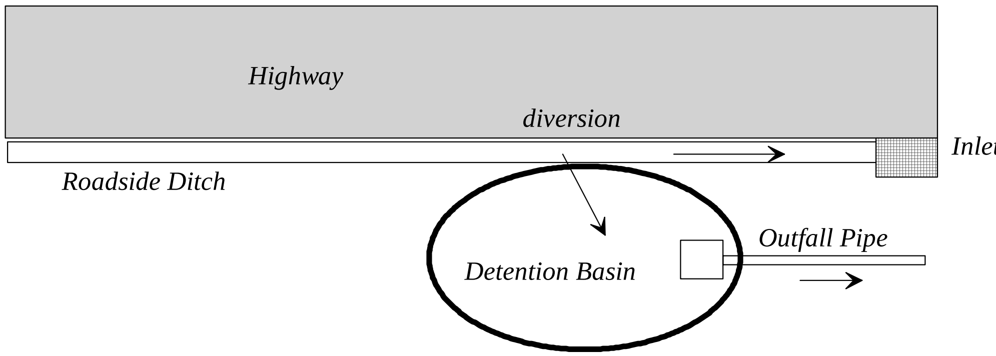

Figure 2 Design Example

As indicated in Eq 10, the detention volume can be maximized by a test over a range of storm duration. For example, try T_d= 50 minutes. The calculations are summarized as follows:

(1) Inflow volume

$$I = \frac{74.1}{(10+50)^{0.786}} = 2.97 \quad \text{inch/hr}$$

$$Q_p = CIA = 0.68 * 2.97 * 62 = 125.2 \quad \text{cfs}$$

$$S_i = \alpha CIAT_d = 1 * 0.68 * 2.97 * 62 * 50 = 8.68 \quad \text{acre-ft}$$

(2) Outflow volume

$$T_b = \frac{Q_b}{Q_p} T_c = \frac{15}{125.2} * 20 = 2.40 \quad \text{minutes}$$

$$m = \frac{1}{2}[1 + \frac{20 - 2 * 2.4}{50}] + \frac{15}{47}(1 + \frac{20 - 2.4}{50}) = 1.1$$

$$S_o = mQ_a T_d = 1.1 * 47 * 50 * 60 / 43560 = 3.51 \quad \text{acre-ft}$$

(3) Storm water detention volume, S_d , for the 50-minute rain storm is:

$$S_d = 8.68 - 3.15 = 5.18 \quad \text{acre-ft}$$

Repeating this process for the range of rainfall duration from 40 to 80 minutes, Table 1 summarizes the variation of detention storage volumes. The maximum storage volume is identified to be 5.22 acre-ft with storm duration of 60.0 minutes.

Duration minutes	Rainfall Intensity inch/hr	Inflow Volume acre-ft	Peak Runoff cfs	Diversion Time T_b minutes	Coeff m	Outflow Volume acre-ft	Storage Volume acre-ft
40.00	3.42	8.02	144.32	2.08	1.16	3.00	5.01
50.00	2.97	8.68	125.05	2.40	1.08	3.51	5.18
60.00	**2.63**	**9.23**	**110.78**	**2.71**	**1.03**	**4.01**	**5.22**
70.00	2.37	9.70	99.75	3.01	1.00	4.52	5.18
80.00	2.16	10.10	90.93	3.30	0.97	5.02	5.08

Table 1 Maximal Detention Volume for Example Design

CONCLUSION

Over years, the FAA method has been used with the assumption that the peak outflow could be estimated by the gravity flow through the outfall pipe, i.e. Manning's equation. As a result, the flow-full capacity was then used to determine the outflow volume, i.e. m=1.0. Recognizing that the value of m must reflect the on-line and off-line operations, the current approach using FAA method underestimated the required storm water storage volume. This paper modifies the FAA method for both on-line and off-line basin designs. The design procedure documented in this paper has been adopted by the Denver metropolitan area in the State of Colorado.

ACKNOWLEDGMENT

The methods presented in this paper have been included in the Urban Storm Water Design Criteria Manual (2001), recommended by Urban Drainage and Flood Control District (UDFCD) for storm water designs in the Denver metropolitan area. The computer model, UD-Detention, can be downloaded with many other EXCEL Spreadsheets from the web site: UDFCD.ORG.

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