OVERFLOW RISK FOR ON-SITE STORM WATER DISPOSAL

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INTRODUCTION

The latest development for stormwater management is to emphasize source controls and on-site storm water disposal. An on-site storm water storage basin is mainly designed to have an extended release over a long period of time, and also to dispose storm water through the infiltrating process. Both processes prefer a long drain time. However, a prolonged occupation of basin storage volume by the previous event increases the potential overflow risk when the next event comes. Therefore this paper expands the previous studies to formulate the overflow risk with consideration of infiltration and gradual release.

BASIN INHERENT OVERFLOW RISK

The inherent overflow risk is defined as the chance to have an event that can produce more runoff volume than the basin storage volume. Therefore, the inherent overflow risk for an on-site storm water disposal basin depends on the basin storage volume and the local rainfall depth distribution. Consider the exponential distribution for the decay nature of rainfall depth distribution. The probability density function (PDF) is written as:

$$f(t) = me^{-mt} \quad for\ t>0 \qquad (1)$$

in which *f(t)* = PDF , m = constant, and t = time variable. The probability cumulative density function (CDF) is an integration of PDF as:

$$P(T_1\ to\ T) = \int_{T_1}^{T} me^{-mt}dt = e^{-mT_1} - e^{-mT} \qquad (2)$$

in which P(T_1 to T) = CDF from time limits T_1 to T, and T = elapse time. When T_1 =0, Eq 2 becomes

$$P(T) = \int_{0}^{T} me^{-mt}dt = 1 - e^{-mT} \qquad (3)$$

When T is infinite, Eq 2 becomes

$$P(T_1\ to\ \infty) = e^{-mT_1} \qquad (4)$$

Of course, for the range from T_1=0.0 to T= ∞, Eq 2 becomes unity. The mean, E(t), and variance, Var(t), of Eq 1 are:

$$E(t) = \frac{1}{m} \qquad (5)$$

$$Var(t) = \frac{1}{m^2} \qquad (6)$$

The Poisson distribution has a standard deviation, SD, of 1.0, and coefficient of skewness, C_s, of 2.0. To apply Eq's 5 and 6 to rainfall depth, the PDF of the rainfall depth distribution is expressed as:

$$f(D) = \frac{1}{D_m} e^{-\frac{D}{D_m}} \qquad (7)$$

in which D = rainfall depth, and D_m = average rainfall depth. The PDF of the interevent time distribution is expressed as:

$$f(T) = \frac{1}{T_m} e^{-\frac{T}{T_m}} \qquad (8)$$

in which T_m = average interevent time. The CPF functions for rainfall depth and rainfall interevent time are similar to Eq's 2 through 4.

OPERATIONAL OVERFLOW RISK

The operation of a basin is a cycle of filling and depletion periods. A WQC basin is usually designed to have a long drain time such as 24 to 48 hours. After the basin is full, the extended drain time warrants a sufficient sedimentation process. During such a long and slow releasing process, the chance for the basin to be overwhelmed by the next rainfall event is a concern. During the draining process, the release volume at time T after the basin was full is

$$V(T) = (q + f)\, T \quad \text{and} \quad T < T_d \qquad (9)$$

in which $V(T)$ = release volume or storage volume available at time T, T_d = drain time, q = release from the basin, f = infiltration rate per watershed. From time T, to the end of the drain time, T_d, the overflow risk, R_d, depends on the two probabilities:

(1) the next event will come between T and T_d, and
(2) the rainfall depth will exceed the available storage volume.

Such a join probability can be estimated as

$$R_d = P(T \le t \le T_d).P(V(T) \le D \le \infty) \qquad (10)$$

in which R_d = overflow risk during a drain time. After the basin becomes empty, the entire storage volume is available. Aided by Eq 4, the overflow risk is described as

$$R_e = P(V_o < D \le \infty) = e^{-\frac{V_o}{D_m}} \qquad (11)$$

in which R_e = overflow risk for an empty basin, and V_o = basin size. Therefore, the total cumulative probability of overflow, R, is:

$$R = P(T \le t \le T_d).P(V(T) \le D \le \infty) + P(T_d \le t \le \infty).P(V_o \le D \le \infty) \tag{12}$$

Aided by Eq 9, Eq 12 is reduced to

$$R = P(T \le t \le T_d).P[(q+f)T \le D \le \infty] + 1 * R_e \tag{13}$$

Aided by Eq's 2, 3, and 4, Eq 13 becomes

$$R = (e^{-\frac{T}{Tm}} - e^{-\frac{T_d}{Tm}})e^{-\frac{(q+f)T}{Dm}} + R_e \tag{14}$$

Eq 14 is the total cumulative overflow risk for an on-site basin. It consists of the overflow probability during the emptying period, and the arrival probability of a rainfall event exceeding the storage capacity of the basin.

DESIGN SCHEMATICS

To illustrate the design procedure, an on-site basin located in Boston, MA is used as a design example. The size of the basin is determined to be 7.62 mm (0.30 inch) per watershed. Based on the characteristics of sediments, the drain time is determined to be 24 hours. The basin bottom area is 404.8 square meters (0.10 acre), and the tributary drainage area to the basin is 8097.8 square meters (2.0 acres). The infiltration rate at the basin site is 6.35 mm/hr (0.25 inch/hr) per square foot. The summary of the design information for the system is listed as:

V_o *= 7.62 mm,*
T_d *= 24 hours,*
$q = V_o/ T_d$ *= 7.62/24.0 = 0.317 mm/hr per watershed*, and
f *= 6.35 mm/hr * basin area/watershed area = 6.35 * 0.10/2.0 = 0.32 mm/hr per watershed*

From EPA report (1986), the rainfall statistics for the City of Boston are: D_m = 3.30 mm and T_m = 69.1 hours. According to Eq 11, the *inherent risk* for an empty basin is

$$R_e = e^{-\frac{7.62}{3.30}} = 0.0995 \tag{15}$$

Substituting Eq 15 and design parameters into Eq 14 yields the *operational risk* as:

$$R = (e^{-0.0145T} - 0.707)e^{-0.194T} + 0.0995 \tag{16}$$

Solutions for Eq 16 depend on the elapsed time. The overflow probabilities at various elapsed times are calculated and presented in the fourth column in Table 1. Of course, the overflow risk begins with its highest level when the basin is full, and then gradually reduces through the emptying process. After the basin becomes empty, the overflow risk converges to a constant level determined by the basin storage volume.

Elapsed Time	Overflow Risk for Various Basin Sizes				
hour	2.54 mm/watershed	5.08 mm/watershed	7.62 mm/watershed	10.16 mm/watershed	15.24 mm/watershed
1	0.709	0.453	0.330	0.269	0.237
2	0.669	0.407	0.280	0.215	0.180
4	0.606	0.340	0.210	0.143	0.107
6	0.561	0.295	0.166	0.101	0.067
10	0.508	0.247	0.123	0.063	0.034
20	0.478	0.224	0.105	0.050	0.023
30	0.467	0.216	0.100	0.047	0.022
50	0.463	0.215	0.099	0.046	0.021

Table 1 Overflow Risk for Various Basin Sizes at Various Elapsed Times

Since a tradeoff exists between basin size and overflow risk, a sensitivity study was conducted for basin sizes ranging from 2.54 to 15.24 mm per watershed. The calculated risk levels are summarized in Table 1. For the range of basin size from 2.54 to 7.62 mm, the basin experiences an increasing return on the reduction of overflow risk, but from 7.62 to 15.24 mm, the basin experiences a diminishing return on the reduction of overflow risk. In other words, when a basin smaller than 7.62 mm per watershed is encouraged to increase its size, but a basin larger than 7.62 mm per watershed is discouraged because of the diminishing return on the reduction of overflow risk. This implies that a basin with a 7.62 mm storage volume is considered as a break-even point as far as the overflow risk is concerned. Therefore, for this case, it is recommended that the proper basin size be 7.62 mm per watershed for 24-hour drain time. Of course, a similar study can be conducted when a different drain time is selected.

CONCLUSION

It is clear that the runoff volume to be captured and treated is a critical factor in the design of on-site stormwater disposal detention or retention basins. In order to capture more storm runoff by a retention system for treatment, it is concluded that the size of the retention system is the bigger, the better. However, after a certain threshold size is reached, further removal of sediment becomes negligible. If the design runoff event is too small, the effectiveness of the detention basin will be reduced due to a large number of storms that exceeds the capacity of the facility. Or if the basin size is too large, the smaller runoff events will flow through the detention basin faster than desired for adequate settling of pollutants. Thus the detention basin would not be fully utilized, except on rare occasions. In this study, a methodology was developed to evaluate the overflow risk using the average rainfall interevent time, average rainfall depth, basin size, and drain time. Based on the sediment characteristics, the drain time of a basin can be determined. The proper basin size can then be chosen from a range of basin sizes, based on the diminishing return on the reduction of the overflow risk. This approach generally leads to a storage volume equivalent to the magnitude of 3 to 4-month event. To apply this method, the required average interevent time and rainfall depth are available in the 1986 EPA report for the United States.

APPENDIX I

Bedient, P.B., and Huber, W.C. (1992). "*Hydrology and Floodplain Analysis*", 2nd Edition, Addison Wesley Inc., New York.

Denver Urban Storm Water Design Criteria Manual, (1999). published by Urban Drainage and Flood Control District, Vol 3, Nov.

EPA Report (1986). *Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality*, U.S Environmental Protection Agency, EPA440/5-87-001, September.

Guo, James C.Y. (2003). "*Design of Infiltrating Basin by Soil Storage and Conveyance Capacities*," IWRA International J. of Water, Vol 28, No. 4, December.

Guo, James C.Y. (2002). "*Overflow Risk of Storm Water BMP Basin Design*," ASCE J. of Hydrologic Engineering, Vol 7, No. 6, Nov.

Guo, James C.Y. and Urbonas, Ben. (2002). "*Runoff Capture and Delivery Curves for Storm Water Quality Control Designs*," ASCE J. of Water Resources Planning and Management, Vol 128, Vo. 3, May/June.

Guo, James C.Y. and Hughes, William. (2001). "*Runoff Storage Volume for Infiltration Basin*," ASCE J. of Irrigation and Drainage Engineering, Vol 127, No. 3, May/June.

Guo, James C.Y. (2001). "*Design of Circular Infiltration Basin Under Water Mounding Effects*," ASCE J. of Water Resources Planning and Management, Vol 127, No.1, Jan/Feb.

Guo, James C.Y. (1999). "*Sand Recovery for Highway Drainage Designs*," ASCE J. of Drainage and Irrigation Engineering, Vol 125, No 6, Nov.

Guo, James C.Y. (1999). "*Detention Basin Sizing for Small Urban Catchments*," ASCE J. of Water Resources Planning and Management, Vol 125, No.6, Nov.

Guo, James C.Y. (1998). "*Risk-cost Approach to Interim Drainage Structure Designs*," ASCE J. of Water Resources Planning and Management, Vol 124, No 6, Nov/Dec.

Guo, James C.Y. (1998). "*Subsurface-surface Hydrologic Model for Infiltration Trenches*," ASCE J. of Water Resources Planning and Management, Vol 124, No 5, Sept.

Urbonas, Ben, Rosner, Larry. and Guo, James C.Y. (1996). "*Hydrology for Optimal Sizing of Urban Runoff Treatment Control System*", Journal of Water Quality International, London, SW1H9BT, UK, February.