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RESEARCH ARTICLE

DESIGN OF A DETENTION BASIN TO MITIGATE FLOOD DUE TO TEMPORAL CHANGE IN LAND USE SYSTEM IN URBAN WATERSHED

Ravikumar B. Choodegowda*, Murukannappa and Kedarnath

Department of Agricultural Engineering, University of Agricultural Sciences, GKVK, Bangalore, India

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ABSTRACT

Temporal change in land use system due to city expansion in urbanized watersheds poses a potential of increasing storm runoff rates, and therefore increasing the risk of flooding. Detention basins or ponds are generally considered as effective structures for storm water quality and quantity control in these areas. The present study was taken up to assess the impact of changed land use system over a period of time on hydrology and preliminary design of a detention basin for three different storms events for a site at Little Kitten Creek watershed near Manhattan, Kansas, USA. Seven different methods for estimating detention basin volumes were investigated in this study. SMADA model was used to develop final designs of the detention basin using the computed mean detention basin storage volumes of seven methods estimated. Three different storm events for 24 hours were used to develop hydrograph. The study found that, larger storms such as 100 year storm event overtops the detention basin by a considerable depth, and also quite expensive to design and construct. Therefore it is recommended to design and construct series of smaller detention basins well spaced within the watershed that are capable of handling storm runoff and also improves the aesthetic value in the urban settlement.

INTRODUCTION

Land development in urbanized watersheds poses a potential of increasing storm runoff rates, and therefore increasing the risk of flooding in the downstream areas of a watershed. Detention basins or ponds are generally considered as effective structures for storm water quality and quantity control in urbanized watersheds. The objective of this study was to develop a preliminary design of a detention basin for three different storms events for a site at Colbert Hill Golf Course on Little Kitten Creek watershed near Manhattan city, Kansas, USA.

METHODS AND MATERIALS

Seven different methods of estimating detention basin volumes were investigated in this study. These methods include: Generalized Planning Model, Loss of Natural Storage, Rational Hydrograph, Baker, Abt and Grigg, Wycoff and Singh, and SCS-TR55 method.

These methods were used to develop an initial estimate of the detention basin storage volume required to handle storm runoff generated from different storm events (5, 25 and 100 year storm events). Detention basin storage volume calculations (for all the seven methods) are presented in the Table1 shows a summary of the calculated estimates of the detention basin storage volumes required to handle runoff from the different storm events. Table 2 contains a summary of the estimated mean and median detention basin storage volumes for the three different storm events. The mean detention basin storage volume was then computed from the initial volume estimates determined using the above methods. Using the computed mean detention basin storage volume as a guide, SMADA model was used to develop final designs of the detention basin. The 5 year, 24 hour storm was used to design the primary spillway, while the 25 year, 24 hour storm was used to design the emergency spillway. The dimension, shape and outlet structures of the detention basin were selected in the model and a stage-storage relationship was developed. In designing the primary spillway, an orifice was selected as the outlet structure for the detention basin. Flow through an orifice is governed by Equation 1. Sizing of the primary spillway was done by trial and error (using the computed mean detention volume and a desired stage as a guide); each time the 5 year post development runoff hydrograph was routed through the detention basin to determine the performance of the basin in reducing the peak flow rate. Likewise, the secondary or emergency spillway was selected as a broad crested weir. The flow through a weir is governed by Equation 2. Sizing of the emergency spillway was also done by trial and error, and each time the 25 year post development hydrograph was routed through the detention basin until desired outlet structure dimensions were determined. In order to investigate the impact of a storm event larger than the 25 year, 24 hour event on the

*Corresponding author: **Ravikumar B. Choodegowda**
Department of Agricultural Engineering, University of Agricultural Sciences, GKVK, Bangalore, India

detention basin, a 100 year, 24 hour storm hydrograph was routed through the basin. Figures 1, 2 and 3 show the pre and post development runoff hydrographs for the 5, 25, and 100 years, 24 hour storm events, respectively used as inflow hydrographs in the model.

$$Q = C \times A\sqrt{2g} \times H^{n} \tag{1}$$

$$Q = B \times C \times H^{n} \tag{2}$$

Where

C = 0.6 and 3.33 for orifice and broadcrested weir, respectively.
n = 0.5 and 1.5 for orifice and broadcrested weir, respectively.
A = Area of orifice (m^2)
H = Height of flow in pipe or weir (m).
B = Width of weir (m).
g = Acceleration due to gravity (m/s^2)

Table 1 Summary of Estimates of Detention Basin Volume (for storm events of different return periods) Calculated Using Different Methods.

Method	R_v	V_s (cm)	V_{st} (ha.m)		
			5 Years	25 Years	100 Years
Generalized model	0.24	2.03	10.02	15.07	19.08
Natural storage lost	0.17	1.40	6.92	9.16	10.51
Rational hydrograph	0.10	0.84	2.77	4.31	5.54
Baker method	0.24	2.04	10.05	14.11	17.04
Abt and Grigg	0.24	0.22	1.11	1.40	1.59
Wycoff and Singh	0.17	2.53	12.51	18.50	23.00
SCS TR-55	0.10	1.18	5.85	9.05	11.61

Note: R_v = Storage volume/runoff volume, V_s=Volume of storage in cm., V_{st}=Storage volume (ha.m)

Table 2 Summary of Mean and Median Estimates of Detention Basin Volume (for storm events of different return periods) Calculated Using Different Methods.

Parameter	5 Year Storm	25 Year Storm	100 Year Storm
Mean (ha.m)	8.02	13.18	14.46
Median (ha.m)	8.47	14.11	14.33

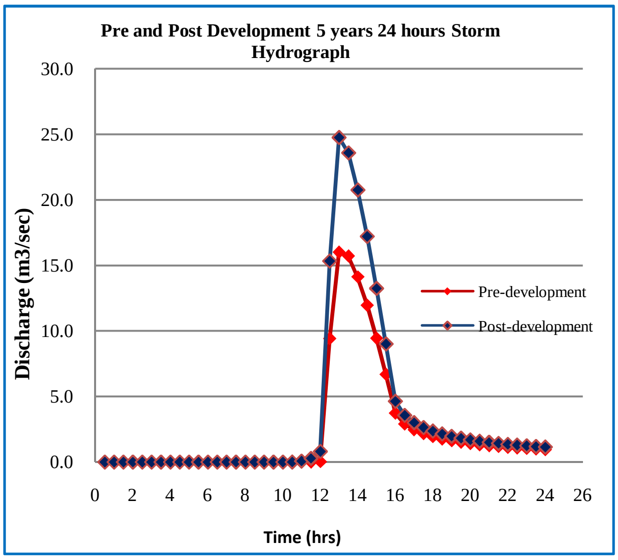

Figure 1 Pre and Post Development 5 Years, 24 Hour Design Hydrograph.

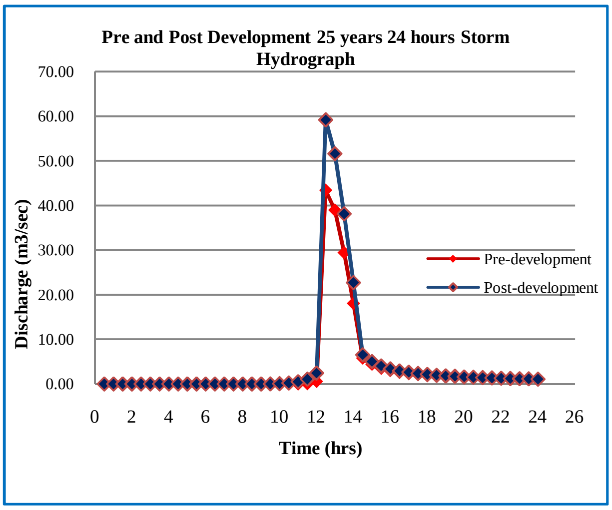

Figure 2 Pre and Post Development 25 Years, 24 Hour Design Hydrograph

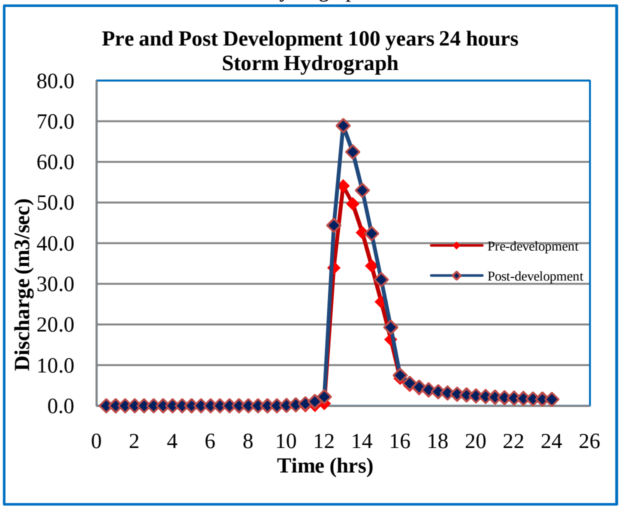

Figure 3 Pre and Post Development 100Years, 24 Hour Design Hydrograph.

RESULTS AND DISCUSSION

The stage-storage relationships developed for the 5, 25, and 100 years, 24 hour storm events, respectively, is shown in Figures 4, 5 and 6.

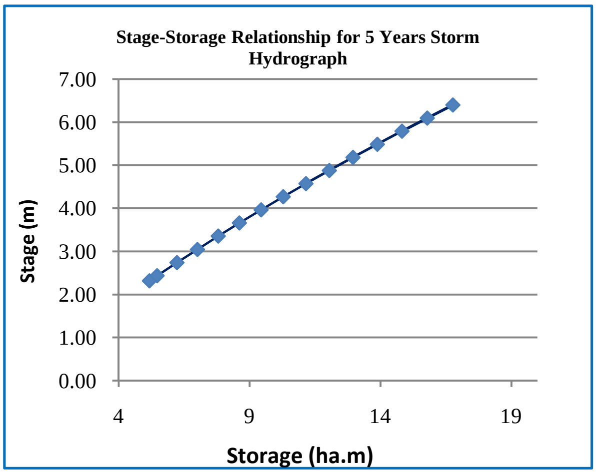

Figure 4 Stage-Storage Relationship to Handle 5 Year, 24 Hour Runoff

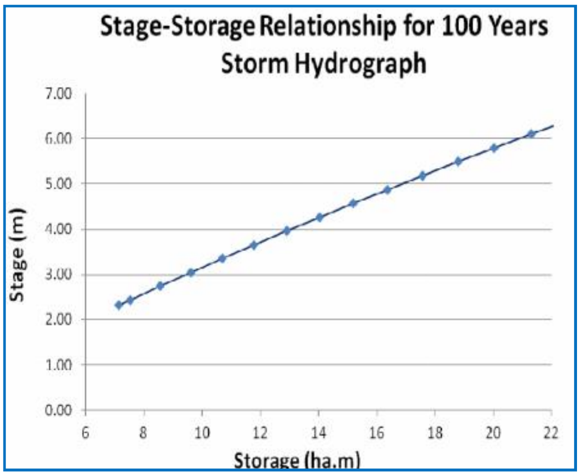

Figure 6 Stage-Storage Relationship to Handle 100 Year, 24 Hour Runoff

Storm hydrographs for three different return intervals were routed through the detention basin. The routing computations of inflow and outflow rates are shown in Tables 3 for the 5 and 25, and 100 years, 24 hour storm events. Figures 4 and 5 show the post development inflow and outflow hydrographs through the detention basin for 5 and 25 years, 24 hour storm events, respectively. From Figures 4 and 5, it is clearly shown that the detention basin is capable of attenuating both 5 and 25 year post development peak runoff rates to rates below predevelopment peak runoff rates. Therefore these designs stand an excellent chance of addressing the flooding problem experienced in lowland areas of the watershed resulting from storm events of equal or less magnitude as the 25 year storm.

Simulations based on the 100 year storm event overtopped the detention basin by approximately 1.37m. Therefore a bigger detention basin is required to contain a larger storm event such as the 100 year storm. However, a larger detention basin implies high costs, and reduced aesthetic value of property in the vicinity of the detention basin. Instead of using one large detention basin within the watershed, it is recommended that a series of smaller detention basins (well spaced within the watershed) be constructed to mitigate impacts of storm events. Smaller detention basins blend in well with the surrounding environment, making it aesthetically pleasing. The areas around these basins can be attractive for real estate development.

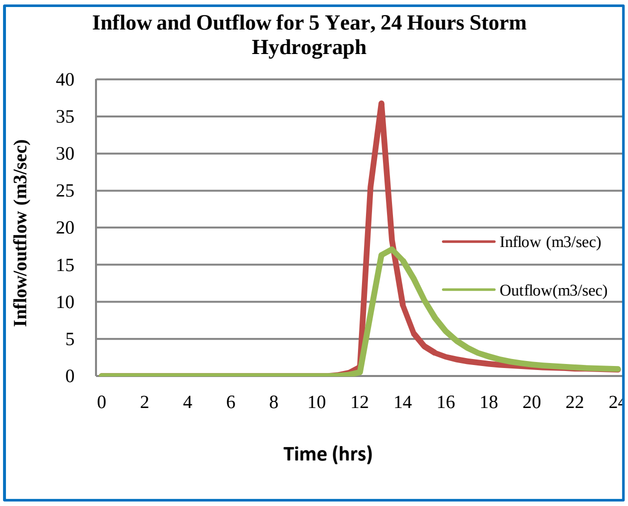

Figure 7 Inflows and Outflow for 5 Year, 24 Hours Storm Hydrograph at Detention Basin.

Table 3 A Summary of Hydrograph Routing Calculations

5 years storm event					25 years storm event					100 years storm event				
Time	Inflow (m3/sec)	Outflow (m^3/sec)	Stage (m)	Storage (ha.m)	Time	Inflow (m^3/sec)	Outflow (m^3/sec)	Stage (m)	Storage (ha.m)	Time	Inflow (m^3/sec)	Outflow (m^3/sec)	Stage (m)	Time (ha.m)
9	0.00	0.00	0.00	0.00	9	0.00	0.00	0.00	0.00	9	0.00	0.00	0.00	0.00
9.5	0.00	0.00	0.00	0.00	9.5	0.00	0.00	0.00	0.00	9.5	0.03	0.01	0.00	0.00
10	0.00	0.00	0.00	0.00	10	0.06	0.02	0.00	0.01	10	0.13	0.04	0.01	0.02
10.5	0.02	0.01	0.00	0.00	10.5	0.22	0.08	0.02	0.04	10.5	0.35	0.11	0.02	0.07
11	0.14	0.05	0.01	0.02	11	0.51	0.22	0.04	0.10	11	0.73	0.25	0.05	0.16
11.5	0.45	0.18	0.03	0.08	11.5	1.06	0.49	0.10	0.22	11.5	1.40	0.52	0.11	0.34
12	1.20	0.51	0.10	0.22	12	2.35	1.10	0.21	0.48	12	3.01	1.09	0.23	0.71
12.5	25.44	8.39	1.64	3.66	12.5	50.33	15.50	3.16	7.29	12.5	73.51	17.72	3.51	11.23
13	36.77	16.31	3.37	7.85	13	70.66	44.33	5.78	14.79	13	101.93	62.32	6.32	22.24
13.5	18.28	17.09	3.59	8.43	13.5	32.07	38.02	5.40	13.61	13.5	43.84	53.91	5.88	20.39
14	9.54	15.58	3.18	7.34	14	15.43	25.33	4.50	10.97	14	20.05	35.34	4.86	16.32
14.5	5.76	13.11	2.59	5.84	14.5	8.67	17.82	3.73	8.80	14.5	10.70	22.71	4.05	13.21
15	4.01	10.22	2.00	4.46	15	5.73	14.96	3.02	6.93	15	6.79	17.30	3.43	10.95
15.5	3.11	7.80	1.53	3.41	15.5	4.29	12.04	2.36	5.27	15.5	4.97	14.22	2.88	9.02
16	2.59	6.02	1.18	2.63	16	3.49	9.14	1.79	3.99	16	3.99	11.48	2.41	7.43
16.5	2.24	4.74	0.93	2.07	16.5	2.99	7.04	1.38	3.08	16.5	3.38	9.46	2.00	6.16
17	1.99	3.80	0.74	1.66	17	2.65	5.54	1.09	2.42	17	2.95	7.88	1.67	5.13
17.5	1.80	3.12	0.61	1.36	17.5	2.38	4.46	0.87	1.95	17.5	2.64	6.60	1.40	4.30
18	1.65	2.62	0.51	1.14	18	2.15	3.67	0.72	1.60	18	2.42	5.58	1.18	3.63
18.5	1.51	2.24	0.44	0.98	18.5	1.97	3.09	0.61	1.35	18.5	2.22	4.76	1.01	3.10
19	1.41	1.96	0.38	0.85	19	1.83	2.67	0.52	1.16	19	2.05	4.10	0.87	2.67
19.5	1.32	1.74	0.34	0.76	19.5	1.71	2.34	0.46	1.02	19.5	1.91	3.57	0.76	2.32
20	1.24	1.57	0.31	0.69	20	1.61	2.09	0.41	0.91	20	1.78	3.13	0.66	2.04
20.5	1.18	1.44	0.28	0.63	20.5	1.51	1.90	0.37	0.83	20.5	1.67	2.78	0.59	1.81
21	1.12	1.33	0.26	0.58	21	1.42	1.74	0.34	0.76	21	1.57	2.48	0.52	1.62
21.5	1.06	1.24	0.24	0.54	21.5	1.35	1.61	0.31	0.70	21.5	1.48	2.24	0.47	1.46
22	1.01	1.16	0.23	0.51	22	1.29	1.50	0.29	0.65	22	1.40	2.04	0.43	1.33
22.5	0.97	1.10	0.22	0.48	22.5	1.23	1.41	0.27	0.61	22.5	1.34	1.87	0.40	1.21
23	0.94	1.05	0.20	0.46	23	1.19	1.33	0.26	0.58	23	1.27	1.72	0.37	1.12
23.5	0.90	1.00	0.20	0.44	23.5	1.15	1.27	0.25	0.56	23.5	1.23	1.60	0.34	1.04
24	0.86	0.95	0.19	0.42	24	1.10	1.22	0.24	0.53	24	1.20	1.50	0.32	0.98

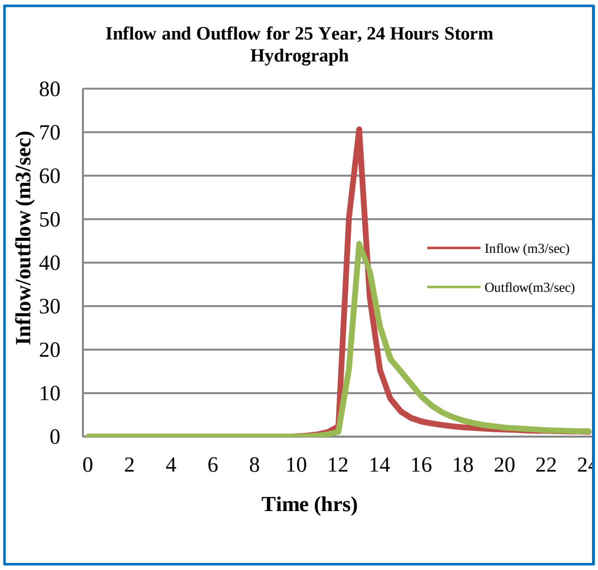

Figure 8 Inflow and Outflow for 25 Year, 24 Hours Storm Hydrograph at Detention Basin.

A summary of design dimensions of the detention basin are presented in Table 4, while design dimensions of the basin outlet structures are presented in Table 5.

Table 4 A Summary of Design Dimensions of the Detention Basin

Design Parameter	Magnitude of Parameter
Detention Basin Shape	Square Shape
Total Volume of Detention Basin (ha.m)	15.79
Total Height of Basin (m)	6.10
Side slope of Detention Basin	1:03
Detention Basin Base Area (ha)	12.35
Elevation of Primary Spillway (m)	345
Elevation of Emergency Spillway (m)	348.7
Elevation of Detention Basin Top (m)	351.1

Note: Elevations based on topographic map.

Table 5 A Summary of Design Dimensions of the Detention Basin Outlet Structures

Primary Outlet Structure: Orifice	Secondary Outlet Structure: Broad crested Weir
Diameter (D) = 2.29 m	Width = 3.66 m
Weir Invert = 0 m	Weir Invert = 3.66 m
Material: Concrete	Material: Concrete

CONCLUSION

Urbanization of a watershed increases storm runoff rates in the watershed as a result of increased impervious area and reduced water infiltration rates. Detention basins are commonly used to control the quality and quantity of storm runoff, therefore mitigating impacts associated with large volumes of storm runoff. Preliminary design estimates for detention basin volume for a site at Colby Hills Golf Course were computed using a host of methods.

SMADA model was then used to develop final design dimensions of the detention basin. Based on simulations performed by the SMADA model, the detention basin designed is capable of attenuating storm runoff peaks without causing undesirable impacts in the watershed. However, larger storms such as the 100 year storm event overtops the detention basin by a considerable depth, and this implies that a larger basin is required to handle or contain storm events as large as the 100 year event.

However, large detention basins are quite expensive to design and construct. It is therefore recommended to design a series of smaller detention basins well spaced within the watershed to handle storm runoff in the watershed. Smaller detention basins are capable of slowing down flow velocities, and look attractive to developers as well as to the general public.

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