DETENTION BASIN DESIGN

Abdelhak Hajjari

CTC 260
Project #: 4

May 6, 2009

Table of Contents

Table of Figures

List of Tables

1. INTRODUCTION

In this report, we present the steps followed to design a detention basin for the proposed tract. The site is located near St. Paul, Minnesota. The TR-55 graphical peak discharge method, described in [1], is used in the runoff computations.

To design the detention basin for the proposed plan, we first calculate the peak runoff for two site conditions: Pre-development phase (present) and Post-development phase (developed).

By trial and error, we design a detention basin and route the inflow hydrograph through the basin. The peak rate of runoff entering the natural stream after development will be attenuated so that it will not exceed the pre-development peak runoff rate for a 100-year frequency storm.

2. SITE INFORMATION AND WATERSHED PARAMETERS

2.1. Site Information

The provided site information and watershed parameters are,

a. Site location: Near St. Paul, Minnesota

b. Type II rainfall distribution (from Figure B-2 in [1])

c. Hydrologic Soil group: B

d. Cover Description:

Predevelopment:
Woods, good condition

Postdevelopment:
Impervious (parking lots, roads and roofs)
Lawns, good condition
Woods, fair condition

2.2. Watershed Delineation and Drainage area calculation

The drainage area tributary to the proposed detention basin is delineated as shown in Figure A.1. Note that the drainage area includes land uphill of the tract that drains onto the tract. This area is used to compute both predevelopment and postdevelopment runoff for detention design because it best represents total runoff leaving the tract.

The area is measured using Autocad software and the value found is:

Area = 631500 ft^2
= 14.5 acres
= 0.023 square mile

Figure 1: Map of Site and Delineated Watershed

3. PEAK DISCHARGE AND HYDROGRAPH COMPUTATION

3.1. Method

The peak runoff is calculated using the graphical peak discharge method, described in TR-55 report [1]. The hydrograph is determined using the exhibits which are also provided in the TR-55 report [1].

The following steps are followed in determining the peak runoff in the graphical peak discharge method:

a) Total drainage area, A_m, in square miles
b) Time of concentration, T_c, in hours
c) Weighted curve number, CN
d) Appropriate rainfall distribution (I, IA, II, or III)
e) Total runoff, Q, in inches computed from CN and rainfall
f) 24-hour rainfall, P, in inches
g) Initial abstraction, Ia (in). From Table 5-1 of [1].
h) Ratio of Ia/P

The peak discharge, q_p, is computed using the following equation,

$$q_p = q_u A_m Q F_p \qquad \text{(Equation 1)}$$

where, q_p is the peak discharge (cfs), q_u is the unit peak discharge from exhibit 4 (csm/in), A_m is the drainage area (mi^2), Q is the runoff (in), and F_p is pond and swamp adjustment factor (In our case, we assume that there is no pond or swamp so F_p =1)

The computation of the hydrograph coordinates for selected T_c, T_t (Note here that T_t = 0 because the flow is running directly to the outlet) and Ia/P is carried out using the appropriate sheets in Exhibit 5-II [1]. The flow at any time of the hydrograph is

$$q = q_t A_m Q \qquad \text{(Equation 2)}$$

where, q is the hydrograph coordinate (cfs) at hydrograph time t, q_t is the tabular hydrograph unit discharge from exhibit 5 (csm/in), A_m is the drainage area (mi^2), and Q is the runoff (in).

3.2. Predevelopment

3.2.1. Time of Concentration

The hydraulic path used to calculate the time of concentration is shown in Figure 2. Segmentation of the hydraulic path is also shown in Figure 2. Note that it is assumed that there is no open channel in the watershed and only two segments are considered. Segment AB corresponds to the sheet flow and Segment BC corresponds to the shallow concentrated flow.

Figure 2: Delineated Watershed and Hydraulic Path - Predevelopment

The two segments have the following parameters:

Sheet flow: Grass
- Length, L = 100 ft
- Slope, s = 10%
- Manning's roughness coefficient, n=0.40

Shallow concentrated flow:
- Length, L = 1180 ft
- Slope, s = 10%

The time of concentration is found to be: (For details, see Table 1)

Sheet flow: T1 = 0.20 hr
Shallow concentrated flow: T2 = 0.07 hr

Time of concentration, Tc: Tc = T1+T2
Tc = 0.27 hr
= 16 min

Note: the Manning's roughness coefficient for the sheet flow is assumed to be equal to 0.40 because the surface is wooded.

Table 1: Time of Concentration Computation – Predevelopment

U.S. Department of Agriculture
Natural Resources Conservation Service

FL-ENG-21B
06/04

TR 55 Worksheet 3: Time of Concentration (T_c) or Travel Time (T_t)

Project: Project 4 Designed By: AH Date: 4/29/09

Location: St Paul, MN Checked By: Date:

Check one: ✓ Present Developed

Check one: ✓ T_c T_t through subarea

NOTES: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

Sheet Flow (Applicable to T_c only)

		Segment 1	Segment 2	Total
	Segment ID	AB		
1. Surface description (Table 3-1)		Woods		
2. Manning's roughness coeff., n (Table 3-1)		0.40		
3. Flow length, L (total L ≤ 100 ft)	ft	100		
4. Two-year 24-hour rainfall, P_2	in	2.8		
5. Land slope, s	ft/ft	0.100		
6. $T_t = \frac{0.007 (nL)^{0.8}}{P_2^{0.5} s^{0.4}}$ Compute T_t	hr	0.20	+	= 0.20

Shallow Concetrated Flow

		Segment 1	Segment 2	Total
	Segment ID	BC		
7. Surface description (paved or unpaved)		Unpaved		
8. Flow length, L	ft	1,180		
9. Watercourse slope, s	ft/ft	0.100		
10. Average velocity, V (Figure 3-1)	ft/s	4.8		
11. $T_t = \frac{L}{3600 V}$ Compute T_t	hr	0.07	+	= 0.07

Channel Flow

		Segment 1	Segment 2	Total
	Segment ID			
12. Cross sectional flow area, a	ft^2			
13. Wetted perimeter, P_w	ft			
14. Hydraulic radius, $r = \frac{a}{P_w}$ Compute r	ft			
15. Channel Slope, s	ft/ft			
16. Manning's Roughness Coeff., n				
17. $V = \frac{1.49 r^{2/3} s^{1/2}}{n}$ Compute V	ft/s			
18. Flow length, L	ft			
19. $T_t = \frac{L}{3600 V}$ Compute T_t	hr		+	=

20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19 ... hr 0.27

3.2.2. Curve Number and Runoff Computation

As cited in the site information, the surface area is wooded and it is in good condition. The curve number, CN, and the runoff, Q, are calculated using Worksheet 2. The computation of CN and Q are shown in Table 2, and the values are found to be

CN = 55.
Q = 1.5 in.

Note here that the runoff, Q, is determined using Table 2-1of [1] using the appropriate CN and the 24-hours storm rainfall P. The 24-hours storm rainfall, P, is determined from IDF curves developed in this study and listed in Appendix A of this report.

Table 2: Curve Number, C, and Runoff, Q, Computation – Predevelopment

U.S. Department of Agriculture
Natural Resources Conservation Service

FL-ENG-21A
06/04

TR 55 Worksheet 2: Runoff Curve Number and Runoff

Project: Project #4 Designed By: AH Date: 4/29/0

Location: St Paul, MN Checked: Date:

Check one: ☑ Present ☐ Developed

1. Runoff curve number (CN)

Soil name and hydrologic group (Appendix A)	Cover description (Cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1/] Table 2-2	CN [1/] Fig. 2-3	CN [1/] Fig. 2-4	Area ☐ acres ☐ mi² ☑ %	Product of CN x area
Soil Name, B	Wooded, Good Condition	55			100.0	5,500.0
				Totals =	100.0	5,500.0

[1/] Use only one CN source per line.

CN (weighted) = total product / total area = 5,500.0 / 100.0 = 55 Use CN = 55

2. Runoff

	Storm #1	Storm #2	Storm #3
Frequency ... years	100		
Rainfall, P (24 hour) ... in.	5.9		
Runoff, Q ... in. (Use P and CN with Table 2-1, Figure 2-1, or equations 2-3 and 2-4.)	1.5		

3.2.3. Peak Discharge

The computation of the peak discharge use Equation 1 and the steps followed are detailed in Worksheet 4 as shown in Table 3. The peak discharge of the site before development is found to be

$$q_p = 20 \text{ cfs}$$

Table 3: Peak Discharge Computation - Predevelopment

U.S. Department of Agriculture
Natural Resources Conservation Service

FL-ENG-21C
06/04

Tr 55 Worksheet 4: Graphical Peak Discharge Method

Project: Project #4 Designed By: AH Date: 4/29/09

Location: St Paul, MN Checked By: Date:

Check one: ✓ Present ___ Developed

1. Data:

Drainage area .... A_m = 0.02 mi² (acres/640)

Runoff curve number .... CN = 55 (From Worksheet 2)

Time of concentration ..... T_c = 0.28 hr (From Worksheet 3)

Rainfall distribution type ...... = II (II, III, DMVIII)

Pond and swamp areas spread throughout watershed .... = 0 percent of A_m (________ acres or mi² covered)

			Storm #1	Storm #2	Storm #3
2.	Frequency	yr	100		
3.	Rainfall, P (24-hour)	in	5.9		
4.	Initial abstraction, I_a (Use CN with Table 4-1.)	in	1.636		
5.	Compute I_a/P		0.28		
6.	Unit peak discharge, q_u (Use T_c and I_a/P with exhibit 4- 10)	csm/in	590		
7.	Runoff, Q (From Worksheet 2)	in	1.50		
8.	Pond and swamp adjustment factor, F_p (Use percent pond and swamp area with Table 4-2. Factor is 1.0 for zero percent pond and swamp area.)	in	1.0		
9.	Peak discharge, q_p (Where $q_p = q_u A_m Q F_p$)	cfs	20		

3.2.4. Discharge Hydrograph

The discharge hydrograph is constructed using Exhibit 5-II for a T_C = 0.3hr, T_t= 0.0 and Ia/P = 0.3. The flow at any time of the hydrograph is calculated using Equation 2. The discharge hydrograph is illustrated in Figure 3.

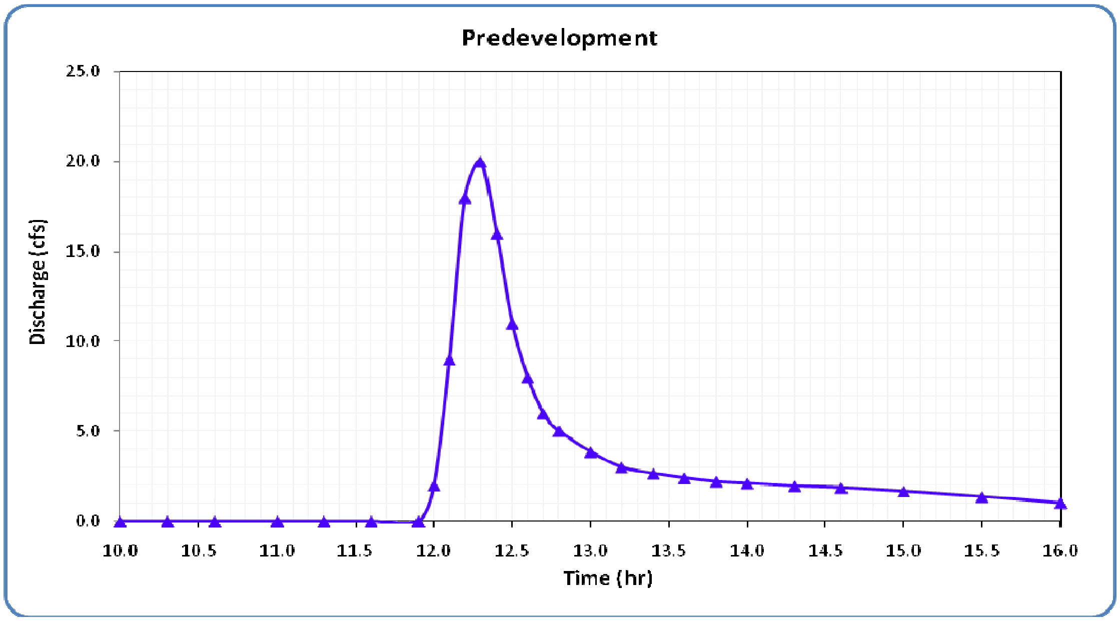

Figure 3: Discharge Hydrograph - Predevelopment

3.3. Postdevelopment

3.3.1. Time of concentration

The hydraulic path used to calculate the time of concentration is shown in Figure 4. Segmentation of the hydraulic path is also shown in Figure 4, where Segment AB is the sheet flow, Segment BC is the Shallow concentrated flow, and Segment CD is the pipe flow. Here, I want to note that I assume that a pipe run from the buildings and the parking into the detention basin, as shown in Figure 4. The design of the pipe is beyond the scope of this report. The travel time within the pipe is assumed to be

T3 = 0.03 hr

The segments AB and BC have the following parameters:

Sheet flow: Grass
Length, L = 100 ft
Slope, s = 14%
Manning's roughness coefficient, n=0.40

Shallow concentrated flow:
Length, L = 624 ft
Slope, s = 14%

The time of concentration is found to be:

Sheet flow: T1 = 0.18 hr
Shallow concentrated flow: T2 = 0.03 hr

Time of concentration, Tc: Tc = T1+T2+T3
Tc = 0.24 hr
= 14 min

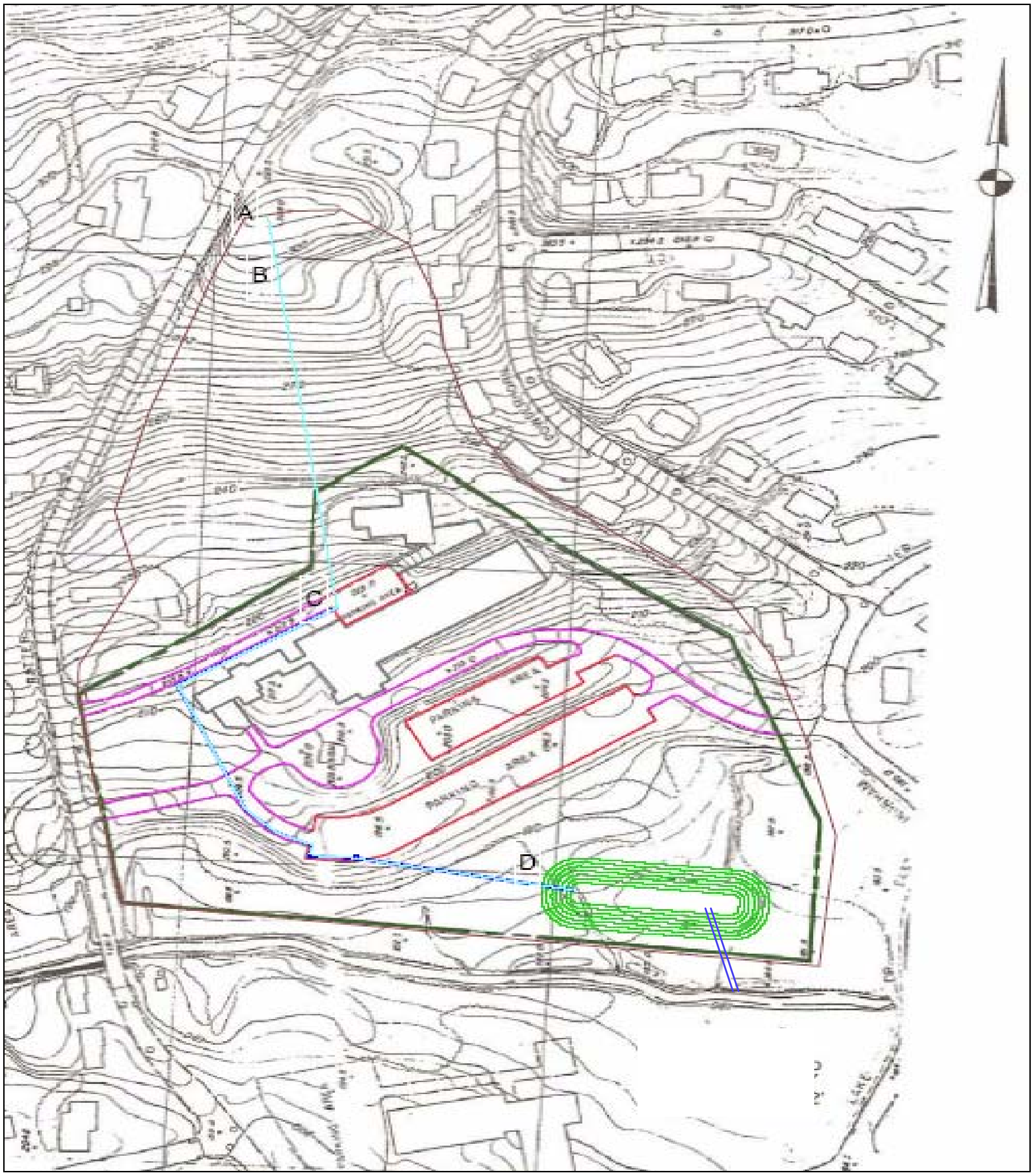

Figure 4: Delineated Watershed and Hydraulic Path – Post-development

3.3.2. Curve Number and Runoff Computation

The computation of the curve number is completed using Worksheet 2 [1]. The curve number is weighted because there are different surface types within the drainage area.

Four types exist in the site under study. The hydrologic soil group B, is assumed for the site.

Type 1: Impervious (Parking lots, Paved roads, and Roofs): 2.76 acres with CN = 98
Type 2: Lawn, Good Condition: 4.49 acres with CN = 61
Type 3: Woods, Fair Condition: 2.9 acres with CN = 60
Type 4: Woods, Good Condition (Part outside the tract): 4.35 acres with CN = 55

The computation of CN and Q are shown in Table 2, and the values are found to be

CN = 66.
Q = 2.4 in.

Table 4: Curve Number, CN, and Runoff, Q, Computation – Post-development

U.S. Department of Agriculture
Natural Resources Conservation Service

FL-ENG-21A
06/04

TR 55 Worksheet 2: Runoff Curve Number and Runoff

Project: Project #4 Designed By: AH Date: 4/29/0
Location: St Paul, MN Checked: Date:

Check one: ☐ Present ☑ Developed

1. Runoff curve number (CN)

Soil name and hydrologic group (Appendix A)	Cover description (Cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1]			Area ☐ acres ☐ mi² ▣ %	Product of CN x area
		Table 2-2	Fig. 2-3	Fig. 2-4		
	Impervious	98			19.0	1,862.0
Soil Name, B	Lawn, Good Condition	61			31.0	1,891.0
Soil Name, B	Woods, Fair Condition	60			20.0	1,200.0
Soil Name, B	Woods, Good Condition	55			30.0	1,650.0
					Totals = 100.0	6,603.0

[1] Use only one CN source per line.

CN (weighted) = total product / total area = 6,603.0 / 100.0 = 66 Use CN = 66

2. Runoff

	Storm #1	Storm #2	Storm #3
Frequency .... years	100		
Rainfall, P (24 hour) .... in.	5.9		
Runoff, Q .... in.	2.4		

(Use P and CN with Table 2-1, Figure 2-1, or equations 2-3 and 2-4.)

3.3.3. Peak Discharge

The computation of the peak discharge use Equation 1 and the steps followed are detailed in Worksheet 4 as shown in Table 5. The peak discharge of the site after development is found to be

$$q_p = 39 \text{ cfs}$$

Table 5: Peak Discharge Computation – Post-development

U.S. Department of Agriculture
Natural Resources Conservation Service

FL-ENG-21C
06/04

Tr 55 Worksheet 4: Graphical Peak Discharge Method

Project: Project #4 Designed By: AH Date: 4/29/09

Location: St Paul, MN Checked By: ______ Date: ______

Check one: ____ Present ✓ Developed

1. Data:

Drainage area .... A_m = 0.02 mi² (acres/640)

Runoff curve number .... CN = 66 (From Worksheet 2)

Time of concentration ..... T_c = 0.24 hr (From Worksheet 3)

Rainfall distribution type ...... = II (II, III, DMVIII)

Pond and swamp areas spread throughout watershed .... = 0 percent of A_m (______ acres or mi² covered)

		Storm #1	Storm #2	Storm #3
2. Frequency	yr	100		
3. Rainfall, P (24-hour)	in	5.9		
4. Initial abstraction, I_a (Use CN with Table 4-1.)	in	1.030		
5. Compute I_a/P		0.17		
6. Unit peak discharge, q_u (Use T_c and I_a/P with exhibit 4- 10)	csm/in	700		
7. Runoff, Q (From Worksheet 2)	in	2.40		
8. Pond and swamp adjustment factor, F_p (Use percent pond and swamp area with Table 4-2. Factor is 1.0 for zero percent pond and swamp area.)	in	1.0		
9. Peak discharge, q_p (Where $q_p = q_u A_m Q F_p$)	cfs	39		

3.3.4. Discharge Hydrograph

The discharge hydrograph is constructed using Exhibit 5-II for a T_C = 0.2hr, T_t= 0.0 and Ia/P = 0.1 and Equation 2. The discharge hydrograph is illustrated in Figure 5.

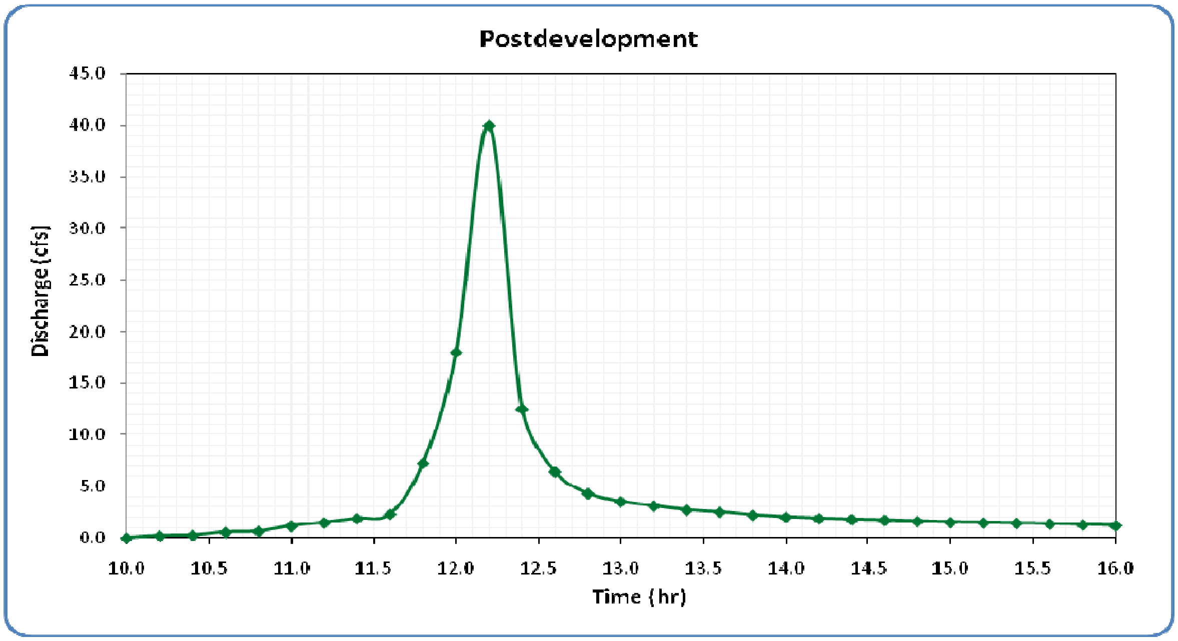

Figure 5: Discharge Hydrograph - Postdevelopment

3.4. *Peak Discharge Comaprison*

The peak discharge of the site before and after development is shown in Figure 6. As seen, the peak discharge increased from 20.00 cfs to 39.00 cfs after development and it occurred in an earlier time. To attenuate the peak runoff to a level equal to less than the predevelopment peak, a detention basin has to be built. The design of the detention basin for this site is given in the following section.

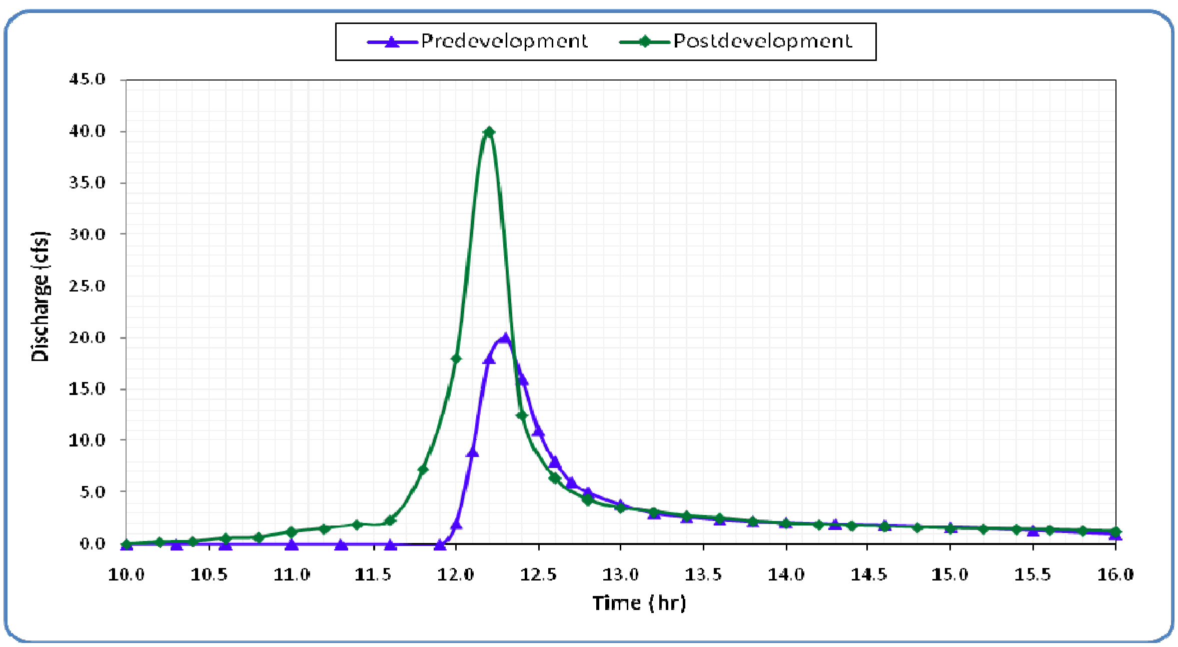

Figure 6: Discharge Hydrograph - Postdevelopment

4. DETENTION BASIN DESIGN

The steps followed for designing the detention basin are:

Step 1: Locate proper site for construction of the basin
Step 2: Determine the required volume and dimensions of detention basin
Step 3: Design outlet structure
Step 4: Route the outflow
Step 5: Check if the design requirements are met. If the design requirements are not met repeat step 2 to step 4 until design requirements are met.

4.1. Design Requirements

The detention basin requirements are:

- The peak runoff leaving the tract after development is equal to or less than the peak runoff leaving the tract before development.
- Runoff and basin routing computations are to be by NRCS Method.
- Basin side slopes are 3:1 (horizontal to vertical).

4.2. Detention Basin Type and Location

In this project, a dry open-cut basin is proposed. The location of the basin is chosen to be along the south-east boundary of the tract as shown in Figure 4 because this is the lowest point on the site and is adjacent the natural stream that flows south of the tract.

Note here that a grading at the southerly border of the tract may be required in order to flow all runoff toward the detention basin.

4.3. Detention Basin Dimensions

The schematic illustration of the proposed detention basin is shown in Figure 7. The dimensions of the basin and the storage volume versus elevation are listed in

. The storage volume versus water elevation level is depicted in Figure 8.

Table 6: Storage Volume Computation

Elevation (ft)	Area (sq. ft)	Incremental Volume (c.f.)	Cumulative Volume (c.f.)
181.50	0	0	0
182.50	7200	3600	3600
183.50	8652	7926	11526
184.50	10176	9414	20940
185.50	12208	11192	32132
186.50	13888	13048	45180

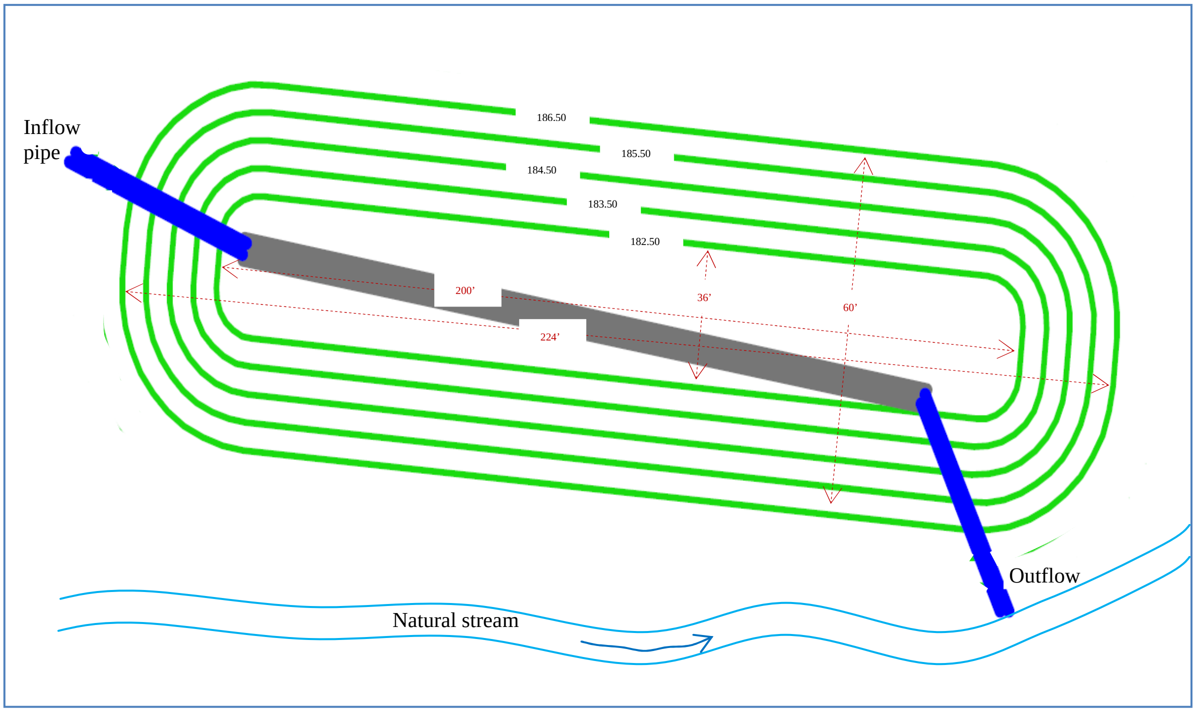

Figure 7: Schematic illustration of the proposed open-cut basin

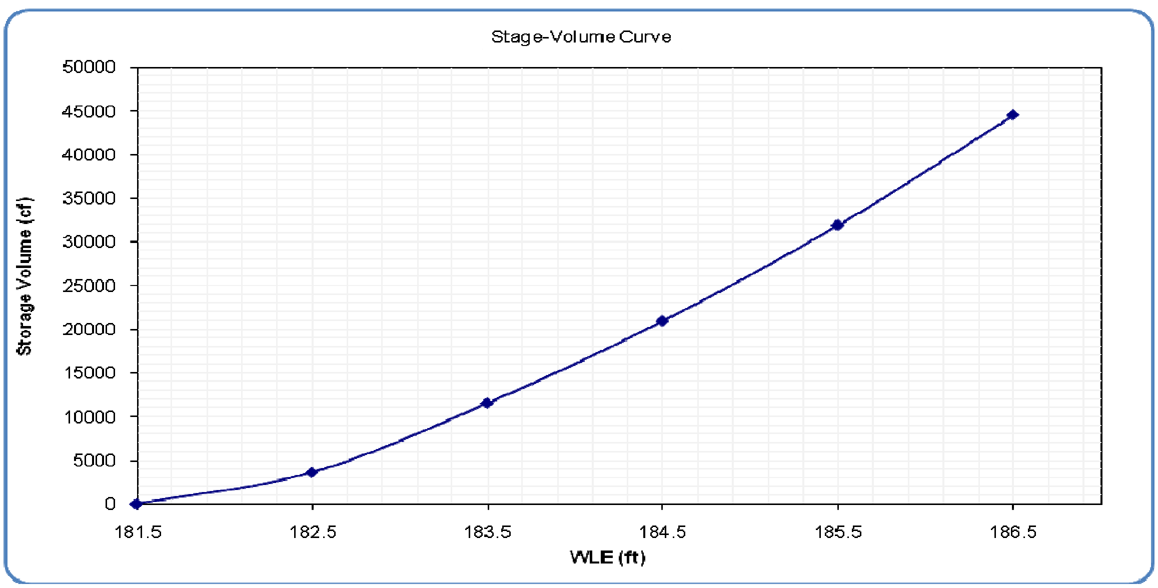

Figure 8: Storage Volume versus Water Elevation Level

4.4. Outlet Structure and Outflow Computation

The detention basin outflow structure is illustrated in Figure 9. As shown in the sketch, two-stage structure is suggested. The parameters of the outflow structure are as the following:

Orifice		**Weir**	
Orifice diameter (ft) :	1.00	Crest length (ft):	1.50
Area of orifice (sq. ft) :	0.785	Wall thickness (ft):	0.50
Invert elevation (ft) :	181.50	Crest elevation (ft):	183.50
Discharge Coefficient, c :	0.62		

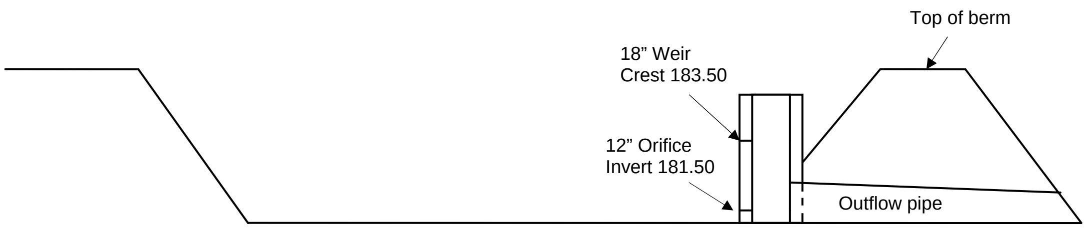

Figure 9: Outflow Structure of Detention Basin

The outflow computation is shown in Table 7, and the discharge rating versus water elevation level is plotted in Figure 10.

Table 7: Outflow Computation

Water Level Elevation (ft)	Orifice		Weir			Total Discharge (cfs)
	Head, h (ft)	*Discharge, Q (cfs)*	*Head, H (ft)*	*Discharge Coefficient, c*	*Discharge, Q (cfs)*	
181.50	0.00	0.00	0.00	-	0.00	0.00
182.50	0.50	2.76	0.00	-	0.00	2.76
183.50	1.50	4.79	0.00	-	0.00	4.79
184.50	2.50	6.18	1.00	3.32	4.98	11.16
185.50	3.00	6.77	2.00	3.32	14.09	20.85
186.50	4.00	7.82	3.00	3.32	25.88	33.69

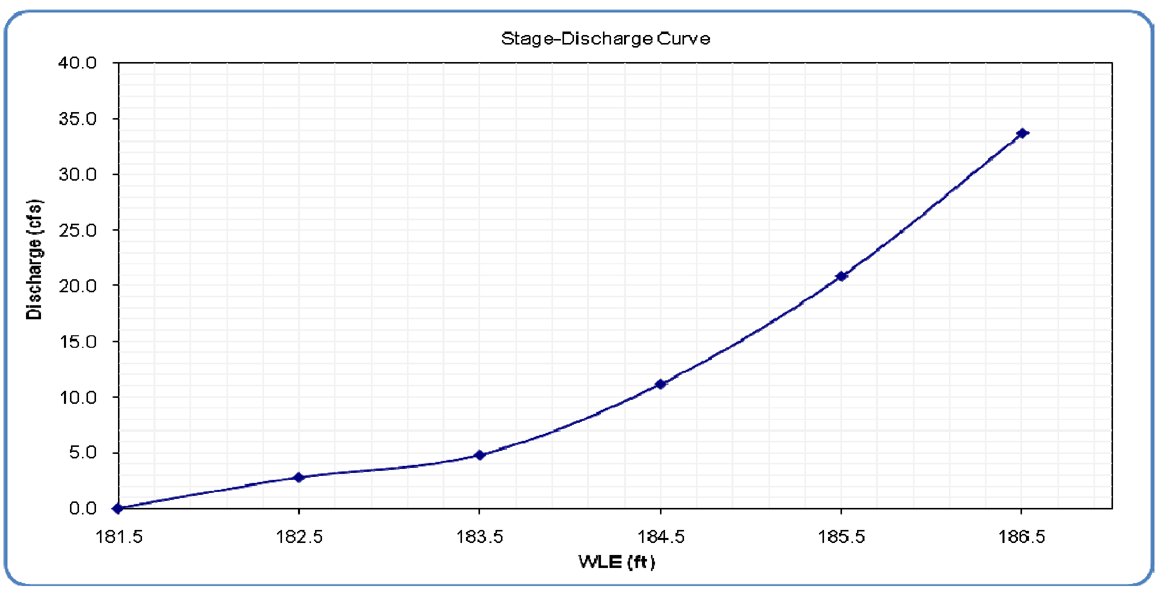

Figure 10: Outflow Discharge versus Water Elevation Level

4.5. Outflow Routing

Now that the detention basin size and the outflow structure are selected, we compute the outflow routings to determine the peak outflow. The routing hydrograph is computed using the routing method which relies on continuity equation [2].

First, we create a table of values of 2S/Δt - O and 2S/Δt + O versus outflow, O. For this purpose, the storage volume and discharge rating, determined in the previous steps, are used. The incremental time period was chosen as Δt = 0.20 hour which is equal to 720 seconds. The results are depicted in

Table 8 and the graph is shown in Figure 11.

Table 8: Routing Computation Parameters

Cu. Volume (c.f.)	*Outflow (cfs)*	*2S/Δt - O (cfs)*	*2S/Δt + O (cfs)*
0	0.00	0.0	0.0
3600	2.76	7.2	12.8
11526	4.79	27.2	36.8
20940	11.16	47.0	69.3
32132	20.85	68.4	110.1
45180	33.69	91.8	159.2

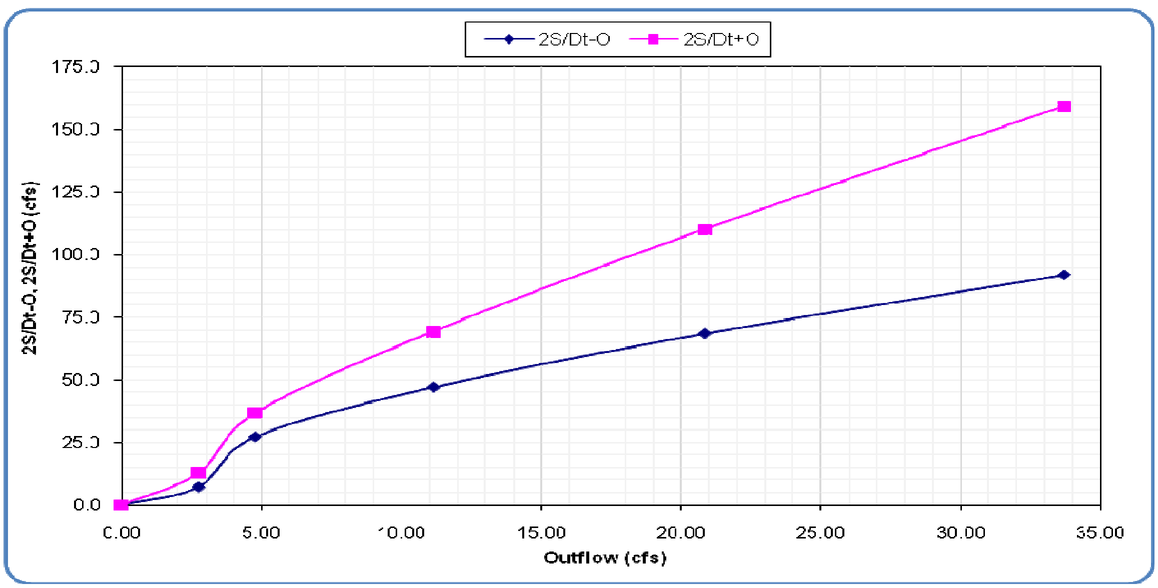

Figure 11: Graph of 2S/Dt+O versus O, and 2S/Dt-O versus O

The detention basin routing table is listed in Table 9. the inflow and outflow hydrograophs are plotted in Figure 12. As seen in Table 9, by routing through the detention basin, the runoff rate was attenuated to rate below predevelopment runoff value. The resulting peak outflow rate is 19.90 cfs, which is less than the peak runoff of the site before development, and hence the detention basin design was accepted.

Table 9: Detention Basin Routing Table

Time (hr)	I1 (cfs)	I1+I2 (cfs)	2S/Dt-O (cfs)	2S/Dt+O (cfs)	O2 (cfs)
10.0	0	0.20	0.00	0.00	0.00
10.2	0.20	0.45	0.10	0.20	0.05
10.4	0.25	0.80	0.17	0.55	0.20
10.6	0.55	1.19	0.25	0.97	0.25
10.8	0.64	1.84	0.35	1.44	0.32
11.00	1.20	2.67	0.42	2.19	0.55
11.20	1.47	3.34	1.50	3.09	0.58
11.40	1.87	4.17	2.72	4.84	1.04
11.60	2.30	9.55	3.93	6.89	1.51
11.80	7.25	25.25	7.76	13.48	2.81
12.00	18.00	58.00	24.03	33.01	4.46
12.20	40.00	52.50	53.60	82.03	14.13
12.40	12.50	18.90	66.30	106.10	19.90
12.60	6.40	10.70	55.34	85.20	14.93
12.80	4.30	7.80	45.02	66.04	10.52
13.00	3.50	6.60	36.96	52.82	7.93
13.20	3.10	5.80	31.32	43.56	6.12
13.40	2.70	5.20	27.40	37.12	4.85
13.60	2.50	4.70	23.70	32.60	4.43
13.80	2.20	4.20	20.20	28.40	4.08
14.00	2.00	3.87	16.87	24.40	3.74
14.20	1.87	3.64	13.82	20.74	3.43
14.40	1.77	3.47	11.08	17.46	3.15
14.60	1.70	3.30	8.66	14.55	2.91
14.80	1.60	3.10	6.73	11.96	2.58
15.00	1.50	2.96	5.53	9.83	2.28
15.20	1.46	2.88	4.78	8.49	2.05
15.40	1.42	2.78	4.31	7.66	1.96
15.60	1.36	2.64	3.99	7.09	1.75
15.80	1.28	2.48	3.73	6.63	1.48
16.00	1.20	2.36	3.49	6.21	1.40
16.20	1.16	2.28	3.29	5.85	1.32
16.40	1.12	2.20	3.13	5.57	1.27

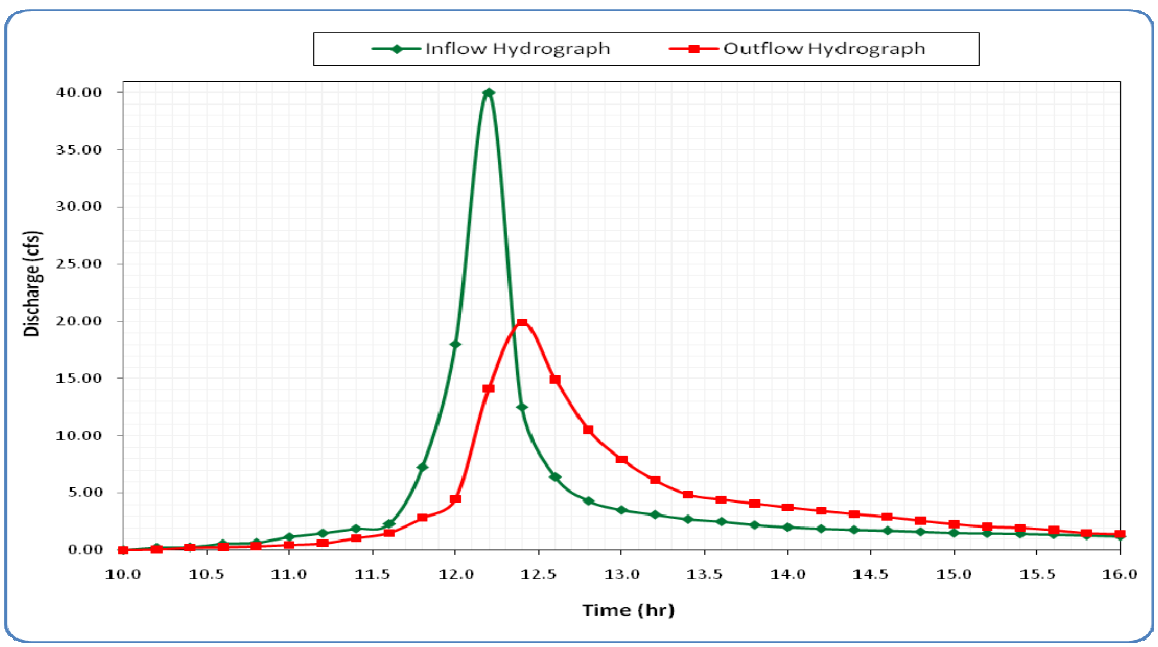

Figure 12: Inflow and Outflow Hydrographs

5. SUMMARY AND CONCLUSION

The values of peak runoff of the site before and after development (with and without detention basin) are listed in Table 10. The hydrographs are plotted in Figure 13. As seen, the peak discharge increased from 20 cfs to 39 cfs after development. The designed detention basin has attenuated the postdevelopment peak runoff to a rate less than the predevelopment rate. The outflow peak 19.90 cfs correspond to a maximum water level of 185.40 ft.

To complete the detention basin design other tasks should be considered. These tasks inlude emergency spillway, erosion control, and maintanance and safety of the detention basin. However and due to time limiltaion these tasks will not be discussed in this report.

Table 10: Peak runoff rate summary

	Peak runoff (cfs)
predevelopment	20.00
Postdevelopment without detention basin	39.00
Postdevelopment with detention basin	19.90

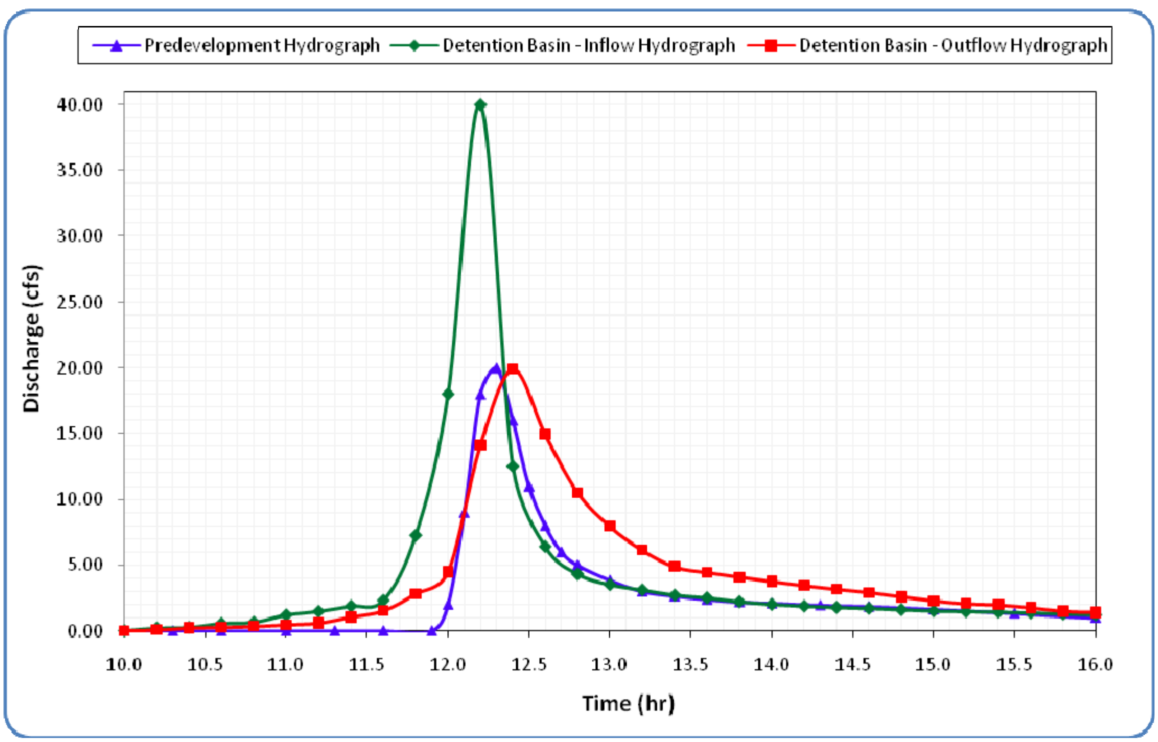

Figure 13: Discharge Hydrographs

APPENDIX A INTENSITY-DURATION-FREQUENCY CURVES

The rainfall Intensity-Duration-Frequency (IDF) curves for St. Paul Minnesota were constructed using the precipitation data generated from the precipitation maps provided in HYDRO-35 [3] and NOAA Atlas 2 [4].

Table A.1 and Table A.2 list the rainfall intensity for storm duration of 5, 10, 15, 30 and 60 minutes and for storm duration of 2, 3, 6, 12 and 24 hours, respectively. The values for 2-year and 100-year frequencies are listed. Figure A.1 and Figure A.2 show the IDF curves for storm duration of 5, 10, 15, 30 and 60 minutes and for storm duration of 2, 3, 6, 12 and 24 hours, respectively.

Table A.1: Rainfall intensity for storm duration of 5, 10, 15, 30, and 60 minutes.

	RAINFALL INTENSITY (in/hr)	
Duration (Minutes)	2-Year	100-Year
5	5.04	10.08
10	3.96	8.28
15	3.32	7.00
30	2.22	4.88
60	1.40	3.15

Table A.2: Rainfall intensity for storm duration of 2, 3, 6, 12, and 12 hours.

	RAINFALL INTENSITY (in/hr)	
Duration (Hours)	2-Year	100-Year
2	0.83	1.75
3	0.57	1.25
6	0.34	0.70
12	0.21	0.43
24	0.11	0.25

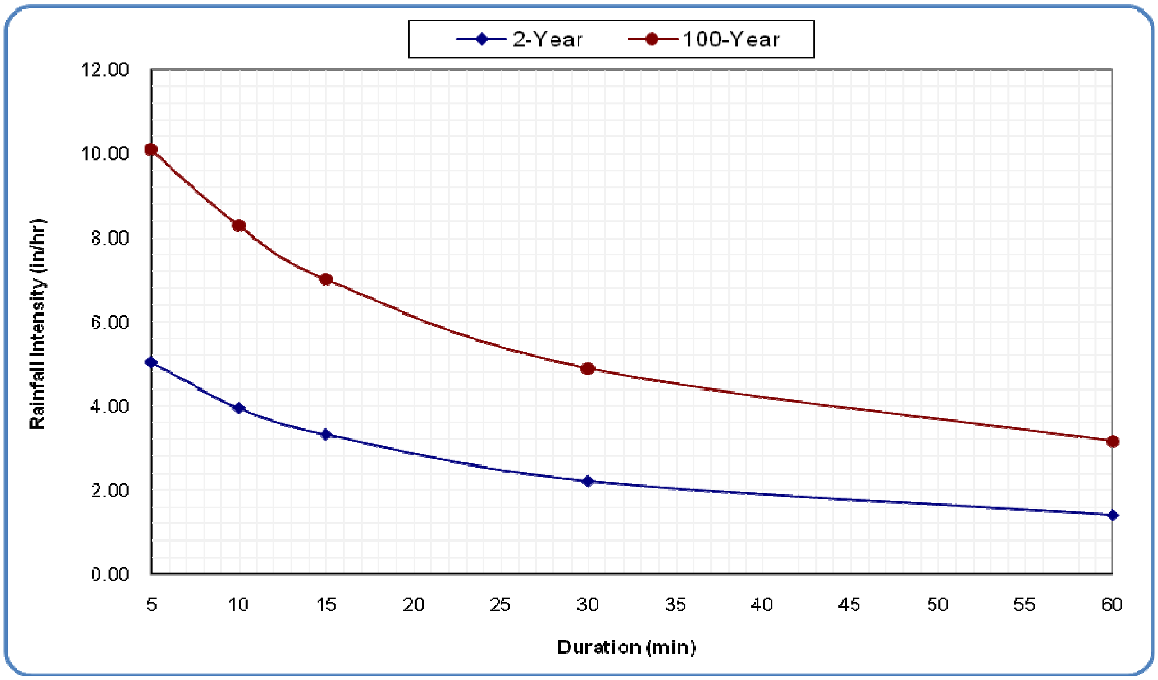

Figure A.1: Rainfall intensity for storm duration of 5, 10, 15, 30, and 60 minutes.

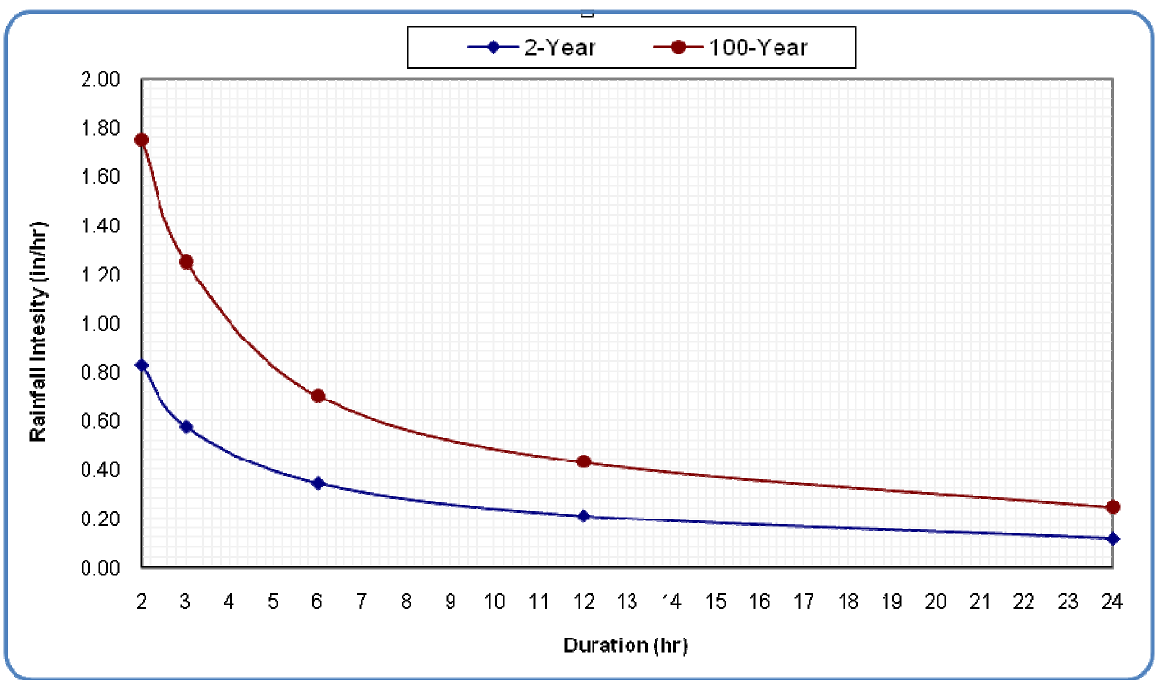

Figure A.2: Rainfall IDF curves for storm duration of 2, 3, 6, 12, and 12 hours.

References:

1. *Urban Hydrology for Small Watersheds*, US Department of Agriculture Soil Conservation Service Technical Release (TR55), http://www.info.usda.gov/CED/ftp/CED/tr55.pdf

2. Gribbin, John E., *Introduction to Hydraulics and Hydrology*, 3rd edition, Prentice Hall, 2007.

3. Five- To 60-Minute Precipitation Frequency for the Eastern and Central United States, NOAA Technical Memorandum NWS Hydro-35, Silver Spring, Md., June 1977.

4. Precipitation Frequency Atlas Maps (Central and Eastern U.S.), http://www.srh.noaa.gov/lub/climate/precip-atlas.