APPENDIX F: EXAMPLE LID PEAK DISCHARGE AND FIRST FLUSH RETENTION CALCULATIONS

Appendix F. Example LID Peak Discharge Calculation

Example calculations are presented in this section for a simple development plan that demonstrate how to determine the first flush retention requirements, the option of determining peak discharge reduction due to stormwater harvesting basins, and how the first flush retention and peak discharge requirements may be satisfied using a detention basin.

An example watershed has a drainage area of 0.8 acres and is within a proposed development with an overall area of 2.0 acres that does not meet detention waiver requirements. The example watershed is 60% B soils and 40% C soils under pre-developed conditions and will be 82% impervious area after development. There is no riparian area within the watershed. The watershed is within a balanced basin and post-developed peak discharge rates must be reduced to pre-developed rates.

The pre-developed peak discharges and the post-developed peak discharges for the watershed before detention or retention are:

Peak Discharge	100-year (cfs)	10-year (cfs)	2-year (cfs)
Pre-developed	4.8	2.0	0.5
Post-Developed Before Detention	7.3	4.4	2.6

The following four scenarios are shown in this example:

Case 1. A detention basin designed to meet the previous threshold retention requirements from PCDOT&FCD (1987).

Case 2. A detention basin designed with retention within the detention basin that meets the current first flush requirements from Section 2.

Case 3. A detention basin designed with stormwater harvesting basins throughout the site and meets the first flush requirement**.** Stormwater harvesting basins are placed in landscaped areas from Case 2 without additional changes to the site layout or reducing the impervious area.

Case 4. A design where stormwater harvesting basins are used to reduce peak discharge rates to pre-developed rates and no detention basin is required. The stormwater harvesting basin is designed at the outlet with a larger area instead of the detention basin from Case 2.

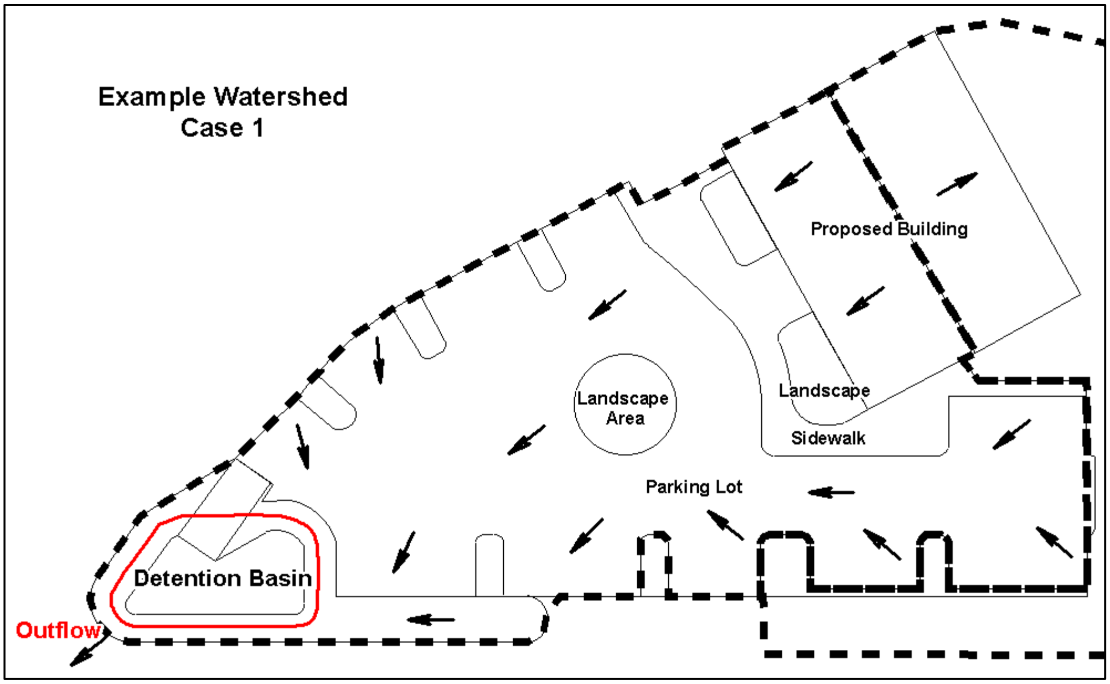

Figure F.1. Case 1 development plan with threshold retention. (Based on a design by WLB Group, Inc.)

Example Case 1

An example detention basin designed to meet past threshold retention requirements from PCDOT&FCD (1987) has the following characteristics:

“Threshold Retention” Volume (ft^3)	2300
Depth of 5-year Detention (ft)	1.19
100-year Ponding Depth (ft):	1.65
Total Detention Basin Depth (ft):	2.25
Freeboard (ft):	0.60
Total Detention Basin Volume (ft^3):	5492
Total Detention Basin Area (ft^2):	4570
2-year Outflow (cfs)	0.4
10-year Outflow (cfs)	1.6
100-year Outflow (cfs):	4.3

Outflow Structures: 5 ft. rectangular outflow weir at an elevation of 1.25 ft above detention basin bottom.

12-inch positive drainage pipe with a 6-inch orifice plate with the invert at the elevation of the basin bottom.

This example detention basin design meets the previous detention requirement using detention of the 2-year, 10-year, and 100-year post-development peak discharges to pre-development peak discharge rates. The threshold retention, the difference in the 5-year pre- and post-developed runoff volumes, is no longer a requirement in this manual and has been detention volume that is released very slowly through the positive drainage pipe. This example detention basin was designed with more than 6 inches of freeboard above the 100-year ponding depth.

Example Case 2

A development plan can meet the first flush retention requirement using retention volume within the detention basin.

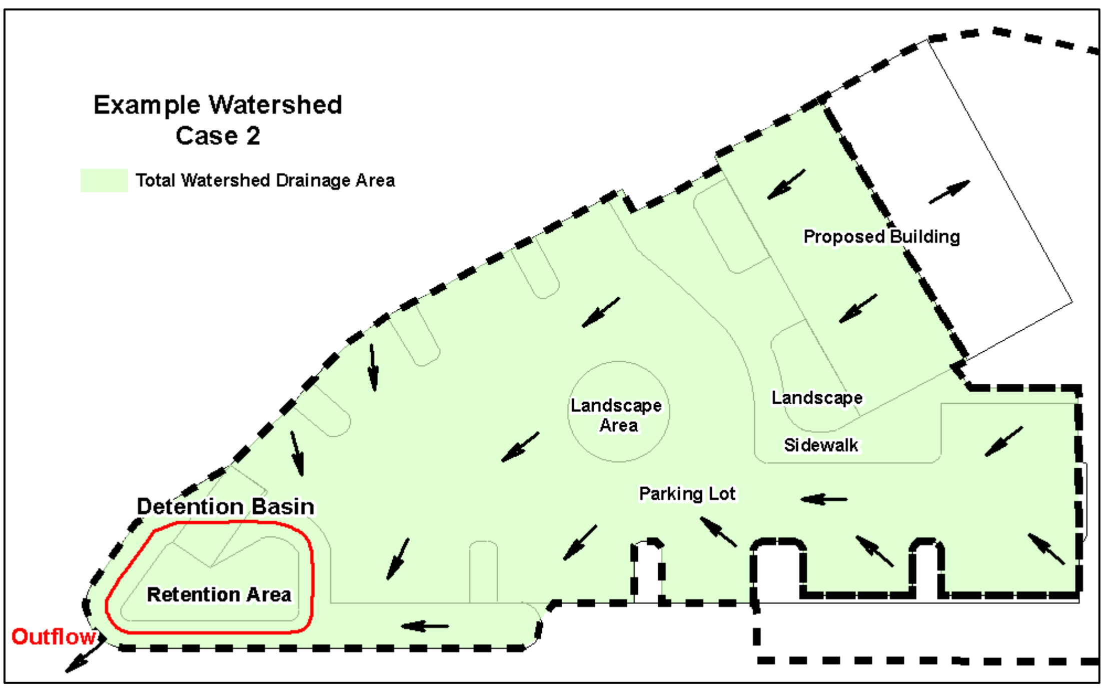

Figure F.2. Case 2 with the required first flush retention designed within the detention basin.

The first flush retention is calculated from Section 2.2:

	Non-Riparian Area	Riparian Area

Proposed Impervious Areas	1440 ft^3/ac	1815 ft^3/ac
Additional Disturbed Areas	140 ft^3/ac	245 ft^3/ac

First Flush Retention = (Acres of Impervious Area) (Factor for non-riparian impervious area)

+ (Acres of Disturbed Pervious Areas) (Factor for non-riparian disturbed areas)

First Flush Retention = (0.80 ac watershed X 82% Impervious) (1440 ft^3/ac)

+(0.80 ac watershed X 18% disturbed) (140 ft^3/ac)

First Flush Retention = 944.6 ft^3 + 20.2 ft^3 = 964.8 ft^3

Using the storage-depth curve for the detention basin design, placing all of the first flush retention in the detention basin requires a retention depth of 0.55 ft. Therefore, the invert of the positive drainage is located above 0.55 ft at an elevation of 0.75 ft above the detention basin bottom which is the maximum allowable retention depth of 9 inches.

Additional outflow structures are designed using the PC-Route spreadsheet (Appendix I) or another accepted method to perform detention routing and demonstrate that the 2-year, 10-year, and 100-year post-developed peak discharge rates are reduced to pre-developed peak discharge rates.

A detention basin design with retention volume within the detention basin that meets the first flush requirement and meets the freeboard requirement has the following characteristics:

Required First Flush Retention Volume (ft3):	965
Retention Volume in Detention Basin (ft3)	1324
Depth of Retention in Detention Basin (ft):	0.75
100-year Ponding Depth (ft):	1.64
Total Detention Basin Depth (ft):	2.25
Freeboard (ft):	0.61
Total Detention Basin Volume (ft^3):	5492
Total Detention Basin Area (ft^2):	4570
2-year Outflow (cfs)	0.4
10-year Outflow (cfs)	1.3
100-year Outflow (cfs):	4.7

Outflow Structures: 5-ft. rectangular outflow weir at an elevation of 1.25 ft above detention basin bottom.
12-inch pipe with the invert at an elevation of 0.75 ft (9 inches) above the basin bottom.

Example Case 3

A development plan can meet the first flush retention requirement and use additional stormwater harvesting basins throughout the site to reduce detention basin volume or eliminate the need for a detention basin altogether. In this case, additional stormwater harvesting basins were designed in landscape areas from Case 2. No other changes have been made to the site layout and the impervious area remains the same as in Case 2. In this example, the area of the watershed draining to the stormwater harvesting basins is not large enough to meet the peak discharge reduction requirements and therefore a detention basin is designed.

The "Stormwater Harvesting Spreadsheet" is available to perform the following calculations.

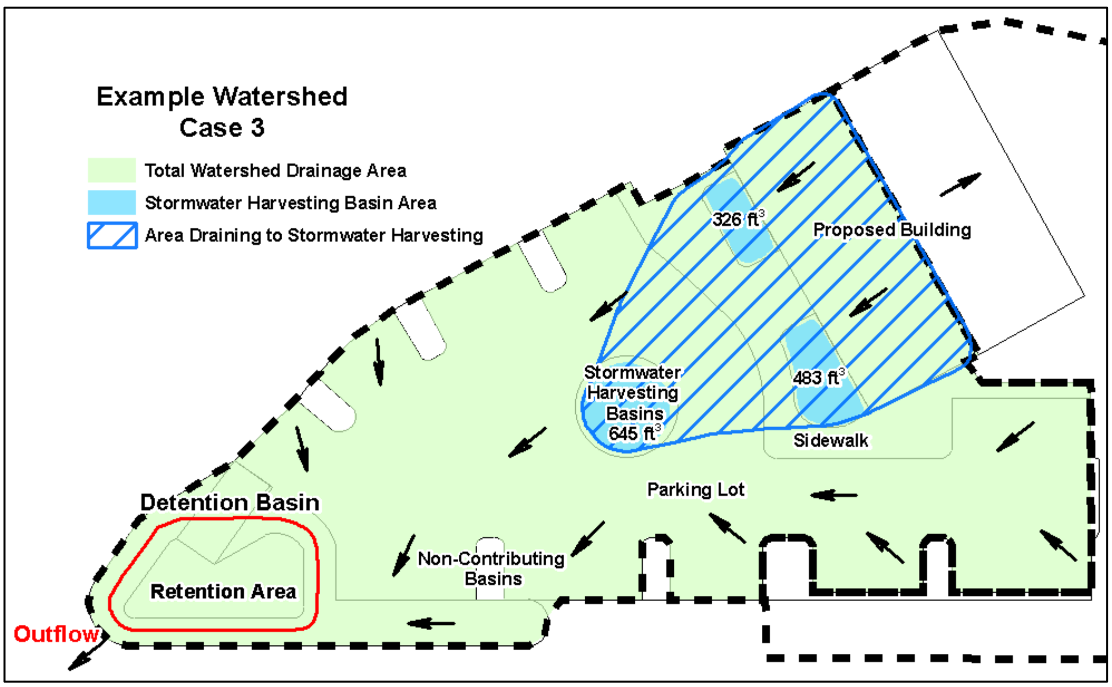

Figure F.3. Case 3 with stormwater harvesting basins in the upstream watershed and retention within the detention basin.

In Case 3, the watershed area is adjusted due to the design of non-contributing basins that meet the specifications described in section 2.4.3. The areas draining to non-contributing basins are removed from the watershed area and not included in additional calculations. The adjusted watershed area is 0.782 acres and the impervious surfaces are 84% of the adjusted area.

The first flush retention for Case 3 is calculated using the same method as Case 2 and the calculated volume is essentially the same because the impervious area remains the same:

First Flush Retention = (0.782 ac watershed X 84% Impervious) (1440 ft^3/ac)

+(0.782 ac watershed X 16% disturbed) (140 ft^3/ac)

First Flush Retention = 945.9 ft^3 + 17.5 ft^3 = 963.4 ft^3

The three stormwater harvesting basins upstream of the detention basin that do not meet the non-contributing basin criteria are used with the method in Sections 3.3.1 and 3.3.2 to determine the reduction in peak discharge and runoff volume for the 2-, 10-, and 100-year events.

1. The post-developed peak discharges and runoff volumes from PC-Hydro using the adjusted watershed area of 0.782 acres are:

	100-year	10-year	2-year
Peak Discharge (cfs)	7.1	4.3	2.5
Runoff Volume (ac-ft)	0.155	0.093	0.055

2. The volume of the stormwater harvesting basins upstream of the detention basin are calculated as:

   V_{bas} = (SWH Basin 1) + (SWH Basin 2) + (SWH Basin 3)

   = (483 ft^3) + (326 ft^3) + (645 ft^3) = 1454 ft^3 (1 ac / 43560 ft^2)

   V_{bas} = 0.0334 ac-ft

3. The percent of the watershed area that will flow to or through stormwater harvesting basins is calculated as:

W_A = Area flowing to SWH Basins / Total Area = 0.179 ac / 0.782 ac = 22.9%

When a small percentage of the watershed is diverted to stormwater harvesting such as in this case, the reduction in peak discharge and volume will be limited by W_A.

4. The ratio (X_{rp}) of the basin volume (V_{bas}) to the post-development runoff volume ($V_{post\text{-}rp}$) is calculated for each return period:

   X_{rp}= V_{bas}/ $V_{post\text{-}rp}$ =

   (Total upstream stormwater harvesting basin volume) /
   (Return Period Runoff Volume)

   or X_{rp}= W_A, whichever is less

   X_2= 0.0334 ac-ft / 0.0548 ac-ft = 61%, therefore X_2 = W_A = 22.9%

   X_{10}= 0.0334 ac-ft / 0.0933 ac-ft = 36%, therefore X_{10} = W_A = 22.9%

   X_{100}= 0.0334 ac-ft / 0.1548 ac-ft = 22%, therefore X_{100} = 22%

5. The stormwater harvesting factor is found from the table in Section 3.3.1 for each return period as:

   H_2 = 18.3%

   H_{10} = 18.3%

   H_{100} = 17.0%

6. The post-development peak discharges rates after accounting for stormwater harvesting basins upstream of the detention basin are determined as:

   $Q_{swh\text{-}rp} = Q_{post\text{-}rp}\ (1 - H_{rp})$

   $Q_{swh\text{-}2}$ = 2.5 cfs (1 - 0.183) = 2.0 cfs

   $Q_{swh\text{-}10}$ = 4.3 cfs (1 – 0.183) = 3.5 cfs

   $Q_{swh\text{-}100}$ = 7.1 cfs (1 – 0.170) = 5.9 cfs

7. The post-developed peak discharge rates are not equal to or less than pre-development peak discharge rates, and therefore further reduction in peak discharge is required. Either a larger portion of the watershed can be directed to stormwater harvesting basins to reduce peak discharges, or a detention basin can be designed to reduce peak discharges. In this case, a detention basin is selected for design.

8. The inflow hydrograph to the detention basin that accounts for the upstream stormwater harvesting basins can be obtained using the Stormwater Harvesting Hydrograph spreadsheet(Appendix E) with the PC-Hydro files from Step 1:

   a. The project information is entered in the worksheet "I. SWH Calculation" based on watershed data, PC-Hydro results, and proposed stormwater harvesting basins.

   b. In worksheets "IIa. 2-yr SWH Hydrograph", "IIb. 10-yr SWH Hydrograph", and "IIc. 100-yr SWH Hydrograph", the 2-yr, 10-yr and 100-yr PC-Hydro hydrographs are entered respectively by copying and pasting the data into the PC-Hydro Hydrograph area of the hydrograph worksheets (Figure 4).

      All stormwater harvesting variables for the return period are entered or calculated by the spreadsheet in the Stormwater Harvesting Variables area (Figure 4). The post-developed runoff volume accounting for upstream stormwater harvesting is calculated by the spreadsheet as:

$$V_{swh-rp} = V_{post}(1 - X_{rp})$$

      $V_{swh\text{-}2}$ = 0.0548 ac-ft(1-0.229) = 0.042 ac-ft

      $V_{swh\text{-}10}$ =0.0933 ac-ft (1-0.229) = 0.072 ac-ft

      $V_{swh\text{-}100}$ = 0.1548 ac-ft (1-0.22) = 0.121 ac-ft

c. The spreadsheet creates a hydrograph using the reduced peak discharge and removes additional volume from the hydrograph. (Figure 4).

9. The stormwater harvesting hydrograph (Figure F5) may be used as the inflow hydrograph to the PC-Route spreadsheet or another accepted method for basin routing. See Appendix I for information on the PC-Route spreadsheet.

Stormwater Harvesting Hydrograph Spreadsheet — Revised 12.19.2011

Prepared by:
Project: Example Site Case 3
Watershed: 01
Date: 12/20/2011

1. Enter PC-Hydro Hydrograph	
$Q_{POST-RP}$ (cfs)	2.50
Rise Time (min)	13.6
Volume (ac-ft)	0.059
Return Period (yr)	2

Stormwater Harvesting Variables

2. Enter Stormwater Harvesting Variables	
Runoff Volume ($V_{POST-RP}$) (ac-ft)	0.059
SWH Volume (V_{BAS}) (ac-ft)	0.033
X_{RP}	0.57
H_{RP} (from Table)	0.608
$\eta = A_B / A_t$	0.229
Q_{SWH-RP} (cfs)	2.15
V_{SWH-RP} (ac-ft)	0.025

SWH - Stormwater Harvesting, RP - Return Period

Stormwater Harvesting Results

Q_{SWH-RP} (cfs)	2.13
V_{SWH-RP} (ac-ft)	0.048
Hydrograph Time Step (dt) (min)	0.50
Reduction in Peak Discharge:	14.6%
Reduction in Runoff Volume:	17.9%
Volume Removed from Front of Intermediate Hydrograph:	5.5%
Peak Discharge Check:	Peak Q OK, Error = 0.8%
Volume Check:	Max Volume Removed, Qp must be reduced to further Reduce Volume

The time step (dt) for the equal time interval hydrograph in cell AL11 may need to be adjusted to prevent peak and volume warnings. When an unequal time interval is OK, the hydrograph without interpolation to the right may be used.

PC-Hydro Hydrograph

Enter PC-Hydro Hydrograph Below		
Time	Discharge	Runoff Volume (ac-ft)
0	0	0.000
1	0	0.000
[illegible]	0.1	0.000
3	0.3	0.000
4	0.4	0.001
5	0.5	0.001
6	0.7	0.002
7	0.9	0.003
8	1.1	0.005
9	1.3	0.006
10	1.6	0.008
11	1.9	0.011
12	2.2	0.014
13	2.4	0.017
14	2.5	0.020
15	2.3	0.023
16	2.2	0.027
17	2	0.029
18	1.8	0.032
19	1.7	0.035
20	1.6	0.037
21	1.4	0.039
22	1.3	0.041
23	1.2	0.042
24	1.1	0.044
[illegible]	[illegible]	0.045

Intermediate Hydrograph				
Ordinates		Intermediate		
t/T_r	q/Q_p	Time (min)	Q (cfs)	Volume (ac-ft)
0.0	0.000	0.0	0.00	0.000
0.1	0.025	1.4	0.05	0.000
0.2	0.087	2.7	0.19	0.000
0.3	0.160	4.1	0.34	0.001
0.4	0.243	5.4	0.52	0.002
0.5	0.346	6.8	0.74	0.003
0.6	0.451	8.2	0.97	0.004
0.7	0.576	9.5	1.24	0.006
0.8	0.738	10.9	1.59	0.009
0.9	0.887	12.2	1.91	0.012
1.0	1.000	13.6	2.15	0.016
1.1	0.924	15.0	1.99	0.020
1.2	0.839	16.3	1.81	0.024
1.3	0.756	17.7	1.63	0.027
1.4	0.678	19.0	1.46	0.030
1.5	0.604	20.4	1.30	0.032
1.6	0.545	21.8	1.17	0.035
1.7	0.482	23.1	1.04	0.037
1.8	0.424	24.5	0.91	0.039
1.9	0.372	25.8	0.80	0.040
2.0	0.323	27.2	0.70	0.042
2.2	0.241	29.9	0.52	0.044
2.4	0.179	32.6	0.39	0.045
2.6	0.136	35.4	0.29	0.047
2.8	0.102	38.1	0.22	0.048
3.0	0.078	40.8	0.17	0.048

Stormwater Harvesting Hydrograph		
Time (min)	Discharge (cfs)	Volume (ac-ft)
0.00	0.00	0.000
0.50	0.02	0.000
1.00	0.03	0.000
1.50	0.05	0.000
2.00	0.09	0.000
2.50	0.13	0.000
3.00	0.17	0.000
3.50	0.21	0.000
4.00	0.26	0.001
4.50	0.31	0.001
5.00	0.36	0.001
5.50	0.41	0.001
6.00	0.47	0.002
6.50	0.54	0.002
7.00	0.60	0.002
7.50	0.66	0.003
8.00	0.73	0.003
8.50	0.80	0.004
9.00	0.88	0.004
9.50	0.95	0.005
10.00	1.05	0.006
10.50	1.15	0.006
11.00	1.24	0.007
11.50	1.28	0.008
12.00	1.33	0.009

Figure F.4. The Stormwater harvesting spreadsheet “IIa. 2-yr SWH Hydrograph” worksheet.

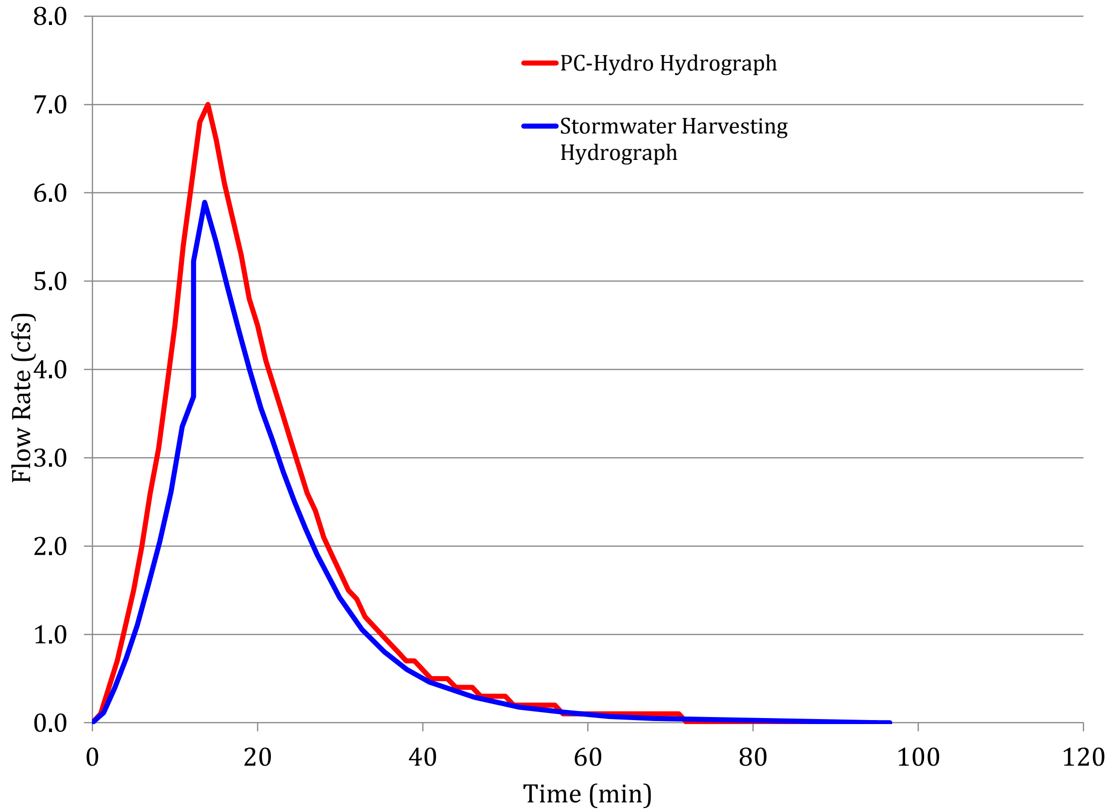

Figure F.5. The 100-year hydrographs for Case 3. The reduction in peak discharge and the volume removed from the 100-yr hydrograph.

The first flush retention requirement is satisfied by the upstream stormwater harvesting basins but additional retention is designed in the detention basin in this case.

A detention basin design that reduces peak discharges to pre-developed rates using the stormwater harvesting inflow hydrographs and meets the freeboard requirement has the following characteristics:

Required First Flush Retention Volume (ft3):	964
Volume of Retention in Detention Basin (ft3):	1324
Depth of Retention in Detention Basin (ft):	0.75
100-year Ponding Depth (ft):	1.21
Total Detention Basin Depth (ft):	1.75
Freeboard (ft):	0.54
Total Detention Basin Volume (ft^3):	3835

Total Detention Basins Area (ft^2):	3030
2-year Outflow (cfs)	0.4
10-year Outflow (cfs)	1.6
100-year Outflow (cfs):	3.7

Outflow Structures: A rectangular outflow weir with a width of 3 ft at an elevation of 0.75 ft above the detention basin bottom.

The detention basin area in Case 3 is 3030 ft^2 or 33% less area than Case 1 and 2 due to the upstream stormwater harvesting basins. Table F.1. at the end of this Appendix summarizes the basin characteristics for each of the cases.

Additional reduction in detention basin volume could be achieved at this site by placing stormwater harvesting basins at locations that will capture flow from a larger portion of the watershed such as immediately upstream of the detention basin. Case 4 replaces the detention basin with a stormwater harvesting basin with a slightly larger area and meets the peak discharge reduction and first flush retention requirements.

Example Case 4

A development plan can meet the first flush retention requirement and use additional stormwater harvesting basins to meet pre-developed peak discharge rates. No detention basin is required in this case.

In this example, the retention area at the outlet is increased from Case 3 and designed as a stormwater harvesting basin with 9 inches of allowable ponding depth and a designed overflow. The watershed area draining to stormwater harvesting is 0.76 ac or 95% of the 0.80 ac watershed compared to the 23% in Case 3.

The "Stormwater Harvesting Spreadsheet" is available to perform the following calculations.

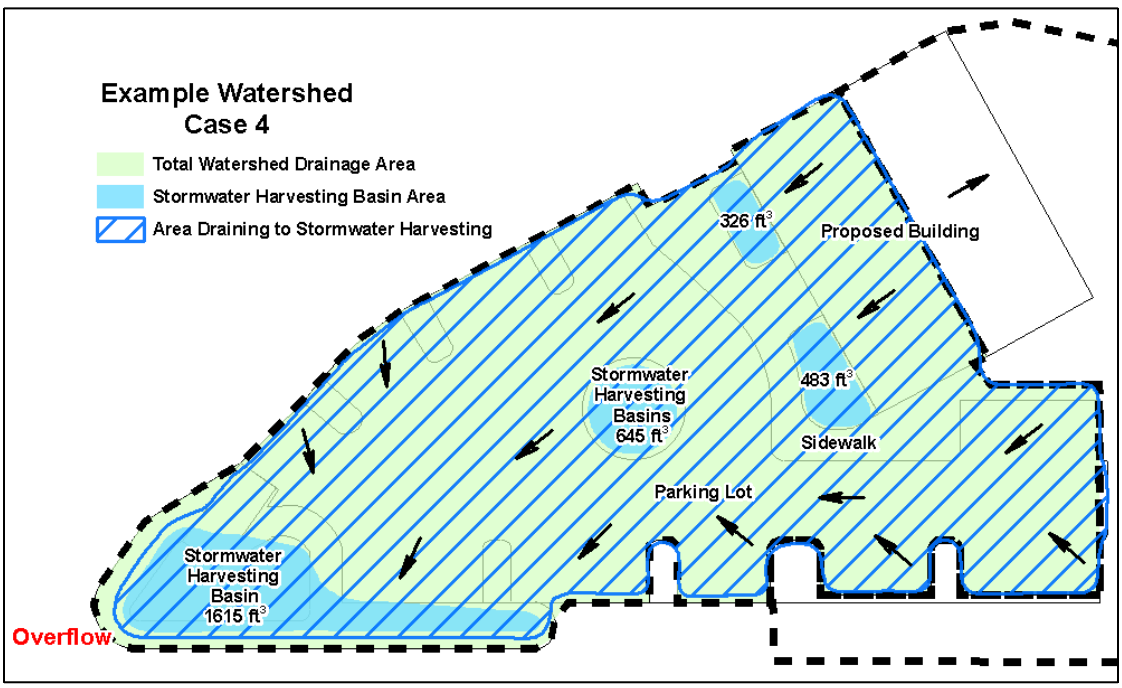

Figure F.6. Case 4 with stormwater harvesting basins that reduce post-developed peak discharges to pre-developed peak discharge rates.

In Case 4, the first flush is calculated the same as in Case 2 as 965 ft^3 because there are no stormwater harvesting basins that meet the non-contributing basin criteria and the total watershed area remains 0.80 acres.

The effect of the stormwater harvesting basins on post-developed peak discharges and runoff volumes is found using the same procedure as in Section 3.3.1 and Case 3 as:

1. The post-developed peak discharges and runoff volumes from PC-Hydro are:

	100-year	10-year	2-year
Peak Discharge (cfs)	7.3	4.4	2.6
Runoff Volume (ac-ft)	0.159	0.096	0.056

2. The volume of the stormwater harvesting basins upstream of the detention basin are calculated as:

   V_{bas} = (SWH Basin 1) + (SWH Basin 2) + (SWH Basin 3) + (SWH Basin 4)

   = (483 ft^3) + (326 ft^3) + (645 ft^3) + (1615 ft^3) = 3069 ft^3 (1 ac / 43560 ft^2)

   V_{bas} = 0.0705 ac-ft

3. The percent of the watershed area that will flow to or through stormwater harvesting basins is calculated as:

   W_A = Area flowing to SWH Basins / Total Area = 0.76 ac / 0.80 ac = 95.0%

4. The ratio (X_{rp}) of the basin volume (V_{bas}) to the post-development runoff volume ($V_{post\text{-}rp}$) is calculated for each return period:

   X_{rp}= V_{bas}/ $V_{post\text{-}rp}$ =

   (Total upstream stormwater harvesting basin volume) /
   (Return Period Runoff Volume)

   or X_{rp}= W_A, whichever is less

   X_2= 0.0705 ac-ft / 0.0562 ac-ft = 125%, therefore X_2 = W_A = 95.0%

   X_{10}= 0.0705 ac-ft / 0.0957 ac-ft = 74%

   X_{100}= 0.0705 ac-ft / 0.1588 ac-ft = 44%

5. The stormwater harvesting factor is found from the table in Section 3.3.1 for each return period as:

   H_2 = 90.9%

   H_{10} = 73.8%

   H_{100} = 43.6%

6. The post-development peak discharges rates after accounting for stormwater harvesting basins upstream of the detention basin are determined as:

   $Q_{swh\text{-}rp}$ = $Q_{post\text{-}rp}$ (1 –H_{rp})

   $Q_{swh\text{-}2}$ = 2.6 cfs (1 – 0.909) = 0.2 cfs

   $Q_{swh\text{-}10}$ = 4.4 cfs (1 –0.738) = 1.2 cfs

   $Q_{swh\text{-}100}$ = 7.3 cfs (1 –0.436) = 4.1 cfs

7. The post-developed discharge rates are equal to or less than pre-development peak discharge rates, and therefore further reduction in peak discharge is not required and a detention basin is not required. All proposed stormwater harvesting basins must be designed to meet the standards in Chapter 5. The 100-yr stormwater harvesting outflow hydrograph is shown in Figure F.7 for comparison with the outflow hydrograph from Case 3 (Figure F.5).

If further reduction in peak discharges was required and detention routing calculations were performed for the downstream basin, then the basin at the outlet would be considered a detention basin as shown in Case 3. In that case, the retention area at the outlet could not to be included in the stormwater harvesting calculations to reduce peak discharge in order to avoid "double-counting" the retention volume that is used for the detention basin's storage-discharge relationship in detention routing.

For comparison, when the stormwater harvesting hydrograph from Case 3 is routed through the stormwater harvesting basin at the outlet in Case 4 using the Detention Routing spreadsheet, the 100-yr peak outflow is 3.2 cfs when assuming a 6-ft wide overflow at an elevation of 0.75 ft, while the stormwater harvesting factors found a 100-yr peak discharge of 4.1 cfs from the site. Both of the methods find a post-developed peak discharge less than pre-developed peak discharge. The maximum 100-yr ponding depth for the detention routing calculation was 1.1 ft or approximately 4 inches above the overflow weir.

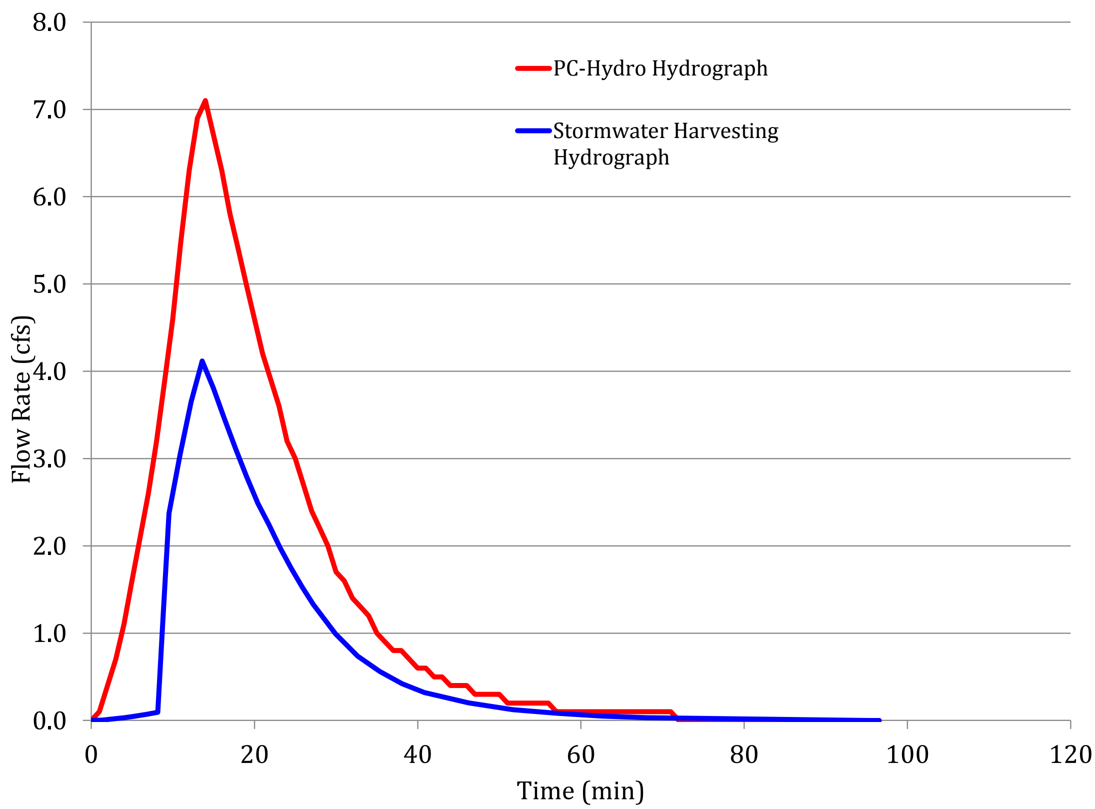

Figure F.7. The 100-yr stormwater harvesting outflow hydrograph from Case 4.

Table F.1. Summary detention and stormwater harvesting basins for the example cases.

	Case 1	Case 2	Case 3	Case 4
Watershed Characteristics				
Non-Contributing Areas (ft^2)	0	0	784	0
Unused Pervious Area (ft^2)	3351	3351	652	1523
Total Pervious Area Used for Ponding (ft^2)*	2922	2922	4707	4750
Total Volume Used for Ponding (ft^3)*	3560	3560	3826	3069
100-yr Peak Outflow (cfs)	4.3	4.4	3.7	4.1
100-yr Outflow Hydrograph Volume (ac-ft)	0.170	0.141	0.101	0.088
Stormwater Harvesting Basins**				
Volume (ft^3)	0	0	1454	3069
Area of Basins (ft^2)	0	0	2249	4750
Depth (ft)	0	0	0.75	0.75
Detention Basin				
Volume (ft^3)	5492	5492	3835	0
Total Basin Depth (ft)	2.25	2.25	1.75	0
Total Basin Area (ft^2)	4570	4570	3030	0
100-yr Ponding Depth (ft)	1.65	1.66	1.21	0
Freeboard (ft)	0.6	0.59	0.54	0
Volume Retained (ft^3)	0	1324	1324	0
Depth Retained (ft)	0	0.75	0.75	0

*For comparison, only includes ponding area or volume in basins and not freeboard

**Does not include non-contributing areas