APPENDIX G: THE METHOD USED BY THE STORMWATER HARVESTING SPREADSHEET TO MODIFY A PC-HYDRO HYDROGRAPH TO ACCOUNT FOR STORMWATER HARVESTING

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This section presents a method to modify a PC-Hydro hydrograph to account for stormwater harvesting based on the peak reduction factors and volume from Section 3.3.

The "Stormwater Harvesting" spreadsheet is available that performs all of the following modifications to a PC-Hydro hydrograph and provides a hydrograph to represent outflow from a watershed with one or more stormwater harvesting basins that may be distributed within the watershed.

Method:

Generate PC Hydro hydrographs that model the post-development discharge without stormwater harvesting basins for each return period. A PC-Hydro calculation is needed to determine the peak discharge ($Qp_{post\text{-}rp}$), runoff volume ($V_{post\text{-}rp}$), and a hydrograph that approximates this runoff volume for the post-developed condition without stormwater harvesting basins.

1. Use the methods in Sections 3.3.1 and 3.3.2 to calculate the stormwater harvesting factor (H_{rp}) and the peak of the post-development hydrograph with stormwater harvesting basins ($Q_{swh\text{-}rp}$) from the volume of the proposed stormwater harvesting basins (V_{bas}), and the post-developed runoff volume ($V_{post\text{-}rp}$). The spreadsheet will perform this calculation when provided with the PC-Hydro peak discharges, runoff volumes, and stormwater harvesting basin volumes.

2. The spreadsheet creates an intermediate hydrograph using the Pima County dimensionless hydrograph (Table G.1) with the reduced peak discharge due to stormwater harvesting ($Q_{swh\text{-}rp}$) and the time to rise from the original PC-Hydro hydrograph (Tr). There may be a slight lag in the hydrograph peak depending on the distribution of the stormwater harvesting basins within the watershed, but quantifying the detention effects of stormwater harvesting would require detailed modeling on a case-by-case basis and the time to rise of the intermediate hydrograph is assumed to remain the same as the original hydrograph for simplification and to reduce analysis time.

   The intermediate hydrograph is created by calculating time (t) and outflow (q) for each point on the hydrograph using the table below based on Table 3.3 from PCDOT&FCD (1987):

Table G.1. Pima County dimensionless hydrograph ordinates.

t/T_r	q/Q_{swh-rp}	t/T_r	q/Q_{swh-rp}
0.00	0.000	1.60	0.545
0.10	0.025	1.70	0.482
0.20	0.087	1.80	0.424
0.30	0.160	1.90	0.372
0.40	0.243	2.00	0.323
0.50	0.346	2.20	0.241
0.60	0.451	2.40	0.179
0.70	0.576	2.60	0.136
0.80	0.738	2.80	0.102
0.90	0.887	3.00	0.078
1.00	1.000	3.40	0.049
1.10	0.924	3.80	0.030
1.20	0.839	4.20	0.020
1.30	0.756	4.60	0.012
1.40	0.678	5.00	0.008
1.50	0.604	7.00	0.000

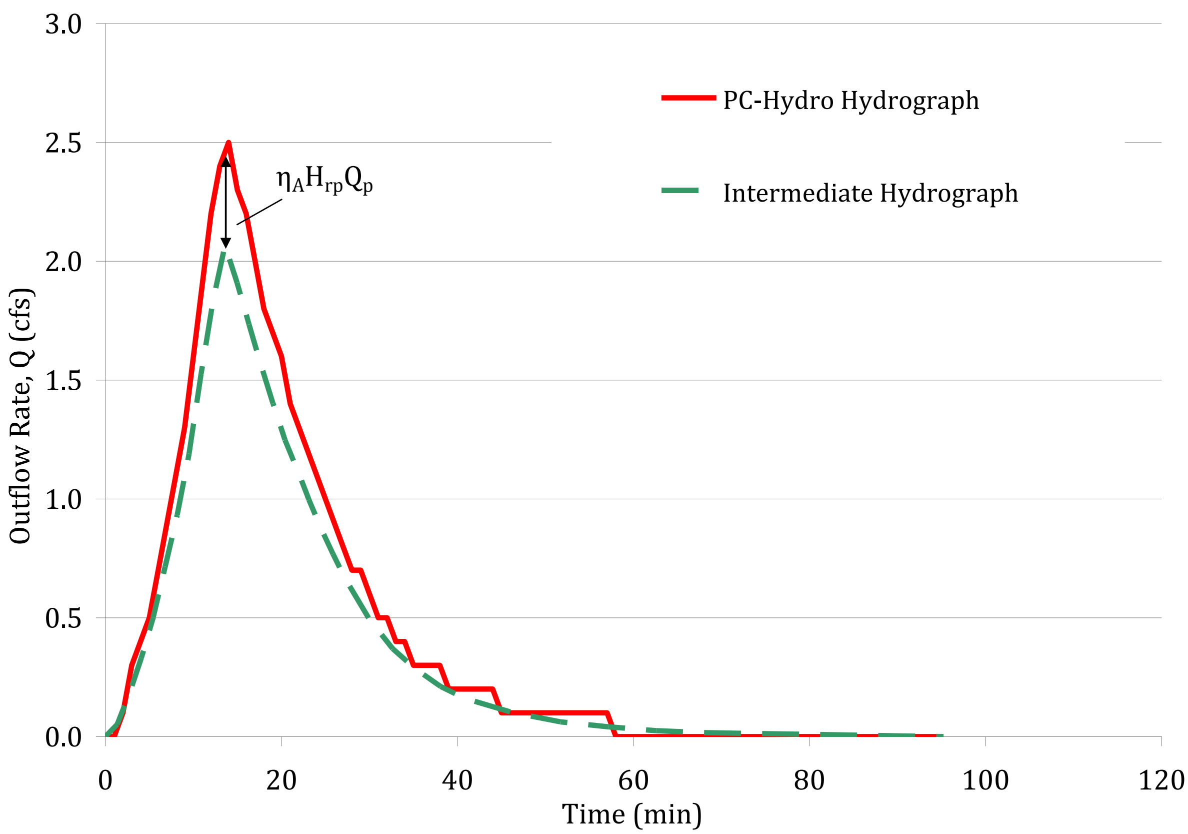

Figure G1. Intermediate hydrograph with peak equal to the reduced peak discharge calculated from Section 3.3.1.

3. The spreadsheet calculates the volume of the intermediate hydrograph (V_{int}), or it may be estimated using Equations G.1 and G.2 for watersheds with Tc less than 60 minutes. When using Equations G.1. and G.2, the Tr of the intermediate hydrograph is the same as the Tr from the PC-Hydro hydrograph in Step 1.

4. The spreadsheet calculates the ratio of the reduced runoff volume due to stormwater harvesting ($V_{swh\text{-}rp}$ from Section 3.3.2) by the volume of the intermediate hydrograph calculated in step 4 (V_{int}). This ratio is defined here as the "volume factor", which is equal to $V_{swh\text{-}rp}$ /V_{int}. The spreadsheet uses the "volume factor" to match the reduced runoff volume when enough of the watershed is diverted to stormwater harvesting basins to utilize the storage capacity of the basins:

a. If the "volume factor" is less than one (this typically occurs when the percent reduction in peak discharge is less than the percent reduction in volume), volume is removed from the intermediate hydrograph in the spreadsheet using the following method:

i. The excess volume of the intermediate hydrograph is calculated by subtracting the reduced runoff volume ($V_{swh\text{-}rp}$) from the intermediate volume (V_{int}).

ii. The front of the intermediate hydrograph is reduced by a volume up to the amount from step (i) that is retained by the stormwater harvesting basins. The outflow rate at the front of the intermediate hydrograph is multiplied by the η_A factor or "stormwater harvesting efficiency" from Section 3.3.1 until the time when the retained volume equals the volume from step (i) or the time step before the peak discharge is reached.

When the volume from (i) is equaled, the flow rates for the remaining time steps are set equal to the flow rates from the intermediate hydrograph. The outflow rate for the time step where the stormwater harvesting basins "overflow" is found based on the sum of the volume that "overflows" the basins and the volume that is directly connected to the outlet (1- η_A) for the time step in order to minimize volume errors. In this case, the volume of the "stormwater harvesting" hydrograph should match the reduced runoff volume calculated in Section 3.3.2 ($V_{swh\text{-}rp}$).

When the removal of the excess volume from the front of the hydrograph would result in removing the peak discharge (such as when a small area of a watershed is diverted to stormwater harvesting basins and the full basin volume may not be utilized), the retention is assumed to stop at the time step immediately before the peak discharge. Therefore, the maximum allowable volume removal from the front of the hydrograph is 24.1% of the intermediate hydrograph volume multiplied by η_A. The remaining flow rates from the intermediate hydrograph are used. In this case, the volume of the hydrograph will be greater than the reduced runoff volume calculated in Section 3.3.2 (V_{swh-rp}). Further reduction in runoff volume can not be achieved unless additional reduction in peak discharge is achieved such as by diverting a larger area of the watershed to stormwater harvesting (increasing η_A).

The time to peak of this stormwater harvesting hydrograph should match the time to peak of the original PC-Hydro hydrograph because the stormwater harvesting basins are treated as “depression storage” and additional detention effects will vary depending on the distribution of the basins and are not included for simplification.

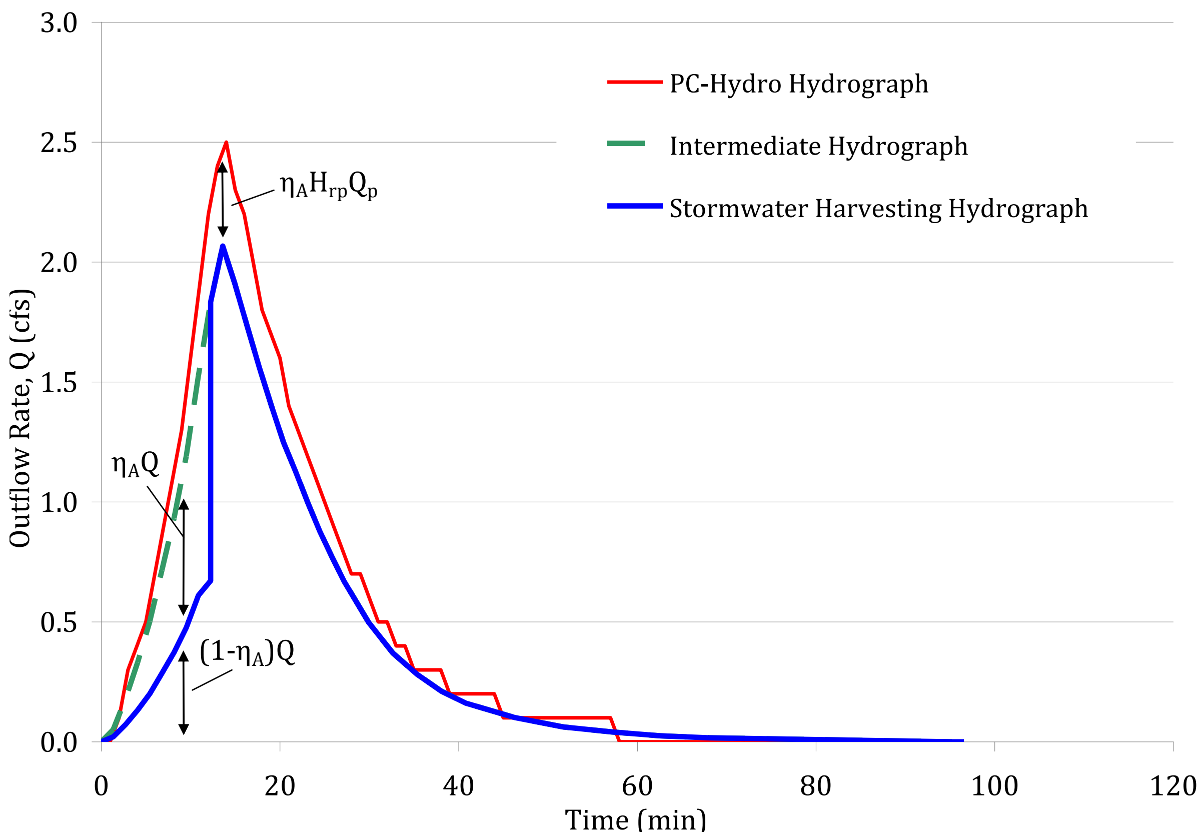

Figure G.2. Stormwater harvesting hydrograph with H_{rp} = 0.289 and η_A = 0.60. The volume factor equals 0.79.

b. If the "volume factor" is greater than one (this may occur in cases where the percent reduction in peak discharge is greater than the percent reduction in volume), too much volume has been removed in the intermediate hydrograph and volume is conserved in the spreadsheet using the following method:

i. Each time step in the hydrograph (i.e. each 't' in Table G.1 above) is multiplied by the volume factor, and all flow rates from the intermediate hydrograph are left unchanged, so that the adjusted hydrograph has a longer duration than the intermediate hydrograph. The volume of the resulting hydrograph is calculated and should match the reduced runoff volume ($V_{swh\text{-}rp}$) calculated in Section 3.3.2.

The time to peak of this stormwater harvesting hydrograph will be slightly longer than the time to peak of the original PC-Hydro hydrograph depending on the volume factor.

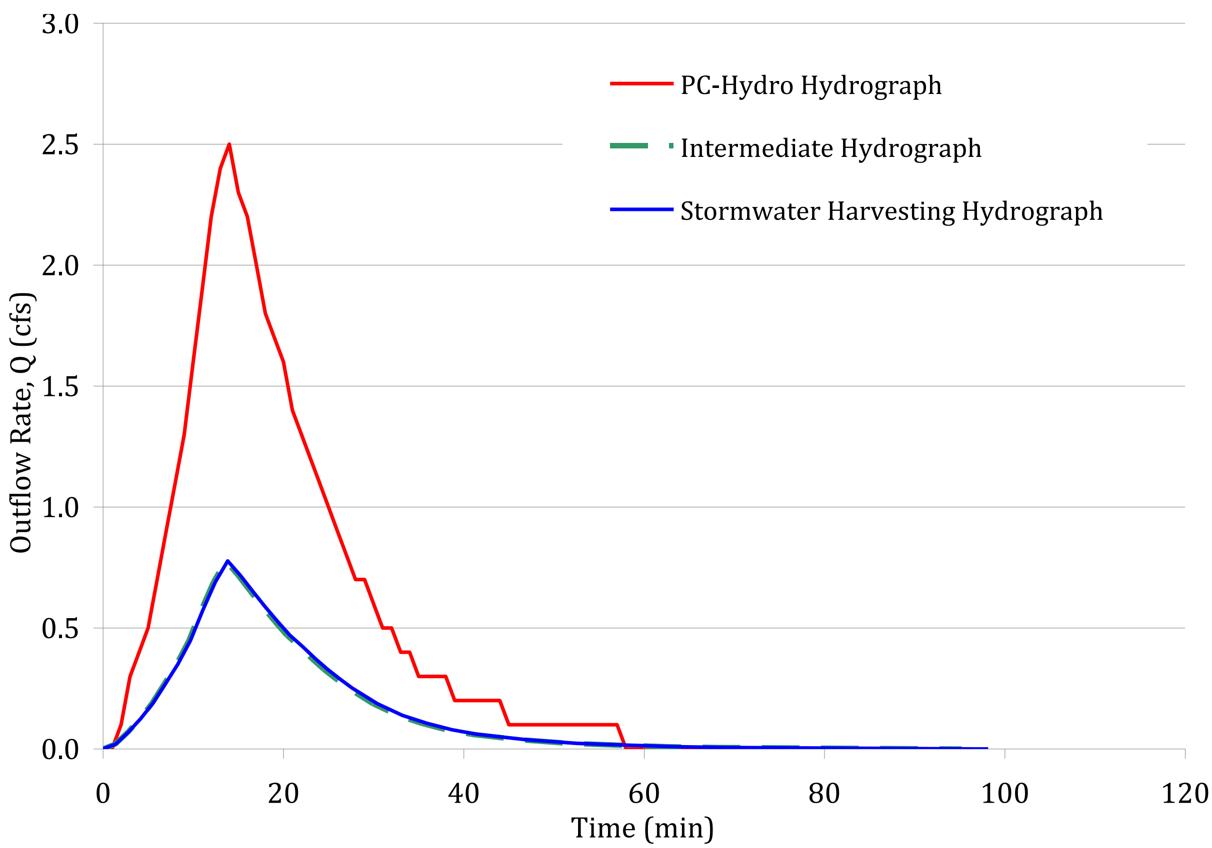

Figure G.3. Stormwater harvesting hydrograph with H_{RP} = 0.725, η_A = 0.95 and a volume factor = 1.02. The Stormwater Harvesting hydrograph is almost identical to the Intermediate hydrograph in this case.

5. The stormwater harvesting hydrograph obtained from completing Step 5 using the spreadsheet may be used as the inflow hydrograph to a detention basin or another concentration point.

Appendix G References

PCDOT&FCD, 1987. Stormwater Detention/Retention Manual. Pima County Department of Transportation and Flood Control District, and the City of Tucson Department of Transportation, Tucson, Arizona.