APPENDIX C: STORMWATER HARVESTING MEMORANDUM

MEMORANDUM
Planning & Development
Regional Flood Control District

	DATE:	February 4, 2013
TO: File	**FROM:**	Dave Stewart, PE

SUBJECT: Development of Peak Discharge Reduction Factors for Stormwater Harvesting Volumes

INTRODUCTION:

A simple method of estimating the reduction in peak discharge and runoff volume due to the placement of stormwater harvesting basins throughout a project site was required that would provide reasonable estimates without extensive modeling effort such as routing flows through the individual stormwater harvesting basins. Modeling studies were completed by the Pima County Regional Flood Control District (PCRFCD) to quantify the reduction in peak discharge and volume for varying scales of stormwater harvesting using a subdivision with measured hydrologic field data and the design of a commercial site from a recent drainage plan.

As described in the “Stormwater Harvesting Factor Study” memo dated 10/31/2011 by PCRFCD, locally available rainfall and runoff data at the 31-acre La Terraza subdivision in Sierra Vista, AZ, were used to measure the degree of accuracy of a runoff model, and then the runoff model was used to develop initial values of “Stormwater Harvesting Factors” for estimating the reduction of peak discharge based on runoff volume and retention volume. Rainfall, runoff, and tension infiltrometer data were collected by the USGS from 2005 – 2008 for the developed watershed and the upstream grassland watershed (Kennedy, et al 2012). The subdivision was selected for this study since it is one of the few if not only residential subdivisions near Pima County with recorded rainfall, runoff, and soil infiltration data. Runoff data collection was discontinued by the USGS in September of 2008.

Kennedy (2007) modeled the La Terraza subdivision using the physically-based USDA-ARS KINEROS2 model. The PCRFCD created an EPA StormWater Management Model (SWMM 5.0, 2010) for the La Terraza subdivision with similar subcatchments and hydrologic parameters based on the KINEROS2 model and the measured field data described by Kennedy (2007). SWMM is a dynamic rainfall-runoff model that was selected due to its applicability for urban drainage systems, its ability to run continuous simulations, and its ability to model Low Impact Development (LID) practices such as stormwater harvesting basins. The EPA SWMM model uses either kinematic wave or dynamic wave routing with a variety of infiltration methods and therefore was able to emulate the KINEROS2 model created by Kennedy (2007) for La Terraza.

As described in a memo dated 11/01/2012, a second modeling study was completed in which a runoff model was developed based on the design in a recent drainage report of a 3.0-acre commercial site (1.6 acres of developed area) located in Pima County, and a validation exercise was performed to measure the ability of the initially-proposed stormwater harvesting factors to predict the modeled peak discharge for various configurations of stormwater harvesting basins. Based on the results from these studies, a table of stormwater harvesting factors for reducing peak discharge based on retention volume and a method for using the table of factors was developed.

METHODS:

La Terraza Modeling

a) La Terraza Model Development

The La Terraza SWMM model was created with subcatchments that followed Kennedy's KINEROS2 model (Figure 1) and the associated data from the KINEROS2 model was used for each subcatchment when applicable (See Appendix D-1 for SWMM subcatchment parameters). Two shallow channels were added in the SWMM model to represent the street system to prevent additional infiltration from routing flow over downstream subcatchments. SWMM subcatchments adjacent to the street drain into the street channel system and are routed to the outlet. Subcatchments not adjacent to the street system in the SWMM model follow the KINEROS2 pattern of routing flow onto downstream subcatchments.

The Green-Ampt infiltration method was used for the SWMM catchments and the saturated hydraulic conductivity (Ks) was used from Kennedy's measurement of effective Ks for La Terraza's urban soils and the upland grassland soils. Kennedy's watershed-scale value of Ks for the urban watershed (2.5 mm/hr or 0.1 in/hr) was used for all subcatchments in the urban area, and the grassland watershed-scale Ks (25 mm/hr or 1 inch/hr) was used for all subcatchments in the grassland area. The Green-Ampt suction head and initial deficit values (6.4 in and 0.15 respectively) were found from Ks using the SWMM manual and other tables based on Rawls (1983).

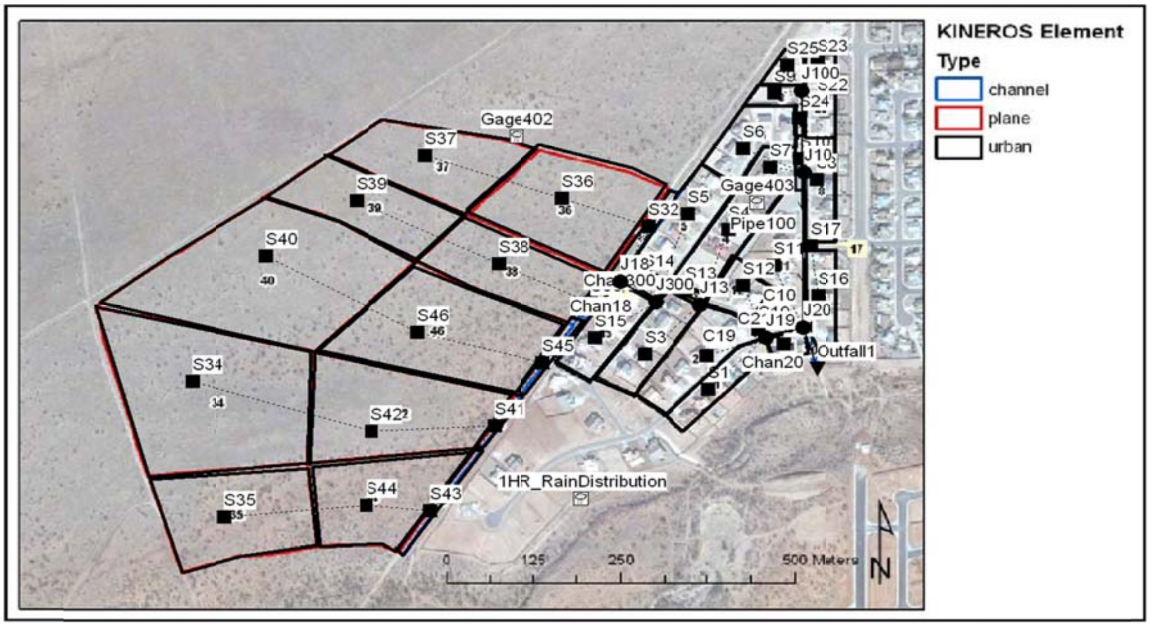

Figure 1. An image of the KINEROS2 model from Kennedy (2007) with the SWMM subcatchments created overtop using the same parameters where appropriate.

b) La Terraza Model Validation

The rainfall from USDA Gage 402 was used for the grassland subcatchments and the rainfall from USDA Gage 403 was used for the urban subcatchments in the SWMM model, and a continuous simulation was developed for the period from 2005 – 2008. The average monthly evapotranspiration (ET) for Sierra Vista based on data from 1991-2003 (Runyon, personal communication) was used in the SWMM continuous simulation.

The runoff data from the grassland watershed (USGS Gage 09470820) was used in the SWMM model as inflow to the urban watershed to evaluate the modeled urban runoff at the outlet compared to the data (USGS Gage 09470825). In addition, the grassland watershed was modeled and the modeled runoff from both the grassland and urban watershed were compared against the gage data.

The peak discharges for the 52 measured precipitation events and the overall runoff volumes for the period of record were compared between the models and the runoff data. The root mean square error (RMSE) was calculated between the modeled peak discharges and the observed peak discharges as:

$$RMSE = \sqrt{\frac{\sum(Modeled - Observed)^2}{n}} \qquad \text{(Equation D-1)}$$

to provide an estimate of model error in predicting peak discharge relative to the gage data.

c) La Terraza Stormwater Harvesting Basin Modeling

The reduction in peak discharge due to overall volume, and distribution of retention volume ("stormwater harvesting") within the La Terraza subdivision were simulated for the 2-year, 10-year, and 100-year rainfall events using the SWMM model. The upland grassland watershed was removed from the models to provide a comparison of the simulated runoff for only the developed area. All stormwater harvesting basins were assumed to have a depth of 1 foot.

The stormwater harvesting areas were modeled in SWMM by creating new subcatchments with an additional 12 inches of depression storage and with the area required to provide the correct stormwater harvesting volume. The area of the upstream subcatchment was reduced by the area of the new stormwater harvesting area and the impervious percent of the upstream subcatchment was increased accordingly to maintain a constant acreage of pervious and impervious areas. The infiltration properties of the stormwater harvesting areas were assumed to be the same as the compacted urban soils of the surrounding pervious areas.

The retention volumes modeled for the La Terraza subdivision were 10.3%, 25.7%, 51.4%, and 85.7% of the 100-yr post-developed runoff volume (which corresponded to larger retention volumes for the 2-year, and 10-year storms). Each of these volumes of stormwater harvesting were modeled for the three return period storms (2, 10, and 100-year) and using three different distributions of stormwater harvesting within the subdivision: 100% of the stormwater harvesting volume located at the subdivision outlet, 50% of the stormwater harvesting volume distributed throughout the subdivision based on subcatchment area and 50% located at the subdivision outlet, and 100% of the stormwater harvesting volume distributed to subcatchments based on subcatchment area, for a total of 36 simulated configurations of stormwater harvesting within the La Terraza subdivision.

Two additional watershed configurations were considered by rearranging some of the La Terraza subcatchments to evaluate the effect of watershed shape on the reduction in peak discharge due to stormwater harvesting basins. A watershed with a shortened flow path was considered by attaching all subcatchments directly to the outlet without any channel systems. A watershed with longer flow paths than La Terraza was considered by moving the eastern half of the La Terraza subcatchments upstream of the channel system of the western half, and multiplying all channel lengths by a factor of two. In the additional cases, the watershed area remains the same and only the length of flow path and order of subcatchments are different. These simulations of two additional watershed shapes were performed for the 100-year rainfall, each of the four volumes of stormwater harvesting, and the three distributions described above (an additional 24 simulations using the alternate watershed shapes).

Commercial Site Modeling

a) Commercial Site Model Development

A SWMM runoff model was developed based on the site design in a recent drainage report of a 3.0-acre commercial site (1.6 acres of developed area) located in Pima County. The SWMM model was created using two of the same watersheds as the drainage report (P1A-NE and P1A-NW), and the remaining watershed (P1B) was divided into five subcatchments in order to allow for simple routing of flow directly from one catchment to the next and to easily model stormwater harvesting as depression storage in three of the subcatchments (Figure 2). The SWMM subcatchments used the watershed areas and slopes from the PC-Hydro models in the drainage report, and used Green-Ampt infiltration parameters for pervious areas based upon measurements of effective saturated hydraulic conductivity (Ks) for urban soils (2.5 mm/hr or 0.1 in/hr) at the La Terraza subdivision in Sierra Vista, AZ, (Kennedy 2007, and Kennedy et al. 2012) in order to provide a consistent application of the SWMM model. The SWMM model parameters are included in Appendix D-2.

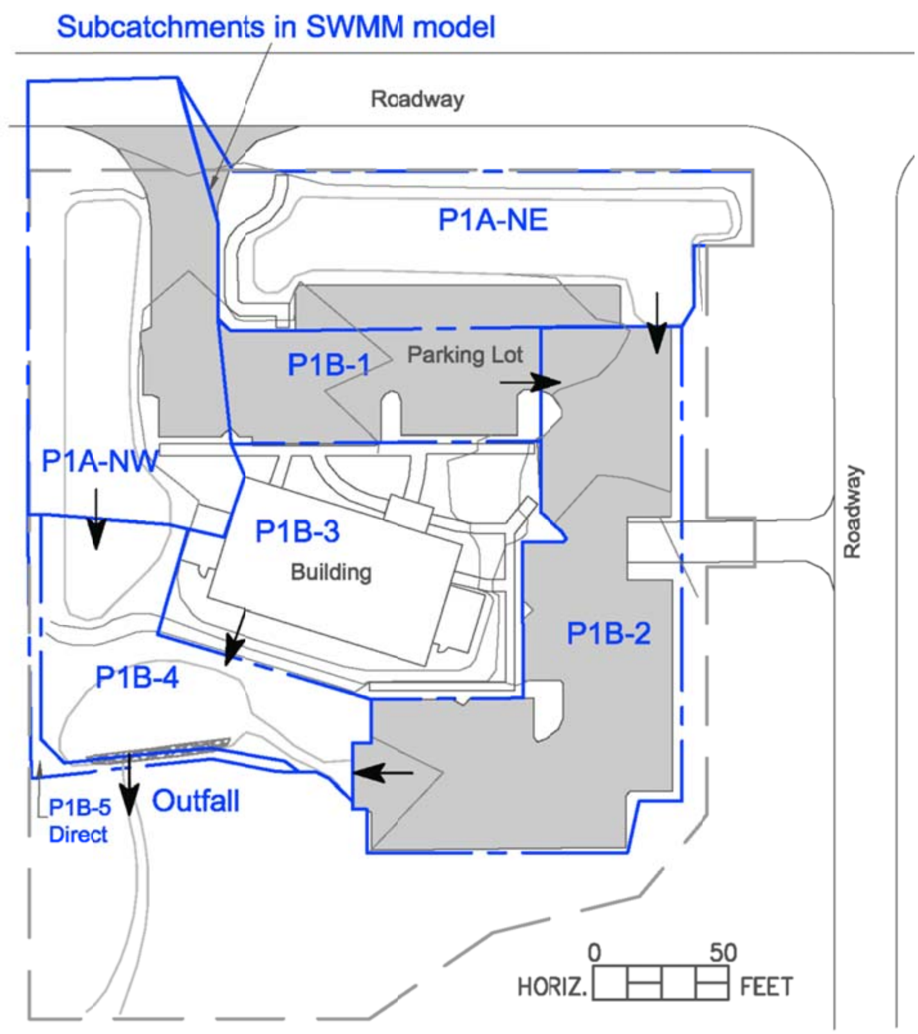

Figure 2. Subcatchments Created for SWMM Modeling of the Commercial Site.

b) Commercial Site Stormwater Harvesting Basin Modeling

Initially, the SWMM subcatchments P1A-NW, P1A-NE, and P1B-4 were modeled without any stormwater harvesting (depression storage) to determine baseline peak discharge rates and runoff volumes. A PC-Hydro model was created that combines the three developed area watersheds presented in the drainage report for comparison with the SWMM modeling of the same area.

Stormwater harvesting basins were modeled in P1B-4 (“Basin 1”), P1A-NW (“Basin 2”), and P1A-NE (“Basin 3”) as depression storage (retention) for pervious areas without any detention effects. The stormwater harvesting volume for a subcatchment was divided by the pervious subcatchment area to provide an average depth of depression storage over the pervious area, and added to the initial storage depth specified for pervious areas within the subcatchment. No outflow occurs from the SWMM subcatchments until the sum of the runoff generated within the subcatchment and runoff flowing onto the subcatchment from upstream exceeds the depression storage. A small area was identified as directly flowing to the outfall that could not be captured by a stormwater harvesting basin, and that area was modeled as the “P1B-5 Direct” subcatchment. The runoff from impervious areas within subcatchments P1A-NW and P1A-NE are directed to pervious areas first, before leaving the subcatchment; while runoff from other impervious areas drains directly to the respective subcatchment outlet.

The stormwater harvesting volumes were varied within the three subcatchments of the commercial site for each of the following:

1. Overall Volume of Retention
   a. 10 percent, 20 percent, 30 percent of the 100-year runoff volume
   b. The 2-year runoff volume
2. Distribution of the Overall Retention Volume between Stormwater Harvesting Basins
   a. All volume in Basin 1 (0 percent distributed) (no Basin 2 or Basin 3)
   b. Weighted by drainage area (62 percent of overall retention volume in Basin 1, 19 percent of overall retention volume in Basin 2 and in Basin 3)
   c. Overall retention volume equally distributed between basins (100 percent distributed) (33.3 percent of overall retention volume in each of Basin 1, Basin 2, and Basin 3)
3. Return-Period Rainfall Event Applied to the SWMM Model
   a. 100-year, 10-year, and 2-year NOAA 14 Upper 90 percent 1-hour rainfall depths

4. Watershed Area Draining to or through Stormwater Harvesting Basins (W_A)

   a. Basin 1, Basin 2, and Basin 3 (“W_A = 99 percent” or 99 percent of watershed drains to stormwater harvesting basins)

   b. Basin 2 and Basin 3 (W_A = 38 percent)

   c. Basin 3 (W_A = 19 percent)

Out of the total of 54 scenarios for the commercial site, 36 of the scenarios have 99 percent of the watershed area draining to some stormwater harvesting (“W_A = 99 percent”), 9 of the scenarios have W_A = 38 percent (using the NW and NE Basins), and 9 of the scenarios have W_A = 19 percent (using the NE basin). It was verified that the stormwater harvesting volume could fit within the subcatchment area at a maximum depth of nine inches for each scenario. The basin volumes are detailed for each model in Appendix D-2.

c) Validation Analysis of Initial La Terraza Stormwater Harvesting Factors

The Commercial Site SWMM model was used to measure ability of an initial set of stormwater harvesting factors from the La Terraza study to predict the reduction in peak discharge for the stormwater harvesting configurations in the Commercial Site study. The estimated peak reduction by the initial factors was plotted versus the modeled reduction in peak discharge by the SWMM model, and the difference between the estimated and modeled peak reduction was used to calculate the explanation of variance (R^2) or prediction ability of the initial factors. After the validation analysis, the modeled results from the Commercial Site study were added to the La Terraza results and a regression was performed to develop an improved set of stormwater harvesting factors.

Design Storms in the La Terraza and Commercial Site Studies

A Depth-Duration-Frequency (DDF) rainfall distribution (Haan et al., 1994) was used to apply 1-hour 100-year, 10-year, and 2-year NOAA 14 Upper 90-percent rainfall depths to the SWMM models. A 1-hour storm duration was chosen to follow the use of a 1-hour rainfall depth in the Pima County Hydrologic Procedures (PC-Hydro) and the small watershed areas (31 acres of development for La Terraza and 1.6 acres of development for the commercial site) indicate that a 1-hr storm is the critical storm and will produce the most conservative peak discharge.

The rainfall intensities for the DDF distribution were obtained using data from NOAA (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html) for the Sierra Vista site (02-7880) for the La Terraza subdivision, and using the latitude and longitude with NOAA 14 for the location of the commercial site. The 90% confidence interval rainfall depths were selected as typically used in Pima County. The 1-hour DDF distribution was used with the highest-intensity 5-minute rainfall depth in the center of the event, surrounded by the 10-minute, 15-minute, 30-minute, and 60-minute rainfall depths (Figure 3). This rainfall distribution was selected because these rainfall intensities are the same values as those that are used to create Intensity-Duration-Frequency curves in the PC-Hydro model for a given location. The placement of the most intense rainfall in the center of the storm is likely to produce conservative peak discharge values because depression storage may have all or part of the storage capacity filled before the most intense rainfall occurs. Results were modeled for the 100-yr, 10-yr, and 2-yr return period rainfall depths.

The DDF distribution results in rainfall intensities that are higher than the 3-hour SCS Type II rainfall distributions and similar peak rainfall intensities to the 3-hour City of Tucson distribution (Figure 4).

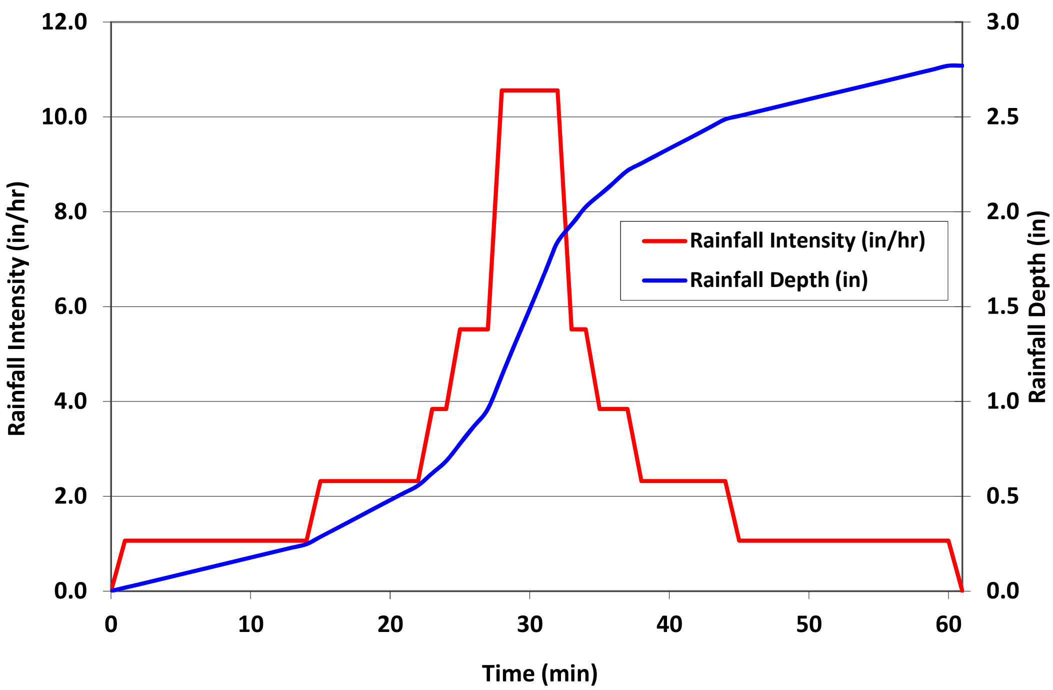

Figure 3. The 1-hour 100-Year Depth-Duration-Frequency Rainfall Distribution Applied to the Commercial Site SWMM Model. 10-Year and 2-Year Rainfall Frequencies were also used.

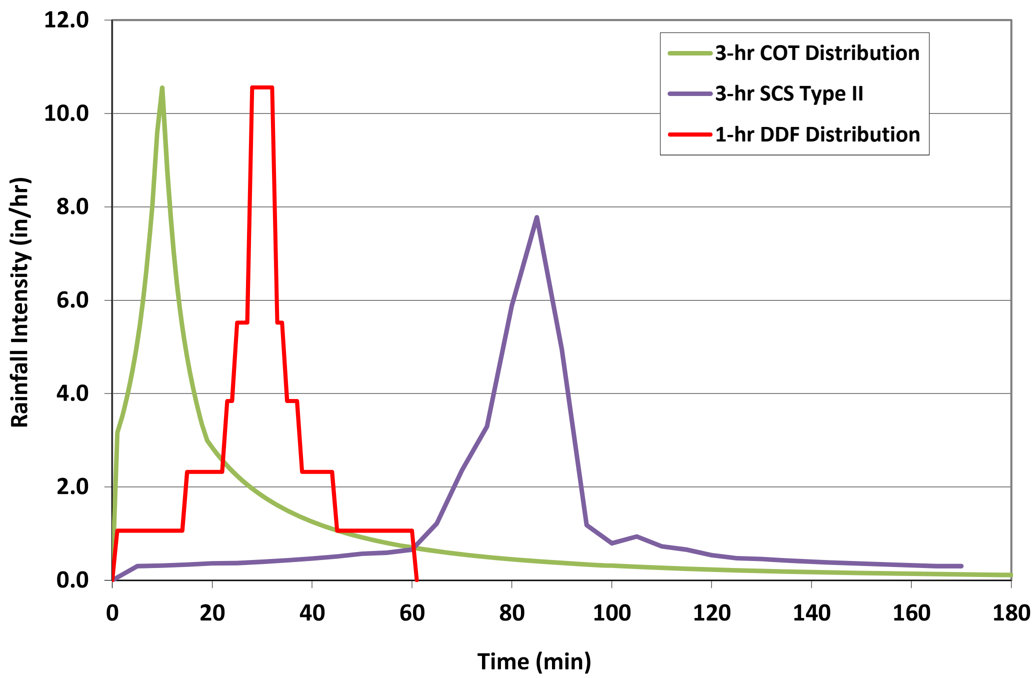

Figure 4. Rainfall Intensity of the 1-Hour Depth-Duration-Frequency Distribution (2.77 Inches of Rainfall Depth) used in the Commercial Site Study Compared with the Rainfall Intensity of the 3-Hour COT and 3-Hour SCS Type II Rainfall Distributions (3.21 inches of rainfall depth).

Regression Analysis of Peak Discharge Reduction and Retention Volume

The modeled results from the 36 Commercial Site configurations with nearly all of the watershed draining to stormwater harvesting and 28 of the La Terraza modeled configurations were used in a regression analysis. The reduced set of the La Terraza results was obtained by selecting the lowest, highest, and median values for each level of stormwater harvesting retention volume where there were previously nine points in order to prevent the regression from being heavily weighted towards the La Terraza results, which had several configurations with values close to the median value at each level of stormwater harvesting volume.

RESULTS

La Terraza Model Validation with Measured Runoff Data

The SWMM model had a root mean square error (RMSE) of 4.6 cfs when predicting the measured peak discharges from the urban watershed (grassland runoff data was used as inflow) and 79% of the variation in peak discharge was explained (R^2 = 0.79) (Figure 5). Fifty nine peak discharges were compared for the period from 2005 – 2008. A larger error is associated with a few of the larger observed peak discharge events, particularly the seven events that recorded a peak discharge of 25 cfs.

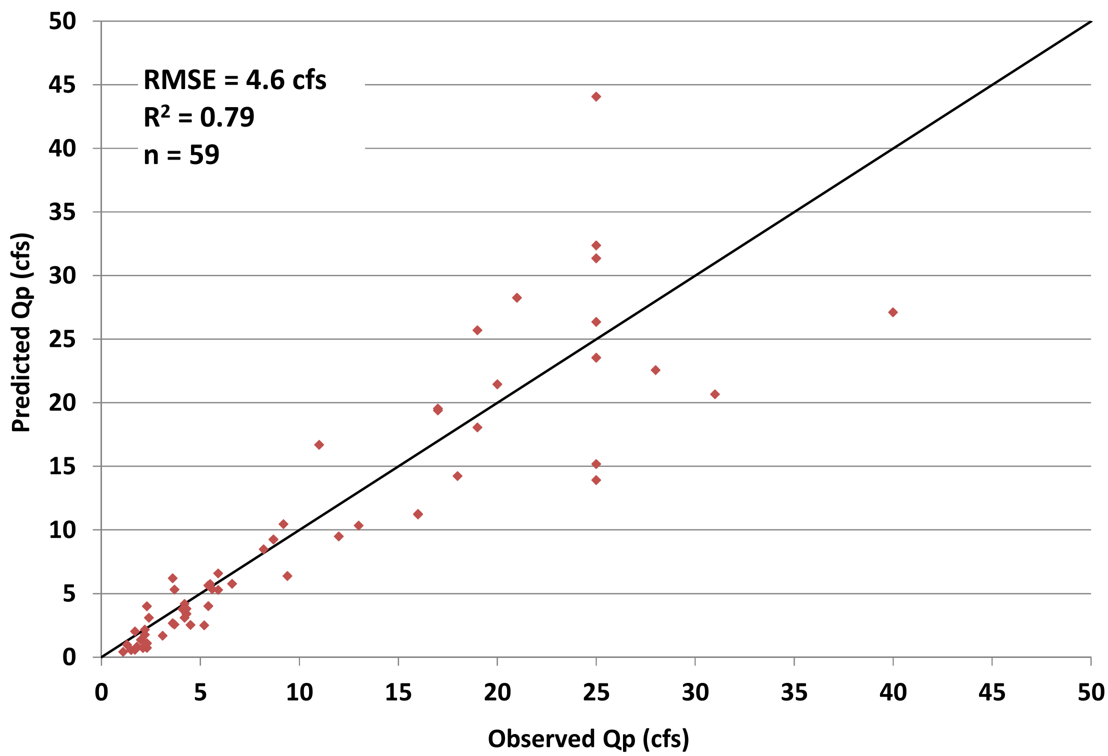

Figure 5. The comparison of modeled peak discharges to observed peak discharges from modeling the urban watershed and using the observed grassland runoff data.

When the urban runoff was modeled and the observed grassland runoff data were introduced into the La Terraza model, the modeled cumulative runoff volume was 43.1 ac-ft or 27% higher compared to the observed cumulative runoff volume of 33.9 ac-ft (Figure 6). When the grassland and urban watersheds were modeled, the cumulative runoff volume was 40.5 ac-ft or 19% higher (there was virtually no modeled runoff from the grassland watershed).

Baseline SWMM Model Results

A comparison of the peak discharges and volumes of the baseline SWMM models (no stormwater harvesting) with PC-Hydro models for the two study areas show a general agreement in peak discharge and runoff volume between PC-Hydro and SWMM models, with the largest difference found for the larger La Terraza study area during the100-year event (Tables 1 and 2). The SWMM model results were used as the baseline peak discharge and runoff volume in determining the percent reduction in peak discharge due to stormwater harvesting volume.

Table 1. Comparison of SWMM-Modeled Peak Discharges to PC-Hydro-Modeled Peak Discharges for the Same Area.

Return Period Event	La Terraza Subdivision (31 ac)		Commercial Site (1.6 ac)	
	PC-Hydro Qp (cfs)	SWMM Qp (cfs)	PC-Hydro Qp (cfs)	SWMM Qp (cfs)
100-year	244	197	13.0	12.8
10-year	123	115	7.0	7.4
2-year	53	59	3.6	4.1

Table 2. Comparison of SWMM Runoff Volumes (V) to PC-Hydro Runoff Volumes.

Return Period Event	La Terraza Subdivision (31 ac)		Commercial Site (1.6 ac)	
	PC-Hydro V (ac-ft)	SWMM V (ac-ft)	PC-Hydro V (ac-ft)	SWMM V (ac-ft)
100-year	5.73	5.57	0.28	0.34
10-year	3.21	3.33	0.15	0.21
2-year	1.59	1.83	0.08	0.13

For the commercial site study area, the modeled outflow hydrographs from the baseline 100-year SWMM model show that a large percentage of runoff drains from subcatchment P1B-2 and upstream subcatchments due to the parking lot, and add up with smaller hydrographs generated from the P1B-3 and P1A-NW subcatchments to produce the outflow from P1B-4 at the outfall of the developed area (Figure 6). The generation of runoff for each small subcatchment in the SWMM models allows the effect of stormwater harvesting volume in one or more of the subcatchments on the overall peak discharge and runoff volume at the outfall to be determined in detail. The La Terraza study area was modeled using the same method.

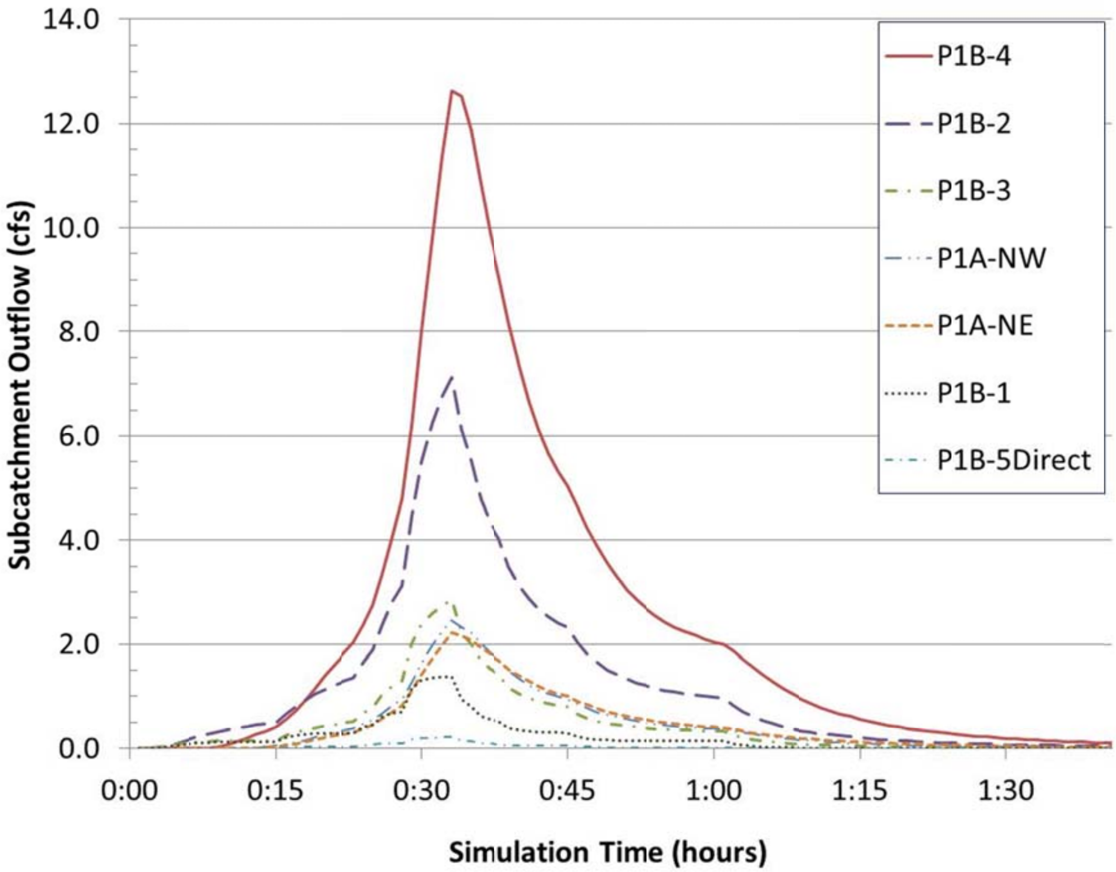

Figure 6. Baseline Outflow Hydrographs from the Commercial Site SWMM Model Subcatchments for the 100-Year Storm (No Stormwater Harvesting Modeled).

Reduction in Peak Discharge Due to Stormwater Harvesting

a) La Terraza SWMM Model Results

The modeled reduction in peak discharge for the 54 configurations of stormwater harvesting volume at the La Terraza subdivision are shown in Figure 7 (Appendix D-3). When the reduction in peak discharge is plotted versus the retention volume as a percent of the runoff volume, a similar pattern is found for all three return period storms. At each percent of volume retained, differences were found in peak discharge reduction due to the distribution of stormwater harvesting volume within the study area, and the additional six simulations for the two watershed shapes modeled in the case of the 100-yr event. The distribution of stormwater harvesting volume within the study area did not indicate a reliable trend in peak reduction in the La Terraza study results and the total retention volume was selected as the indicator of pea discharge reduction from this initial study.

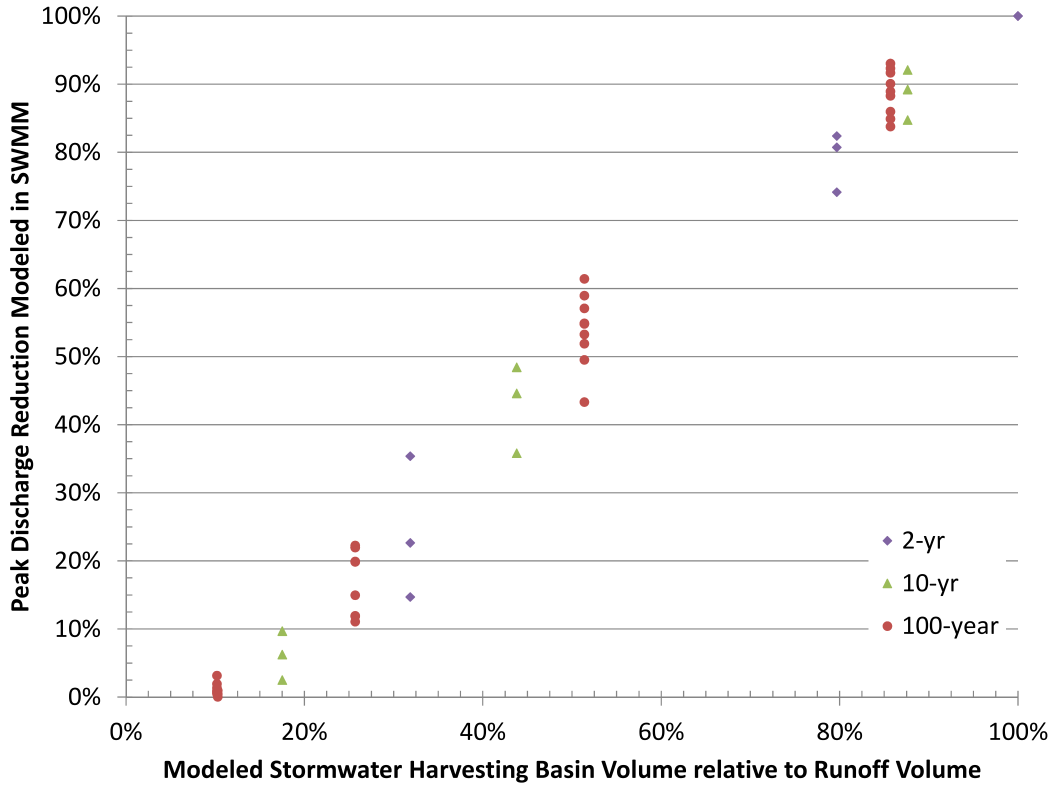

Figure 7. Modeled Reduction in Peak Discharge due to Stormwater Harvesting Volume for the La Terraza subdivision.

b) Commercial Site SWMM Model Results

The Commercial Site SWMM model results from the 36 configurations with about 99 percent of the watershed draining to some stormwater harvesting (“W_A = 99 percent”) showed that the area-weighted distribution of volume among three basins (“Basin 1, Basin 2, and Basin 3 Area-Weighted”) and the distribution of one large basin at the outlet (“Basin 1”) reduced peak discharge the most in the model (with the area-weighted, three-basin distribution performing slightly better in all cases). The equal distribution of volume among three basins (“Basin 1, Basin 2, and Basin 3 Equal Distribution”) showed less efficiency in reducing peak discharge at higher volumes of stormwater harvesting (although slightly better at lower volumes) (Figure 8, Appendix D-4).

The lower reduction in peak discharge for the equal distribution of volume is attributed to stormwater harvesting basins at the top of the watershed being oversized and not filling up with runoff during smaller storm events (i.e. the 2-year event), which results in non-utilized stormwater harvesting volume. The equal distribution of stormwater volume is considered to be a less-than-ideal design in this case, but the modeling results are used to measure the reduction in peak discharge and calibrate stormwater harvesting factors in case of a less-than-ideal design.

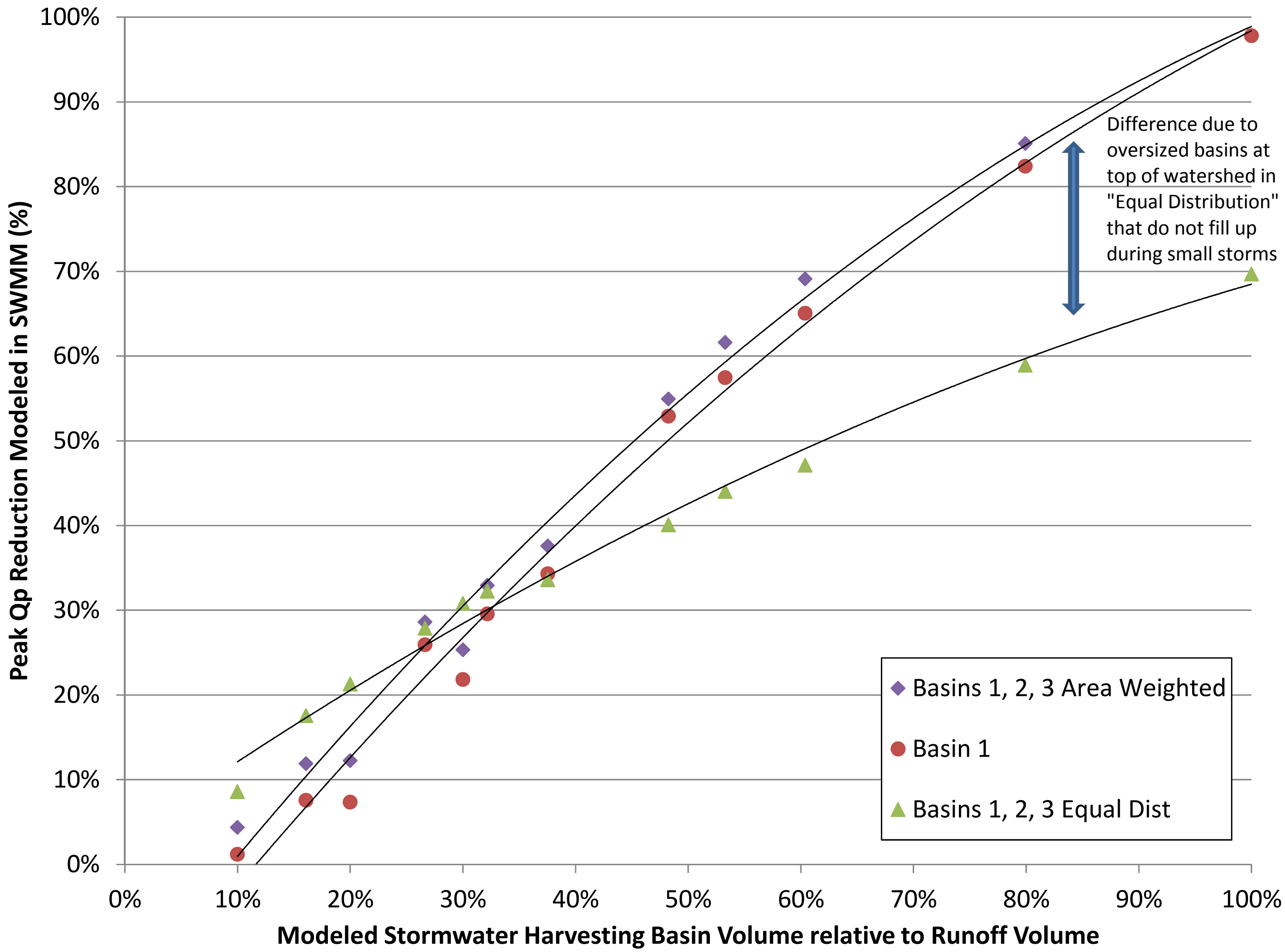

Figure 8. Modeled Reduction in Peak Discharge due to Stormwater Harvesting Volume by Distribution of Volume between Basins using the Commercial Site SWMM Model.

c) Validation Analysis of Initial Stormwater Harvesting Factors using the Commercial Site SWMM Model

The ability of an initial set of stormwater harvesting factors which were obtained from a regression of the La Terraza study results to predict the reduction in peak discharge was measured using the Commercial Site SWMM Model. The explanation of variance (R^2) in peak reduction of the initial factors was found to be 82.2% by comparing the estimated reduction in peak discharge using the initial factors to the modeled peak discharge reduction from the SWMM model.

When the prediction ability of the initial factors was grouped by the distribution of retention volume within the study area, the initial stormwater harvesting factors provided a very good ability to predict reduction in peak discharge for the one large basin at the outfall ("Basin 1", R^2 = 98.5 percent) as well as the three basins with volumes weighted by contributing drainage area ("Basin 1, Basin 2, and Basin 3 Area-Weighted", R^2 = 93.4 percent). However, the initial factors showed a poor ability to predict peak discharge reduction for the three basins of equal size distribution ("Basin 1, Basin 2, and Basin 3 Equal Distribution", R^2 = 21.0 percent) due to the larger basin volumes at the top of the watershed that were not utilized during the smaller 2-year and 10-year storms and therefore did not provide additional reduction in peak discharge. All of the Commercial Site SWMM modeling results were included in the final regression after the validation analysis to improve the accuracy of the stormwater harvesting factors, and the results from these "less-than-ideal" configurations brought the regression line lower to provide a factor of safety for estimating peak discharge reduction when using the stormwater harvesting factors.

Regression Analysis of Peak Discharge Reduction and Retention Volume

Sixty-four modeled data points were used in the regression, with 28 data points from the 31-acre La Terraza subdivision result set, and 36 data points from the 1.6-acre commercial site SWMM modeling results. The least-squares polynomial equation applied to the total modeled points has a correlation coefficient (R^2) of 0.946 (Figure 9) and a Root Mean Squared Error (RMSE) of 6.9%. The regression shows that reduction in peak discharge is approximately zero when the volume retained is less than or equal to 10% of the runoff volume. The results used in the regression analysis include several "less-than-ideal" designs which displayed significantly less reduction in peak discharge, particularly during smaller storms which were likely to have the retention volume equal to 60% or more of the runoff volume. These points provide a factor of safety by weighting the regression line towards lower reduction factors. For example, although stormwater harvesting volumes may be designed to capture 100% of the runoff volume, the maximum amount of peak discharge reduction found is 94.5% from the regression analysis, which indicates that some flow is not expected to be captured by the basins.

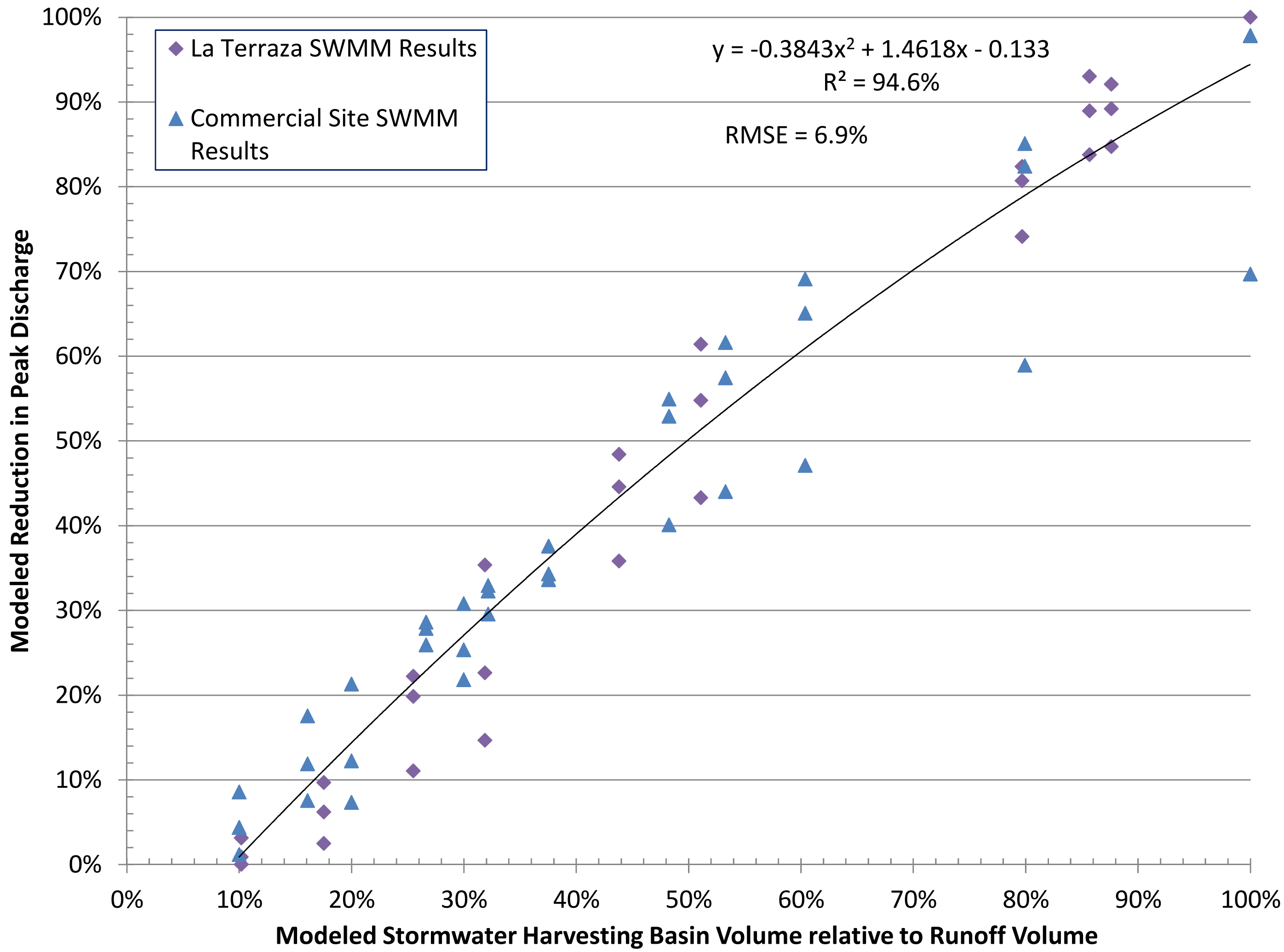

Figure 9. Modeled Peak Discharge Reduction Versus Stormwater Harvesting Volume for the Commercial Site and La Terraza Results.

The following equation from the regression analysis was used to develop a table of stormwater harvesting factors for peak discharge reduction (Table 3) based on the total retention volume in the watershed:

$$H_{rp} = -0.3843X_{rp}^2 + 1.4618X_{rp} - 0.133 \qquad \text{(Equation D-2)}$$

for $0.10 \leq \boldsymbol{X_{rp}} \leq 1.00$

Table 3. Storm Water Harvesting Factors (H_{rp}) for Peak Discharge Rate Reduction Based on Total Volume Retained (X_{rp})

$\boldsymbol{X_{rp}}$	$\boldsymbol{H_{rp}}$
< 10%	0.0%
10%	0.9%
11%	2.3%
12%	3.7%
13%	5.1%
14%	6.4%
15%	7.8%
16%	9.1%
17%	10.4%
18%	11.8%
19%	13.1%
20%	14.4%
21%	15.7%
22%	17.0%
23%	18.3%
24%	19.6%
25%	20.8%
26%	22.1%
27%	23.4%
28%	24.6%
29%	25.9%
30%	27.1%
31%	28.3%
32%	29.5%
33%	30.8%
34%	32.0%
35%	33.2%
36%	34.3%
37%	35.5%
38%	36.7%
39%	37.9%
40%	39.0%
41%	40.2%
42%	41.3%
43%	42.5%
44%	43.6%
45%	44.7%
46%	45.8%
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87%	84.8%
88%	85.6%
89%	86.4%
90%	87.1%
91%	87.9%
92%	88.7%
93%	89.4%
94%	90.2%
95%	90.9%
96%	91.6%
97%	92.3%
98%	93.0%
99%	93.8%
≥ 100%	94.5%

Using Watershed Area Draining to Stormwater Harvesting, "W_A", to Account for Limited Runoff

Eighteen of the 54 Commercial Site SWMM model configurations had smaller percent of watershed areas draining to stormwater harvesting ("W_A") than the 36 configurations used in the regression analysis. Nine of these configurations had stormwater harvesting in the NE and NW Basins at the top of the watershed (W_A = 38 percent), and 9 configurations had stormwater harvesting in only the NE Basin (W_A = 19 percent). The modeling results indicate that a stormwater harvesting basin at the top of the watershed can significantly reduce the peak discharge at the outlet by retaining runoff volume as long as the contributing drainage area to the basin is large enough that runoff will utilize the volume of the basin.

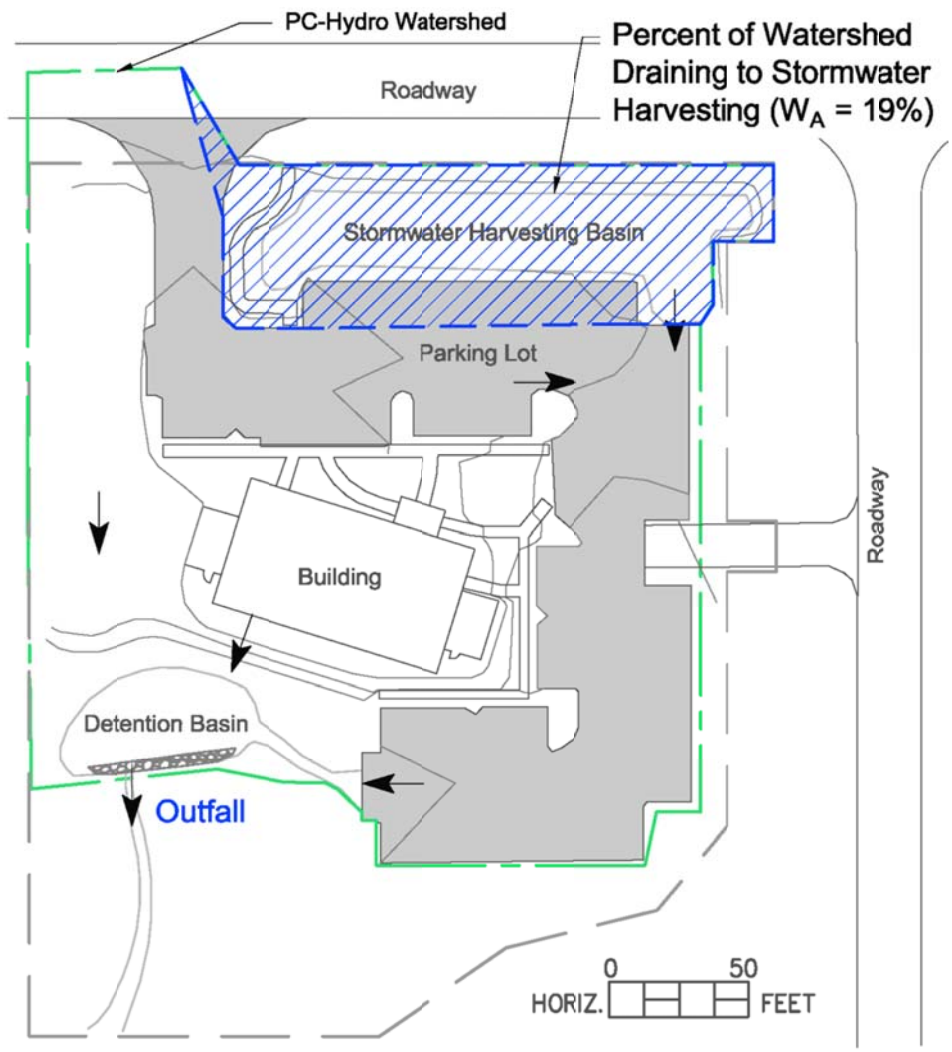

Figure 11. Example of a PC-Hydro Watershed with a Portion Draining to a Stormwater Harvesting Basin.

To account for the availability of runoff to one or more upstream stormwater harvesting basins within a watershed, an assumption can be made for simplification that the runoff volume reaching the basins will be approximately equal to the percent of the watershed area draining to the basins multiplied by the total runoff volume at the watershed outlet. This procedure can be summarized as follows:

1. Determine the area of the watershed that will flow to or through stormwater harvesting basins (A_s) and the total watershed area (A_t), and calculate the percent watershed area draining to stormwater harvesting (W_A) using the following equation:

$$W_A = \frac{A_s}{A_t} \qquad \text{(Equation D-3)}$$

2. Calculate the ratio (X_{rp}) of the sum of the stormwater harvesting basin volumes (V_{bas}) to the post-development runoff volume(V_{post}) with the following equation:

$$X_{rp} = \frac{V_{bas}}{V_{post}}$$

or $X_{rp} = W_A$, whichever is less. (Equation D-4)

3. Find the Storm Water Harvesting Factor (H_{rp}) for peak discharge reduction from the table based on the total retention volume within the watershed (X_{rp}).

This "limiting runoff volume" ($X_{rp} = W_A$) allows the full volume of stormwater harvesting within the watershed to be counted, including a basin near the top of a watershed, unless it is limited by runoff (found by W_A) without the need for additional PC-Hydro models. The runoff volume reaching the outlet of the watershed after accounting for stormwater harvesting basins can then be found as:

$$V_{swh-rp} = V_{post}(1 - X_{rp}) \qquad \text{(Equation D-5)}$$

When this "limiting volume" method is used to predict peak reduction for 27 scenarios from the Commercial Site that have varying draining watershed area (W_A) (Appendix D-4 Table 2), the explanation of variance (R^2) is 62.4% using this assumption while R^2 is -38.1% when no assumption is made to account for limited runoff reaching stormwater harvesting basins. If more detail is required, this assumption (W_A) can be avoided by calculating the discharge for the area draining to the inlet of the basins, which would find W_A = 100% in the above method.

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Appendix D-1. La Terraza SWMM Model parameters.

Appendix D-1, Table 1. Base La Terraza SWMM Model subcatchment parameters.

SUBCATCHMENTS Name	Watershed	Outlet	Total Area (ac)	Pcnt. Imperv	Width	Pcnt. Slope	N-Imperv	N-Perv	S-Imperv	S-Perv	PctZero	RouteTo	PctRouted
S1	**Urban**	J19	1.46	43	587.9	2.0	0.013	0.130	0.018	0.079	14	PERVIOUS	67.4
S2		J19	2.98	27	581.1	0.2	0.013	0.130	0.018	0.079	6	PERVIOUS	77.8
S3		J13	2.46	29	539.6	0.2	0.013	0.130	0.018	0.079	7	PERVIOUS	75.9
S4		J13	2.46	25	628.9	0.5	0.013	0.130	0.018	0.079	7	PERVIOUS	72.0
S5		J300	2.72	29	602.2	6.8	0.013	0.130	0.018	0.079	7	PERVIOUS	75.9
S6		J10	2.14	30	458.4	3.7	0.013	0.130	0.018	0.079	7	PERVIOUS	76.7
S7		J10	0.98	29	198.0	0.5	0.013	0.130	0.018	0.079	7	PERVIOUS	75.9
S8		J10	1.64	44	532.2	5.0	0.013	0.130	0.018	0.079	11	PERVIOUS	75.0
S9		J100	0.56	22	103.6	2.0	0.013	0.130	0.018	0.079	4	PERVIOUS	81.8
S10		J10	0.20	12	268.1	5.7	0.013	0.130	0.018	0.079	0	PERVIOUS	100.0
S11		J20	3.44	21	829.8	2.0	0.013	0.130	0.018	0.079	6	PERVIOUS	71.4
S12		J19	1.23	21	259.1	3.0	0.013	0.130	0.018	0.079	6	PERVIOUS	71.4
S13		J13	0.13	22	178.9	3.0	0.013	0.130	0.018	0.079	0	PERVIOUS	100.0
S14		J300	0.46	30	101.0	5.0	0.013	0.130	0.018	0.079	9	PERVIOUS	70.0
S15		J300	2.23	30	506.6	3.0	0.013	0.130	0.018	0.079	7	PERVIOUS	76.7
S16		J20	1.55	48	503.2	5.0	0.013	0.130	0.018	0.079	16	PERVIOUS	66.7
S17		S16	0.03	100	42.8	0.5	0.013	0.130	0.018	0.079	100	PERVIOUS	0.0
S19		J19	0.06	61	24.3	0.8	0.013	0.130	0.018	0.079	0	PERVIOUS	100.0
S21		J20	0.44	45	178.9	2.0	0.013	0.130	0.079	0.004	0	PERVIOUS	73.3
S22		J100	0.95	45	307.6	2.0	0.013	0.130	0.018	0.079	9	PERVIOUS	80.0
S23		J100	0.35	32	113.8	2.0	0.013	0.130	0.018	0.079	9	PERVIOUS	71.9
S24		J100	0.13	13	157.5	4.3	0.013	0.130	0.018	0.079	0	PERVIOUS	100.0
S25		J100	0.56	27	162.2	2.0	0.013	0.130	0.018	0.079	6	PERVIOUS	77.8
S34	**Grassland**	S42	14.47	0	710.6	4.1	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S35		S44	7.28	0	452.0	3.2	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S36		S32	8.31	0	537.3	4.3	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S37		S36	5.78	0	344.2	4.3	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S38		S33	5.89	0	341.4	4.1	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S39		S38	5.21	0	303.4	4.9	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S40		S46	14.75	0	712.3	4.9	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S42		S41	8.77	0	436.1	3.5	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S44		s43	6.57	0	480.9	1.7	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S46		S45	10.35	0	515.3	3.2	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S43		s41	0.14	0	9.8	1.7	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S41		S45	0.07	0	9.8	1.3	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S45		S33	0.10	0	9.8	1.0	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S32		J18	0.12	0	9.8	2.1	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0
S33		J18	0.07	0	9.8	1.5	0.013	0.130	0.018	0.079	0	PERVIOUS	0.0

Appendix D-1, Table 2. Base La Terraza SWMM Model conduit parameters.

CONDUITS Name	Inlet Node	Outlet Node	Length	Manning N
C10	J10	J20	846.2	0.025
C19	J13	J19	315.0	0.025
C21	J19	J20	223.6	0.025
Chan18	J18	J300	210.0	0.030
Chan20	J20	Outfall1	203.4	0.014
Chan300	J300	J13	304.5	0.025
Pipe100	J100	J20	700.0	0.020

Appendix D-1, Table 3. La Terraza SWMM Model cross section variables.

XSECTIONS Link	Shape	Geom1	Geom2	Geom3	Geom4	Barrels
Chan20	TRAPEZOIDAL	6	10	0.5	0.5	1
Pipe100	CIRCULAR	2	0	0	0	1
Chan300	RECT_OPEN	3	24	0	0	1
Chan18	TRAPEZOIDAL	5	5	0.25	0.25	1
C19	RECT_OPEN	3	24	0	0	1
C21	RECT_OPEN	3	24	0	0	1
C10	RECT_OPEN	3	24	0	0	1

Appendix D-1, Table 4. La Terraza SWMM Model junction variables.

JUNCTIONS Name	Invert Elev.	Max. Depth
J20	4683	5
J100	4684	6
J300	4697	5
J18	4700	5
J13	4692	5
J19	4686	5
J10	4688	5

Appendix D-2, Table 1. Commercial Site SWMM Model Parameters.

Subcatchments							
Name	Raingage	Outlet	Total Area	Pcnt. Impervious (%)	Length	Width	Percent Slope (%)
P1A-NW	1-hr 100-yr, 10-yr or 2-yr	P1B-4	0.3	36	160	82	1.1
P1A-NE	1-hr 100-yr, 10-yr or 2-yr	P1B-2	0.3	34	175	75	0.8
P1B-1	1-hr 100-yr, 10-yr or 2-yr	P1B-2	0.13	93	115	49	2.4
P1B-2	1-hr 100-yr, 10-yr or 2-yr	P1B-4	0.37	97	254	64	1.6
P1B-3	1-hr 100-yr, 10-yr or 2-yr	P1B-4	0.30	45	116	110	1.0
P1B-4	1-hr 100-yr, 10-yr or 2-yr	Outfall1	0.18	2	74	104	1.0
P1B-5 Direct	1-hr 100-yr, 10-yr or 2-yr	Outfall 1	0.02	0	10	97	1.0

Subcatchments							
Name	N-Imperv	N-Pervious	S-Imperv	S-Perv	PctZero	RouteTo	PctRouted
P1A-NW	0.013	0.13	0.018	0.079	0	Pervious	100
P1A-NE	0.013	0.13	0.018	0.079	0	Pervious	100
P1B-1	0.013	0.13	0.018	0.079	0	Outlet	100
P1B-2	0.013	0.13	0.018	0.079	0	Outlet	100
P1B-3	0.013	0.13	0.018	0.079	0	Outlet	100
P1B-4	0.013	0.13	0.018	0.079	0	Outlet	100
P1B-5 Direct	0.013	0.13	0.018	0.079	0	Outlet	100

Infiltration	Green-Ampt		
Subcatchment	Suction	HydrCon	Initial Moisture Deficit
P1A-NW	6.4	0.1	0.15
P1A-NE	6.4	0.1	0.15
P1B-1	6.4	0.1	0.15
P1B-2	6.4	0.1	0.15
P1B-3	6.4	0.1	0.15
P1B-4	6.4	0.1	0.15
P1B-5 Direct	6.4	0.1	0.15

Appendix D-2, Table 2. The volume of stormwater harvesting basins used in the Commercial Site SWMM model for W_A = 99%.

Model	Basin Volume as Percent of Post-Developed Runoff Volume (%)	Location of Retention	Basin 1 (P1B-4) Volume (ac-ft)	Basin 2 (P1A-NW) Volume (ac-ft)	Basin 3 (P1A-NE) Volume (ac-ft)	Watershed D-Storage Basin 1 (in)	Watershed D-Storage Basin 2 (in)	Watershed D-Storage Basin 3 (in)	Basin 1 Area required for 9 in depth	Basin 2 Area required for 9 in depth	Basin 3 Area required for 9 in depth	Basin 1 Area as % of Pervious P1B-4 Subcatch-ment Area	Basin 2 Area as % of Pervious P1A-NW Subcatch-ment Area	Basin 3 Area as % of Pervious P1A-NE Subcatch-ment Area
SWH100yr_Vol2yr_Dist0	38%	Basin 1	0.128	0.000	0.000	8.612	0.079	0.079	7434	0	0	95%	0%	0%
SWH100yr_Vol2yr_Dist100	38%	Basins 1, 2, 3	0.043	0.043	0.043	2.923	2.746	2.665	2478	2478	2478	32%	30%	29%
SWH100yr_Vol2yr_DistAreaWght	38%	Basins 1, 2, 3 Area Weighted	0.080	0.024	0.024	5.412	1.579	1.534	4646	1394	1394	59%	17%	16%
SWH100yr_Vol30_Dist0	30%	Basin 1	0.102	0.000	0.000	6.899	0.079	0.079	5942	0	0	76%	0%	0%
SWH100yr_Vol30_Dist100	30%	Basins 1, 2, 3	0.034	0.034	0.034	2.352	2.210	2.146	1981	1981	1981	25%	24%	23%
SWH100yr_Vol30_DistAreaWght	30%	Basins 1, 2, 3 Area Weighted	0.064	0.019	0.019	4.342	1.278	1.242	3713	1114	1114	47%	13%	13%
SWH100yr_Vol20_Dist0	20%	Basin 1	0.068	0.000	0.000	4.626	0.079	0.079	3961	0	0	51%	0%	0%
SWH100yr_Vol20_Dist100	20%	Basins 1, 2, 3	0.023	0.023	0.023	1.595	1.500	1.457	1320	1320	1320	17%	16%	15%
SWH100yr_Vol20_DistAreaWght	20%	Basins 1, 2, 3 Area Weighted	0.043	0.013	0.013	2.921	0.878	0.854	2476	743	743	32%	9%	9%
SWH100yr_Vol10_Dist0	10%	Basin 1	0.034	0.000	0.000	2.352	0.079	0.079	1981	0	0	25%	0%	0%
SWH100yr_Vol10_Dist100	10%	Basins 1, 2, 3	0.011	0.011	0.011	0.837	0.789	0.768	660	660	660	8%	8%	8%
SWH100yr_Vol10_DistAreaWght	10%	Basins 1, 2, 3 Area Weighted	0.021	0.006	0.006	1.500	0.479	0.467	1238	371	371	16%	4%	4%
SWH10yr_Vol2yr_Dist0	60%	Basin 1	0.128	0.000	0.000	8.612	0.079	0.079	7434	0	0	95%	0%	0%
SWH10yr_Vol2yr_Dist100	60%	Basins 1, 2, 3	0.043	0.043	0.043	2.923	2.746	2.665	2478	2478	2478	32%	30%	29%
SWH10yr_Vol2yr_DistAreaWght	60%	Basins 1, 2, 3 Area Weighted	0.080	0.024	0.024	5.412	1.579	1.534	4646	1394	1394	59%	17%	16%
SWH10yr_Vol30_Dist0	48%	Basin 1	0.102	0.000	0.000	6.899	0.079	0.079	5942	0	0	76%	0%	0%
SWH10yr_Vol30_Dist100	48%	Basins 1, 2, 3	0.034	0.034	0.034	2.352	2.210	2.146	1981	1981	1981	25%	24%	23%
SWH10yr_Vol30_DistAreaWght	48%	Basins 1, 2, 3 Area Weighted	0.064	0.019	0.019	4.342	1.278	1.242	3713	1114	1114	47%	13%	13%
SWH10yr_Vol20_Dist0	32%	Basin 1	0.068	0.000	0.000	4.626	0.079	0.079	3961	0	0	51%	0%	0%
SWH10yr_Vol20_Dist100	32%	Basins 1, 2, 3	0.023	0.023	0.023	1.595	1.500	1.457	1320	1320	1320	17%	16%	15%
SWH10yr_Vol20_DistAreaWght	32%	Basins 1, 2, 3 Area Weighted	0.043	0.013	0.013	2.921	0.878	0.854	2476	743	743	32%	9%	9%
SWH10yr_Vol10_Dist0	16%	Basin 1	0.034	0.000	0.000	2.352	0.079	0.079	1981	0	0	25%	0%	0%
SWH10yr_Vol10_Dist100	16%	Basins 1, 2, 3	0.011	0.011	0.011	0.837	0.789	0.768	660	660	660	8%	8%	8%
SWH10yr_Vol10_DistAreaWght	16%	Basins 1, 2, 3 Area Weighted	0.021	0.006	0.006	1.500	0.479	0.467	1238	371	371	16%	4%	4%
SWH2yr_Vol2yr_Dist0	100%	Basin 1	0.128	0.000	0.000	8.612	0.079	0.079	7434	0	0	95%	0%	0%
SWH2yr_Vol2yr_Dist100	100%	Basins 1, 2, 3	0.043	0.043	0.043	2.923	2.746	2.665	2478	2478	2478	32%	30%	29%
SWH2yr_Vol2yr_DistAreaWght	100%	Basins 1, 2, 3 Area Weighted	0.080	0.024	0.024	5.412	1.579	1.534	4646	1394	1394	59%	17%	16%
SWH2yr_Vol30_Dist0	80%	Basin 1	0.102	0.000	0.000	6.899	0.079	0.079	5942	0	0	76%	0%	0%
SWH2yr_Vol30_Dist100	80%	Basins 1, 2, 3	0.034	0.034	0.034	2.352	2.210	2.146	1981	1981	1981	25%	24%	23%
SWH2yr_Vol30_DistAreaWght	80%	Basins 1, 2, 3 Area Weighted	0.064	0.019	0.019	4.342	1.278	1.242	3713	1114	1114	47%	13%	13%
SWH2yr_Vol20_Dist0	53%	Basin 1	0.068	0.000	0.000	4.626	0.079	0.079	3961	0	0	51%	0%	0%
SWH2yr_Vol20_Dist100	53%	Basins 1, 2, 3	0.023	0.023	0.023	1.595	1.500	1.457	1320	1320	1320	17%	16%	15%
SWH2yr_Vol20_DistAreaWght	53%	Basins 1, 2, 3 Area Weighted	0.043	0.013	0.013	2.921	0.878	0.854	2476	743	743	32%	9%	9%
SWH2yr_Vol10_Dist0	27%	Basin 1	0.034	0.000	0.000	2.352	0.079	0.079	1981	0	0	25%	0%	0%
SWH2yr_Vol10_Dist100	27%	Basins 1, 2, 3	0.011	0.011	0.011	0.837	0.789	0.768	660	660	660	8%	8%	8%
SWH2yr_Vol10_DistAreaWght	27%	Basins 1, 2, 3 Area Weighted	0.021	0.006	0.006	1.500	0.479	0.467	1238	371	371	16%	4%	4%

Appendix D-2, Table 3. The volume of stormwater harvesting basins used in the Commercial Site SWMM model for the W_A = 19%, 39%, and 99% scenarios.

Model	Basin Volume as Percent of Post-Developed Runoff Volume (%)	Location of Retention	Basin 1 (P1B-4) Volume (ac-ft)	Basin 2 (P1A-NW) Volume (ac-ft)	Basin 3 (P1A-NE) Volume (ac-ft)	Watershed D-Storage Basin 1 (in)	Watershed D-Storage Basin 2 (in)	Watershed D-Storage Basin 3 (in)	Basin 1 Area required for 9 in depth	Basin 2 Area required for 9 in depth	Basin 3 Area required for 9 in depth	Basin 1 Area as % of Pervious P1B-4 Subcatch-ment Area	Basin 2 Area as % of Pervious P1A-NW Subcatch-ment Area	Basin 3 Area as % of Pervious P1A-NE Subcatch-ment Area
SWH100yr_Vol10_Dist38%	10%	Basins 2, 3	0.000	0.017	0.017	0.079	1.145	1.112	0	990	990	0%	12%	11%
SWH10yr_Vol10_Dist38%	16%	Basins 2, 3	0.000	0.017	0.017	0.079	1.145	1.112	0	990	990	0%	12%	11%
SWH2yr_Vol10_Dist38%	27%	Basins 2, 3	0.000	0.017	0.017	0.079	1.145	1.112	0	990	990	0%	12%	11%
SWH100yr_Vol20_Dist38%	20%	Basins 2, 3	0.000	0.034	0.034	0.079	2.210	2.146	0	1981	1981	0%	24%	23%
SWH10yr_Vol20_Dist38%	32%	Basins 2, 3	0.000	0.034	0.034	0.079	2.210	2.146	0	1981	1981	0%	24%	23%
SWH2yr_Vol20_Dist38%	53%	Basins 2, 3	0.000	0.034	0.034	0.079	2.210	2.146	0	1981	1981	0%	24%	23%
SWH100yr_Vol30_Dist38%	30%	Basins 2, 3	0.000	0.051	0.051	0.079	3.276	3.179	0	2971	2971	0%	36%	34%
SWH10yr_Vol30_Dist38%	48%	Basins 2, 3	0.000	0.051	0.051	0.079	3.276	3.179	0	2971	2971	0%	36%	34%
SWH2yr_Vol30_Dist38%	80%	Basins 2, 3	0.000	0.051	0.051	0.079	3.276	3.179	0	2971	2971	0%	36%	34%
SWH100yr_Vol10_Dist19%	10%	Basin 3	0.000	0.000	0.034	0.079	0.079	2.146	0	0	1981	0%	0%	23%
SWH10yr_Vol10_Dist19%	16%	Basin 3	0.000	0.000	0.034	0.079	0.079	2.146	0	0	1981	0%	0%	23%
SWH2yr_Vol10_Dist19%	27%	Basin 3	0.000	0.000	0.034	0.079	0.079	2.146	0	0	1981	0%	0%	23%
SWH100yr_Vol20_Dist19%	20%	Basin 3	0.000	0.000	0.068	0.079	0.079	4.212	0	0	3961	0%	0%	46%
SWH10yr_Vol20_Dist19%	32%	Basin 3	0.000	0.000	0.068	0.079	0.079	4.212	0	0	3961	0%	0%	46%
SWH2yr_Vol20_Dist19%	53%	Basin 3	0.000	0.000	0.068	0.079	0.079	4.212	0	0	3961	0%	0%	46%
SWH100yr_Vol30_Dist19%	30%	Basin 3	0.000	0.000	0.102	0.079	0.079	6.279	0	0	5942	0%	0%	69%
SWH10yr_Vol30_Dist19%	48%	Basin 3	0.000	0.000	0.102	0.079	0.079	6.279	0	0	5942	0%	0%	69%
SWH2yr_Vol30_Dist19%	80%	Basin 3	0.000	0.000	0.102	0.079	0.079	6.279	0	0	5942	0%	0%	69%
SWH100yr_Vol30_DistAreaWght	30%	Basins 1, 2, 3	0.064	0.019	0.019	4.342	1.278	1.242	3713	1114	1114	47%	13%	13%
SWH100yr_Vol20_DistAreaWght	20%	Basins 1, 2, 3	0.043	0.013	0.013	2.921	0.878	0.854	2476	743	743	32%	9%	9%
SWH100yr_Vol10_DistAreaWght	10%	Basins 1, 2, 3	0.021	0.006	0.006	1.500	0.479	0.467	1238	371	371	16%	4%	4%
SWH10yr_Vol30_DistAreaWght	48%	Basins 1, 2, 3	0.064	0.019	0.019	4.342	1.278	1.242	3713	1114	1114	47%	13%	13%
SWH10yr_Vol20_DistAreaWght	32%	Basins 1, 2, 3	0.043	0.013	0.013	2.921	0.878	0.854	2476	743	743	32%	9%	9%
SWH10yr_Vol10_DistAreaWght	16%	Basins 1, 2, 3	0.021	0.006	0.006	1.500	0.479	0.467	1238	371	371	16%	4%	4%
SWH2yr_Vol30_DistAreaWght	80%	Basins 1, 2, 3	0.064	0.019	0.019	4.342	1.278	1.242	3713	1114	1114	47%	13%	13%
SWH2yr_Vol20_DistAreaWght	53%	Basins 1, 2, 3	0.043	0.013	0.013	2.921	0.878	0.854	2476	743	743	32%	9%	9%
SWH2yr_Vol10_DistAreaWght	27%	Basins 1, 2, 3	0.021	0.006	0.006	1.500	0.479	0.467	1238	371	371	16%	4%	4%

Appendix D-3, Table 1. La Terraza SWMM Modeling Base Peak Discharge results.

Watershed	RP	V (ac-ft)	Qp (cfs)
La Terraza (Base)	2-yr	1.83	59.2
La Terraza (Base)	10-yr	3.33	115.0
La Terraza (Base)	100-yr	5.57	197.2
Shorter La Terraza	100-yr	5.65	225.1
Longer La Terraza	100-yr	5.60	159.7

Appendix D-3, Table 2. La Terraza SWMM Modeling Stormwater Harvesting Peak Discharge results.

Watershed	Return Period	Distribution	SWH Volume / Runoff Volume	Qp (cfs)	Qp Reduction (%)
La Terraza (Base)	2-yr	0%	31.9%	45.8	22.6%
La Terraza (Base)	2-yr	50%	31.9%	50.5	14.7%
La Terraza (Base)	2-yr	100%	31.9%	38.3	35.4%
La Terraza (Base)	2-yr	0%	79.7%	11.4	80.7%
La Terraza (Base)	2-yr	50%	79.7%	15.3	74.1%
La Terraza (Base)	2-yr	100%	79.7%	10.4	82.4%
La Terraza (Base)	2-yr	0%	>100%	0.0	100.0%
La Terraza (Base)	2-yr	50%	>100%	0.0	100.0%
La Terraza (Base)	2-yr	100%	>100%	0.0	100.0%
La Terraza (Base)	10-yr	0%	17.5%	107.9	6.2%
La Terraza (Base)	10-yr	50%	17.5%	112.2	2.5%
La Terraza (Base)	10-yr	100%	17.5%	103.9	9.7%
La Terraza (Base)	10-yr	0%	43.8%	63.7	44.6%
La Terraza (Base)	10-yr	50%	43.8%	73.8	35.8%
La Terraza (Base)	10-yr	100%	43.8%	59.4	48.4%
La Terraza (Base)	10-yr	0%	87.6%	9.1	92.1%
La Terraza (Base)	10-yr	50%	87.6%	17.6	84.7%
La Terraza (Base)	10-yr	100%	87.6%	12.4	89.2%
La Terraza (Base)	100-yr	0%	10.3%	195.3	0.9%
La Terraza (Base)	100-yr	50%	10.3%	197.1	0.0%
La Terraza (Base)	100-yr	100%	10.3%	196.3	0.4%
La Terraza (Base)	100-yr	0%	25.7%	153.9	21.9%
La Terraza (Base)	100-yr	50%	25.7%	173.7	11.9%
La Terraza (Base)	100-yr	100%	25.7%	153.4	22.2%
La Terraza (Base)	100-yr	0%	51.4%	81.0	58.9%
La Terraza (Base)	100-yr	50%	51.4%	99.5	49.5%
La Terraza (Base)	100-yr	100%	51.4%	89.2	54.8%
La Terraza (Base)	100-yr	0%	85.7%	13.7	93.0%

Appendix D-3, Table 2 (continued). La Terraza SWMM Modeling Stormwater Harvesting Peak Discharge results.

Watershed	Return Period	Distribution	SWH Volume / Runoff Volume	Qp (cfs)	Qp Reduction (%)
La Terraza (Base)	100-yr	50%	85.7%	29.8	84.9%
La Terraza (Base)	100-yr	100%	85.7%	21.8	88.9%
Shorter La Terraza	100-yr	0%	10.2%	218.0	3.1%
Shorter La Terraza	100-yr	50%	10.2%	223.1	0.9%
Shorter La Terraza	100-yr	100%	10.2%	222.1	1.3%
Shorter La Terraza	100-yr	0%	25.7%	175.6	22.0%
Shorter La Terraza	100-yr	50%	25.7%	198.4	11.9%
Shorter La Terraza	100-yr	100%	25.7%	180.3	19.9%
Shorter La Terraza	100-yr	0%	51.4%	86.9	61.4%
Shorter La Terraza	100-yr	50%	51.4%	105.3	53.2%
Shorter La Terraza	100-yr	100%	51.4%	96.7	57.1%
Shorter La Terraza	100-yr	0%	85.7%	18.8	91.7%
Shorter La Terraza	100-yr	50%	85.7%	31.6	86.0%
Shorter La Terraza	100-yr	100%	85.7%	22.4	90.0%
Longer La Terraza	100-yr	0%	10.2%	158.5	0.7%
Longer La Terraza	100-yr	50%	10.2%	158.9	0.5%
Longer La Terraza	100-yr	100%	10.2%	156.6	1.9%
Longer La Terraza	100-yr	0%	25.7%	128.0	19.8%
Longer La Terraza	100-yr	50%	25.7%	142.0	11.0%
Longer La Terraza	100-yr	100%	25.7%	135.8	14.9%
Longer La Terraza	100-yr	0%	51.4%	72.1	54.9%
Longer La Terraza	100-yr	50%	51.4%	90.5	43.3%
Longer La Terraza	100-yr	100%	51.4%	76.8	51.9%
Longer La Terraza	100-yr	0%	85.7%	12.3	92.3%
Longer La Terraza	100-yr	50%	85.7%	25.9	83.8%
Longer La Terraza	100-yr	100%	85.7%	18.7	88.3%

Appendix D-4, Table 1. Commercial Site SWMM Modeling peak discharge results for W_A = 99%.

Model	Return Period	Qp (cfs)	Outflow Runoff Volume (ac-ft)	Total Volume of Basins (ac-ft)	Basin Volume as Percent of Post-Developed Runoff Volume (%)	Location of Retention	W_A	Qp Reduction (cfs)	Qp Reduction (%)
SWH100yr_Vol2yr_Dist0	100	8.43	0.211	0.128	38%	Basin 1	99%	4.40	34%
SWH100yr_Vol2yr_Dist100	100	8.52	0.212	0.128	38%	Basins 1, 2, 3 Equal	99%	4.31	34%
SWH100yr_Vol2yr_DistAreaWght	100	8.01	0.211	0.128	38%	Basins 1, 2, 3 Area Weighted	99%	4.82	38%
SWH100yr_Vol30_Dist0	100	10.03	0.237	0.102	30%	Basin 1	99%	2.80	22%
SWH100yr_Vol30_Dist100	100	8.88	0.238	0.102	30%	Basins 1, 2, 3	99%	3.95	31%
SWH100yr_Vol30_DistAreaWght	100	9.58	0.237	0.102	30%	Basins 1, 2, 3 Area Weighted	99%	3.25	25%
SWH100yr_Vol20_Dist0	100	11.89	0.271	0.068	20%	Basin 1	99%	0.94	7%
SWH100yr_Vol20_Dist100	100	10.1	0.272	0.068	20%	Basins 1, 2, 3	99%	2.73	21%
SWH100yr_Vol20_DistAreaWght	100	11.26	0.272	0.068	20%	Basins 1, 2, 3 Area Weighted	99%	1.57	12%
SWH100yr_Vol10_Dist0	100	12.68	0.306	0.034	10%	Basin 1	99%	0.15	1%
SWH100yr_Vol10_Dist100	100	11.73	0.307	0.034	10%	Basins 1, 2, 3	99%	1.10	9%
SWH100yr_Vol10_DistAreaWght	100	12.27	0.306	0.034	10%	Basins 1, 2, 3 Area Weighted	99%	0.56	4%
SWH10yr_Vol2yr_Dist0	10	2.59	0.082	0.128	60%	Basin 1	99%	4.82	65%
SWH10yr_Vol2yr_Dist100	10	3.92	0.093	0.128	60%	Basins 1, 2, 3	99%	3.49	47%
SWH10yr_Vol2yr_DistAreaWght	10	2.29	0.083	0.128	60%	Basins 1, 2, 3 Area Weighted	99%	5.12	69%
SWH10yr_Vol30_Dist0	10	3.49	0.107	0.102	48%	Basin 1	99%	3.92	53%
SWH10yr_Vol30_Dist100	10	4.44	0.11	0.102	48%	Basins 1, 2, 3	99%	2.97	40%
SWH10yr_Vol30_DistAreaWght	10	3.34	0.109	0.102	48%	Basins 1, 2, 3 Area Weighted	99%	4.07	55%
SWH10yr_Vol20_Dist0	10	5.22	0.143	0.068	32%	Basin 1	99%	2.19	30%
SWH10yr_Vol20_Dist100	10	5.02	0.143	0.068	32%	Basins 1, 2, 3	99%	2.39	32%
SWH10yr_Vol20_DistAreaWght	10	4.97	0.143	0.068	32%	Basins 1, 2, 3 Area Weighted	99%	2.44	33%
SWH10yr_Vol10_Dist0	10	6.85	0.177	0.034	16%	Basin 1	99%	0.56	8%
SWH10yr_Vol10_Dist100	10	6.11	0.178	0.034	16%	Basins 1, 2, 3	99%	1.30	18%
SWH10yr_Vol10_DistAreaWght	10	6.53	0.177	0.034	16%	Basins 1, 2, 3 Area Weighted	99%	0.88	12%
SWH2yr_Vol2yr_Dist0	2	0.09	0.001	0.128	100%	Basin 1	99%	4.00	98%
SWH2yr_Vol2yr_Dist100	2	1.24	0.039	0.128	100%	Basins 1, 2, 3	99%	2.85	70%
SWH2yr_Vol2yr_DistAreaWght	2	0.09	0.003	0.128	100%	Basins 1, 2, 3 Area Weighted	99%	4.00	98%
SWH2yr_Vol30_Dist0	2	0.72	0.024	0.102	80%	Basin 1	99%	3.37	82%
SWH2yr_Vol30_Dist100	2	1.68	0.049	0.102	80%	Basins 1, 2, 3	99%	2.41	59%
SWH2yr_Vol30_DistAreaWght	2	0.61	0.026	0.102	80%	Basins 1, 2, 3 Area Weighted	99%	3.48	85%
SWH2yr_Vol20_Dist0	2	1.74	0.059	0.068	53%	Basin 1	99%	2.35	57%
SWH2yr_Vol20_Dist100	2	2.29	0.061	0.068	53%	Basins 1, 2, 3	99%	1.80	44%
SWH2yr_Vol20_DistAreaWght	2	1.57	0.059	0.068	53%	Basins 1, 2, 3 Area Weighted	99%	2.52	62%
SWH2yr_Vol10_Dist0	2	3.03	0.093	0.034	27%	Basin 1	99%	1.06	26%
SWH2yr_Vol10_Dist100	2	2.95	0.093	0.034	27%	Basins 1, 2, 3	99%	1.14	28%
SWH2yr_Vol10_DistAreaWght	2	2.92	0.094	0.034	27%	Basins 1, 2, 3 Area Weighted	99%	1.17	29%

Appendix D-4, Table 2. Commercial Site SWMM Modeling results for W_A = 19%, 39%, and 99% that show modeled peak reduction and predicted peak reduction for the proposed stormwater harvesting factors.

Model	Return Period	Qp (cfs)	Outflow Runoff Volume (ac-ft)	Total Volume of Basins (ac-ft)	Percent of Post-Developed Runoff Volume (%)	Location of Retention	W_A	Qp Reduction (cfs)	Qp Reduction (%)	X_{rp} (V_{bas}/V_{post} or W_A)	H_{rp}	Predicted Qp Reduction (Base Qp * H_{rp}) (cfs)	Error (Predicted - Simulated Qp Reduction) (cfs)
SWH100yr_Vol10_Dist38%	100	10.97	0.307	0.034	10%	Basins 2, 3	38%	1.86	14%	10%	0.9%	0.12	-1.74
SWH10yr_Vol10_Dist38%	10	5.63	0.178	0.034	16%	Basins 2, 3	38%	1.78	24%	16%	9.1%	0.64	-1.14
SWH2yr_Vol10_Dist38%	2	3.1	0.094	0.034	27%	Basins 2, 3	38%	0.99	24%	27%	23.4%	0.84	-0.15
SWH100yr_Vol20_Dist38%	100	9.17	0.273	0.068	20%	Basins 2, 3	38%	3.66	29%	20%	14.4%	1.87	-1.79
SWH10yr_Vol20_Dist38%	10	5.37	0.144	0.068	32%	Basins 2, 3	38%	2.04	28%	32%	29.5%	2.07	0.02
SWH2yr_Vol20_Dist38%	2	3.1	0.084	0.068	53%	Basins 2, 3	38%	0.99	24%	38%	36.7%	1.32	0.33
SWH100yr_Vol30_Dist38%	100	9.1	0.239	0.102	30%	Basins 2, 3	38%	3.73	29%	30%	27.1%	3.52	-0.21
SWH10yr_Vol30_Dist38%	10	5.37	0.136	0.102	48%	Basins 2, 3	38%	2.04	28%	38%	36.7%	2.57	0.53
SWH2yr_Vol30_Dist38%	2	3.1	0.084	0.102	80%	Basins 2, 3	38%	0.99	24%	38%	36.7%	1.32	0.33
SWH100yr_Vol10_Dist19%	100	11.23	0.307	0.034	10%	Basin 3	19%	1.6	12%	10%	0.9%	0.12	-1.48
SWH10yr_Vol10_Dist19%	10	6.54	0.178	0.034	16%	Basin 3	19%	0.87	12%	16%	9.1%	0.64	-0.23
SWH2yr_Vol10_Dist19%	2	3.69	0.106	0.034	27%	Basin 3	19%	0.4	10%	19%	13.1%	0.47	0.07
SWH100yr_Vol20_Dist19%	100	11.23	0.279	0.068	20%	Basin 3	19%	1.6	12%	19%	13.1%	1.70	0.10
SWH10yr_Vol20_Dist19%	10	6.54	0.174	0.068	32%	Basin 3	19%	0.87	12%	19%	13.1%	0.92	0.05
SWH2yr_Vol20_Dist19%	2	3.69	0.106	0.068	53%	Basin 3	19%	0.4	10%	19%	13.1%	0.47	0.07
SWH100yr_Vol30_Dist19%	100	11.23	0.279	0.102	30%	Basin 3	19%	1.6	12%	19%	13.1%	1.70	0.10
SWH10yr_Vol30_Dist19%	10	6.54	0.174	0.102	48%	Basin 3	19%	0.87	12%	19%	13.1%	0.92	0.05
SWH2yr_Vol30_Dist19%	2	3.69	0.106	0.102	80%	Basin 3	19%	0.4	10%	19%	13.1%	0.47	0.07
SWH100yr_Vol30_DistAreaWght	100	9.58	0.237	0.102	30%	Basins 1, 2, 3	99%	3.25	25%	30%	27.1%	3.52	0.27
SWH100yr_Vol20_DistAreaWght	100	11.26	0.272	0.068	20%	Basins 1, 2, 3	99%	1.57	12%	20%	14.4%	1.87	0.30
SWH100yr_Vol10_DistAreaWght	100	12.27	0.306	0.034	10%	Basins 1, 2, 3	99%	0.56	4%	10%	0.9%	0.12	-0.44
SWH10yr_Vol30_DistAreaWght	10	3.34	0.109	0.102	48%	Basins 1, 2, 3	99%	4.07	55%	48%	48.0%	3.36	-0.71
SWH10yr_Vol20_DistAreaWght	10	4.97	0.143	0.068	32%	Basins 1, 2, 3	99%	2.44	33%	32%	29.5%	2.07	-0.38
SWH10yr_Vol10_DistAreaWght	10	6.53	0.177	0.034	16%	Basins 1, 2, 3	0.99	0.88	12%	16%	9.1%	0.64	-0.24
SWH2yr_Vol30_DistAreaWght	2	0.61	0.026	0.102	80%	Basins 1, 2, 3	99%	3.48	85%	80%	79.0%	2.84	-0.64
SWH2yr_Vol20_DistAreaWght	2	1.57	0.059	0.068	53%	Basins 1, 2, 3	99%	2.52	62%	53%	53.4%	1.92	-0.60
SWH2yr_Vol10_DistAreaWght	2	2.92	0.094	0.034	27%	Basins 1, 2, 3	99%	1.17	29%	27%	23.4%	0.84	-0.33