

- ii. Type of maintenance activities;
- iii. Exhibit showing the location(s) of the dry well(s); and
- iv. Contact information of the driller or authorized maintenance professional.

10.5 Required Summary Table for All Projects

1. A table of the 2-, 10- and 100-year peak discharges for pre-developed, post-developed without detention/retention and post-developed with detention/retention at all concentration points where flows exit the project site shall be provided in the main body of the report.
 - a. The table shall demonstrate that the post-developed with detention/retention peak discharges do not exceed the pre-developed peak discharges or are reduced, as required.
 - b. If developed conditions watersheds have a different configuration than pre-developed conditions watersheds, the table shall correlate the post-developed concentration points with the pre-developed concentration points. The location of post-developed concentration points at the downstream property boundary must approximate the location of the pre-developed concentration points at the downstream property boundary.

11. REQUIREMENTS FOR PLATS, DEVELOPMENT PLANS AND CONSTRUCTION PLANS

The following information shall be placed on or submitted with plats and development plans.

11.1 Required Content for Tentative Plats and Development Plans

11.1.1 Detention Waiver

1. If a Detention Waiver has been granted for the project, provide a General Note:

“A waiver of detention requirements has been granted for this project by the Floodplain Administrator. The owner has paid a fee in lieu of providing stormwater detention facilities.”

11.1.2 General Notes and Permitting Notes

1. If Detention and/or Retention is provided, provide the following General Note, with the relevant volumes:

“This project is required to provide stormwater detention and/or retention. The total volume of detention provided is _____ cubic feet. The total volume of retention provided is _____ cubic feet.”

2. When a project includes LID practices, embankments, an underground storage system, pumps or a dry well, provide the following General Note:

“This project includes _____ [LID practices, embankments, underground storage system, pumps or drywell(s)]. An inspection and maintenance protocol has been provided to the entity responsible for maintenance. An inspection and maintenance covenant has been recorded in the Public Records of Pima County.”

3. When a project has drainage and grading improvements that are required to mitigate off-site adverse impacts to the proposed development, an As-Built Certification or plan shall be prepared and submitted to the Floodplain Administrator. The As-Built Certification or plan requires approval prior to the issuance of any building permits, except for model home permits and any permits necessary to build drainage infrastructure.

Provide the following Permitting Note for development plans and General Note for tentative plats to disclose this requirement:

“Prior to issuance of any building permits an As-Built Certification(Plan) of the drainage and grading improvements that are required to mitigate off-site adverse impacts to the project shall be prepared and submitted to the Floodplain Administrator. Upon approval of the as-built plan by the Floodplain Administrator, the hold to issuance of building permits can be removed.”

4. When a project has drainage and grading improvements that are required to mitigate off-site adverse impacts to adjacent properties, an As-Built Certification or plan shall be prepared and submitted to the Floodplain Administrator. The As-Built Certification requires approval prior to the Certificate of Occupancy for development plans and prior to the final Release of Assurances for plats. Provide the following Permitting Note for development plans and General Note for tentative plats to disclose this requirement:

“Prior to issuance of the [Certificate of Occupancy/final Release of Assurances] an As-Built Certification(Plan) of the drainage and grading improvements that are required to mitigate off-site adverse impacts to adjacent properties shall be prepared and submitted to the Floodplain Administrator. Upon approval of the as-built plan by the Floodplain Administrator, the hold to issuance of [Certificate of Occupancy/final Release of Assurances] can be removed.”

11.1.3 Required Descriptions for Detention Basins and Stormwater Harvesting Basins

1. Provide a descriptor box adjacent to each basin. Include a leader arrow to the basin or provide a label for the basin and reference the label on the top of the descriptor box. Include the following applicable information in the descriptor box:
 - a. Total volume, cubic feet or acre feet;
 - b. If applicable, detention volume, cubic feet or acre feet;
 - c. If applicable, retention volume, cubic feet;
 - d. If applicable, first-flush retention volume, cubic feet;
 - e. If applicable, Q_{100} in, cubic feet per second;
 - f. If applicable, Q_{100} out, cubic feet per second;
 - g. Basin top elevation, feet;
 - h. 100-year water surface elevation, feet; and
 - i. 100-year ponding depth, (measured from the lowest elevation of the basin), feet.
2. For tentative plats, the basin(s) shall be shown within a Common Area, and the plat shall indicate in the title block that the Common Area includes drainage.
3. Label each basin as a Private Detention or Stormwater Harvesting Basin.

4. Show conceptual grading for each basin and include the following information:

For detention and stormwater harvesting basins include:

- a. Location of maintenance access;
- b. Conceptual grade contours;
- c. Side-slope horizontal-to-vertical ratio with slope treatment;
- d. Location and dimensions, feet, of outlet or slope protection; and
- e. For drainage infrastructure requiring a covenant, provide the Sequence Number adjacent to the applicable structure and/or basin or a note indicating that the covenant has been recorded in the Public Records of Pima County.

For detention basins also include:

- f. Location of the sediment level device;
- g. Security barriers, if applicable, with height (minimum of 42 inches high) and material type indicated;
- h. If no retention is proposed within the detention basin, positive drainage to the outlet structure, minimum 0.5% slope; and
- i. Location of inlet and outlet structures with inverts or other inlet and outlet elevations. Call out dimensions and materials. Call out the Q_{100} , cubic feet per second, for all structures.

5. When a retaining wall is utilized as a basin side, a preliminary structural design detail for the retaining wall must be provided. The preliminary design shall include at a minimum the wall and footing dimensions. The intent is to demonstrate that the foundation of the wall will not negatively impact property setbacks or easements and to provide assurance that soil saturation has been considered. The preliminary design detail may be marked preliminary and should be attributed to the design engineer, if the design engineer is different from the project engineer. Complete structural design and construction drawings will be submitted as required by development services during the construction permitting process.

6. When an underground storage system is proposed, show the following on the tentative plat or development plan:

- a. Location of the underground storage system;
- b. Appropriate building setbacks from the underground storage system related to structural integrity, feet;
- c. Locations of inlets and outlets with Q_{100} s and location of emergency overflows.

7. When the project includes a pump(s), the following information shall be included on the plan view:
 - a. Location of the service equipment;
 - b. Location of the sump with dimensions shown; and
 - c. Q_{100} discharge, cubic feet per second.

8. When the project includes a dry well(s):
 - a. The location of the drywell(s);
 - b. Slope to the dry well(s); and
 - c. Elevation of the dry well inlet(s), feet.

9. When Non-contributing Basins or Bioretention Basins are proposed, the following shall be shown:
 - a. The location of the basin(s);
 - b. If applicable, location of sediment trap;
 - c. Retention volume, cubic feet.

11.1.4 Requirements for LID Practices other than Stormwater Harvesting Basins

1. When LID Practices other than Stormwater Harvesting Basins are proposed, the following shall be shown:
 - a. The location and dimensions of swales and other constructable site features, with proposed surface treatment called out.

2. It is optional to call out site planning techniques, such as reduced disturbance or disconnected impervious surfaces.

11.2 Required Detention Basin and LID Practices Content for Final Plats

11.2.1 Detention Waiver

1. If a Detention Waiver has been granted for the project, provide a General Note:

“A waiver of detention requirements has been granted for this project by the Floodplain Administrator. The owner has paid a fee in lieu of providing stormwater detention facilities.”

11.2.2 General and Permitting Notes

1. If Detention and/or Retention is provided, provide the following General Note, with the relevant volumes:

“This project is required to provide stormwater detention and/or retention. The total volume of detention provided is _____ cubic feet. The total volume of retention provided is _____ cubic feet.”

2. If applicable, provide the General Note:

“This project includes _____ [LID practices, embankments, an underground storage system, pumps or dry well(s)]. An inspection and maintenance protocol has been provided to the entity homeowners association. The inspection and maintenance requirements are included in the Conditions, Covenants and Restrictions which have been recorded in the Public Records of Pima County.”

3. When a project has drainage and grading improvements that are required to mitigate off-site adverse impacts to the proposed development, an As-Built Certification or plan shall be prepared and submitted to the Floodplain Administrator. The As-Built Certification or plan requires approval prior to the issuance of any building permits, except for model home permits and any permits necessary to build drainage infrastructure.

Provide the following Permitting Note to disclose this requirement:

“Prior to issuance of any building permits an As-Built Certification(Plan) of the drainage and grading improvements that are required to mitigate off-site adverse impacts to the project shall be prepared and submitted to the Floodplain Administrator. Upon approval of the as-built plan by the Floodplain Administrator, the hold to issuance of building permits can be removed.”

4. When a project has drainage and grading improvements that are required to mitigate off-site adverse impacts to adjacent properties, an As-Built Certification or plan shall be prepared and submitted to the Floodplain Administrator. The As-Built Certification requires approval prior to the final Release of Assurances.

Provide the following Permitting Note to disclose this requirement:

“Prior to the final Release of Assurances, an As-built Certification(Plan) of the drainage and grading improvements that are required to mitigate off-site adverse impacts to adjacent properties shall be prepared and submitted to the Floodplain

Administrator. Upon approval of the as-built plan by the Floodplain Administrator, the hold to the final Release of Assurances can be removed."

11.2.3 Requirements for Detention Basins and Stormwater Harvesting Basins

1. Show the areas where basins are located as Common Area, and indicate in the title block that the Common Area includes drainage features.

11.3 Required Detention Basin and LID Practices Content for Construction Plans

1. Show all basins and other LID practices on the plan view, calling out applicable setbacks. Label all basins as private.
2. On detail sheets, show cross sections of basins, including detention basins, stormwater harvesting basins, and bioretention basins, with the following information as applicable:
 - a. For detention and stormwater harvesting basins include:
 - i. Dimensions of top and bottom areas, feet;
 - ii. Top and bottom elevation, feet;
 - iii. Freeboard elevation, feet;
 - iv. 100-year water surface elevation, feet;
 - v. Side-slope horizontal-to-vertical ratio with slope treatment;
 - vi. Setbacks from property boundaries or other suitable access area (4-foot minimum);
 - vii. Weir or other outlet structure elevation(s), feet;
 - viii. Location and dimensions of inlets; and
 - ix. Dimensions, rock sizing, fabric filter placement, and/or cutoff walls for any proposed erosion protection. The erosion protection shall be shown extended below finished grade.
 - b. For detention basins only include:
 - i. Security barriers, if applicable, with material type and height; and
 - ii. For embankment conditions indicate the following:
 1. Freeboard elevation, feet, (1 foot minimum);
 2. 95% compaction; and
 3. For embankments designed to impound more than 1 foot of water, the following shall be included:
 - a. Emergency spillway location; and
 - b. Impervious treatment with toe down (minimum depth of 18 inches).

Typical cross sections are provided in Appendix E.

- c. For bioretention basins include:
 - i. Depth and length, feet;

- ii. Depression depth, inches;
 - iii. Base layer depth, inches, and material type;
 - iv. Depth of soil medium, inches, and material type; and
 - v. Dimensions of sediment trap.
3. On a detail sheet, show cross sections perpendicular and parallel to inlet and/or outlet structures with the following information:
 - a. Dimensions, feet;
 - b. Material type;
 - c. Invert elevations, feet; and
 - d. 100-year peak discharge, cubic feet per second.

A typical detail is provided in Appendix E.

4. When an underground storage system is proposed, show the following, at a minimum:
 - a. Location of the underground storage system;
 - b. Appropriate building setbacks from the underground storage system related to structural integrity;
 - c. Locations of inlets and outlets with Q_{100} 's and locations of emergency overflows;
 - d. Dimensions and material; and
 - e. Any recommended compaction or bedding material.
5. When the project includes a pump, the following information shall be included on the plan view:
 - a. Location of the service equipment;
 - b. Location of the sump with dimensions shown;
 - c. Q_{100} discharge, cubic feet per second;
 - d. Manufacturer's specifications; and
 - e. Elevations of pump components.
6. When the project includes a dry well, the following shall be shown on the plan view:
 - a. The location of the drywell;
 - b. Slope to the dry well;
 - c. Elevation of the dry well inlet;
 - d. A detail showing the typical dry well installation; and
 - e. A detail showing the words "Stormwater Only" stamped in raised letters on the drywell grate.

11.3.1 Requirements for LID Practices other than Stormwater Harvesting Basins

1. When LID Practices other than stormwater harvesting basins are proposed, the following shall be shown:

- a. The location and dimensions of swales and other constructible site features, with proposed surface treatment called out.
2. It is optional to call out site planning techniques, such as reduced disturbance or disconnected impervious surfaces.

12. REQUIRED CONTENT FOR AS-BUILT CERTIFICATION AND PLANS

12.1 General Requirements

1. Drainage and grading improvements required by the Floodplain Administrator shall be inspected by a Professional Engineer registered in the State of Arizona. The Engineer shall certify that the improvements were built in substantial conformance with the approved plans.
2. When the improvements have been constructed in substantial conformance with the approved construction plans, an As-Built Certification is sufficient. When construction is not in substantial conformance, an as-built plan shall be submitted for review and approval along with the certification document. The as-built plan may be the original plan sheets with exceptions noted on the plan or new plan sheets. The submitted plan sheets shall be stamped or labeled As-Built and signed and sealed by the certifying Engineer.

12.1.1 Detention Basins

1. The following, at minimum, shall be certified;
 - a. Top and bottom elevation, feet;
 - b. Side-slope horizontal-to-vertical ratio;
 - c. Inlet and outlet locations, dimensions and elevations, feet;
 - d. Setbacks from property boundaries and, if applicable, structures, feet;
 - e. Maintenance access;
 - f. 0.5% slope along basin bottom for positive drainage to the outlet structure when retention is not provided within the detention basin;
 - g. Erosion protection, including material and dimensions, feet;
 - h. Slope treatment;
 - i. Sediment level device;
 - j. If applicable security barrier material and location;
 - k. When the basin includes embankment conditions, the following:
 - i. Toe-down dimensions, feet; and
 - ii. For embankments designed to impound more than 1 foot of water:
 1. Emergency spillway location and dimensions; and
 2. 95% compaction of the embankment materials.
 - p. When the basin includes a retaining wall, the following:
 - i. Dimensions, feet; and
 - ii. Setbacks, feet.
 - q. For underground storage, the following:
 - i. Building setbacks, feet;
 - ii. Type of material;
 - iii. Bedding material;

- iv. System dimensions, feet; and
- v. Inlets, outlets, and overflows.
- r. When the basin includes a pump:
 - i. Pump sump dimensions and location;
 - ii. Pump specifications;
 - iii. Inlets, outlets, and overflows; and
 - iv. Alarm system.
- s. When a project includes a dry well:
 - i. Drywell grate with the words “Stormwater Only;”
 - ii. Drywell specifications and location; and
 - v. Verification of ADEQ drywell registration.

12.2 Stormwater Harvesting Basins

- 1. The following at minimum, shall be certified:
 - a. Location as proposed;
 - b. Dimensions of top and bottom areas, feet;
 - c. Top and bottom elevation, feet;
 - d. Side slope ratio;
 - e. Setbacks, feet;
 - f. Maintenance access;
 - g. Slope treatment;
 - h. Location of the sediment trap.
- 2. When bioretention basins are used, the following shall be certified:
 - a. Depth, inches or feet;
 - b. Top dimensions, feet;
 - c. Location of the sediment trap;
 - d. Vertical inspection pipe; and
 - e. Material types.

12.3 Other LID Practices

- 1. The following, at minimum, shall be certified:
 - a. Location of LID Practice(s);
 - b. If disconnection of impervious surfaces or pervious pavement is being claimed as a LID practice, construction as designed; and
 - c. If lengthened flow paths are incorporated as a LID practice, site layout as designed, dimensions of swale and surface treatment of swale.

13. GLOSSARY OF TERMS

The following terms are in addition to the terms defined by the Ordinances of jurisdictions within incorporated and unincorporated Pima County.

Adverse Impact – A change in flow conditions as a result of a development that creates a violation of an applicable floodplain ordinance, a safety issue or property damage.

Approval – Written notice by the Floodplain Administrator approving a submittal including development plans; plats; drainage reports; waivers; proposed pumps, drywells, or underground stormwater storage; and requests to provide designs, analyses or reporting which is different from the requirements stated in this manual

Approved Plan – The most current development plan, plat or construction permit which bears the authorized signature of approval.

Arizona Department of Water Resources (ADWR) - The state agency assigned with oversight of flood control as provided in Title 48 Chapter 21 of the A.R.S.

Attenuation – The collective effect of peak discharge or volume reductions achieved by routing flood waters through a detention basin or approved Low Impact Development Practices.

Concentration Point – A hydrologic term which describes any specific point within a watershed where surface drainage is to be analyzed.

Construction Permit - An engineering document which shows the site layout for a proposed project overlaid on a map of the site and the surrounding area. The plan shows the proposed building locations and footprints, parking lot layout, access, drainage facilities, construction details, site grading and utilities locations for conformance review with applicable regulations.

Covenant – Written agreements that impose responsibilities on the land owners and restrictions upon the use of land.

Dams – The Arizona Department of Water Resources (ADWR), Surface Water Division, has legal jurisdiction over all dams which exceed certain height and storage limits.

Arizona State Statutes, article 45-1201., defines a dam as any artificial barrier, including appurtenant works for the impounding or diversion of water, twenty-five feet or more in height or the storage capacity of which will be more than fifty acre-feet but does not include:

- Any barrier that is or will be less than 6 feet in height, regardless of storage capacity.

- Any barrier that has or will have a storage capacity of 15 acre-feet or less, regardless of height.
- Any barrier for the purpose of controlling liquid-borne material.
- Any barrier that is a release-contained barrier.
- Any barrier that is owned, controlled, operated, maintained or managed by the United States government or its agents or instrumentalities if a safety program that is at least as stringent as the state safety program applies and is enforced against the agent or instrumentality.

Development Plan – An engineering document which shows the site layout for a proposed project overlaid on a map of the site and the surrounding area. The plan shows the proposed building locations and footprints, parking lot layout, access, drainage facilities and utilities for conformance review with applicable regulations.

Disposal Time – The time period during which standing water must be eliminated from a detention basin or Low Impact Development Practice.

Disturbance – The condition of land areas that have been graded, compacted, or significantly altered.

Drainage Report – A report that provides a description of existing and future site conditions supporting hydraulic and hydrologic data, a delineation of the flood prone areas, and a detailed description of the proposed manner in which drainage shall be handled.

Embankment – A linear, usually trapezoidal in cross section, compacted soil feature which is constructed along 1 or more sides of a detention basin. The linear extent of the embankment is constructed above the predominant finished grade. The embankment may be constructed of in-situ or imported soils. Incidental fills to restore predominant natural grade or mass-grading to establish project overall grades are not considered to be embankments.

Emergency Spillway – An outflow spillway from a detention basin which is provided to allow for the safe overflow of floodwaters.

Filter Fabric – Fabric, typically non-woven, used for soil stabilization to prevent soil shifts and movements.

Final Plat – A survey document suitable for recordation of all or part of a subdivision conforming to an approved tentative plat.

First-flush – The delivery of a highly concentrated pollutant loading during the early stages of a storm due to the washing effect of runoff on pollutants that have accumulated on drainage surfaces.

Flood Control – The control of flood waters by employing methods of containment such as a detention system that stops and slows down the downstream progress of flood waters.

Freeboard – The distance measured from the top of an impoundment to the 100-year water surface elevation.

Finished Grade – Any ground elevation which has been cut to or built to the design elevation.

Hard Durable Stones – Stones highly resistant to deterioration by natural processes.

HEC-HMS – Hydrologic Modeling System (HEC-HMS) designed to simulate the precipitation-runoff processes of dendritic drainage basins.

Human Activity Zones – Areas used within a basin for multiple purposes other than detention where human recreational activities are involved.

Hydrograph – A graph showing changes over time in the stormwater runoff from a drainage area.

Hydroseed – A mixture of seed, mulch and soil ameliorants applied by spraying or other mechanical means.

Impervious – Not allowing entrance or passage by water.

Impervious Treatment – A process that renders a surface impervious to water.

Inflow – Runoff which flows into a stormwater storage facility from the upstream watershed.

Inlet – Structural element that serves as the entrance where stormwater is directed into a basin.

Inspection – Examination of the conditions of drainage structures to ensure their proper functioning.

Invasive Plants – Plants that invade ecosystems beyond their historical range. Dependent on these ecosystems, invasive plants can threaten native ecosystems or commercial, agricultural, or recreational activities dependent on these ecosystems costing the economy billions of dollars on an annual basis.

Landscape Bufferyard – A strip of land used for landscaping to separate one type of land use/zoning from another.

Length of Watercourse – The length of the flow path taken by water runoff from a surface.

Low Impact Development (LID) – Practices that utilize basic principles modeled after the natural environment by managing runoff and urban water use at the source using uniformly distributed small-scale controls.

Maintenance – The upkeep of drainage structures to assure conformance with approved design and storage volume over time.

Maintenance and Inspection Protocol – A document describing items to be inspected to assure proper functioning of drainage structures over the life of a project and the maintenance activities, if any, to be completed to resolve issues noted during an inspection.

Major Watercourse – For the purposes of this manual, a natural channel which conveys a 100-year peak discharge of 10,000 cfs or more, or a watercourse which has been designated as a major watercourse for an individual instance based on engineering justification accepted by the Floodplain Administrator.

Multiple-Use Concepts – Concepts employed in an engineered basin that provide benefits in addition to the primary function of flood control. Such benefits may include recreation, water harvesting, or visual buffers.

Outflow – The discharge which exits a stormwater storage facility by means of an outlet structure.

Outlet – The point at which stormwater runoff flows out of an engineered basin.

PC-Hydro – A semi-empirical rainfall-runoff model accepted in Pima County for predicting flood peaks from ungauged watersheds under natural and developed hydrologic conditions.

Peak Discharge – The maximum flow rate, in terms of volume per time, passing a particular location during a storm event.

Pima County – The incorporated, as well as the unincorporated areas of Pima County, including public lands, but excluding tribal and military reservations and those incorporated areas of cities or towns which have elected to assume separate floodplain management powers and duties pursuant to Section 48-3610 of the Arizona Revised Statutes.

Pre-Developed Conditions – Site conditions related to drainage prior to land development.

Primary Tributary – A channel which flows directly into a major watercourse.

Project Boundary – The boundary that sets the limits of the project site.

Post-Developed Conditions – Site conditions related to drainage after land development.

Positive Drainage – The drainage condition which provides for removal of stormwater from a site within the required disposal time and prevention of ponding of water for periods exceeding the required disposal time.

Rainwater – Liquid water that has precipitated from atmospheric water vapor but has not yet landed on the earth’s surface or any protrusions on the earth’s surface.

Recorded – Placed into the public record by the Pima County Recorder.

Regional Detention Basin – A detention basin which collects stormwater runoff from a relatively large area, and has been designed to use storage as a means of reducing downstream flood peaks, reducing possible flood damage, or reducing downstream channel construction costs. Regional facilities are usually multi-purpose, and normally are the responsibility of a public entity.

Riprap – A rock layer combination of large stone, cobbles and boulders that protects earthen surfaces from erosion.

Routing – A mathematical procedure for predicting the changing magnitude, speed, and shape of a flood wave as it travels through a detention basin.

Runoff – Stormwater flowing over a surface.

Secondary Tributary – A natural channel which discharges into a primary tributary.

Setback – The horizontal distance between an object of interest and perimeter of a basin or property boundary or public access limit.

Sediment – An earthen material that is carried and deposited by water.

Site – Area where a project is located including improved areas, open space, floodplains and other regulatory development areas.

Storage – Volumetric measurement of the water stored in the detention basin.

Stormwater – Rainwater that has landed on a surface.

Stormwater Harvesting – The process of intercepting stormwater from a surface such as a roof, parking area, or land surface, and putting it to beneficial use.

Subdivision – Improved or unimproved land or lands divided or proposed to be divided for the purpose of sale, lease, or for cemetery purposes, whether immediate or future, into 6 or more lots, parcels or fractional interests.

Subsoil – The layer of soil under the topsoil.

Sustainability Principles – The development and construction principles that support a sustainable future.

Swale – A depression that is cut into the soil for the purpose of conveying stormwater.

Technical Policy (Policies) – Publications by the District which clarify the permitting requirements of the Pima County Floodplain and Erosion Hazard Management Ordinance.

Tentative Plat – A tentative plat is a map showing the existing conditions of the property and surrounding area on which proposed development is overlaid, which can include topography, infrastructure improvements, and existing structures.

Time of Concentration – The time required for storm runoff to flow from the hydraulically most remote point of a catchment or drainage area to the outlet or point under consideration.

Watershed – The contributing drainage area located upstream of a specific point along a watercourse.

Weir – A structure placed at the basin outlet to control the volume of outflow.

14. REFERENCES

American Society of Civil Engineers, 1998, *Urban Runoff Quality Management*, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, by Joint Task Force of the Water Environment Federation and the American Society of Civil Engineers, Larry A. Roesner and Ben R. Urbonas, chmn. (pages 175-178 [approximately the 85th percentile 24-hour storm runoff event]).

Arizona State Revised Statutes, Title 45-Waters, Chapter 6 Dams and Reservoirs, Article 1 Supervision of Dams, Reservoirs and Projects, Section 1201 Definitions.

California Stormwater Quality Association, Stormwater Best Management Practice Handbook: Construction. Available at: <http://www.cabmphandbooks.com/Documents/Construction/SE-4.pdf>

City of Tucson, Standards Manual for Drainage Design and Floodplain Management in Tucson Arizona. December 1989, revised July 1998.

City of Tucson, Water Harvesting Guidance Manual. October 2005. Available at <http://dot.ci.tucson.az.us/stormwater/downloads/2006WaterHarvesting.pdf>

Drainage and Channel Design Standards for Local Drainage for Floodplain Management within Pima County, Arizona. June 1, 1984.

Federal Highway Administration, Hydraulic Engineer Circular No. 14; HEC-14, Third Edition. Hydraulic Design of Energy Dissipators for Culvert and Channel. July 2006.

Hydrologic Engineering Center - Hydrologic Modeling System, HEC-HMS, User's Manual, Version 3.5. January 2001.

PC-Hydro V5, Pima County Hydrology Procedures. A Computer Program for Predicting Peak Discharges of Surface Runoff from Small Semi-Arid Watersheds in Pima County, Arizona. PC-Hydro User Guide. Arroyo Engineering, March 2007.

Pima County Title 16, Floodplain and Erosion Hazard Management Ordinance No. 2010-FC5.

Pima County Regional Flood Control District, Regulated Riparian Habitat Mitigation Standards and Implementation Guidelines. October 2009. Available [through](#) the Rules and Procedure's Page of the Pima County Regional Flood Control District web page.

Pima County Regional Flood Control District, Technical Policy, TECH-015, Acceptable Methods for Determining Peak Discharges. October 1, 2007. Available through the Rules and Procedures page of the Pima County Regional Flood Control District web page.

Pima County Subdivision and Development Street Standards. April 5, 2005.

Pima County Department of Transportation & Flood Control District/City of Tucson Stormwater Detention/Retention Manual. February 1987. Available through the Rules and Procedures page of the Pima County Regional Flood Control District web page..

Pima County Zoning Code, Chapter 18.73, Landscaping, Buffering and Screening Standards. October 1985.

San Diego, County of, Low Impact Development Handbook: Stormwater Management Strategies. Department of Planning and Land Use, San Diego, California. Available at: <http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf> 2007.

Truckee Meadows Low Impact Development Handbook: Guidance on LID Practices for New Development and Redevelopment. Available at: <http://www.cityofreno.com/Index.aspx?page=996> 2005.

United States Department of Agriculture, Urban Hydrology for Small Watersheds, Technical Release 55, June, 1986.

United States Green Building Council. 2009 (updated November, 2011). *LEED for Neighborhood Development Rating System*. USGBC.org.

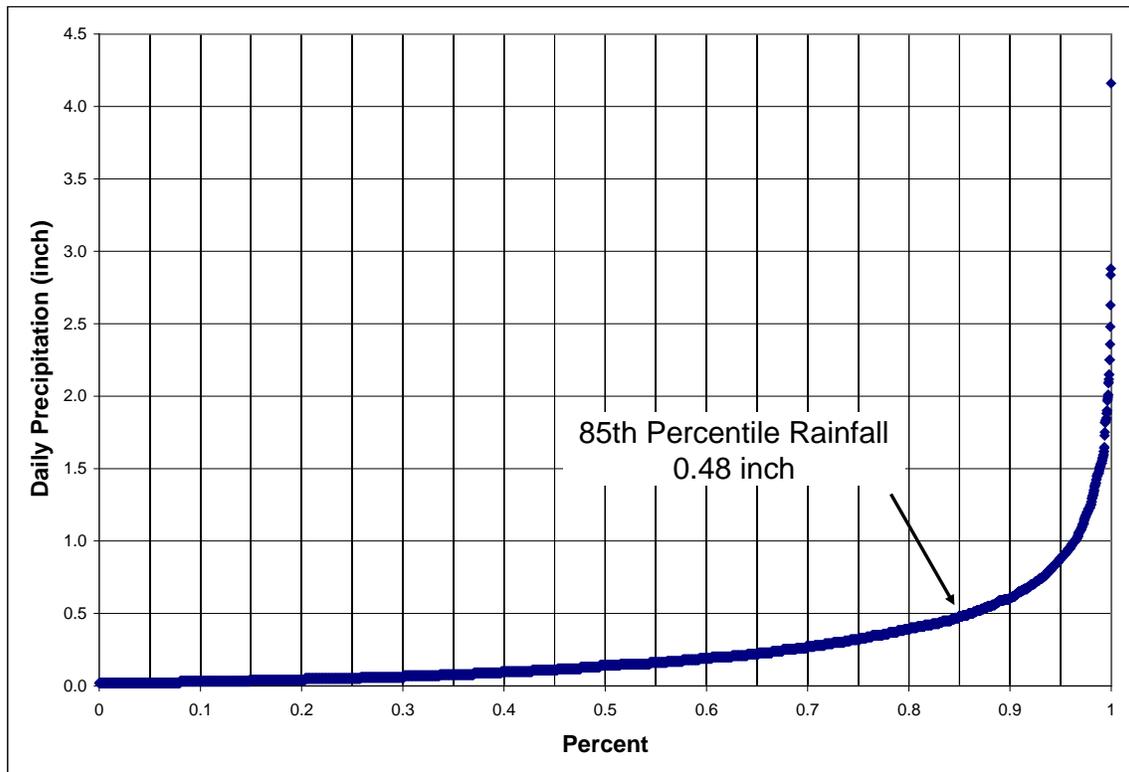
Watershed Management Group, *Green Infrastructure for Southwestern Neighborhoods, Version 1.0*, August 2010.

Zeller, M.E., Hydrology Manual for Engineering Design and Floodplain Management within Pima County, Arizona. Pima County Department of Transportation and Flood Control District, September 1979.

APPENDIX A: FIRST-FLUSH RETENTION

Appendix A – First-flush Retention

The District selected a first flush retention requirement to capture the 0.5 inch rainfall event. This value is approximately the 85% daily rainfall depth (i.e. 85% of all daily rainfall depths are less than this value). The American Society of Civil Engineers (ASCE, 1998) identified capture of this 85% precipitation event as a useful target for mitigating stormwater volume impacts regardless of climate, and many regulatory agencies have found it to be a reasonable and attainable target. Using the 105 years of daily rainfall collected at the University of Arizona, the 85% precipitation event has been determined to be 0.48 inch as shown in the figure below:



While the 85% precipitation event can be expected to vary across Pima County because of orographic effects, selecting the 0.5 inch value allows for more simplified calculation of the first flush.

In most cases, capturing more stormwater can be viewed as greater net benefit. The United States Green Building Council (USGBC) LEED for neighborhood development therefore awards LEED points for Green Infrastructure based on the 80th to 95th percentile rainfall volume captured by a neighborhood site design (USGBC – Green Infrastructure Credit 8, 2009). Based on 105 years of daily rainfall at the University of Arizona, these values are as follows:

- 80th Percent – 0.37 inch
- 85th Percent – 0.48 inch

- 90th Percent – 0.61 inch
- 95th Percent – 0.88 inch

It is also important to note, however, that in some cases, capture of greater volumes of stormwater may reduce flows into riparian areas that rely on the upstream flows. Therefore, while stormwater harvesting is an important tool for mitigating the impacts of development, the decision to capture volumes above the first flush requirement must be made on a case by case basis.

American Society of Civil Engineers. 1998. *Urban Runoff Quality Management*, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, by Joint Task Force of the Water Environment Federation and the American Society of Civil Engineers, Larry A. Roesner and Ben R. Urbonas, chmn. (pages 175-178 [approximately the 85th percentile 24-hour storm runoff event]).

United State Green Building Council. 2009 (updated November, 2011). *LEED for Neighborhood Development Rating System*. USGBC.org

**APPENDIX B: EXAMPLE LID PEAK DISCHARGE AND FIRST FLUSH
RETENTION CALCULATIONS**

Appendix B: 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.

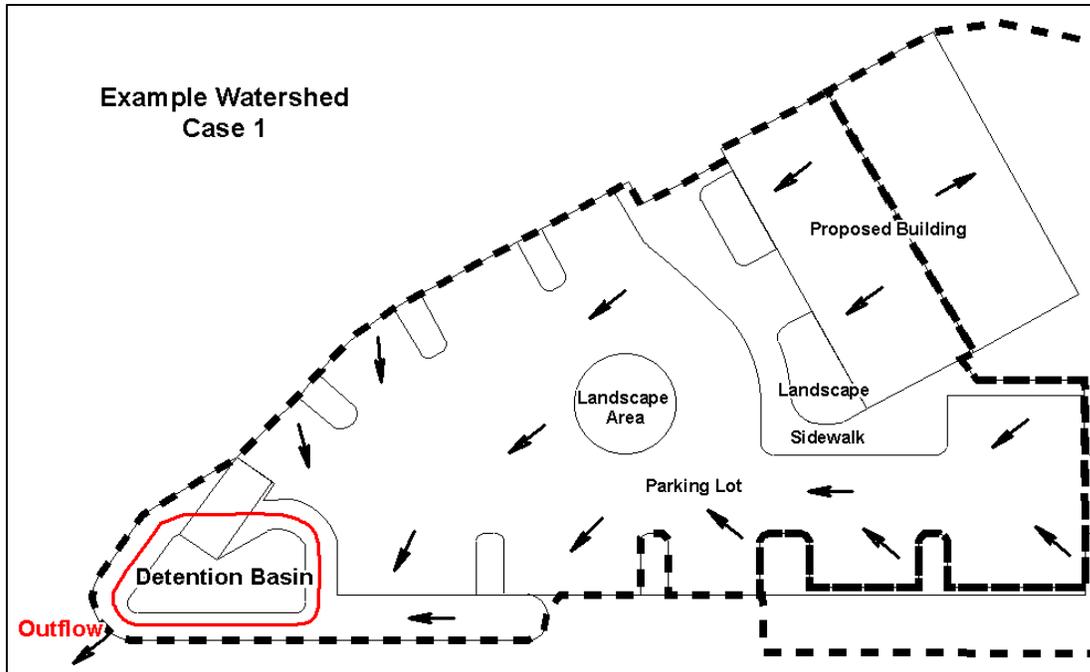


Figure F.1. Case 1 development plan with threshold retention.

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 actually 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.

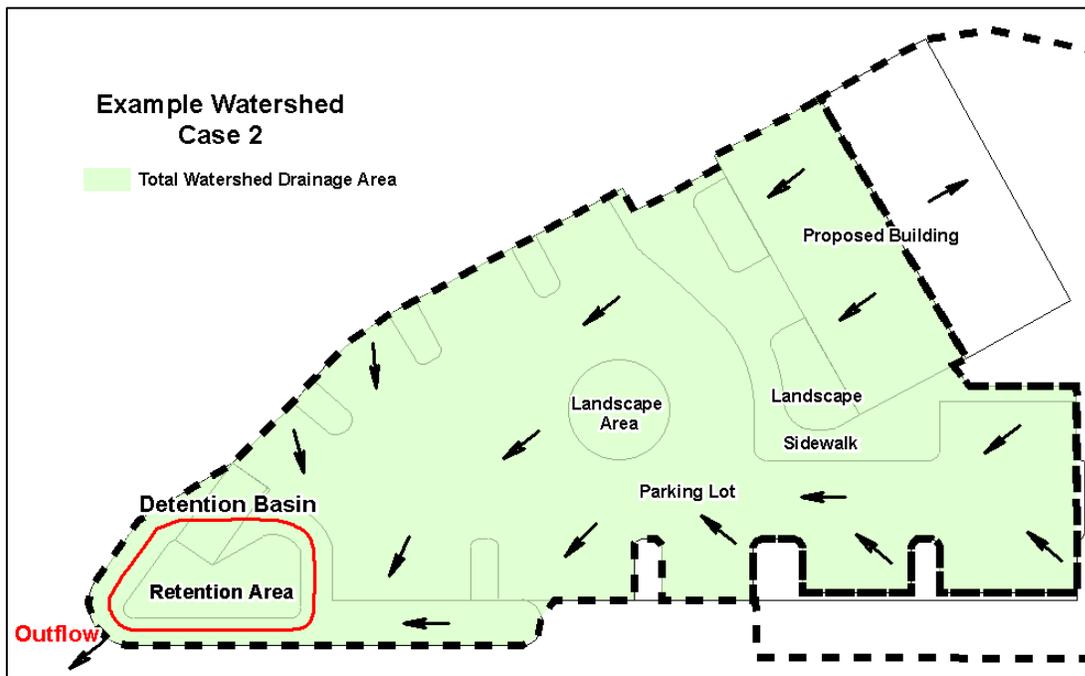


Figure F.2. Case 2 with the required first flush retention designed within the detention basin.

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

$$\begin{aligned} \text{First Flush Retention} &= (\text{Acres of Impervious Area}) (\text{Factor for non-riparian} \\ &\quad \text{impervious area}) \\ &+ (\text{Acres of Disturbed Pervious Areas}) (\text{Factor for} \\ &\quad \text{non-riparian disturbed areas}) \end{aligned}$$

$$\begin{aligned} \text{First Flush Retention} &= (0.80 \text{ ac watershed} \times 82\% \text{ Impervious}) (1440 \text{ ft}^3/\text{ac}) \\ &+ (0.80 \text{ ac watershed} \times 18\% \text{ disturbed}) (140 \text{ ft}^3/\text{ac}) \end{aligned}$$

$$\text{First Flush Retention} = 944.6 \text{ ft}^3 + 20.2 \text{ ft}^3 = 964.8 \text{ ft}^3$$

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 (ft ³):	965
Retention Volume in Detention Basin (ft ³)	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.

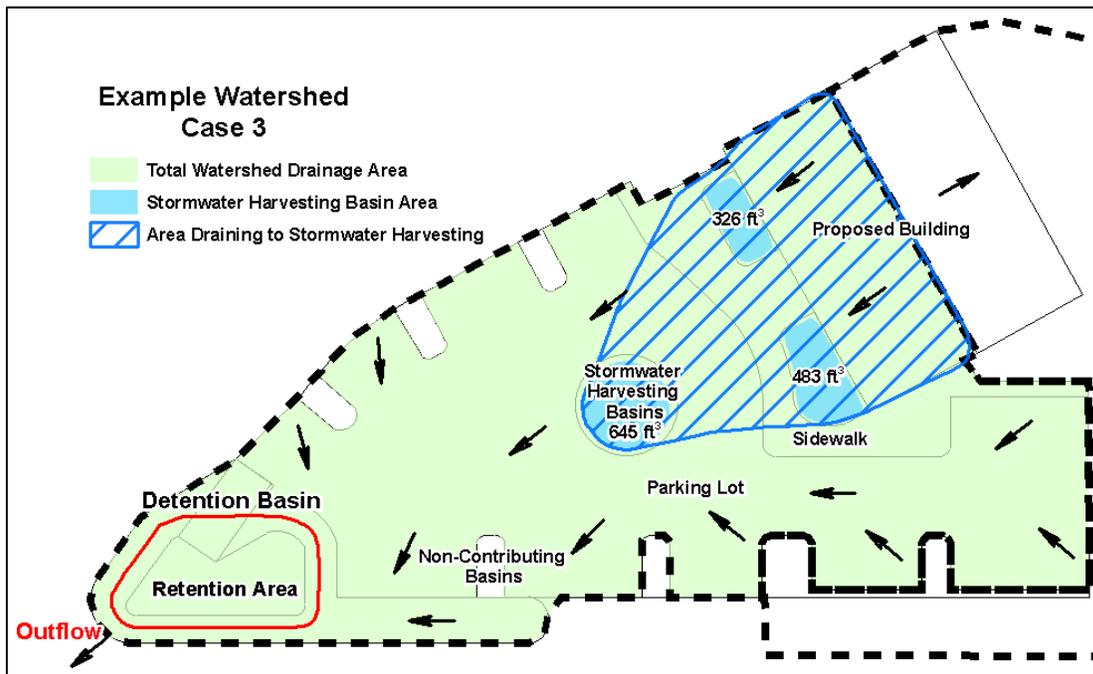


Figure F.3. Case 3 with stormwater harvesting basins in the upstream watershed and retention within the detention basin.

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:

$$\begin{aligned} \text{First Flush Retention} &= (0.782 \text{ ac watershed} \times 84\% \text{ Impervious}) (1440 \text{ ft}^3/\text{ac}) \\ &\quad + (0.782 \text{ ac watershed} \times 16\% \text{ disturbed}) (140 \text{ ft}^3/\text{ac}) \\ \text{First Flush Retention} &= 945.9 \text{ ft}^3 + 17.5 \text{ ft}^3 = 963.4 \text{ ft}^3 \end{aligned}$$

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)	0.169	0.102	0.059

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

$$\begin{aligned} V_{\text{bas}} &= (\text{SWH Basin 1}) + (\text{SWH Basin 2}) + (\text{SWH Basin 3}) \\ &= (483 \text{ ft}^3) + (326 \text{ ft}^3) + (645 \text{ ft}^3) = 1454 \text{ ft}^3 (1 \text{ ac} / 43560 \text{ ft}^2) \\ V_{\text{bas}} &= 0.033 \text{ ac-ft} \end{aligned}$$

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

$$\begin{aligned} X_{rp} &= V_{\text{bas}} / V_{\text{post-rp}} = \\ &\quad \frac{(\text{Total upstream stormwater harvesting basin volume})}{(\text{Return Period Runoff Volume})} \end{aligned}$$

$$X_2 = 0.033 \text{ ac-ft} / 0.059 \text{ ac-ft} = 0.566$$

$$X_{10} = 0.033 \text{ ac-ft} / 0.102 \text{ ac-ft} = 0.327$$

$$X_{100} = 0.033 \text{ ac-ft} / 0.169 \text{ ac-ft} = 0.198$$

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

$$H_2 = 0.608$$

$$H_{10} = 0.274$$

$$H_{100} = 0.098$$

5. The area of the watershed that flows through any stormwater harvesting basins upstream of the detention basin is determined, and the ratio to the watershed area is calculated as:

$$\eta_A = A_s / A_t = (\text{Area draining to stormwater harvesting}) / (\text{Total watershed area})$$

$$\eta_A = 0.179 \text{ ac} / 0.782 \text{ ac} = 0.229$$

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

$$Q_{\text{sw h-rp}} = Q_{\text{post-rp}} (1 - \eta_A H_{\text{rp}})$$

$$Q_{\text{sw h-2}} = 2.5 \text{ cfs} [1 - 0.229 (0.608)] = 2.2 \text{ cfs}$$

$$Q_{\text{sw h-10}} = 4.3 \text{ cfs} [1 - 0.229 (0.274)] = 4.0 \text{ cfs}$$

$$Q_{\text{sw h-100}} = 7.1 \text{ cfs} [1 - 0.229 (0.098)] = 6.9 \text{ cfs}$$

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 in the spreadsheet using the equation in Section 3.3.2 as:

$$V_{\text{sw h-rp}} = V_{\text{post-rp}} - V_{\text{bas}}$$

$$V_{\text{sw h-2}} = 0.059 \text{ ac-ft} - 0.033 \text{ ac-ft} = 0.026 \text{ ac-ft}$$

$$V_{\text{sw h-10}} = 0.102 \text{ ac-ft} - 0.033 \text{ ac-ft} = 0.069 \text{ ac-ft}$$

$$V_{\text{sw h-100}} = 0.169 \text{ ac-ft} - 0.033 \text{ ac-ft} = 0.136 \text{ ac-ft}$$

The spreadsheet creates a hydrograph with the reduced peak discharge and removes additional volume from the front of the hydrograph.

In cases where a small portion of the watershed is diverted to stormwater harvesting, the stormwater harvesting basins will be relatively ineffective in reducing peak discharges and the full storage capacity of the stormwater harvesting basins may not be utilized by the spreadsheet calculation (See Appendix G for the method used by the Stormwater Harvesting spreadsheet).

The relatively low η_A of 0.229 in this example causes the volume captured by stormwater harvesting basins to be less than the full storage capacity of the basins, and the runoff volumes ($V_{\text{sw h-rp}}$) calculated by the spreadsheet are larger than the values calculated above.

Directing more of the watershed to stormwater harvesting basins will increase η_A and allow reduced $V_{\text{sw h}}$ values in the spreadsheet.

- c. The peak discharge and runoff volume after stormwater harvesting are verified in the Stormwater Harvesting Results area of the hydrograph worksheets (Figure 4).

The time step (dt) of the hydrograph may be adjusted to accurately capture the rise time of the peak discharge and the runoff volume. Warnings are displayed when the error in the output hydrograph is greater than 1% of the peak discharge and runoff volume. When warnings are displayed, the stormwater harvesting hydrograph time step should be adjusted.

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.

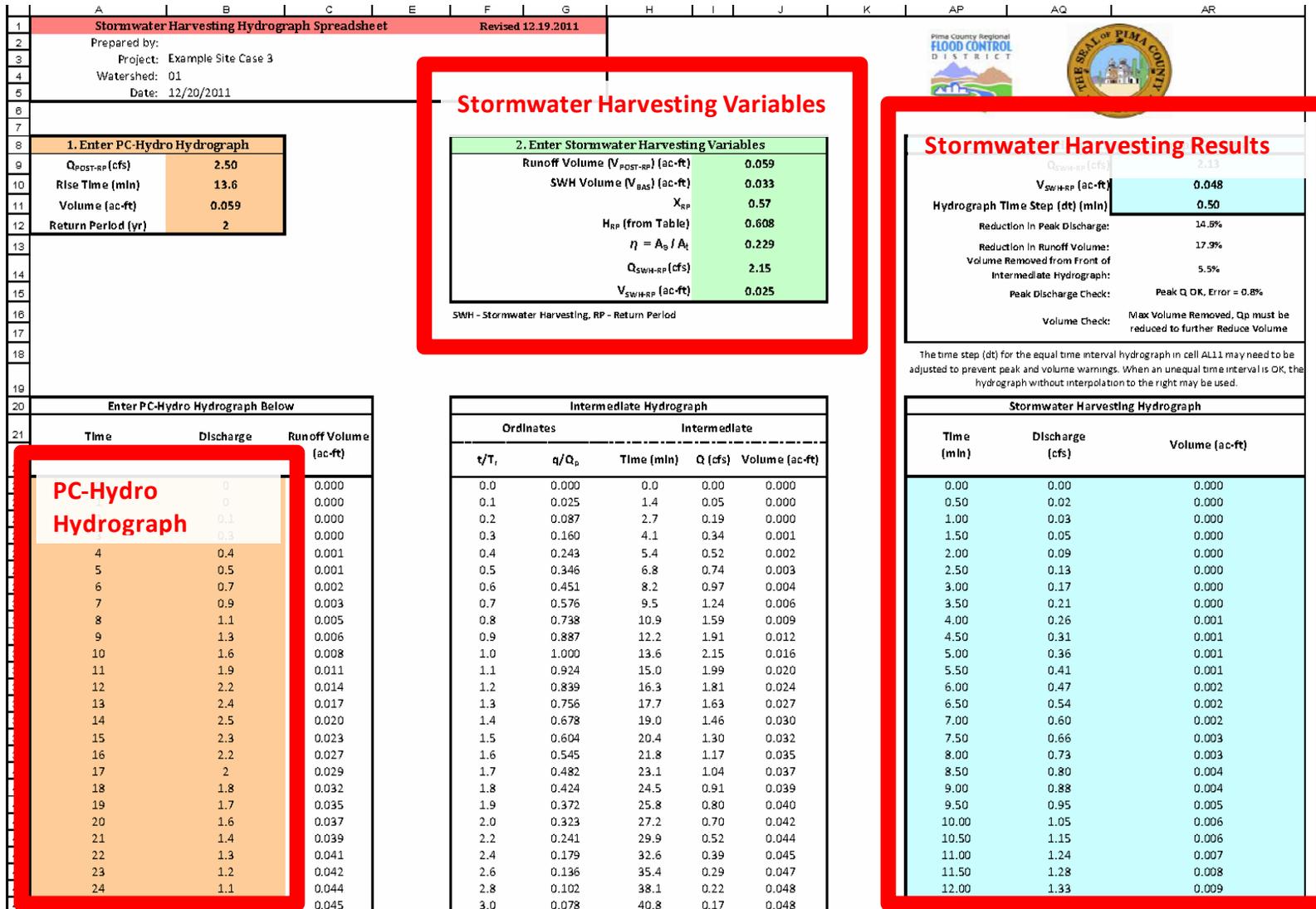


Figure F.4. The Stormwater harvesting spreadsheet “1a. 2-yr SWH Hydrograph” worksheet.

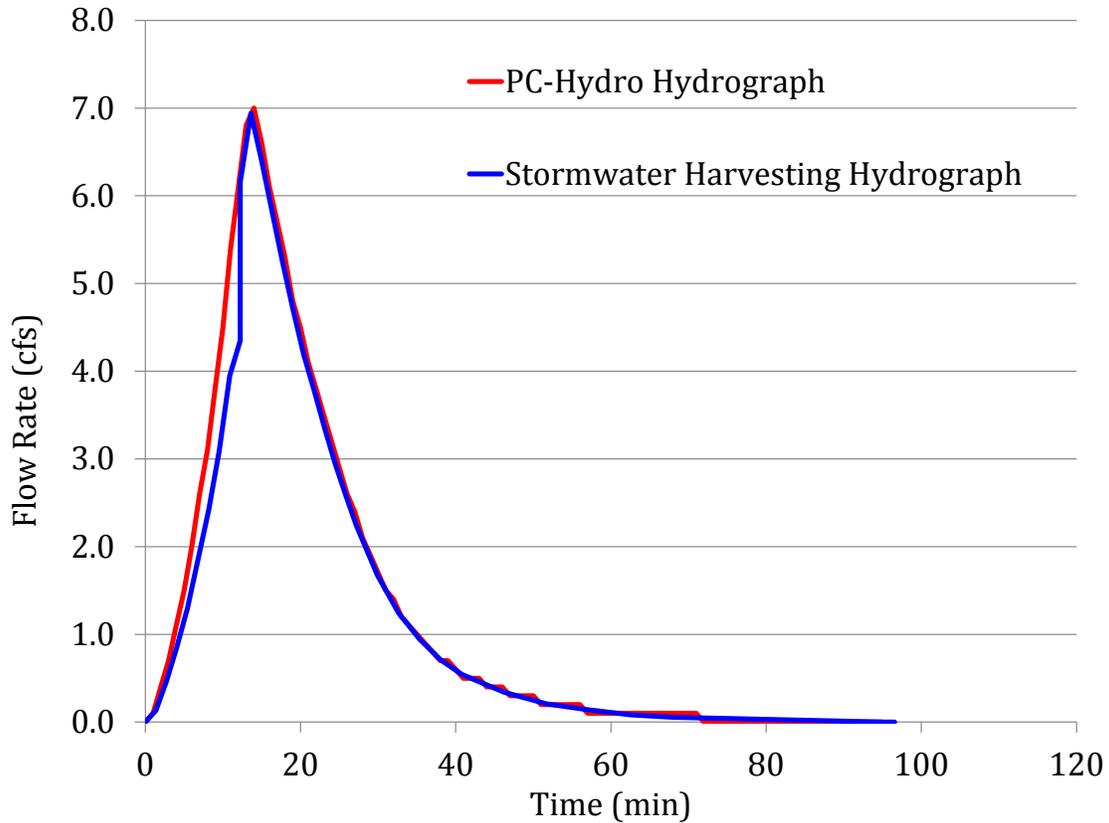


Figure F.5. The 100-year hydrographs for Case 3. The reduction in peak discharge and the volume removed from the front of the 100-yr hydrograph are limited by the small area of the watershed diverted to stormwater harvesting (η_A) in this case.

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 (ft ³):	964
Volume of Retention in Detention Basin (ft ³):	1324
Depth of Retention in Detention Basin (ft):	0.75
100-year Ponding Depth (ft):	1.34
Total Detention Basin Depth (ft):	2.00
Freeboard (ft):	0.66
Total Detention Basin Volume (ft ³):	4525

Total Detention Basins Area (ft ²):	3299
2-year Outflow (cfs)	0.5
10-year Outflow (cfs)	1.9
100-year Outflow (cfs):	4.5

Outflow Structures: A rectangular outflow weir with a width of 2 ft at an elevation of 0.75 ft and a width of 5 ft at 1 ft above the detention basin bottom.

The detention basin area in Case 3 is 3299 ft² or 27.8% less 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.

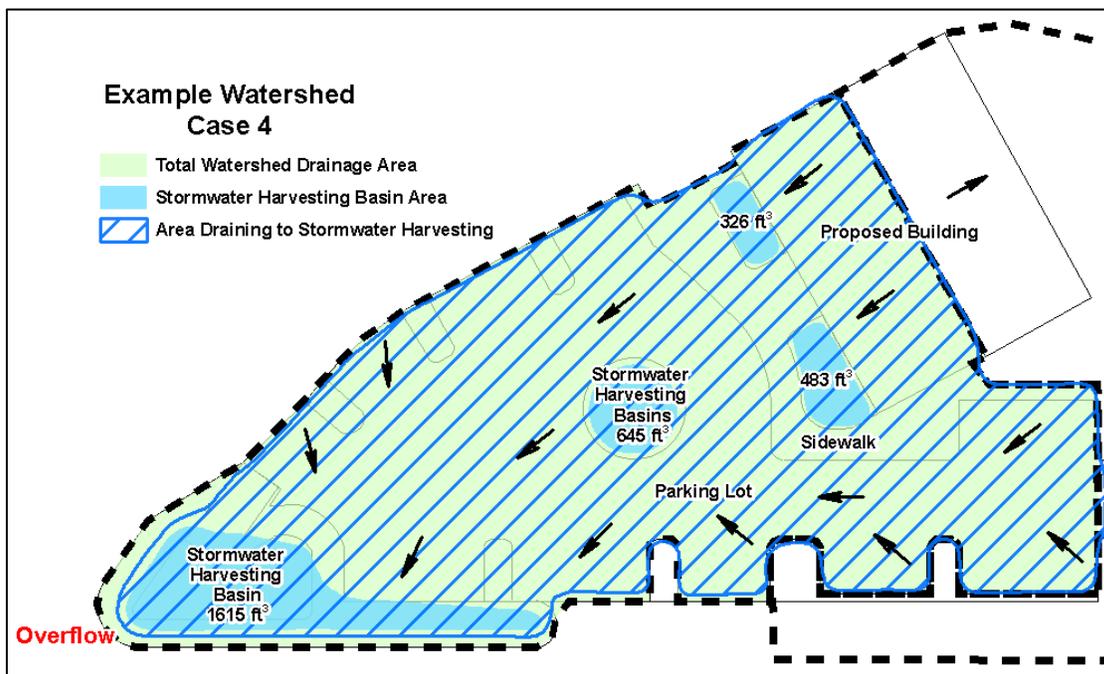


Figure F.6. Case 4 with stormwater harvesting basins that reduce post-developed peak discharges to pre-developed peak discharge rates.

In Case 4, the first flush is calculated the same as in Case 2 as 965 ft³ 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)	0.173	0.105	0.060

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

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

$$= (483 \text{ ft}^3) + (326 \text{ ft}^3) + (645 \text{ ft}^3) + (1615 \text{ ft}^3) = 3069 \text{ ft}^3 \text{ (1 ac / 43560 ft}^2\text{)}$$

$$V_{\text{bas}} = 0.070 \text{ ac-ft}$$

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

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

$$\frac{\text{(Total upstream stormwater harvesting basin volume)}}{\text{(Return Period Runoff Volume)}}$$

$$X_2 = 0.070 \text{ ac-ft} / 0.060 \text{ ac-ft} = 1.17 \text{ (= 1.00)}$$

$$X_{10} = 0.070 \text{ ac-ft} / 0.105 \text{ ac-ft} = 0.67$$

$$X_{100} = 0.070 \text{ ac-ft} / 0.173 \text{ ac-ft} = 0.41$$

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

$$H_2 = 1.000$$

$$H_{10} = 0.716$$

$$H_{100} = 0.392$$

- The area of the watershed that flows through any stormwater harvesting basins is determined, and the ratio to the watershed area is calculated as:

$$\eta_A = A_s / A_t = \text{(Area draining to stormwater harvesting)} / \text{(Total watershed area)}$$

$$\eta_A = 0.76 \text{ ac} / 0.80 \text{ ac} = 0.95$$

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

$$Q_{\text{sw h-rp}} = Q_{\text{post-rp}} (1 - \eta_A H_{\text{rp}})$$

$$Q_{\text{sw h-2}} = 2.6 \text{ cfs} [1 - 0.95 (1.00)] = 0.1 \text{ cfs}$$

$$Q_{\text{sw h-10}} = 4.4 \text{ cfs} [1 - 0.95 (0.716)] = 1.4 \text{ cfs}$$

$$Q_{\text{sw h-100}} = 7.3 \text{ cfs} [1 - 0.95 (0.392)] = 4.5 \text{ cfs}$$

- 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 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 4.2 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 4.6 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.

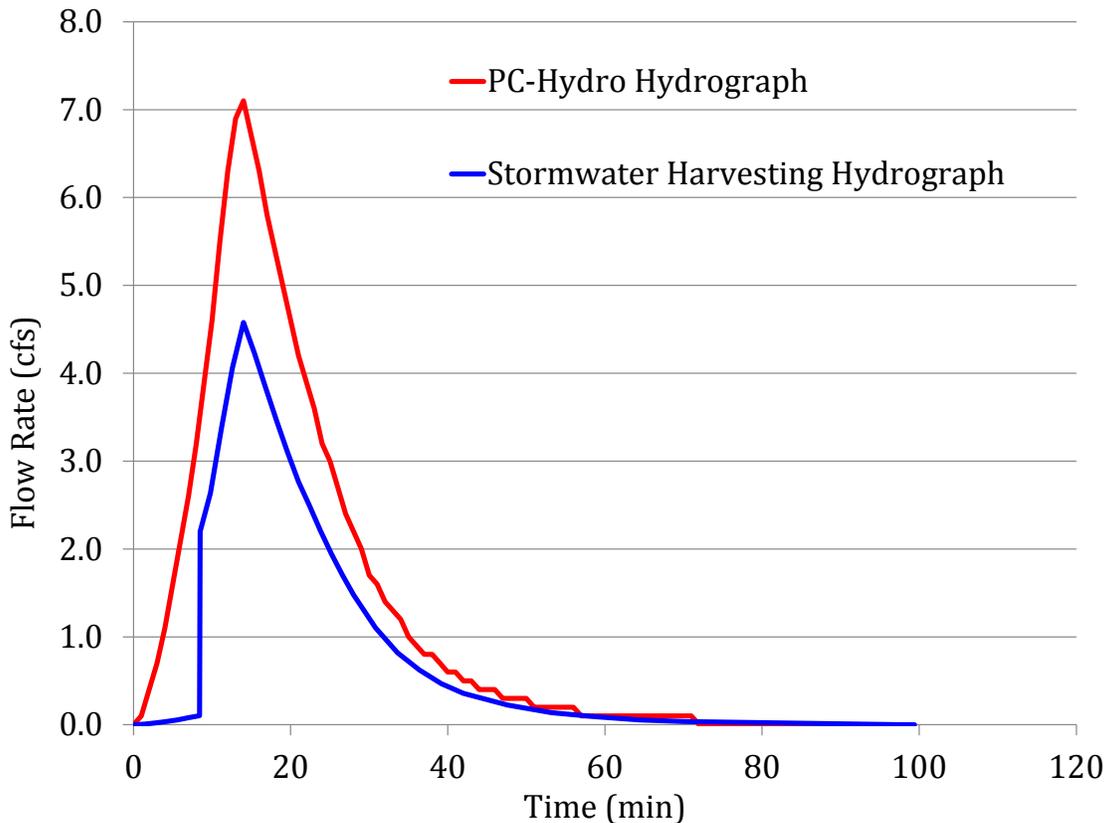


Figure F.7. The 100-yr stormwater harvesting outflow hydrograph from Case 4.

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	4837	4750
Total Volume Used for Ponding (ft ³)*	3560	3560	4157	3069
100-yr Peak Outflow (cfs)	4.3	4.4	4.5	4.5
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	4525	0
Total Basin Depth (ft)	2.25	2.25	2	0
Total Basin Area (ft ²)	4570	4570	3299	0
100-yr Ponding Depth (ft)	1.65	1.66	1.34	0
Freeboard (ft)	0.6	0.59	0.66	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

APPENDIX C: STORMWATER HARVESTING MEMORANDUM



MEMORANDUM

Planning & Development

Regional Flood Control District



TO: File
DATE: February 4, 2013
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 (PCRFCDD) 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 PCRFCDD, 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 PCRFCDD 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).

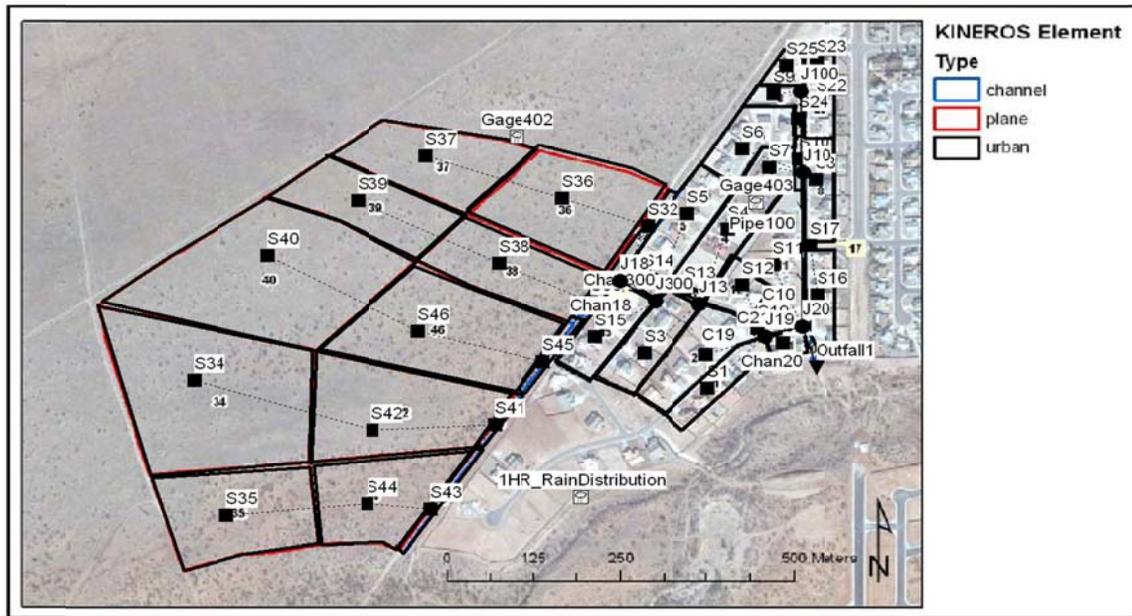


Figure 1. An image of the KINEROS2 model from Kennedy (2007) with the SWMM subcatchments created overtop using the same parameters where appropriate.

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:

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

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.

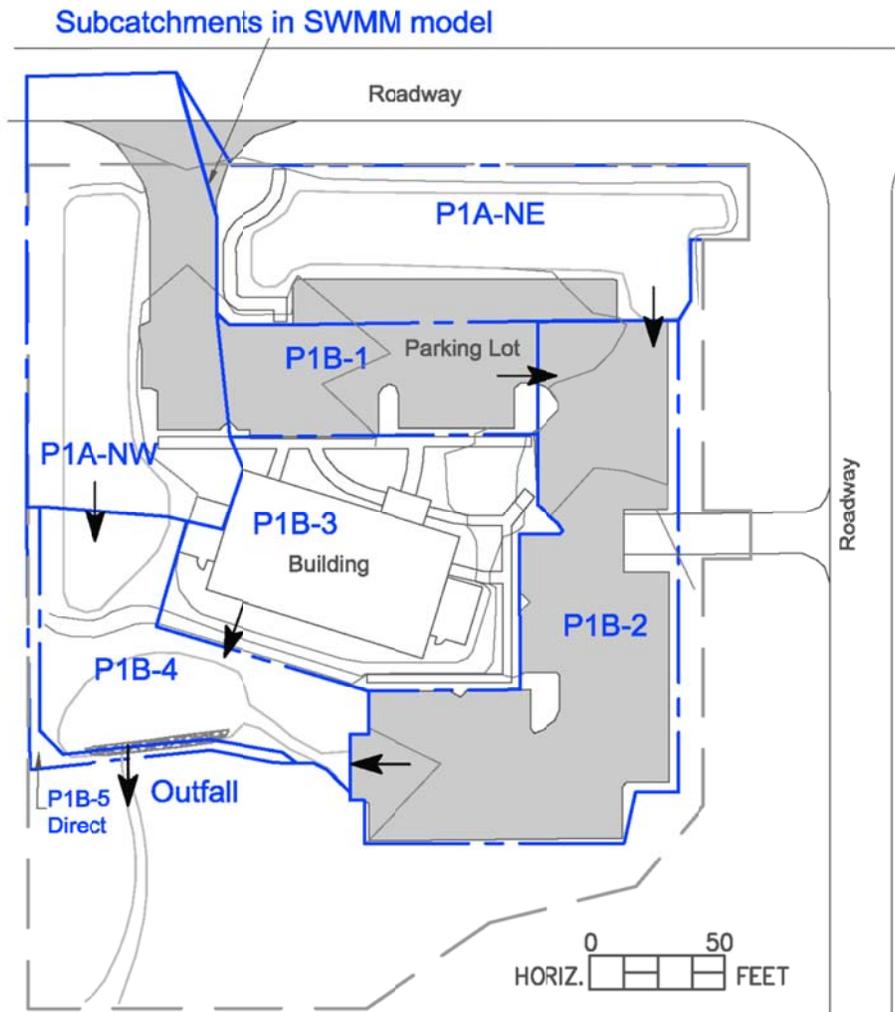


Figure 2. Subcatchments Created for SWMM Modeling of the Commercial Site.

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).

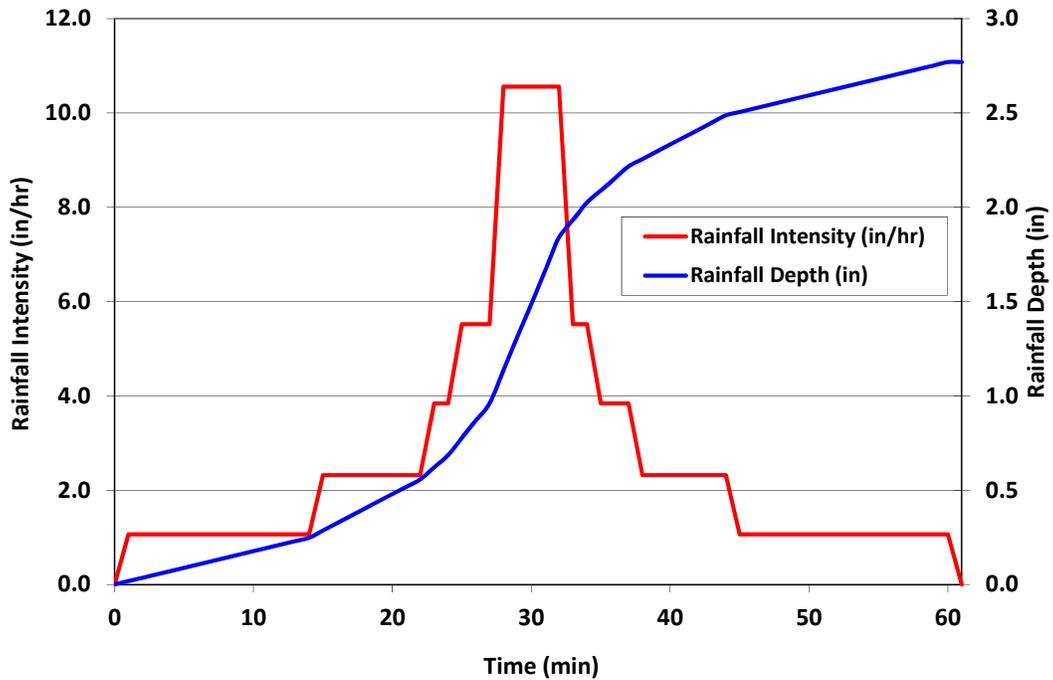


Figure 3. The 1-hour 100-Year Depth-Duration-Frequency Rainfall Distribution Applied to the Commercial Site SWMM Model. 10-Year and 2-Year Rainfall Frequencies were also used.

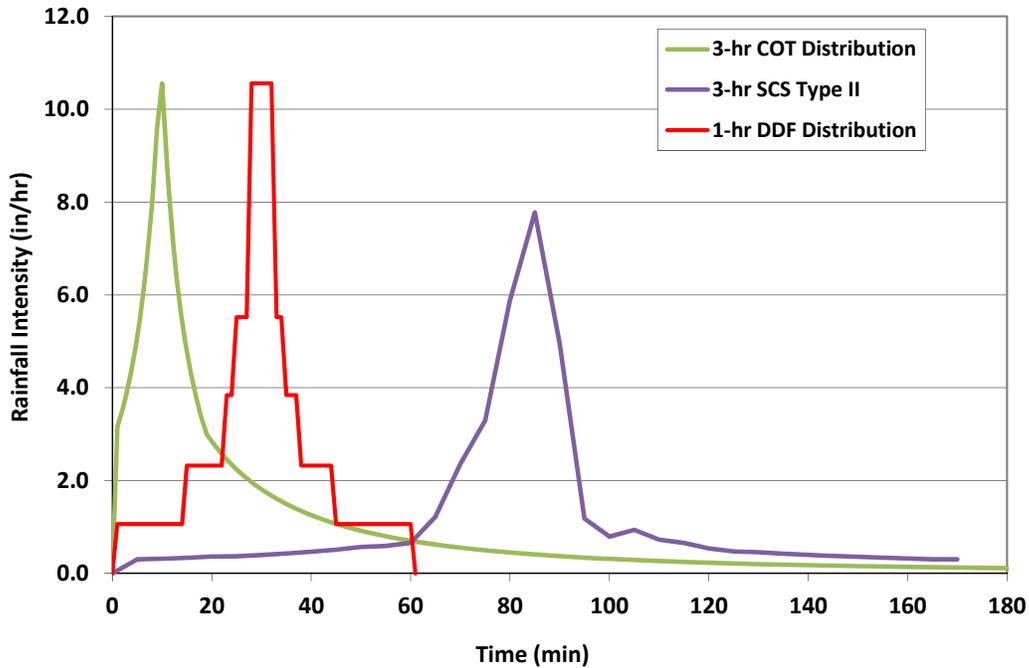


Figure 4. Rainfall Intensity of the 1-Hour Depth-Duration-Frequency Distribution (2.77 Inches of Rainfall Depth) used in the Commercial Site Study Compared with the Rainfall Intensity of the 3-Hour COT and 3-Hour SCS Type II Rainfall Distributions (3.21 inches of rainfall depth).

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.

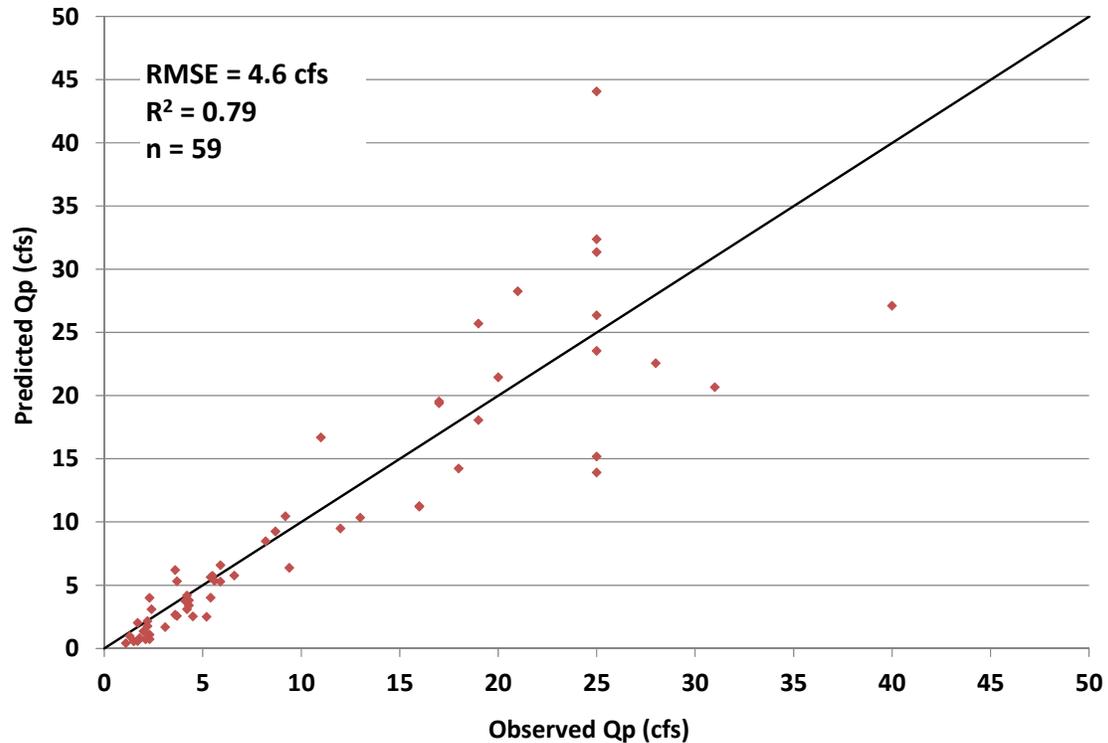


Figure 5. The comparison of modeled peak discharges to observed peak discharges from modeling the urban watershed and using the observed grassland runoff data.

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 the 100-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.