

CUHP 2005 USER MANUAL

Version 2.0.0

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1 Introduction

1.1 Manual Overview

This manual is intended primarily to familiarize you with the mechanics of running the CUHP. Extensive technical documentation of the underlying theory and mathematic computations is provided in Appendix B of this manual. This manual provides:

- A brief overview of the CUHP 2005 program and run process
- Instructions for creating and running a new CUHP input worksheet
- Instructions for importing a worksheet from an older version of CUHP 2005
- Instructions for navigating the CUHP result files
- Instructions for using EPA SWMM 5.0 to route CUHP 2005 output data
- Instructions for running multiple CUHP and SWMM files simultaneously

1.2 CUHP Overview

The Colorado Urban Hydrograph Procedure (CUHP) is an evolution of the Snyder unit hydrograph. It was originally calibrated to the Colorado Front Range using data collected by the U.S. Geological Survey beginning in 1969. Data from 30 sites, representing a full range of land uses in the Denver Metro Area, was used to develop empirical relationships between the input hyetograph and observed output flow. Further details on this original calibration study can be found in Appendix C. The resulting algorithms, named CUHP, use a concept called effective precipitation that accounts for volume losses, and a unit hydrograph that accounts for flow routing and subcatchment size. An overview of this process is provided in Figure 1.1.

To perform calculations, CUHP needs at least one subcatchment and at least one raingage. The subcatchment parameters include size, shape, and storage/infiltration parameters. The raingage provides a storm hyetograph. In any single run of CUHP, each subcatchment may only be analyzed with one raingage, but raingages may be used for multiple subcatchments. The effective rainfall calculations modify the input hyetograph by accounting for a subcatchment's infiltration losses, depression storage, and the distribution of pervious and impervious areas (i.e. DCIA level) in the subcatchment. The unit hydrograph is based on the shape, slope, and imperviousness of the subcatchment. The results from the effective rainfall and unit hydrograph calculations are combined to produce the final storm hydrograph for a given subcatchment and rainfall hyetograph. This is done by shifting the unit hydrograph to the start time of the rainfall increment, then scaling the unit hydrograph by the incremental depth as shown in Figure 1.2. The scaled unit hydrographs are then added together to produce a storm hydrograph as shown in Figure 1.3.

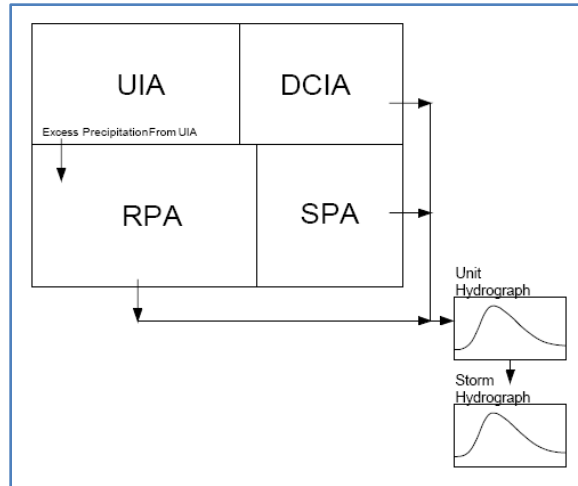


Figure 1.1 - Overview of the CUHP Process

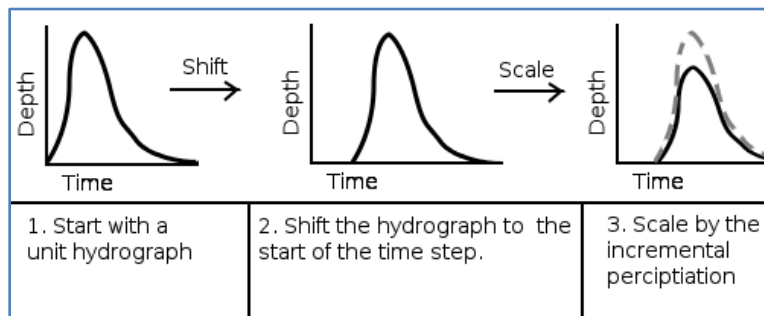


Figure 1.2 – The Unit Hydrograph Scaling Process

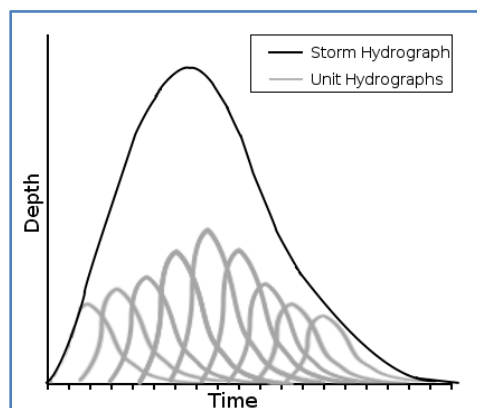


Figure 1.3 – Superposition of Unit Hydrographs to form a Storm Hydrograph

CUHP repeats this process for each storm-subcatchment pair to produce an output workbook and optionally an EPA SWMM 5 text file. The output workbook contains the program inputs, the final results, and the results of intermediate calculations performed by CUHP, including unit hydrographs, storm hydrographs, and effective rainfall calculations. The CUHP/SWMM interface text file contains only the information required for interfacing with EPA SWMM 5 including information to associate CUHP storm hydrographs (associated with CUHP subcatchments) to SWMM 5 nodes. A more detailed description of the CUHP model, including equations and sample calculations, is available in Chapter 5, Section 3 of the USDCM *Volume 1*.

Since its conception in 1978, numerous modifications have been made to the CUHP program to adapt to changing computational equipment as well as to refine and expand its capabilities. An extensive overview of these changes is provided in Appendix A. With the release of CUHP v1.4 in 2013, the program was converted to function as a stand-alone macro-enabled Microsoft[™] Excel[®] Workbook Template (.xltm). Most recently in 2016, a re-calibration study was performed using updated rainfall (GARR, Gage Adjusted Radar Rainfall) and recorded runoff data (USGS and Alert 5 gages) and then testing the results with frequency design storms and statistical gage analysis using existing studies within the UDFCD. This re-calibration study resulted in the release of CUHP v2.0 which includes modifications to the unit hydrograph shaping parameters P , C_p and C_T .

1.3 Known Limitations and Issues

The following is a list of known limitations for the current version of CUHP 2005.

- CUHP 2005 is only tested for Windows-based PC's running Excel[®] 2007 or later. CUHP is not supported for other system configurations.
- Macros must be enabled in a Desktop version of Excel[®] to run CUHP 2005. Office Online (web browser version of Excel) does not support macros and therefore cannot run CUHP.
- Macros in other open Workbooks with the same name as macros in the current CUHP workbook may cause CUHP to malfunction.
- The row and column limits for the Excel (.xlsx and .xlsm) worksheet are 1,048,576 and 16,384 (respectively). This is considerably larger than previous versions of CUHP and should alleviate any concerns with size limitations.

2 System Requirements

This section of the manual details the system requirements for CUHP 2005 Version 2.0. In order to run this version of CUHP 2005, your system must meet the following minimum requirements:

- Operating System: Microsoft Windows XP with Service Pack 2 or later
- Physical Memory: 256MB of RAM
- Hard Disk Space: At least 5MB of Hard Disk Space, not including 3rd party software and saved workbooks.
- Additional 3rd Party Software:
 - Microsoft Excel[®] 2007 or newer (Desktop version only, Online versions will not work).
 - Adobe Acrobat Reader[®] is required to view the User Manual and technical details of the program.

3 Workbook Structure

The following sections describe each of the worksheets in version 2.0 of the CUHP 2005 Workbook. These sections also indicate the input data that each worksheet requires and the information that CUHP 2005 communicates back to the user.

3.1 Workbook Overview

The CUHP 2005 Workbook initially has six worksheets: four worksheets for user input data and two hidden worksheets for program data. The user can then supplement these by adding a minimum of one user defined raingage worksheet and any additional worksheets the user may want to create for notes or summary information. By default the program data worksheets are hidden and write protected.

Each worksheet requires user input. To aid you in data entry, input cells (or column headers) have been color coded. **Light blue** cells indicate required inputs that are used when running the CUHP. **Lavender** cells indicate optional override values that the user can enter to override the default values used in CUHP calculations. **Green** cells indicate results that will be calculated by CUHP. Any attempt to enter values in green cells will be overwritten by CUHP.

3.2 The Introduction Worksheet

The *Intro* worksheet provides the main process control for CUHP and is shown in Figure 3.1. Version information and UDFCD contact information are provided at the top of the worksheet and acknowledgements are provided at the bottom of the worksheet. There are seven functions provided in this worksheet which allow the user to jump to other worksheets, import older CUHP 2005 files, check subcatchment parameters for reasonableness, check for consistency with SWMM nodes, and run the CUHP model. The project settings are also included on this worksheet and are used to define the project, set the calculation time step, and provide file names and directory paths for associated files.

Each of the seven functions included on the *Intro* worksheet are described in more detail below:

- **Edit Raingages:** Jumps to the *Raingage Management* worksheet where the user can create new raingages.
- **Edit Subcatchments:** Jumps to the *Subcatchments* worksheet where the user can enter input parameters for each subcatchment.
- **Edit Multiple Run Options:** Jumps to the *Run Multiple CUHP and SWMM Scenarios* worksheet where the advanced user can develop several different scenarios for land use (existing vs. future), design storm return period, and rainfall area correction. These different scenarios can then all be run together creating several CUHP and SWMM output files.
- **Import CUHP 2005 File:** This function allows the user to upgrade an older CUHP 2005 input file to the current version of CUHP. The current workbook must be empty to use

this function. All of the data from the older workbook is copied and then pasted into the appropriate location in the new workbook. Any information not provided in the old workbook will be left blank in the new workbook.

- **Check Subcatchments:** This function allows the user to check several of their subcatchment parameters to make sure they are within UDFCD guidelines. These parameters include area, length to centroid, length, and slope. Detailed descriptions of the guidelines for these parameters are discussed in Section 3.4.3. This function can also be run from a button on the *Subcatchments* worksheet.

	A	B	C	D	E	F
1	Colorado Urban Hydrograph Procedure					
2						
3	Version 2.0.0 - Release Date: 9/9/2016					
4						
5	Urban Drainage and Flood Control District					
6	Denver, Colorado					
7	email: udfcd@udfcd.org					
8						
9	Purpose:	This program produces hydrographs using the Colorado Unit Hydrograph Procedure (CUHP)				
10						
11	Functions:					
12						
13	Edit Raingages	Add/Remove Raingages and change names				
14						
15	Edit Subcatchments	Edit subcatchment parameters				
16						
17	Edit Multiple Run Options	Edit the Multiple Run options (Advanced User Features)				
18						
19	Import CUHP 2005 File	Import an older CUHP 2005 workbook into this updated version of CUHP				
20						
21	Check Subcatchments	Check whether subcatchment inputs conform to UDFCD guidelines				
22						
23	Check SWMM Nodes	Check whether all subcatchment target nodes are included in the SWMM .inp file				
24						
25	Run CUHP	Calculate effective precipitation and generate hydrographs for each subcatchment				
26						
27						
28		Fill in the blue cells to begin:				
29	Settings:	Project Title:				
30		Project Comment:				
31		Time Step Between Computations:	5	Minute(s); typically 5 or 1 (peak flow rate will differ slightly)		
32			<input type="checkbox"/>	Use Relative Path Names		
33		Output Workbook Filename:				
34		CUHP/SWMM Interface Filename (Optional):				
35		EPA SWMM 5 Input Filename (Optional):				
36		EPA SWMM 5 Application File (Optional):				
37		SWMM Hydrograph Start Time (Optional):				
38						
39	Acknowledgements:	Thanks to Ben Urbonas, P.E., D.WRE and James C.Y.Guo, PhD, P.E., for the development of the CUHP project.				
40						
41						
42						

Intro
Raingages
Subcatchments
Multiple Runs
+

Figure 3.1 – The CUHP 2005 Intro Worksheet

- **Check SWMM Nodes:** This function allows the user to check for consistency between the CUHP inputs and the EPA SWMM input file (.inp). The function checks to make sure the hydrograph start times match and that the SWMM nodes entered on the *Subcatchments* worksheet are available in the SWMM input file to receive runoff. This function can also be run from a button on the *Subcatchments* worksheet.
- **Run CUHP:** This function runs the CUHP once for the given input parameters on the *Intro*, *Raingages*, and *Subcatchments* worksheets. The program calculates effective precipitation and unit hydrographs then generates storm hydrographs for each subcatchment. When CUHP is finished running the user will be notified and the Output Workbook will be opened for the user to review the results.

Below the Functions are the Project Settings for CUHP. Each setting is described below:

- **Project Title:** An optional user-defined name for the project.
- **Project Comment:** An optional user-defined comment to describe the project
- **Time Step:** The required time step in minutes that will be used for computations. The default value is 5 minutes. Typical values include 1 and 5 minutes. It should be noted that resulting peak flows will differ slightly based on the time step used.
- **Use Relative Path Names:** When checked this box will shorten the file path names below it so that only the relative path with respect to the current CUHP workbook are shown. If the Output files are going to be located in the same subfolder as the Input workbook, then the relative path will only show the file name preceded by the characters “.\” and will drop the remaining file path. For example, “C:\Users\MyDocuments\CUHP_Runs\Creek.xlsx” would become “.\Creek.xlsx”. This option can be used regardless of the location of the output files with respect to the input workbook.
- **Output Workbook Filename:** The required file name and path of the output workbook where CUHP results will be saved. It does not matter if this file exists or not prior to running CUHP. If the file does exist, when CUHP is run, the user will be prompted as to whether or not they want to overwrite the existing file.
- **CUHP/SWMM Interface Filename:** The optional file name and path for the output text file that CUHP will create to link CUHP hydrographs with EPA SWMM nodes. If a file name is provided, CUHP will generate a text file that contains the storm hydrographs for each subcatchment that has a corresponding SWMM node entered on the *Subcatchments* worksheet. The EPA SWMM model can then be setup to use this text file for input hydrographs by going to Options>Interface Files and adding a new “Inflows” file.
- **EPA SWMM 5 Input Filename:** The optional file name and path for an existing EPA SWMM input file (.inp) that the user wants to link with CUHP. This file name and path allow the user to use the *Check SWMM Nodes* function described above to check for consistency between the start times and nodes between the two files. This file name and

path also are used when running EPA SWMM from the CUHP *Multiple Runs* worksheet as explained in Section 3.5 of this manual.

- **EPA SWMM 5 Application File:** The optional file path to the SWMM.exe application file. Providing this path allows EPA SWMM to be run from the CUHP *Multiple Runs* worksheet as explained in Section 3.5 of this manual. EPA SWMM must be installed on the same computer in order to use this option. The default file path is typically “C:\Program Files (x86)\EPA SWMM 5.0\swmm5.exe”.
- **SWMM Hydrograph Start Time:** The optional start date and time defined in the EPA SWMM model found under Options> Dates. The default is set to 1/1/2005 12:00AM. In order for the CUHP hydrographs to link correctly with the SWMM nodes these times must match.

3.3 The Raingage Management Worksheet

The *Raingages* worksheet is where new raingage worksheets are created. It contains a drop-down menu for selecting raingage types, a button to create a new raingage worksheet of the selected type, and a list of the raingage sheets in the current CUHP workbook. You must always create raingages using this page; CUHP will not recognize raingages created by other methods. If it is necessary to remove a raingage, make sure to delete the raingage from the list on this worksheet and to delete the entire worksheet for the corresponding raingage as describe later in this section. Figure 3.2 shows the *Raingages* worksheet.

To create a new raingage, you must first select the desired type. Three types of raingage can be selected from the drop down box:

1. The User-Defined Hyetograph option allows for a custom rainfall distribution based on time/incremental depth pairs.
2. The Rainfall by Distribution option allows the user to create a NOAA 1-hour distribution, as described in *Chapter 4, Section 3 of the USDCM Volume 1*, using the one hour rainfall depth and the return period.
3. The Rainfall by Distribution with Area Correction option allows the user to create a raingage based on the modified NOAA distribution described in Chapter 4, Section 3.2 of the USDCM Volume 1.

Each of these is covered in more detail in the following sections. Pressing the *Add* button will prompt you to input a name for the new worksheet. Once a unique name is entered, the CUHP workbook creates a new raingage sheet with inputs for the required data at the end of the workbook, updates the list on the *Raingages* worksheet, and switches over to the newly created raingage worksheet so the inputs can be entered.

To remove or rename a raingage you must follow three steps. Incorrectly removing or renaming a worksheet will prevent the CUHP model from running correctly.

1. Update the specific raingage worksheet by either renaming the worksheet tab or deleting the worksheet completely.
2. Update the Raingage Management table by removing rows for deleted worksheets or modifying entries for both “Raingage Name” and “Raingage Type”.
3. Update all subcatchments on the *Subcatchments* worksheet that reference the old raingage name.

There is currently no method for changing a raingage's type; you must either create a new raingage of the desired type with a different name, or remove the raingage and create a new raingage of the desired type.

	A	D	E
1	CUHP RAINGAGE MANAGEMENT		
2	Use this worksheet to create raingages by temporal distribution or by user-defined hyetograph.		
3	Raingage is a design storm by temporal distribution of one-hour rain depth with area correction factors <input type="button" value="Add"/>		
4			
5	Design Storm (Hyetograph) Name and Type		
6	Raingage Name	Raingage Type	
7	User Defined	sheet://User Defined	
8	NOAA Gage	dist://NOAA Gage	
9	Area Corrected	distarea://Area Corrected	
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
	Intro	Raingages	Subcatchments Multiple Runs User Defined NOAA Gage Area Corrected

Figure 3.2 – The CUHP 2005 Raingages Worksheet

3.3.1 User-Defined Hyetograph Raingages

User-Defined distributions allow the CUHP model to function with storms that do not match the NOAA Atlas storm described in *Chapter 4, Section 3 of the USDCM Volume 1*. The user is encouraged to enter a comment in cell B1 to indicate the basis for the distribution. Rainfall data is entered starting at row 6 by specifying times in column A and corresponding depths in column B. The final entry in these columns should have an incremental depth of 0 to indicate to the model the end of the distribution. Times must be specified in HH:MM format, and rainfall depths are assumed to be in inches. Figure 3.3 shows a sample User-Defined raingage worksheet.

Unformatted numbers are interpreted as days from 1/0/1900 12:00 AM, and will reset the cell format. If the time format gets reset, you may reapply it using Excel's *Format Cells* dialog. To do this:

1. Select the cells you want to reformat
2. Right click and select *Format Cells...*
3. Switch to the *Number* tab
4. Select "Custom" in the *Category* selection box, and select "h:mm" in the *Type* selection box.

	A	B	C	D	E
1	Comment	Manual Hyetograph			
2	Note: Time must be of the form h:mm. Entering an improperly formatted time value (eg: 0:120 instead of 2:00) may reset the				
3	The number format can be reapplied in the "Format Cells" Dialog Window.				
4					
5	Time	Depth			
6	0:05	0.019			
7	0:10	0.036			
8	0:15	0.084			
9	0:20	0.148			
10	0:25	0.243			
11	0:30	0.126			
12	0:35	0.056			
13	0:40	0.043			
14	0:45	0.035			
15	0:50	0.035			
16	0:55	0.029			
17	1:00	0.029			
18	1:05	0.029			
19	1:10	0.029			
20	1:15	0.024			
21	1:20	0.021			
22	1:25	0.021			
23	1:30	0.021			
24	1:35	0.021			
25	1:40	0.015			
26	1:45	0.015			
27	1:50	0.015			
28	1:55	0.015			
29	2:00	0.015			
30					

Figure 3.3 – The CUHP 2005 User-Defined Hyetograph Raingage

3.3.2 NOAA Distribution Raingages

Distribution raingages allow you to quickly model a design storm using the 1-hour NOAA Atlas distribution. The method used in this worksheet is recommended only for watersheds that are less than 1 square mile. Larger watersheds should use a raingage with area correction, as described in Section 3.3.3. The method used for NOAA Distribution raingages is described in *Chapter 4, Section 3 of the USDCM Volume 1*. For this method, the user must enter a 1-hour rainfall depth (inches) in cell B2 and a return period (years) in cell B3. The worksheet formulas will automatically calculate the incremental depth for each time increment from 5 to 120 minutes. Column B shows the incremental depths. Figure 3.4 shows a sample NOAA Distribution Raingage worksheet.

	A	B	C	D
1	Comment	NOAA Gage Distribution		
2	1Hr Depth	0.97	NOAA Atlas 14 Point Precipitation Frequency Estimates: CO (Note: Use 60-minute recurrence interval)	
3	Return Period	5	Years	
4	Time	Depth	CurveValue	
5	0:05	0.019		0.02
6	0:10	0.036		0.037
7	0:15	0.084		0.087
8	0:20	0.148		0.153
9	0:25	0.243		0.25
10	0:30	0.126		0.13
11	0:35	0.056		0.058
12	0:40	0.043		0.044
13	0:45	0.035		0.036
14	0:50	0.035		0.036
15	0:55	0.029		0.03
16	1:00	0.029		0.03
17	1:05	0.029		0.03
18	1:10	0.029		0.03
19	1:15	0.024		0.025
20	1:20	0.021		0.022
21	1:25	0.021		0.022
22	1:30	0.021		0.022
23	1:35	0.021		0.022
24	1:40	0.015		0.015
25	1:45	0.015		0.015
26	1:50	0.015		0.015
27	1:55	0.015		0.015
28	2:00	0.013		0.013
29	2:05	0		
30				

Figure 3.4 – The CUHP 2005 NOAA Distribution Raingage

3.3.3 NOAA Distribution Raingages with Area Correction

Like NOAA Distribution Raingages, raingages with area correction allow you to quickly model a design storm using a NOAA Atlas distribution. The differences are described in *Chapter 4, Section 3.2 of the USDCM Volume 1*. For this method, you must enter a 1-hour rainfall depth (inches) in cell B2, a 6-hour rainfall depth (inches) in cell B3, the catchment area (square miles) in cell B4, and the return period (years) in cell B5. Once the required information has been entered, the CUHP workbook will automatically fill in the bottom portion of the worksheet with the incremental times (column A), adjusted rainfall depths (column B), and unadjusted rainfall depths (column C). The worksheet will automatically update. However, if you feel that your design distribution does not match the data entered, buttons are provided to manually *Calculate*

and/or *Clear* the worksheet. Figure 3.5 shows a sample NOAA Distribution with Area Correction Raingage worksheet.

	A	B	C	D	E	F	G	H	I	J
1	Comment	NOAA Distribution with Area Correction								
2	1Hr Depth	0.97	inches	2hr Depth	1.08	inches				
3	6Hr Depth	1.3	inches	3hr Depth	1.17	inches				
4	Correction Area	50	Sq. Mi.	Calculate	Clear					
5	Return Period	5	Years							
6	Time	Adjusted Depth	Unadjusted Depth		NOAA Atlas 14 Point Precipitation Frequency Estimates: CO					
7	0:05	0.0194	0.0194							
8	0:10	0.0359	0.0359							
9	0:15	0.0549	0.0844							
10	0:20	0.0623	0.1484							
11	0:25	0.1019	0.2425							
12	0:30	0.0530	0.1261							
13	0:35	0.0506	0.0563							
14	0:40	0.0384	0.0427							
15	0:45	0.0353	0.0349							
16	0:50	0.0353	0.0349							
17	0:55	0.0294	0.0291							
18	1:00	0.0294	0.0291							
19	1:05	0.0294	0.0291							
20	1:10	0.0294	0.0291							
21	1:15	0.0245	0.0243							
22	1:20	0.0216	0.0213							
23	1:25	0.0216	0.0213							
24	1:30	0.0216	0.0213							
25	1:35	0.0216	0.0213							
26	1:40	0.0147	0.0146							
27	1:45	0.0147	0.0146							
28	1:50	0.0147	0.0146							
29	1:55	0.0147	0.0146							
30	2:00	0.0127	0.0126							
31	2:05	0.0070	0.0070							
32	2:10	0.0070	0.0070							
	Intro	Raingages	Subcatchments	Multiple Runs	User Defined	NOAA Gage	Area Corrected			

Figure 3.5 – The CUHP 2005 NOAA Area Corrected Raingage

3.4 The Subcatchment Parameters Worksheet

The *Subcatchments* worksheet contains a list of all subcatchments and their parameters. This worksheet allows the user to add one subcatchment per row. The user is required to enter parameters in the cells under the light blue headers and has the option to enter override values in the cells under the lavender headers. The cells below the green headers are for values that will be calculated by the CUHP. The user can copy and paste from other sources directly into the user input rows of the *Subcatchments* worksheet. The user can also delete entire subcatchment rows from the worksheet if necessary.

There are also four buttons on the *Subcatchments* worksheet that allow the user to run functions to check subcatchment parameters for reasonableness, check for consistency with SWMM nodes, and change the units for length and area (e.g. feet vs. miles). These functions are intended to help the user reduce erroneous values in the input parameters that may not have been noticed otherwise. A description of each parameter and function button in the *Subcatchments* worksheet is explained below. More information on the subcatchment parameters can be found in *Chapter 5, Section 3 of the USDCM Volume 1*.

3.4.1 Subcatchment Required Parameters

Figure 3.6 shows the first 14 columns of the *Subcatchments* worksheet and includes the required input parameters and the function buttons.

CUHP SUBCATCHMENTS													
Click Here For Explanation Of Input Checks		Columns with this color heading are for required user-input Columns with this color heading are for optional override values Columns with this color heading are for program-calculated values						Click Here for Recommended Value Tables					
Check Subcatchment Inputs	Check SWMM Nodes	Units are in miles and square miles (click to change)						Maximum Depression Storage (Watershed inches)		Horton's Infiltration Parameters		DCIA	
Subcatchment Name	EPA SWMM Target Node	Raingage	Area (mi ²)	Length to Centroid (mi)	Length (mi)	Slope (ft/ft)	Percent Imperviousness	Pervious	Impervious	Initial Rate (in/hr)	Decay Coefficient (1/seconds)	Final Rate (in/hr)	Level 0, 1, or 2
1	101	Area Corrected	0.1726	0.318	0.687	0.047	8	0.035	0.1	3	0.0018	0.5	0
2	102	Area Corrected	0.1028	0.273	0.546	0.052	23	0.035	0.01	3	0.0018	0.5	0
3	103	Area Corrected	0.1062	0.155	0.407	0.056	8	0.035	0.01	3	0.0018	0.5	0
4	104	Area Corrected	0.1792	0.192	0.515	0.058	58	0.035	0.01	3	0.0018	0.5	0
5	105	Area Corrected	0.0991	0.242	0.492	0.046	53	0.035	0.01	3	0.0018	0.5	1
6	106	Area Corrected	0.171	0.348	0.974	0.035	95	0.035	0.01	3	0.0018	0.5	1
7	107	Area Corrected	0.167	0.47	0.87	0.025	35	0.035	0.01	3	0.0018	0.5	1
8	108	Area Corrected	0.1596	0.297	0.735	0.039	75	0.035	0.01	3	0.0018	0.5	1
9	109	Area Corrected	0.0841	0.183	0.531	0.032	80	0.035	0.01	3	0.0018	0.5	2
10	110	Area Corrected	0.0632	0.165	0.462	0.027	85	0.035	0.01	3	0.0018	0.5	2
11	111	Area Corrected	0.1477	0.156	0.4	0.024	52	0.035	0.01	3	0.0018	0.5	2
12	112	Area Corrected	0.177	0.37	0.733	0.021	35	0.035	0.01	3	0.0018	0.5	2
13	113	Area Corrected	0.1943	0.358	0.861	0.024	60	0.035	0.01	3	0.0018	0.5	0
14	114	Area Corrected	0.1527	0.323	0.724	0.034	75	0.035	0.01	3	0.0018	0.5	0
15	115	Area Corrected	0.1294	0.093	0.5	0.042	85	0.035	0.01	3	0.0018	0.5	0
16	116	Area Corrected	0.1365	0.447	0.777	0.051	70	0.035	0.01	3	0.0018	0.5	0

Figure 3.6 – The CUHP Subcatchments Worksheet (Inputs)

- **Subcatchment Name:** A short name or abbreviation indicating the ID that CUHP will use to identify this subcatchment.
- **EPA SWMM Target Node:** The name of the target node (e.g. junction, divider, or storage unit) in the EPA SWMM input file (.inp) that will be receiving runoff from the corresponding CUHP subcatchment on the same row. This parameter is only required if the user will be routing the CUHP storm hydrographs using EPA SWMM.
- **Raingage:** Specifies the raingage to use for this subcatchment. Before running the model, the specified raingage must be created using the *Raingages* worksheet.
- **Area:** Subcatchment area in square miles. CUHP is applicable for areas ranging in size from 0 to 3000 acres (roughly 0 to 5 square miles). For areas less than 90 acres, it is recommended that a 1-minute time step be used when running CUHP. For areas greater than 3000 acres, it is recommended that the catchment be divided into smaller subcatchments prior to running CUHP.
- **Length to Centroid:** Distance in miles from the design point of the subcatchment along the main drainageway path to the subcatchment's centroid.
- **Length:** Distance in miles from the downstream design point of the subcatchment along the main drainageway path to the furthest point on the subcatchment boundary. When a catchment is divided into a series of subcatchments, the subcatchment length shall include the distance required for runoff to reach the major drainageway from the farthest point in the subcatchment.

- **Slope:** The length-weighted, corrected average slope of the subcatchment in feet per foot. Follow the recommendations in *Chapter 5, Section 3 of the USDCM Volume 1*.
- **Percent Imperviousness:** The portion of the subcatchment's total surface area that is impervious, expressed as a percent value between 0 and 100.
- **Maximum Pervious Depression Storage:** Maximum depression storage on pervious surfaces in inches. A table of recommended values is provided in cells AG1:AI9 of the Subcatchments worksheet.
- **Maximum Impervious Depression Storage:** Maximum depression storage on impervious surfaces in inches. A table of recommended values is provided in cells AG1:AI9 of the Subcatchments worksheet.
- **Initial Infiltration Rate:** Initial infiltration rate for pervious surfaces in the subcatchment in inches per hour. If this entry is used by itself without a final infiltration rate and decay rate, then this value will be used as a constant infiltration rate throughout the storm. If the next two entries are made, then this value will be used as the initial infiltration rate in Horton's equation. A table of recommended values is provided in cells AK1:AN7 of the Subcatchments worksheet.
- **Infiltration Decay Rate:** Exponential decay coefficient used in Horton's equation in "per second" units (1/sec). A table of recommended values is provided in cells AK1:AN7 of the Subcatchments worksheet.
- **Final Infiltration Rate:** Final infiltration rate for pervious surfaces in the subcatchment in inches per hour. A table of recommended values is provided in cells AK1:AN7 of the Subcatchments worksheet.
- **DCIA Level:** The minimized directly connected impervious area (DCIA) level to be used with this subcatchment. May be blank or zero for standard practice, or you may specify 1 or 2 for DCIA Level 1 or DCIA Level 2, respectively. These levels of DCIA practice are defined in *Chapter 3, Section 4 of the USDCM Volume 3*.

3.4.2 Subcatchment Override Parameters

Figure 3.7 shows the remaining 14 columns of the Subcatchments worksheet and includes override parameters and calculated results. By default, the CUHP calculates all of these parameters when it runs. However, the user has the option to override the default values with user-defined values. **For Drainage and flood studies within the UDFCD, unless pre-approved in writing by the UDFCD, the default program values shall be used.**

	A	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	
1	CUHP SUBCATCHMENTS															
2																
3																
4	Click Here For Explanation Of Input Checks															
5																
6																
7																
8	Check Subcatchment Inputs															
9		DCIA	Directly Connected Impervious Fraction DCIF (Decimal)		Receiving Pervious Fraction RPF (Decimal)		Effective Imperviousness		C _I		C _P		Width of Unit Hydrograph (Minutes)		Fraction of Width Before Peak (Decimal)	
	Subcatchment Name	Level 0, 1, or 2	Override	Used	Override	Used	(Percent)	Override	Used	Override	Used	Override At 50%	Override At 75%	Override At 50%	Override At 75%	Comment
10																
11	1	0		0.16		0.08	6.26		0.140		0.192					
12	2	0		0.46		0.14	19.99		0.110		0.131					
13	3	0		0.16		0.08	6.26		0.140		0.154					
14	4	0		0.89		0.26	56.13		0.085		0.264					
15	5	1		0.64		0.39	48.21		0.089		0.189					
16	6	1		0.96		0.58	94.12		0.074		0.298					
17	7	1		0.44		0.31	29.98		0.100		0.182					
18	8	1		0.81		0.49	71.57		0.080		0.273					
19	9	2		0.60		0.69	73.89		0.079		0.206					
20	10	2		0.70		0.72	80.17		0.077		0.185					
21	11	2		0.26		0.53	43.48		0.091		0.215					
22	12	2		0.18		0.44	27.73		0.102		0.178					
23	13	0		0.90		0.27	58.22		0.085		0.274					
24	14	0		0.93		0.32	73.51		0.079		0.270					
25	15	0		0.91		0.29	63.29		0.083		0.239					
26	16	0		0.92		0.30	68.38		0.081		0.251					
	Intro	Raingages	Subcatchments	Multiple Runs	User Defined	NOAA Gage	Area Corrected									

Figure 3.7 – The CUHP Subcatchments Worksheet (Overrides and Calculated Results)

- **DCIF:** The Directly Connected Impervious Fraction (DCIF or D) as a decimal fraction (e.g. 0.5 = 50%). The DCIF is equal to the percent of the impervious area that is directly connected to the drainage system ($DCIF = A_{DCIA} / A_{Imp}$). Values range from 0.01 to 1.0.
- **RPF:** The Receiving Impervious Fraction (RPF or R) as a decimal fraction. The RPF is equal to the percent of the pervious area that is receiving runoff from the “disconnected” impervious areas ($RPF = A_{RPA} / A_{Perv}$). Values range from 0.01 to 1.0.
- **Effective Imperviousness:** Effective imperviousness is a function of the total area-weighted imperviousness (based on the DCIF and RPF) and the ratio of infiltration rate to the rainfall intensity, expressed as a percent value between 0 and 100. CUHP uses the conveyance-based approach as outlined in *Chapter 3, Section 4.3 of USDCM Volume 3*.
- **C_T:** Time to Peak Coefficient that relates the imperviousness of a subcatchment to the Time to Peak (T_p), as determined by Figure B-7 in Appendix B of this User Manual.
- **C_P:** Peak Runoff Rate Coefficient that relates imperviousness and area to the peak flow of the Unit Hydrograph, as computed by Equation B-28 in Appendix B of this User Manual.
- **W₅₀:** Width of the Unit Hydrograph at 50% of the peak flow, in minutes.
- **W₇₅:** Width of the Unit Hydrograph at 75% of the peak flow, in minutes.
- **K₅₀:** Fraction of Unit Hydrograph Width Before Peak at 50% of the peak flow, as a decimal fraction.
- **K₇₅:** Fraction of Unit Hydrograph Width Before Peak at 75% of the peak flow, as a decimal fraction.
- **Comment:** A field that allows the user to provide notes or additional information about the corresponding subcatchment.

3.4.3 Subcatchment Function Buttons

The four buttons on the *Subcatchments* worksheet that allow the user to run functions are described below. These functions are intended to help the user reduce erroneous values in the input parameters that may not have been noticed otherwise.

- **Check Subcatchment Inputs:** This function allows the user to check several of their subcatchment parameters to make sure they are within UDFCD guidelines. These parameters include area, length to centroid, length, and slope. For any subcatchment parameter that is questionable with respect to the UDFCD guidelines, the corresponding cell is highlighted in yellow. If a subcatchment parameter is unacceptable, the cell is highlighted in red. This function can also be run from a button on the *Intro* worksheet. The UDFCD guidelines are explained as part of the following button description.
- **Explanation of Input Checks:** This button brings up a dialog window (as seen in Figure 3.8) with five tabs to help explain what the highlighted cells from the *Check Subcatchment Inputs* button mean. Yellow cells are questionable and red cells are unacceptable with respect to the UDFCD guidelines.

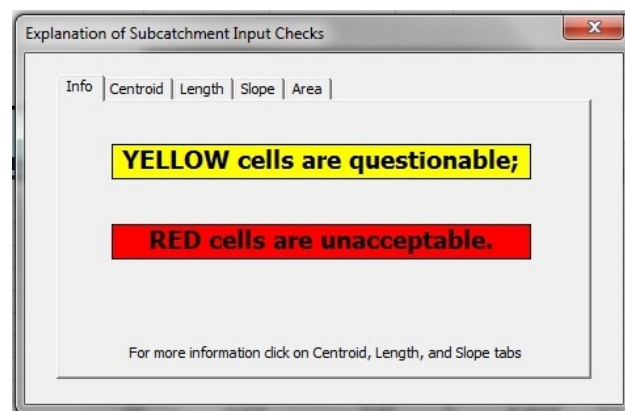


Figure 3.8 – The CUHP Subcatchment Input Checks Explanation

- **Area** – This check evaluates the area parameter as shown in Figure 3.9. Red cells indicate a negative area. Yellow cells indicate either an area less than 5 acres or an area greater than 5 square miles. For areas less than 5 acres, a 1-minute time step needs to be used for calculations. For areas greater than 5 square miles, the catchment should be broken into smaller subcatchments.

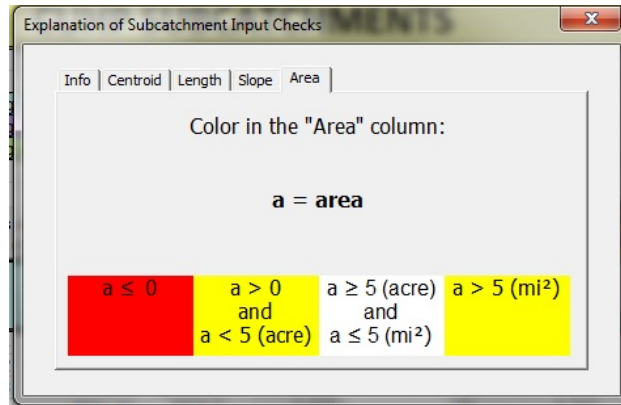


Figure 3.9 – The CUHP Subcatchment Area Guidelines

- **Centroid** – This check evaluates the ratio $r = \text{Length to Centroid} / \text{Total Length}$. Red cells indicate an r value of less than 0.1 or greater than 0.9 which are unacceptable. These values most likely indicate a typographical error as the two lengths are drastically different or are almost identical. Yellow cells indicate an r value of between 0.1 and 0.3 which are questionable. Values in this range indicate that the total length is much longer than the centroid length meaning the shape of the subcatchment has an elongated tail which is not well-represented by the hydrologic processes used in CUHP.

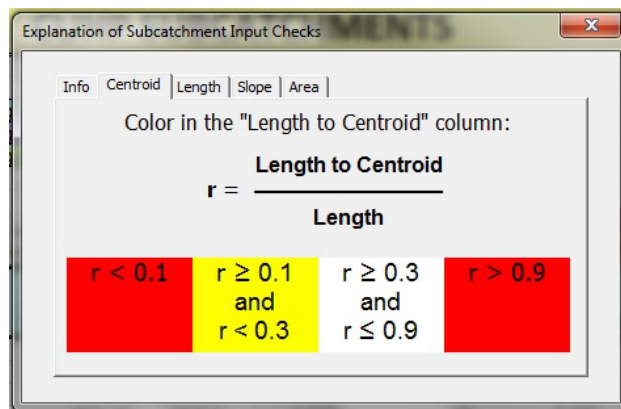


Figure 3.10 – The CUHP Subcatchment Length to Centroid Guidelines

- **Length** – This check evaluates the ratio $r = \text{Length}^2 / \text{Area}$ which is a shape parameter to evaluate the length to width ratio of the subcatchment. Red cells indicate an r value less than 1.0 which is unacceptable. These values would indicate that the width of the subcatchment is greater than the length and it should be delineated differently. Yellow cells indicate an r value greater than 4 which is questionable. These values would indicate a very narrow and long subcatchment which would have long travel times and unrealistic peak flows.

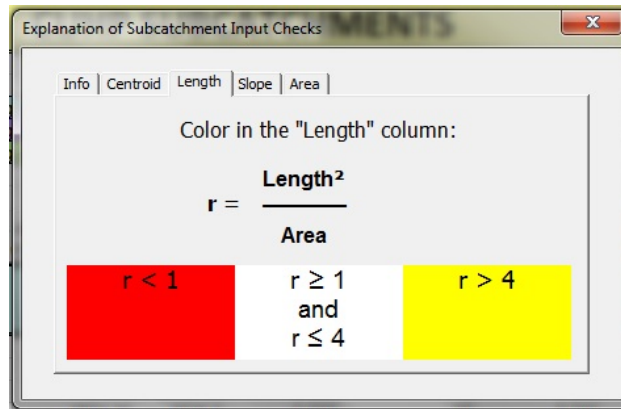


Figure 3.11 – The CUHP Subcatchment Length Guidelines

- **Slope** – This check evaluates the slope parameter. Red cells indicate a negative slope which is unacceptable. Yellow cells indicate a slope less than 0.005 feet per foot or greater than 0.06 feet per foot which are questionable. Very flat or very steep slopes are not well-represented by the hydrological processes used in CUHP.

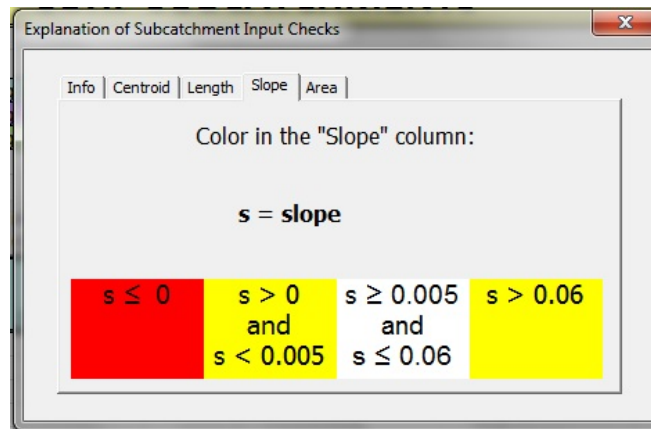


Figure 3.12 – The CUHP Subcatchment Slope Guidelines

- **Check SWMM Nodes:** This function allows the user to check for consistency between the CUHP inputs and the EPA SWMM input file (.inp). The function checks to make sure the hydrograph start times match and that the SWMM nodes entered in column B are available in the SWMM input file to receive runoff. This function can also be run from a button on the *Intro* worksheet.
- **Click to Change Units:** This function allows the user to change the units for *Area*, *Length* to *Centroid* and *Length* from “miles and square miles” to “feet and square feet” or “feet and acres”. This allows the user to input the subcatchment parameters in whatever set of units they have available or are most comfortable with. Regardless of the units the user inputs values in; CUHP will always convert back to “miles and square miles” in order to run the model calculations.

- **Click Here for Recommended Value Tables:** This function simply scrolls across the worksheet to show tables of the UDFCD recommended values for Depression Losses and Horton's Equation Parameters (Columns AG:AN).

3.5 The Run Multiple Scenarios Worksheet

The *Multiple Runs* worksheet allows the advanced user to run multiple CUHP and SWMM scenarios from a single input workbook. The user should have a good understanding of how to run the CUHP model and what effect each input parameter has on the run process prior to attempting to use this worksheet. The *Multiple Runs* worksheet was designed with the goal of helping to reduce the amount of repetitive runs a user had to conduct in order to run various combinations of land use (existing vs. future percent imperviousness), return period (2-, 5-, 10-, 25-, 50-, 100- and 500-yr), and areal rainfall correction. Once the user has completed the first three worksheets in the workbook and has successfully run the CUHP model from the button on the *Intro* worksheet they can setup the *Multiple Runs* worksheet to handle additional scenarios.

The user can create an unlimited number of scenario combinations, each of which consists of a Scenario ID, Land Use Description, Return Period, and Correction Area. A detailed description of how to setup the scenarios is provided below. Once all of the scenarios are setup, the user can click the *Run Multiple CUHP Scenarios* button, which will run CUHP for all of the scenarios (one row at a time) and create separate output files (output workbook and optional SWMM interface text file) for each one. In addition, a summary workbook is created to summarize the peak flow results for each subcatchment under each scenario.

There is also an option to run the EPA SWMM model for each scenario from the CUHP workbook using the *Run Multiple SWMM Scenarios* button. However, it is recommended that prior to using this function, the user open the EPA SWMM program directly and make sure the SWMM model is correctly setup to import the CUHP inflows text file and that the SWMM model runs successfully. Before clicking the *Run Multiple SWMM Scenarios* button, the user must supply the appropriate SWMM file paths and names on the *Intro* worksheet and must have already clicked the *Run Multiple CUHP Scenarios* button and received the "CUHP has Run Successfully for # Scenarios" message.

Figure 3.13 shows the *Multiple Runs* worksheet with 14 different scenarios. There is a button in the upper left corner of the worksheet that provides brief instructions on how to properly fill out the worksheet. A more detailed explanation of the required steps is provided below. There is also a button in the right corner that allows the user to clear the worksheet and start over.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P		
1	RUN MULTIPLE CUHP AND SWMM SCENARIOS																	
2	Instructions on How To Use Multiple Run Tool			Columns with this color heading are for required user-input										Clear Worksheet			(Optional) SWMM Time Series Inflow "Modification Type" (LU, RP, or LU&RP) RP	
Columns with this color heading are for program-calculated values																		
5	Fill Out Subcatchment Names			Create List of Raingages with Area Correction										Run Multiple CUHP Scenarios			SWMM Run Wait Time (sec) 5	
7														Run Multiple SWMM Scenarios				
9																		
10	Subcatchment Name	Existing Landuse % Imperviousness	Future Landuse % Imperviousness	Raingage	Return Period (Years)	1 Hr Depths (in)	6 Hr Depths (in)	Enter "X" to Run Scenario	Scenario ID	Land Use (E or F)	Return Period (yr)	Correction Area (Sq.Mi.)	(Optional) SWMM Time Series Inflow Table "NAME"					
11	1	8	40	Area Corrected	WQ	0.6	N/A	X	1	E	WQ	0	DryCreek					
12	2	23	35		2	0.82	1.02	X	2	E	10	0	SPlatte					
13	3	8	40		5	0.97	1.3	X	3	E	50	0						
14	4	58	58		10	1.14	1.58	X	4	E	100	0						
15	5	53	53		25	1.32	1.81	X	5	F	WQ	0						
16	6	95	95		50	1.57	2.05	X	6	F	10	0						
17	7	35	95		100	1.88	2.29	X	7	F	50	0						
18	8	75	75		500	2.12	2.61	X	8	F	100	0						
19	9	80	80					X	9	E	10	25						
20	10	85	85					X	10	E	50	25						
21	11	52	80					X	11	E	100	25						
22	12	35	35					X	12	F	10	25						
23	13	60	60					X	13	F	50	25						
24	14	75	75					X	14	F	100	25						
25	15	65	80															
26	16	70	70															

Figure 3.13 – The CUHP Multiple Runs Worksheet

3.5.1 Define Existing and Future Land Uses

The first step is to define the percent imperviousness for each subcatchment under existing and future land use conditions. Columns A through C are used to define these values for each subcatchment. The user is required to provide both existing and future values for all subcatchments listed on the *Subcatchments* worksheet regardless of whether they will be used in a scenario (Note: If future land use values for column C are unknown, the existing land use values from column B can be copied over as a placeholder to allow the models to run and vice versa).

The *Fill out Subcatchment Names* button is provided to copy the list of subcatchments from column A of the *Subcatchments* worksheet to column A of this worksheet. Using this button helps to ensure consistency between the two worksheets. If at any time, additional subcatchments are added to the Subcatchments worksheet, this button can be pressed again and the subcatchment list will be updated (note: imperviousness values will need to be shifted, recopied or updated manually).

After all inputs are completed and the *Run Multiple CUHP Scenarios* button is clicked, the program will cycle through each scenario row, one at a time, and run CUHP for each scenario. For each scenario row, the user-defined land use value (E or F) will determine which column of imperviousness values (B or C, respectively) to copy and paste into column H of the *Subcatchments* worksheet for that CUHP run. Once all of the scenarios have been run, the original percent imperviousness values from column H of the Subcatchments worksheet will be placed back into that column.

3.5.2 Select Raingages and Rainfall Depths

The second step is to create a list of all available raingages with area correction that exist within the workbook and then provide 1-hour and 6-hour rainfall depths for each raingage.

The *Create List of Raingages with Area Correction* button is provided to automatically create rainfall depth tables (columns E through H) for the available raingages with area correction. For each raingage, the automated table includes a row for each return period including the water quality (WQ) event, 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, 100-yr, and 500-yr. For each return period the user must enter the 1-hour and 6-hour rainfall depths. For the water quality event, the 1-hour rainfall depth is pre-defined as 0.6 inches and the 6-hour rainfall depth is not applicable (correction area for WQ events is always zero). For all other return periods, the user can find the appropriate rainfall depths in *Chapter 4 of the USDCM Volume 1* or directly from the [NOAA Atlas 14 Point Precipitation Frequency Estimates](#) website.

After all inputs are completed and the *Run Multiple CUHP Scenarios* button is clicked, the program will cycle through each scenario row, one at a time, and run CUHP for each row. For each scenario row, the user-defined return period will be used to lookup the 1-hour and 6-hour rainfall depths in columns G and H for each raingage. These rainfall depths along with the user-defined return period and area correction for the scenario will be pasted into cells B2:B5 of each area corrected raingage worksheet, which will in effect change the rainfall distributions used for that CUHP run. Once all of the scenarios have been run, the original raingage values from each raingage worksheet will be placed back into cells B2:B5.

It is important to note that the *Multiple Runs* worksheet is only intended to be used with area corrected raingages of type “distarea”. User-defined raingages (type “sheet”) are unique and there is no way to update them based on rainfall depths, return period or area correction. Raingages without area correction (type “dist”) are also not compatible with the *Multiple Runs* worksheet since they do not include inputs for the 6-hour rainfall depth or area correction factor. However, the actual rainfall distribution from a type “dist” raingage can be duplicated with the type “distarea” raingage by simply setting the area correction factor equal to zero. If the area correction factor is set equal to zero, the 6-hour rainfall depth is not used and the resulting rainfall distribution will be a 2-hour distribution without area adjustment. If on the *Subcatchments* worksheet, the user specifies a raingage of type “sheet” or “dist” for a subcatchment, that subcatchment will continue to be run for each scenario but with the original raingage distribution regardless of the return period selected for the scenario on the *Multiple Runs* worksheet.

3.5.3 Create Scenarios Table

The third step is to create the user-defined scenarios that CUHP will run. The Scenarios Table includes columns J through N of the *Multiple Runs* worksheet. Each row, starting on row 11, represents a single scenario.

The “X” in column J tells the CUHP model whether or not to run this particular scenario. If an “X” is placed in this column, CUHP will run the scenario. If this column is blank, or anything other than “X”, the scenario will be skipped. This allows the user to set up several different scenarios, but only run specific scenarios if desired. For example, the user may

have 100 scenarios (50 for existing conditions and 50 for future conditions), but only wants to rerun the future condition scenarios to evaluate the impact of a subcatchment with an updated future imperviousness.

The **Scenario ID** in column K is used to help organize the output files for each scenario. For each scenario the output filenames as defined on the *Intro* worksheet are given a prefix to make them unique. The prefix is comprised of the four user-defined variables for the scenario (Scenario ID, Land Use, Return Period, and Correction Area) combined into a string of characters. For example, with the following scenario variables: Scenario ID = “1”, Land Use = “E”, Return Period = “2”, and Correction Area = “15”; the prefix would be “1_Ex_2yr_15mi^2”. Since the Scenario ID comes first in the prefix, it is recommended that sequential numbering (e.g. 1, 2, 3, 4, etc.) be used so that output files are arranged in the same order as in the Scenarios Table.

The **Land Use** in column L can be either “E” or “F” for existing conditions and future conditions, respectfully. Any other value in this column will not be accepted and the user will be notified to change the input. If “E” is selected for a scenario, the percent imperviousness values from column B of this worksheet will be copied and pasted to column H of the *Subcatchments* worksheet for that scenario’s model run. Similarly, if “F” is selected for a scenario, the percent imperviousness values from column C of this worksheet will be copied and pasted to column H of the *Subcatchments* worksheet for that scenario’s model run.

The **Return Period** in column M can be either WQ, 2, 5, 10, 25, 50, 100, or 500. Any other value will not be recognized by CUHP or the raingages and the user will be notified to change the input. For each scenario, the return period is used to lookup the appropriate 1-hour and 6-hour rainfall depths for each area corrected raingage in columns G and H. The rainfall depths along with the return period and correction area are then copied into each “distarea” raingage worksheet to update the rainfall distributions for that scenario’s model run.

The **Correction Area** in column N can range from 0 to 75 square miles. Any negative values will be rejected. Any values greater than 75 will be treated as 75 square miles. For each scenario, the correction area is used to adjust the rainfall distributions to account for larger watershed areas. It should be noted that the WQ event always has a correction area equal to zero since it is only evaluated for watersheds less than one square mile in size. The correction area, return period and rainfall depths are copied into each “distarea” raingage worksheet to update the rainfall distributions for that scenario’s model run.

3.5.4 Run Multiple CUHP Scenarios

After all of the required inputs are completed, the user is ready to run the different scenarios. By clicking on the *Run Multiple CUHP Scenarios* button, the program will run each scenario

one at a time. For each scenario the model will update the percent imperviousness values (existing or future) on the *Subcatchments* worksheet and raingage parameters (1-hour rainfall depth, 6-hour rainfall depth, return period, and correction area) on each area corrected raingage worksheet based on the user-defined values in the Scenario Table. Once the stated parameters have been updated, the CUHP model will be run for that scenario and the output workbook and optional SWMM interface text file will be created. The output files will include a prefix describing the scenario. This process will repeat for all scenarios in the Scenario Table that are marked with an “X”. After all scenarios have been run successfully, a summary workbook will be created to summarize the peak flows for each subcatchment under each scenario. This summary workbook will be opened automatically once the “Successful” message is closed.

The *Multiple CUHP Run Summary* workbook consists of a worksheet for each subcatchment and a summary worksheet which is just a copy of the *Multiple Runs* worksheet from the input workbook. On each subcatchment worksheet, the storm hydrographs for each scenario are listed in adjacent columns. This allows the user to quickly double check that the results for each scenario are consistent with expectations. For example: Do the peak flows increase with increasing return period, do the peak flows increase with increasing watershed area, etc.

3.5.5 Run Multiple SWMM Scenarios

After the multiple CUHP files have been created, there is an option to run the EPA SWMM model for each scenario from the CUHP workbook using the *Run Multiple SWMM Scenarios* button. The SWMM model must be completely setup and properly reference the CUHP output storm hydrographs as an interface file prior to using this option. Therefore, the user should double check by opening the EPA SWMM program directly and making sure the SWMM model is correctly setup to use the CUHP/SWMM interface text file specified on the *Intro* worksheet. This interface file reference is setup in SWMM by clicking “Options” in the upper left corner of the SWMM screen, then double-clicking “Interface Files” in the lower left corner. This brings up a dialog box with the “files” tab selected. On this tab, click “Add” and choose “INFLOWS” under the “File Type:” pull down menu. Next, type in the file path and name, or browse to the file by clicking on the binoculars icon (see Section 4.3 of this User Manual for more information on this process). Once this connection is made, it is a good idea to run EPA SWMM from the EPA SWMM window to make sure it runs successfully prior to running it from the CUHP workbook.

Before clicking the *Run Multiple SWMM Scenarios* button, the user must supply the appropriate SWMM file paths and names on the *Intro* worksheet and must have already clicked the *Run Multiple CUHP Scenarios* button and received the “CUHP has Run Successfully for # Scenarios” message.

When the *Run Multiple SWMM Scenarios* button is clicked, the program runs the EPA SWMM model for each scenario one at a time. To do this, it opens the EPA SWMM input

file (.inp) specified on the *Intro* worksheet, copies it and renames the copied version with the same prefix described above for the CUHP files. Within the SWMM input file, it enters the scenario prefix on the Title/Comment line and replaces the filename reference for the “Inflows” interface file with the filename for the CUHP output file that has the matching prefix. It then runs the EPA SWMM model executable file using a DOS command and the SWMM output files (.out and .rpt) files are renamed with the same prefix. After the run is complete, the next scenario follows the same procedure. Once all scenarios have been run, a message indicating the number of successful SWMM model runs is displayed. After clicking “OK” on the successful message a summary workbook will open. The *Multiple SWMM Run Summary* workbook consists of a summary worksheet which is just a copy of the *Multiple Runs* worksheet from the input workbook and a separate worksheet for each scenario. Each scenario worksheet is simply a copy of the SWMM report file (.rpt) imported into Excel using a space delimited format. This summary workbook provides all of the SWMM results (nodes depths, node inflows, link flows, storage unit release rates and volumes, outfall flows, etc.) in an Excel format so the user can easily compare results from the SWMM output. If for any reason the SWMM report file is not fully copied over to the summary workbook for each scenario, the user can override the default SWMM Run Wait Time of 5 seconds in cell N8. By increasing this Wait Time, it causes the CUHP program to pause long enough to allow the SWMM program to run to completion prior to importing the report file.

An optional feature is included to allow the user to modify time series inflow hydrographs in EPA SWMM from the CUHP interface. Time series inflows are often used in SWMM models at the upstream node of a routing network to account for offsite flows or discharges from a reservoir. If the time series inflow varies with respect to land use conditions or design storm return periods, it may be necessary to change the time series table used for each SWMM scenario. If this is the case, the SWMM input file must contain numerous time series tables that can be connected to the same node, but only one table is used for each model run. In order to change the time series table name used in the SWMM input file for each scenario from the CUHP interface, the user needs to name the various time series tables in the SWMM input file using the specified format “NAME_LU_RP”, where the “NAME” can be anything the user chooses and is typically descriptive of the channel or reservoir. The “LU” represents the land use conditions, either “Ex” for existing land use or “Fut” for future land use. The “RP” represents the return period, either “WQ”, “2yr”, “5yr”, “10yr”, “25yr”, “50yr”, “100yr”, or “500yr”. An example time series table name is “DryCreek_Fut_100yr”.

On the CUHP *Multiple Runs* worksheet, the user would then need to specify the time series “Modification Type” in cell P8 and each of the time series table name prefixes (“NAME”) in column P starting in row 11. The Modification Type can be “LU”, “RP”, or “LU&RP” as shown in the comment when the user hovers over cell P4. The modification type tells the program how to change the time series table name for each of the scenarios so that it references the correct time series table in the SWMM input file. As discussed in Section

3.5.3, each row in the scenarios table has a specific land use “LU” and return period “RP” associated with it. Therefore, when each scenario is run, either or both of these parameters can be changed in the time series table name to reference the appropriate time series inflow tables for that particular scenario. If the modification type is left blank the program assumes that either there are no time series inflows in the SWMM input file or that the user does not want to modify them. If the modification type is “LU” the program will change only the land use conditions for each scenario. If the modification type is “RP” the program will change only the return period for each scenario. If the modification type is “LU&RP” the program will change both the land use conditions and the return period for each scenario.

An example is provided below to help illustrate how this feature works. In this example, assume the SWMM input file has a node that receives discharges from a reservoir which vary based on both land use conditions and return period (default time series table name referenced in the node inflows box is “DryCreek_Fut_100yr”). Also, assume there is a SWMM node that receives overflows from an irrigation ditch which vary based on return period only (default time series table name referenced in the node inflows box is “SPlatte_Fut_100yr”). The user would then need to make sure SWMM time series tables are created for each node and for each desired scenario. The user would also need to enter a modification type in cell P8 and the table name prefixes “DryCreek” and “SPlatte” in cells P11 and P12 as shown in Figure 3.13.

Model results for this example could be achieved in two different ways. The first way would be to select “LU&RP” for the modification type in cell P8 and to create twelve time series tables in the SWMM input file. The first six would be for the “DryCreek” node, three for existing conditions (2yr, 10yr and 100yr) and three for future conditions (2yr, 10yr and 100yr). The remaining six would be for the “SPlatte” node, three for the future conditions (2yr, 10yr and 100yr) and a duplicate copy of these for the existing conditions but with the “LU” changed in the table name. This would allow the user to select the modification type “LU&RP” which would change the land use and return period in each table name for each scenario. The table below shows the time series table names that would be referenced for each node in each scenario.

Run “X”	Scenario	Land Use	Return Period	Time Series Table <u>Name</u> for “DryCreek” Node Inflows	Time Series Table Name for “SPlatte” Node Inflows
X	1	E	2	DryCreek_Ex_2yr	SPlatte_Ex_2yr (duplicate)
X	2	E	10	DryCreek_Ex_10yr	SPlatte_Ex_10yr (duplicate)
X	3	E	100	DryCreek_Ex_100yr	SPlatte_Ex_100yr (duplicate)
X	4	F	2	DryCreek_Fut_2yr	SPlatte_Fut_2yr
X	5	F	10	DryCreek_Fut_10yr	SPlatte_Fut_10yr
X	6	F	100	DryCreek_Fut_100yr	SPlatte_Fut_100yr

The second way to achieve the desired results would be to create only the nine time series tables required in the SWMM input file (6 for “DryCreek” and 3 for “SPlatte”), but to run

two different sets of scenarios by clicking the *Run Multiple SWMM Scenarios* button on two separate setups. The first click of the button would be run for six scenarios, a modification type of “LU&RP”, and only the table name “DryCreek” in Cell P11. The table below shows the time series table names that would be referenced for the “DryCreek” node.

Run “X”	Scenario	Land Use	Return Period	Time Series Table Name for “DryCreek” Node Inflows
X	1	E	2	DryCreek_Ex_2yr
X	2	E	10	DryCreek_Ex_10yr
X	3	E	100	DryCreek_Ex_100yr
X	4	F	2	DryCreek_Fut_2yr
X	5	F	10	DryCreek_Fut_10yr
X	6	F	100	DryCreek_Fut_100yr

The second click of the button would be run for only three scenarios, a modification type of “RP”, and only the table name “SPlatte” in Cell P11. The table below shows the time series table names that would be referenced for the “SPlatte” node.

Run “X”	Scenario	Land Use	Return Period	Time Series Table Name for “SPlatte” Node Inflows
	1	E	2	
	2	E	10	
	3	E	100	
X	4	F	2	SPlatte_Fut_2yr
X	5	F	10	SPlatte_Fut_10yr
X	6	F	100	SPlatte_Fut_100yr

3.6 User Worksheets

CUHP allows you to add your own custom worksheets to the CUHP workbook provided that you do not remove or replace any of the default worksheets. These worksheets can be used for calculations or to store important information relating to your CUHP model. The information in these sheets will not be reported in the output workbook or SWMM interface text file.

3.7 Non-User Worksheets

CUHP contains two hidden worksheets for its internal use. The *Program Data* worksheet contains tables, headers, and formulas to be used in calculations or copied to other areas of the workbook, and the *Rainage_Template* worksheet provides macros for use with Rainfall Distribution Rainages with Area Correction. These worksheets should never be removed or modified.

4 Guides and Tutorials

The purpose of this section is to provide instructions for various common tasks in the CUHP workbook, and to help you avoid various common mistakes. If this section is unable to meet your needs, you can always contact the UDFCD for more information.

4.1 Creating a New CUHP Workbook

Due to the large number of inputs required to accurately run the CUHP, creating a new workbook from scratch can be a daunting task. This section will walk you through the process for creating a new CUHP workbook and running it.

To create a new CUHP workbook, you will need:

1. An up-to-date version of the CUHP 2005 workbook. The latest version is available from the UDFCD website at <http://udfcd.org/software>.
2. Information on at least one subcatchment. The required information is described in Section 3.4 of this manual, and in *Chapter 5, Section 3 of the USDCM Volume 1*.
3. Information for at least one design storm. The required information is summarized below:
 - **NOAA Distribution Raingages:** A 1-hour rainfall depth for the storm, and a return period.
 - **NOAA Distribution Raingage with Area Correction:** A 1-hour rainfall depth for the storm, a 6-hour rainfall depth for the storm, the area correction factor based on the watershed size, and the return period.
 - **User-Defined Hyetograph:** A collection of time and incremental depth pairs that represents the storm.

After the required information has been collected, you are ready to begin creating your workbook.

1. The first step in creating your CUHP project is to open the Excel macro-enabled template (.xltm) and save it as an Excel macro-enabled workbook (.xlsm) with your chosen filename and directory. The downloaded version is in a template format so that it can be used for several different projects without the concern that it has been in some way modified.
2. In your new copy of the CUHP workbook, scroll down on the *Intro* worksheet and enter your project settings:
 - a. The *Project Title* and *Project Comment* fields are optional but are recommended for the benefit of users who open this workbook in the future.
 - b. Choose your *Time Step*, typically 1 minute or 5 minutes.
 - c. Depending on the location of your output files, you may want to check the box for *Use Relative Path Names*. For longer file paths, the filename may not be visible,

so it is useful to shorten the file path down to only show the relative path with respect to the input workbook.

- d. The *Output Workbook Filename* is required and is the location where all CUHP output information will be saved.
 - e. The *CUHP/SWMM Interface Filename* is only required if you are planning to route the CUHP storm hydrographs using EPA SWMM. If you are, then this will be the location where the text file containing the storm hydrographs will be saved.
 - f. The *EPA SWMM 5 Input Filename* is also optional, but if you are going to route the hydrographs in SWMM, it is recommended that this file be specified so that you can confirm the SWMM nodes are consistent between the CUHP workbook and the SWMM input file. Also, if you are going to use the *Multiple Runs* worksheet to run SWMM from the CUHP workbook, this file will be required.
 - g. The *EPA SWMM 5 Application File* is only required if you are going to be running SWMM from the *Multiple Runs* worksheet. This executable file is typically located at C:\Program Files (x86)\EPA SWMM 5.0\.
 - h. The SWMM Hydrograph Start Time is only required if you are planning to route the CUHP storm hydrographs using EPA SWMM. This ensures that the storm hydrographs start at the same time as the SWMM model run. The default time is 1/1/2005 12:00 AM.
3. Next, switch to the *Raingages* worksheet and create the appropriate raingages. To do this, you must do the following for each rainfall hyetograph you want to create:
- a. Select the appropriate type of raingage from the drop down menu.
 - b. Press the *Add* button and enter a unique name for the raingage.
 - c. Fill in all required information on the raingage worksheet that appears. Section 3.3 of this User Manual provides information on which inputs are required.
 - d. Return to the *Raingages* worksheet to verify that the hyetograph table has been updated and to add additional raingages.

Tip: Subcatchments can share hyetographs. Creating one hyetograph and sharing it (where appropriate) will save time both during creation and if you need to update the raingage input parameters.

4. Next, switch to the *Subcatchments* worksheet and enter the required inputs for each subcatchment that you want to add. Section 3.4 of this User Manual provides information on which inputs are required. You can also use Excel formulas in this worksheet.

Tip: You can copy and paste raingage names from the *Raingages* worksheet to prevent typing errors. To specify a raingage, you can also enter a reference to an entry in the hyetograph table (e.g. “=Raingages!A7”) for the same effect.

Tip: If you have several subcatchments that differ only by one or two parameters, such as a catchment being analyzed with two raingages, you can enter values for one subcatchment on a row, then use Excel's copy and paste functionality to make copies of the subcatchment on different rows.

Tip: If you are more comfortable working in units of “feet and square feet” or “feet and acres” than “miles and square miles” you can change the units by pressing the (*click to change*) button prior to entering the parameters.

5. After all subcatchments have been entered, it is recommended that you check the subcatchment parameters for reasonableness. This can be done by pressing the *Check Subcatchment Inputs* button which will highlight the cells for any parameter that does not meet UDFCD guidelines. A description of these guidelines is provided in Section 3.4.3 of this User Manual.
6. If you are going to be routing the resulting storm hydrographs with EPA SWMM, it is recommended that you press the *Check SWMM Nodes* button to check for consistency between the CUHP workbook and the SWMM input file (.inp). This function will make sure the start times match for the two files and that the SWMM nodes specified in the CUHP workbook exist within the SWMM input file.
7. Once all of the required parameters have been entered, switch back to the *Intro* worksheet and save your file. Then press the *Run CUHP* button to run the model. Running the model will produce the Output Workbook (.xlsx) and optionally the CUHP/SWMM Interface file (.txt) specified in the *Settings* on the *Intro* worksheet.

4.2 Importing Old CUHP 2005 Workbooks

When you upgrade CUHP 2005 to the latest available version, it is important to manually upgrade your previous CUHP 2005 input workbooks to this version also. Failure to do so may prevent the old workbook from taking advantage of interface enhancements and cause the old workbook to produce results that are not consistent with current UDFCD criteria. Workbook versions prior to version 1.4.0 required a separate math engine to run the CUHP model, so without the appropriate math engine files, those workbooks will not run at all. Therefore, anytime a new project is started it is recommended that the user check the UDFCD website at <http://udfcd.org/software> to get the latest version.

To import an old CUHP 2005 workbook, you will need the latest version of the CUHP 2005 workbook and an old CUHP 2005 workbook that you want to update. After you have these files, you are ready to begin the import process by following the steps below:

1. Open the old CUHP 2005 workbook and review the information included to be sure you know what is in the workbook prior to conversion. Then close the old workbook prior to the next step.

2. Open the latest version of the CUHP 2005 workbook which will be in an Excel macro-enabled template (.xltm) format. Then save the workbook as an Excel macro-enabled workbook (.xlsm) with the file name and directory of your choice.
3. On the *Intro* worksheet, click on the *Import CUHP 2005 File* button, select your old CUHP 2005 workbook file in the dialog box and press *Open*. This will start an automated process that copies information from the old workbook, including any user created worksheets, into the new workbook. You will be notified when the process is complete. If you have made any modifications to the new workbook (e.g. adding raingages or entering subcatchment parameters) prior to trying to import an old file, the process will not run and the user will be notified.
4. The user should then review the new CUHP workbook to ensure that all of your data has been transferred, and has been placed in the appropriate cells. Any values that were not provided in the old workbook will be left blank in the new workbook.

Tip: You will most likely want to update to the project settings on the new *Intro* worksheet to reflect the desired file paths on your computer. Often the file paths imported from the old workbook do not exist on your computer if the old workbook was originally created by another user.

5. Finally, save the new workbook. You can either overwrite the old file or save the file with a new name.

4.3 Using CUHP 2005 Output with EPA SWMM 5

Often it is desirable to use the output data from CUHP 2005 in another program, such as EPA SWMM 5. Since using the output workbook directly is usually not possible in another program, CUHP 2005 provides a method for producing a text file (.txt) containing selected runoff data that meets the specifications of an EPA SWMM *Inflows* interface file.

To use your CUHP 2005 output storm hydrographs with EPA SWMM 5, you will need:

- A CUHP 2005 workbook that has been completed using one of the previously described methods.
- An installed copy of EPA SWMM 5. SWMM 5 is not developed or supported by the UDFCD. For more information on EPA SWMM 5, you should refer to <https://www.epa.gov/water-research/storm-water-management-model-swmm>. This link provides access to installers, product manuals and source code, as well as general product and support information.
- An EPA SWMM input file (.inp) with the desired flow routing network.

Once these requirements have been met, you are ready to begin the process:

1. Open your SWMM input file (.inp) using the EPA SWMM 5 program, and navigate to the “Dates” pane of the “Simulation Options” dialog, as shown in Figure 4.1 and indicated below:
 - a. In EPA SWMM, select the “Data” tab in the upper left
 - b. Select “Options” in the “Data” tab
 - c. Double-click “Dates” in the “Options” list in the lower left

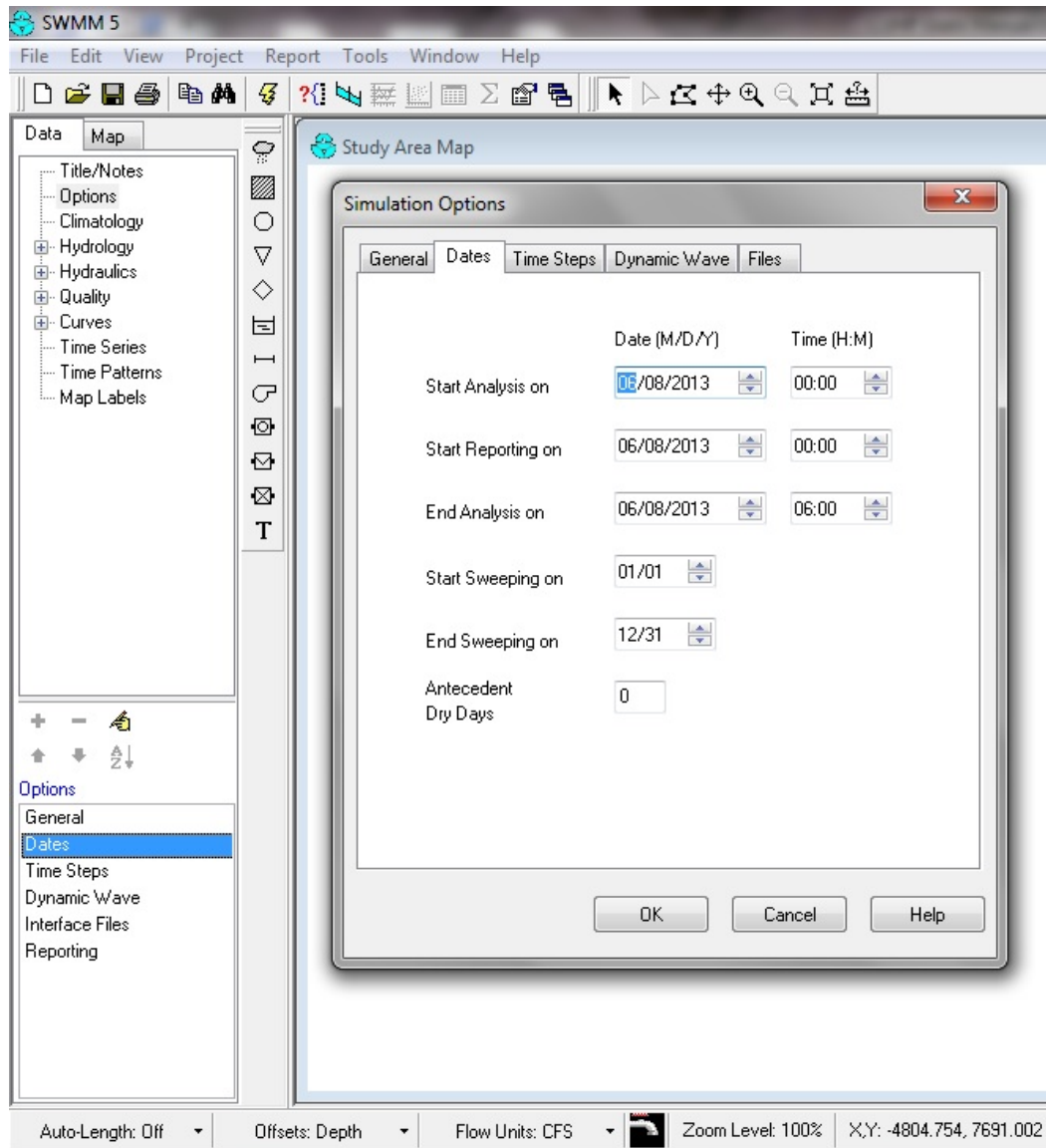


Figure 4.1 – The EPA SWMM 5 Date Settings

2. Set the appropriate values for all date options in this dialog box. You will need to remember the values you enter for “Start Analysis On” and “End Analysis On”, so it is advisable to write these down. Then save the EPA SWMM input file and close it.
3. Open your CUHP 2005 workbook and on the *Intro* worksheet under Settings, enter values for *CUHP/SWMM Interface Filename*, *EPA SWMM 5 Input Filename*, and

SWMM Hydrograph Start Time. These fields are explained in more detail in Section 3.2 of this User Manual. If the value you pick for the *SWMM Hydrograph Start Time* is not between the values you picked in your SWMM input file for “Start Analysis On” and “End Analysis On”, a CUHP/SWMM Interface file (.txt) will still be generated, but you will not see any results when you run EPA SWMM 5.

4. In column B of the *Subcatchments* worksheet, type the names of the *EPA SWMM Target Nodes* that you want each subcatchment to drain into. Make sure the SWMM node names in CUHP are written the same as they are entered in your SWMM input file (.inp). Any CUHP subcatchment in column A that does not have a corresponding SWMM Target Node in column B will not be included in the CUHP/SWMM Interface file (.txt).
5. Once the dates and target nodes are entered it is recommended that the user press the *Check SWMM Nodes* button on either the *Intro* worksheet or the *Subcatchments* worksheet to make sure all values are consistent between the two files.
6. If everything is consistent, save the CUHP workbook, and press the *Run CUHP* button on the *Intro* worksheet. This will create the Output Workbook (.xlsx) and the CUHP/SWMM Interface file (.txt). To interface with EPA SWMM, only the text file is required.
7. Open your SWMM input file (.inp) again using the EPA SWMM 5 program, and navigate to the “Files” pane of the “Simulation Options” dialog and select an Inflows file, as shown in Figure 4.2 and indicated below:
 - a. In EPA SWMM, select the “Data” tab in the upper left
 - b. Select “Options” in the “Data” tab
 - c. Double-click “Interface Files” in the “Options” list in the lower left
 - d. Click the “Add” button on the “Files” tab of the dialog box
 - e. Under the “File Type” pull-down menu, select “INFLOWS”
 - f. Then click on the binocular icon and browse to the text file created by CUHP. Once the file is found, select it and press “Open”
 - g. Then press “OK” on both SWMM dialog boxes and save your SWMM input file.
8. You can now run EPA SWMM and it will route the CUHP storm hydrographs through the SWMM routing network.

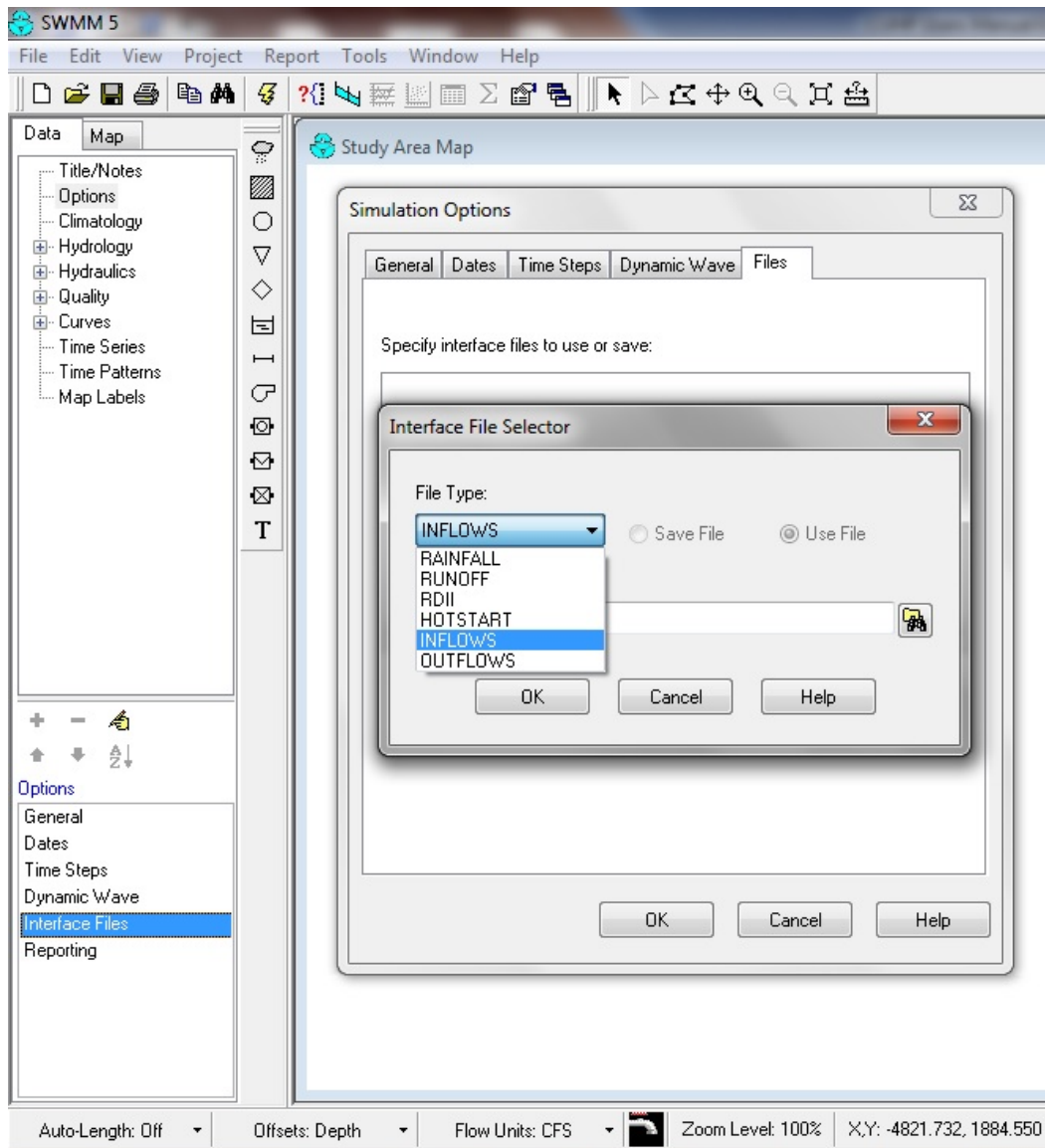


Figure 4.2 – The EPA SWMM 5 Interface Files

4.4 Running Multiple Scenarios of CUHP and SWMM

CUHP and EPA SWMM are often used for master planning purposes and several different model scenarios are required to develop the baseline hydrology for a project. The *Multiple Runs* worksheet allows the advanced user to run multiple CUHP and SWMM scenarios from a single input workbook. This limits the number of repetitive runs a user must make, helps to reduce potential mistakes in the input, and creates a consistent format for output files from a review perspective. The user should have a good understanding of how to run the CUHP model and what effect each input parameter has on the run process prior to attempting to use this worksheet.

To use the *Multiple Runs* worksheet to run various scenarios of CUHP, you will need:

- A CUHP 2005 input workbook that runs “successfully” from the *Intro* worksheet
- At least one area-corrected raingage (type “distarea”)

If you intend to run various scenarios of SWMM from the *Multiple Runs* worksheet, you will also need to provide the following settings on the *Intro* worksheet:

- The file name and path for the CUHP/SWMM Interface file (.txt).
- The file name and path of an EPA SWMM 5 input file (.inp) with a flow routing network that is setup correctly to run with CUHP inflow hydrographs.
- The file path to the EPA SWMM 5 executable file (swmm5.exe) located on your local machine. EPA SWMM 5 must be installed and run successfully on your local machine.
- The SWMM Hydrograph Start Time consistent with the SWMM input file (.inp)

Once these requirements have been met, you are ready to begin setting up the Multiple Runs worksheet.

1. On the Multiple Runs worksheet, click the *Fill Out Subcatchment Names* button and column A will be populated with the subcatchment names from the Subcatchments worksheet as shown in Figure 4.3. You must then fill out the appropriate percent imperviousness values for existing and future land use conditions. Both existing and future values are required.

Tip: If future land use values are unknown or not needed, then existing land use values from column B can be copied over as a placeholder to allow the models to run.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	RUN MULTIPLE CUHP AND SWMM SCENARIOS															
2	Instructions on How To Use Multiple Run Tool	Columns with this color heading are for required user-input										Clear Worksheet				
3		Columns with this color heading are for program-calculated values														
4																
5																
6	Fill Out Subcatchment Names				Create List of Raingages with Area Correction				Run Multiple CUHP Scenarios				SWMM Run Wait Time (sec)			
7													5			
8									Run Multiple SWMM Scenarios							
9																
10	Subcatchment Name	Existing Landuse % Imperviousness	Future Landuse % Imperviousness		Raingage	Return Period (Years)	1 Hr Depths (in)	6 Hr Depths (in)	Enter "X" to Run Scenario	Scenario ID	Land Use (E or F)	Return Period (yr)	Correction Area (Sq.Mi.)	(Optional) SWMM Time Series Inflow Table "NAME"		
11	1															
12	2															
13	3															
14	4															
15	5															
16	6															
17	7															
18	8															
19	9															
20	10															
21	11															
22	12															
23	13															
24	14															
25	15															
26	16															

Figure 4.3 – The CUHP Multiple Runs Land Use Information

- Next click the *Create List of Raingages with Area Correction* button to create a rainfall depth input table for each “distarea” type raingage. A separate table will be created for all “distarea” raingages included in the workbook as shown in Figure 4.4. Raingages of type “sheet” and “dist” are not compatible with the *Multiple Runs* worksheet as described in Section 3.5.2 of this User Manual.

Tip: If you only have a type “dist” raingage because you have a small watershed area and don’t need area correction, this is not a problem. You can still use the *Multiple Runs* worksheet, you just need to create a duplicate “distarea” raingage for each “dist” raingage you have. The exact same rainfall distribution can be created by simply setting the “correction area” value equal to zero.

RUN MULTIPLE CUHP AND SWMM SCENARIOS															
Instructions on How To Use Multiple Run Tool				Columns with this color heading are for required user-input Columns with this color heading are for program-calculated values								Clear Worksheet			
Fill Out Subcatchment Names				Create List of Raingages with Area Correction				Run Multiple CUHP Scenarios				SWMM Run Wait Time (sec) 5		(Optional) SWMM Time Series Inflow "Modification Type" (LU, RP, or LU&RP)	
								Run Multiple SWMM Scenarios						(Optional) SWMM Time Series Inflow Table "NAME"	
Subcatchment Name	Existing Landuse % Imperviousness	Future Landuse % Imperviousness		Raingage	Return Period (Years)	1 Hr Depths (in)	6 Hr Depths (in)	Enter "X" to Run Scenario	Scenario ID	Land Use (E or F)	Return Period (yr)	Correction Area (Sq.Mi.)			
1	8	40		Area Corrected	WQ	0.6	N/A								
2	23	35			2										
3	8	40			5										
4	58	58			10										
5	53	53			25										
6	95	95			50										
7	35	95			100										
8	75	75			500										
9	80	80													
10	85	85													
11	52	80													
12	35	35													
13	60	60													
14	75	75													
15	65	80													
16	70	70													

Figure 4.4 – The CUHP Multiple Runs Raingage Depth Table

- Once the raingage tables are created, the 1-hour and 6-hour rainfall depths need to be filled out. For the water quality event, the 1-hour rainfall depth is pre-defined as 0.6 inches and the 6-hour rainfall depth is not applicable. For the 2-yr, 5-yr, 10-yr, 25-yr, 50-yr and 100-yr return periods, the user can find the appropriate rainfall depths on the [NOAA Atlas 14 Point Precipitation Frequency Estimates](#) website for Colorado.

Tip: If you are dealing with a small watershed that does not require area correction and you don’t need the 6-hour rainfall depths, you can always copy the 1-hour rainfall depths over to column H as a placeholder to allow the models to run. This option is only acceptable as long as the correction area for all scenarios is set to zero. When the correction area equals zero, the storm distribution is only two hours long and the 6-hour rainfall depth is not used.

- After all rainfall depths are filled in, the next step is to create the individual scenarios that will be run in CUHP and optionally SWMM. Each row in columns J through N, starting

on row 11, represents a unique scenario. You should have a good idea at this point which scenarios you want to run. This example includes 14 scenarios based on existing and future land use conditions for the WQ event, 10-yr, 50-yr and 100-yr design storms including area correction for a 25 square mile watershed as shown in Figure 4.5 below.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	RUN MULTIPLE CUHP AND SWMM SCENARIOS															
2	Instructions on How To Use Multiple Run Tool				Columns with this color heading are for required user-input				Clear Worksheet							
Columns with this color heading are for program-calculated values																
5	Fill Out Subcatchment Names				Create List of Raingages with Area Correction				Run Multiple CUHP Scenarios				SWMM Run Wait Time (sec)		(Optional) SWMM Time Series Inflow "Modification Type" (LU, RP, or LU&RP)	
6													5			
7									Run Multiple SWMM Scenarios							
8																
9															(Optional) SWMM Time Series Inflow Table "NAME"	
10	Subcatchment Name	Existing Landuse % Imperviousness	Future Landuse % Imperviousness	Raingage	Return Period (Years)	1 Hr Depths (in)	6 Hr Depths (in)	Enter "X" to Run Scenario	Scenario ID	Land Use (E or F)	Return Period (yr)	Correction Area (Sq.Mi.)				
11	1	8	40	Area Corrected	WQ	0.6	N/A	X	1	E	WQ	0				
12	2	23	35		2	0.82	1.02	X	2	E	10	0				
13	3	8	40		5	0.97	1.3	X	3	E	50	0				
14	4	58	58		10	1.14	1.58	X	4	E	100	0				
15	5	53	53		25	1.32	1.81	X	5	F	WQ	0				
16	6	95	95		50	1.57	2.05	X	6	F	10	0				
17	7	35	95		100	1.88	2.29	X	7	F	50	0				
18	8	75	75		500	2.12	2.61	X	8	F	100	0				
19	9	80	80					X	9	E	10	25				
20	10	85	85					X	10	E	50	25				
21	11	52	80					X	11	E	100	25				
22	12	35	35					X	12	F	10	25				
23	13	60	60					X	13	F	50	25				
24	14	75	75					X	14	F	100	25				
25	15	65	80													
26	16	70	70													

Figure 4.5 – The CUHP Multiple Runs Scenario Table

- In setting up the scenarios table, it is often easiest to start with the **Return Period** in column M because the required return periods are typically defined in the project scope. The return periods can include WQ, 2, 5, 10, 25, 50, 100, or 500, but you only need to include the ones relevant to your project. In the example from Figure 4.5, only four return periods are included (WQ, 10, 50, and 100). These four values were entered in rows 11 through 14, respectively.
- If you are modeling both existing and future land use conditions, you can then fill out the **Land Use** in column L which is either "E" or "F" for existing conditions and future conditions, respectfully. In the example from Figure 4.5, rows 11 through 14 were assigned a land use of "E". Those four rows were then copied down to rows 15 through 18 and the land use was changed to "F", creating a total of 8 scenarios (4 existing and 4 future).
- Next, the **Correction Area** in column N can range from 0 to 75 square miles. The first 8 scenarios in the example from Figure 4.5 do not have an area correction and were given a correction area value of zero (these 8 scenarios will be based on a 2-hour rainfall distribution). For example purposes an area correction of 25 square miles was included in Figure 4.5. It should be noted that the WQ event always has a correction area equal to zero since it is only evaluated for watersheds less than one square mile in size. Therefore, only the 10-yr, 50-yr and 100-yr scenarios (rows 12 to 14 and 16 to 18) were copied down to rows 19 through 24 to create an additional six scenarios with an area correction of 25 square miles.

8. The **Scenario ID** in column K is used to help organize the output files for each scenario by being the first character in the output file name prefix. The prefix is comprised of the four user-defined variables for the scenario (Scenario ID, Land Use, Return Period, and Correction Area) combined into a string of characters. For example, in the first scenario of Figure 4.5: Scenario ID = “1”, Land Use = “E”, Return Period = “WQ”, and Correction Area = “0”; the prefix would be “1_Ex_WQ_0mi^2”.

Tip: Since the Scenario ID comes first in the prefix, it is recommended that sequential numbering (e.g. 1, 2, 3, 4, etc.) be used so that output files are arranged in the same order as in the Scenarios Table. However, any value can be used for the Scenario ID.

9. Finally, place an “**X**” in column J if you want the CUHP model to run this particular scenario. This allows you to setup several different scenarios, but only run specific scenarios if desired.
10. Once all of the scenario information is complete, you can press the *Run Multiple CUHP Scenarios* button and CUHP will begin running the scenarios. You can follow the status of the model run process by looking at the status bar in the lower left corner of the input workbook. Once all scenarios are finished running, a message box will indicate how many models ran “successfully”. After clearing this message, a summary workbook will open with the peak flow results for each subcatchment under each scenario. Separate output workbooks and CUHP/SWMM Interface files (if selected) will be created for each scenario and saved in the specified directory.
11. Once you are satisfied with the CUHP multiple run results, you can run multiple SWMM scenarios (assuming you have provided the required SWMM file names, paths, and optional time series inflow information in column P). Simply press the *Run Multiple SWMM Scenarios* and the SWMM model will be run for each scenario row listed in the Scenarios Table. Once all scenarios are finished running, a message box will indicate how many models ran “successfully”. Separate SWMM files will be created for each scenario including input (.inp), settings (.ini), output (.out), and report (.rpt) files. In addition, a Multiple SWMM Run Summary workbook will be created which includes a copy of each SWMM run’s report file (.rpt) imported into Excel in a space delimited format. If the SWMM report file doesn’t import completely and the bottom part of the report is cutoff, go back and increase the SWMM Run Wait Time in cell N8 of the input workbook and rerun the SWMM scenarios again. The user can then compare and analyze the SWMM results in Excel without having to import each file manually.

Tip: There are many ways to summarize the SWMM output data. One example is to create a summary table of peak flows at specific nodes or conduits by using the *VLookup* and *Indirect* functions in Excel. For example, a summary table of *Node Inflows* for each scenario could be developed by including the node names in the first column and the *Scenario IDs* (worksheet names) as column headers in the first row. The *VLookup*

function could then be used to fill out the table. The first argument of the *VLookup* function is the “lookup_value” which would be the first column of the summary table. The second argument of the *VLookup* function is the “table_array” which could be referenced using the *Indirect* function, such as `indirect(B$1&”!B375:I656”)`. In this example, the B\$1 represents the Scenario ID listed in the header row of the table, which is also the name of the corresponding worksheet for that scenario. The part in quotations is the cell range on the imported SWMM report file that includes the *Node Inflows*. When combined with the “&” and the “!”, the two sides make up the cell range reference to a different worksheet with the first column being the node names. The third argument of the *VLookup* function is the “column_index_number”, which is the column in the referenced cell range that includes the maximum total inflow (column 4 in this example). The fourth and last argument would be “FALSE” meaning that only exact node name matches are acceptable.

5 CUHP Output Files

Depending on your settings, CUHP 2005 will generate up to two output files each time it is run: A Microsoft Excel® output workbook (.xlsx) and optionally a CUHP/SWMM Interface file (.txt). Each of these files is covered in detail below.

5.1 The Output Workbook

The purpose of the CUHP 2005 Output Workbook is to display the results from your CUHP analysis in a format that is easy to understand. The output workbook is automatically created and opened each time CUHP is run. The workbook will contain five summary worksheets and an additional worksheet for each subcatchment included in the model. The summary worksheets include *Project Settings*, *Subcatchment Parameters*, *Calculated Parameters*, *Unit Hydrographs*, and *Storm Hydrographs*.

The *Project Settings* worksheet provides summary information about the CUHP run. It includes information pertaining to the CUHP version number, the user's operating system and Excel version that the model was run on, and the time and date of the model run. It also provides the information from the Settings section of the *Intro* worksheet (e.g. project title and comments, time step, filenames and paths, etc.).

The *Subcatchment Parameters* worksheet presents a copy of the values that were provided in the *Subcatchments* worksheet of the input workbook. It also includes the calculated values for Directly Connected Impervious Fraction (DCIF or D), Receiving Pervious Fraction (RPF or R) and the Percent Effective Imperviousness for each subcatchment.

The *Calculated Parameters* worksheet includes fifteen calculated parameters for each subcatchment. Calculated parameters for the Unit Hydrograph include C_T , C_p , W_{50} , K_{50} , W_{75} , and K_{75} which are explained in Section 3.4.2 of this User Manual. Other calculated Unit Hydrograph parameters include the time to peak (minutes), peak flow (cfs), and runoff volume (cubic feet). Calculated parameters for excess precipitation include depth (inches) and volume (cubic feet). Calculated parameters for the storm hydrograph include the time to peak (minutes), peak flow (cfs), total volume (cubic feet), and runoff per unit area (cfs/acre).

The *Unit Hydrographs* worksheet includes the full unit hydrograph time series for each subcatchment.

The *Storm Hydrographs* worksheet includes the full storm hydrograph time series for each subcatchment.

For each subcatchment an additional worksheet is created to provide all of the effective rainfall calculations at each time step. Each worksheet is named after the subcatchment prefixed by "Sub_" (e.g. "Sub_1"). In versions of CUHP prior to version 1.4.0, this information was only provided in an Access Database.

The Output Workbook file can be modified. However, you should remember that the Output Workbook is overwritten every time you run your CUHP input workbook. If you want changes to be preserved, you must either move the Output Workbook to a new location, rename the Output Workbook, or change the *Output Workbook Filename* on the *Intro* worksheet of your CUHP input workbook. If the Output Workbook file is locked or read-only, you will be unable to run the CUHP model until you unlock the workbook or choose another filename for the Output Workbook.

5.2 The CUHP/SWMM Interface File

If you have entered a value for the “SWMM Hydrograph Filename” on the CUHP *Intro* worksheet in your CUHP input workbook, an ASCII format text file is created to interface with EPA SWMM. This file follows the format specified in the RDII / Routing File Format section specified in the EPA SWMM 5 manual. The EPA SWMM 5 manual can be downloaded from <https://www.epa.gov/water-research/storm-water-management-model-swmm>. The *Guides and Tutorials* section of this manual provides instructions for using this file with EPA SWMM 5.

Appendix A – History of the CUHP

HISTORY OF THE CUHP

The following is a brief history of the development of the CUHP.

- Program developed in 1971 by Ben Urbonas and Stewart McGuire, URS/Ken R. White Co. This version of CUHP ran on a mainframe computer.
- Program revised in February 1977 for UDFCD by Gary Walkovitz, URS Company.
- Program revised in December 1977 for UDFCD by Ben Urbonas to permit:
 - Variable use of Horton's Equation to define variable infiltration rates,
 - Modifying infiltration by storm event,
 - Overriding of default unit hydrograph shape,
 - Generation of output to file for HEC flood flow frequency analysis program.
- Program revised in February 1983 for UDFCD by David Lombard to interface with Multi-Plan River Routing Routine of HEC-1
- Program revised in December 1984 for UDFCD by Young S. Yoon and Niem-Sheng Hsu, Boyle Engineering Corporation. This version, which ran on a personal computer, was written to:
 - Write storm hydrograph file for subsequent use with the routing routine portion of UDSWM2-PC (a modified version of the Runoff Block of EPA's SWMM),
 - Modify input to agree with the 1984 USDCM revisions,
 - Permit an estimate of hydrographs for small drainage areas using time of concentration input and comparison of the results with those estimated using the Rational Method.
- Program revised in May 1995 by Curtis Neufeld, UDFCD intern, to:
 - Account for additional losses due to unconnected impervious areas in the catchment.
 - Permit an estimate of the effects on runoff rates due to a specified on-site Water Quality Capture Volume being released over a specified time. Default values provided.
- Program converted in 2000 for UDFCD by David Kurtz, UDFCD intern, to operate under Microsoft™ Windows 95® or later version operating system.

- Program rewritten in C language in 2004 by John-Michael Obrien and James Lester, UDFCD interns and John Obrien, Wright Water Engineers, Inc.
- Excel user interface developed in 2005 by John-Michael Obrien, UDFCD intern and John Obrien, Wright Water Engineers, Inc., to execute the C-language version of the software and to interface with EPA SWMM 5.0 software.
 - Ended support for DCIA level 3.
 - Removed input for t_c . Instead, t_c was calculated from basin parameters when needed. Subsequent versions of CUHP have removed the need for t_c altogether.
 - Included development of a converter to translate legacy files from CUHP 2000 and UDSWMM to appropriate files for CUHP 2005 and EPA SWMM 5.0.
 - Technical guidance and oversight provided by Ben Urbonas and Ken MacKenzie. Assistance and guidance in how to interface the CUHP 2005 output hydrographs with EPA SWMM 5.0 was provided by Lewis Rossman, U.S. EPA.
 - Alpha and beta testing provided by Teresa L. Patterson, Moser & Associates Engineering, Inc. and Ted Johnson, Travis Bogan, Suzanne Pass and John Rehling, CDM. The software authors and the UDFCD are most appreciative of their assistance.
- On 2006-01-31, Corrected misprint in Horton's Equation.
- On 2006-03-20, Removed requirement to use same time increment for hyetograph and unit hydrograph.
- 2007-07-26 (Version 1.1.4): Corrected method for rainfall distribution with area correction to more closely match USDCM Volume 1, Table RA-14. This is accomplished using exponential decay models that closely approximate Table RA-14 for 2, 3 and 6 hour storms.
- 2007-08-13 (Version 1.1.4a): Corrected user defined hyetograph so that [H:MM] is default format. Added comments to warn the user that this format is required. This version also moved code for rainfall distribution with area correction into VBA macros, and modified the algorithm slightly to allow generation of hyetographs for a wider range of input values.
- 2008-02-20 (Version 1.2.1c): Review and revision of the effective runoff calculations to produce correct values. Effective rainfall table for the criteria manual was also revised. Modified the C_p and C_t equations to more closely follow the Rational Method for small areas, and to eliminate the need for Rational Method calculations.

- 2008-08-11 (Version 1.3.1): Major review and revision of the CUHP workbook by Daniel Miller, Ken MacKenzie, Barbara Chongtoua and Dr. James C.Y. Guo. This resulted in:
 - Further revision of the C_p and C_t equations to more closely follow the Rational Method for small areas.
 - Removal of unused fields and program code.
 - Generation of additional program documentation, including a revised User Manual and updated information in *Chapter 3, Section 5 of the USDCM Volume 1*.
 - Refactored code for faster workbook execution, particularly for the workbook generation.
 - Corrected a bug in the output workbook that printed output flows one time step early.
 - Fixed a bug that prevented the CUHP from running when the user entered a relative path instead of an absolute path (i.e. file.mdb vs C:\Projects\file.mdb).
 - Began work to correct the 1-minute vs. 5-minute discretization issue where 5-minute analyses consistently had higher runoff than 1-minute analyses. This is an ongoing issue.

- 2009-03-09 (Version 1.3.2): Revision by Daniel Miller, Ken MacKenzie, Gerald Blackler, and Dr. James C.Y. Guo of the D and R equations used with CUHP for DCIA levels 0, 1 and 2 to reduce the sag produced in basins with low imperviousness. This release also introduced version checking in both the CUHP workbook and the CUHP math engine.

- 2009-11-29 (Version 1.3.3): Revision by Daniel Miller, Ken MacKenzie, Gerald Blackler, and Dr. James C.Y. Guo of the D and R equations, the Effective Imperviousness equations, and the effective precipitation calculations. This version also added additional checks in the model. In this release the CUHP/SWMM Converter was moved to a separate installer along with the new *CUHP Batch Run* and *CUHP Batch Upgrade* tools.

- 2013-06-30 (Version 1.4.0): Major update to CUHP by Derek Rapp, Peak Stormwater Engineering, LLC. Updates include:
 - Math engine rewritten from C to VBA to eliminate the need for a separate math engine (DLL file). The entire CUHP program now runs within Excel eliminating the need for matching versions of the workbook with the math engine DLL file. This also eliminates the need to install the CUHP program on your computer; all you need is Excel 2007 or later.

- Simplified the user interface by removing unnecessary worksheets and consolidating user-input cells.
 - Updated the rainfall depth-area reduction factors (DARFs) and effective imperviousness calculations to be consistent with recent USDCM updates.
 - Added a tool to allow the user to change input units from “miles and square miles” to “feet and square feet” or “feet and acres”.
 - Added a tool to allow the user to run reasonableness checks on area, length, centroid length and slope parameters.
 - Added a check to compare SWMM target nodes and start times for consistency with the actual SWMM input file.
 - Added the ability to create a single input file and then run several CUHP & SWMM scenarios to generate multiple output files with the click of a button. Summary workbook is also created to summarize the results from the different scenarios. Assistance in the development of the code to run multiple scenarios and to interface with the SWMM executable file was provided by Teresa L. Patterson and David Delagarza with RESPEC Water & Natural Resources. This assistance was very much appreciated.
 - Removed the output database file due to compatibility issues with 64-bit versions of Excel. All output results are now recorded in the output workbook.
- 2013-09-03 (Version 1.4.1): Minor update by Derek Rapp, Peak Stormwater Engineering, LLC. Updates include:
 - This update did not affect any CUHP or SWMM calculation results, only the format of the summary output tables.
 - Fixed “time in minutes” values for Unit and Storm Hydrograph summary tables in output workbook. Version 1.4.0 was reporting 1-minute increments (column A) even when the data in all other columns was based on 5-minute time steps.
 - Fixed truncation error in storm hydrograph summary tables of output workbook. Summary tables were mistakenly dropping the flow values for the first three time steps and the flow from the fourth time step was showing up in the first time step row.
- 2013-10-16 (Version 1.4.2): Minor update by Derek Rapp, Peak Stormwater Engineering, LLC. Updates include:
 - This update did not affect any CUHP or SWMM calculation results, it only added additional features and modified the format of summary output tables.
 - Removed external links to other workbooks that were used for testing purposes in the previous release.
 - Changed the default order of the raingage types in the pull down list on the Raingages worksheet so that the user-defined hyetograph was last instead of first.

- Added tables of UDFCD recommended values for Depression Storage and Horton's Infiltration Parameters to the Subcatchments worksheet in columns AG:AN. Also provided a shortcut button above the input cells in columns I:L.
 - Eliminated potential error that could occur if a user tried to run the CUHP program while the output workbook was still open from a previous run.
 - Added cell border formatting to the last three rows of the storm hydrograph worksheet of the output workbook. Also widened column B on the Project Settings worksheet of the output workbook.
 - Eliminated potential error that could occur if a user tried to create a list of raingages on the Multiple Runs worksheet when no raingages had been created.
 - Modified the code for the Multiple Run Summary output workbook to make sure all of the rows from the Multiple Runs input worksheet were copied over to the summary output worksheet.
 - Added "Wait" function to the "Run Multiple SWMM Scenarios" code so that larger SWMM files can run to completion before the report file is copied to the Multiple SWMM Run Summary workbook. The user has the ability to override the default wait time of 5 seconds to account for different SWMM file sizes and computer processing speeds.
 - Added a new feature on the Multiple Runs worksheet to allow SWMM time series inflow table names to be changed from the CUHP interface when running multiple scenarios. This is an optional feature that can be used when the SWMM input file contains nodes that use time series inflow hydrographs defined within SWMM instead of CUHP inflow hydrographs. Options are available to change the time series table used based on land use, return period, or both.
- 2014-1-24 (Version 1.4.3): Minor update by Derek Rapp, Peak Stormwater Engineering, LLC. Updates include:
 - Fixed error in upper boundary condition for effective imperviousness calculation. For catchments with 100% imperviousness, code for effective imperviousness was assigning a value of 1 instead of 100.
 - Updated code for importing input values from CUHP version 1.4.2 to make sure time series inputs on Multiple Runs worksheet get copied over.
 - Changed subcatchment slope upper boundary warning level from 0.08 to 0.06 consistent with the UDSCM.
 - Updated code for "Override Files" warning message that is given when the Run Multiple CUHP Scenarios button is clicked. If the user selects "NO", the code now makes sure that the original input values are replaced before exiting the code.

- 2014-9-30 (Version 1.4.4): Minor update by Derek Rapp, Peak Stormwater Engineering, LLC. Updates include:
 - The code for the Multiple Runs tab was updated to allow the user to input the subcatchment imperviousness by referencing another cell instead of having to enter the value directly. This was done by replacing the Copy/Paste code with Copy/PasteSpecial(PasteValues) so that the cell reference doesn't get copied and shifted or create a circular reference.

- 2016-9-09 (Version 2.0.0): Major update by Derek Rapp, Peak Stormwater Engineering, LLC. The update modified the underlying Unit Hydrograph shaping parameters based on a re-calibration study performed by Gerald Blacker (Enginuity Engineering Solutions, LLC) on behalf of UDFCD. Updates include:
 - Elimination of the adjusted C_t parameter. CUHP now just uses the original C_T parameter without any adjustments based on area.
 - Modification of the Peaking Parameter (P) figure and equation coefficients based on the re-calibration study. The peaking parameter equation form did not change, but all of the coefficients did. Also, the Impervious range cutoff point changed from 40% impervious to 25% impervious.
 - Modification of the C_p equation based on the re-calibration study. There are now two equations, one for areas less than or equal to 120 acres (0.1875 square miles) and one for areas greater than 120 acres.
 - A hyperlink was added to the rain gage sheets to provide a direct link to the website: NOAA Atlas 14 Point Precipitation Frequency Estimates for Colorado.
 - The Import Old CUHP workbooks function was updated to accommodate imports of v2.0 workbooks.

Appendix B - Technical Details of CUHP 2005

TECHNICAL DETAILS OF CUHP 2005

Revised: September 9, 2016

Introduction

For watersheds that are larger than 90 acres, the UDFCD recommends that the design storm runoff be analyzed by deriving synthetic unit hydrographs. Sherman originally developed the unit hydrograph principle in 1932. In 1938, Snyder developed the synthetic unit hydrograph, which is used for analysis when there are no rainfall-runoff data for the catchment under study, as is often the case in the Denver region. The Colorado Urban Hydrograph Procedure (CUHP) is an evolution of the Snyder unit hydrograph and is so named because the coefficients and the form of the equations are based upon data collected in the Denver region of Colorado and on studies conducted or financed by UDFCD. The U.S. Geological Survey (USGS) collected the data for use in the development of the 1982 version of CUHP between the years of 1969 and 1981 under a cooperative agreement with UDFCD. Data from 30 sites, representing a full range of land uses in the Denver Metro Area, was used to develop empirical relationships between the input hydrograph and observed output flow. Further details on this study can be found in Appendix C. In 2016, a re-calibration study was conducted was performed using updated rainfall (GARR, Gage Adjusted Radar Rainfall) and recorded runoff data (USGS and Alert 5 gages) and then testing the results with frequency design storms and statistical gage analysis using existing studies within the UDFCD. This re-calibration study resulted in the release of CUHP v2.0 which includes modifications to the unit hydrograph shaping parameters P, Cp and CT.

Since its conception in 1978, numerous modifications have been made to the CUHP program to adapt to changing computational equipment as well as to refine and expand its capabilities. An extensive overview of these changes is provided in the CUHP User Manual and Appendix A. The CUHP User Manual and the latest version of the CUHP program can be downloaded from the District's website at <http://udfcd.org/software>.

The purpose of this Appendix is to describe the theories and calculations performed by the CUHP. Information on the mechanical details of using the CUHP is provided in the CUHP User Manual.

Method Overview

CUHP uses a concept called effective precipitation that accounts for volume losses combined with a unit hydrograph that accounts for flow routing and catchment size. An overview of this process is provided in Figure B-1.

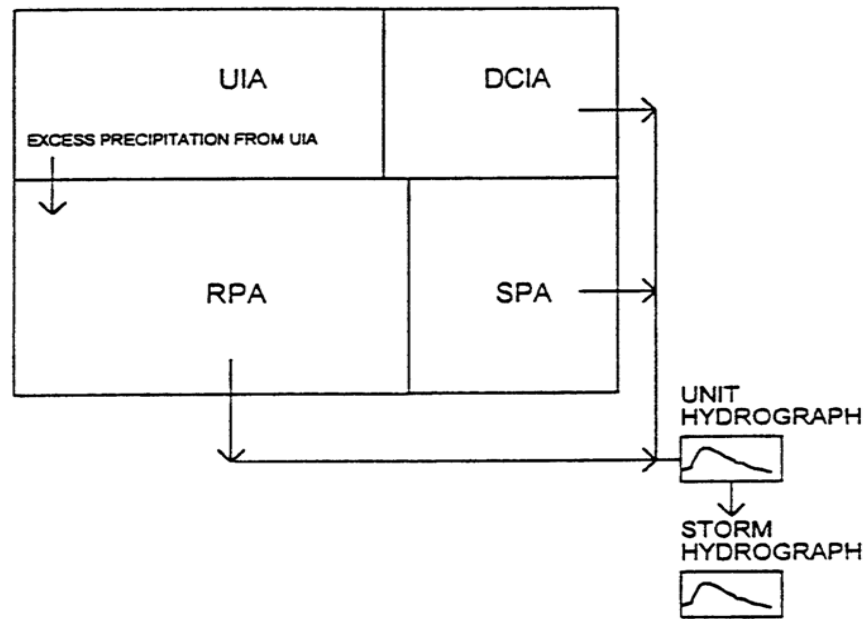


Figure B-1: CUHP Process Overview

To perform calculations, CUHP needs at least one subcatchment and at least one raingage. The subcatchment parameters include size, shape, and storage/infiltration parameters. The raingage provides a storm hyetograph. CUHP's effective precipitation calculations modify the input hyetograph by accounting for a subcatchment's infiltration, depression storage, and the distribution of pervious and impervious areas (i.e. DCIA level); while CUHP's unit hydrograph adjusts runoff based on the shape, slope, and imperviousness of the subcatchment. The results from the effective precipitation and unit hydrograph calculations are combined to produce the final storm hydrograph for a given subcatchment and rainfall hyetograph. Further information on the calculation of effective precipitation and the development of the unit and storm hydrographs is provided below.

Assumptions and Limitations of the CUHP Method

The following assumptions were used in the development of the CUHP method:

1. The intensity of a unit-storm is constant over the duration of the unit storm.
2. Rainfall is uniformly distributed over the subcatchment area.
3. Infiltration can be accurately modeled using Horton's exponential decay.
4. The subcatchment does not receive runoff from other subcatchments and flow that leaves a subcatchment leaves through a single outlet at the design point.
5. The given parameters, particularly imperviousness, are approximately uniform over the subcatchment (uniform land use). Subcatchments with different land-use zones should be broken into multiple smaller subcatchments and routed using EPA SWMM or other suitable flow routing software.

6. The time duration of the unit hydrograph resulting from an effective rainfall of unit duration is constant.
7. The ordinates of the design runoff with a common unit of time are directly proportional to the total amount of direct runoff represented by each sub-hydrograph.
8. The effects of all physical characteristics of a given watershed, including shape, slope, detention, infiltration, drainage pattern, channel storage, etc., are reflected in the shape of the unit hydrograph for that watershed.

Additionally, CUHP is subject to the following limitations:

1. For most urban studies, the unit storm duration, t_u , should be 1 or 5 minutes. However, the unit duration may be increased for larger catchments. It is convenient to have the unit duration incremented in multiples of 5 minutes (i.e., 10 or 15 minutes) with the maximum unit duration recommended at 15 minutes. An acceptable unit storm duration, whenever it is larger than 5 minutes, should not exceed one-third of t_p . As an example, if the catchment has a t_p equal to 35 minutes, then an appropriate unit storm duration would be 5 minutes or 10 minutes (i.e., less than or equal to $1/3 t_p$).
2. The rainfall-runoff data used in the development of CUHP were obtained primarily from small catchments that ranged from 0.15 square miles to 3.08 square miles. Although some extrapolation is justified, unlimited extrapolation of how the catchment responds to rainfall is not justified. It is recommended that the maximum size of a catchment to be analyzed with a single unit hydrograph be limited to 5 square miles (3200 acres). Whenever a larger catchment needs to be studied, it is suggested that it be subdivided into subcatchments of 5 square miles or less and individual subcatchment storm hydrographs be routed downstream using appropriate channel routing procedures such as EPA SWMM. The routed hydrographs then need to be added to develop a single composite storm hydrograph. Because of the way a unit hydrograph responds, it is also suggested that the minimum catchment size be 0.003 square miles (2 acres).
3. CUHP was developed using data from catchments having a range of major drainageway slopes between 0.005 ft/ft and 0.037 ft/ft. Caution must be used when extrapolating beyond this range.
4. The catchment shape can have a profound effect on the final results. When catchment length is much larger than catchment width, CUHP tends to underestimate peak flows. Therefore, it is recommended to subdivide irregularly shaped or very long catchments (i.e. catchment length to width ratio of four or more) into more regularly shaped subcatchments. A single composite storm hydrograph can then be developed using appropriate routing procedures and adding the individual routed hydrographs together.
5. The CUHP was developed using data from the Colorado Front range and is not applicable outside of this region.

Effective Precipitation Calculations

Effective precipitation is that portion of precipitation during a storm event that runs off a subcatchment into a drainageway. This effective precipitation is always less than the input hyetograph, and typically has a different shape because infiltration and depression storage remove more from the leading edge of the storm than from the end of the storm. Starting in 1995, the CUHP model was modified to recognize the effects of directly connected impervious areas on effective precipitation and its response in calculating runoff volumes and peaks. Improvements to the effective precipitation calculations in CUHP have continued over the years based on additional research.

Coefficient Areas

Since different land uses intercept flow in different ways, the total area for each subcatchment must be divided into different types. CUHP allows areas to be divided into the following four separate surface runoff components. This concept is illustrated in Figure B-1.

- *Directly Connected Impervious Area (DCIA)*: The portion of the impervious area that is directly connected to a drainageway (sq.mi.).
- *Unconnected Impervious Area (UIA)*: The portion of the impervious area that must first flow over pervious areas to reach a drainageway (sq.mi.).
- *Receiving Pervious Area (RPA)*: The portion of the pervious area that receives flow from the *UIA* (sq.mi.).
- *Separate Pervious Area (SPA)*: The portion of the pervious area that does not receive flow from the *UIA* (sq.mi.).

For watershed-level assessments and master planning, CUHP provides options for users to model effects of Low Impact Development (LID) or minimizing DCIA (MDCIA) through “D” and “R” curves that are embedded in the model. Since the actual area of each land use type is not considered in the effective precipitation calculations, it is more appropriate to divide the land use types through by the appropriate areas to get a fraction as defined below. The “D” curve relates the ratio of DCIA to total impervious area as shown in Equation B-1. The remaining impervious area is defined as the Unconnected Impervious Fraction (UIF) as shown in Equation B-2. The “R” curve relates the ratio of RPA to total pervious area as shown in Equation B-3. The remaining pervious area is defined as the Separate Pervious Fraction (SPF) as shown in Equation B-4. The equations and figures presented later in this section use the following four variables.

$$D = \frac{DCIA}{I * A} \quad \text{Eqn. B-1}$$

$$UIF = 1 - D \quad \text{Eqn. B-2}$$

$$R = \frac{RPA}{A - (I * A)} \quad \text{Eqn. B-3}$$

$$SPF = 1 - R$$

Eqn. B-4

Where:

D = Fraction of the total impervious area that is directly connected to a drainage path.

UIF = The fraction of the total impervious area that is not directly connected to a drainage path (drains onto the *RPA*).

R = The fraction of the total pervious area that receives runoff from the *UIA*.

SPF = The fraction of the total pervious area that does not receive runoff from the *UIA*.

I = The unadjusted imperviousness of the subcatchment (percent)

A = The area of the subcatchment (sq.mi.)

Since site-level details (i.e., specific percentages of DCIA, UIA, RPA and SPA for a parcel or site-level catchment) are not generally known at the master planning level, UDFCD has developed default values for *D* and *R* in CUHP based on SWMM modeling and analysis of typical developments in the Denver metropolitan area. For any given value of total imperviousness, the CUHP model assigns values of *D* and *R* based on overall imperviousness and typical development patterns for two levels of LID or MDCIA implementation.

1. **Level 1:** The primary intent is to direct runoff from impervious surfaces to flow over grass-covered areas and/or permeable pavement, and to provide sufficient travel time to facilitate the removal of suspended solids before runoff leaves the site, enters a curb and gutter system, or enters another stormwater collection system. Thus, at Level 1, to the extent practical, impervious surfaces are designed to drain over grass buffer strips or other pervious surfaces before reaching a stormwater conveyance system.
2. **Level 2:** As an enhancement to Level 1, Level 2 replaces solid street curb and gutter systems with no curb or slotted curbing, low-velocity grass-lined swales and pervious street shoulders, including pervious rock-lined swales. Conveyance systems and storm sewer inlets will still be needed to collect runoff at downstream intersections and crossings where stormwater flow rates exceed the capacity of the swales. Small culverts will be needed at street crossings and at individual driveways until inlets are provided to convey the flow to the storm sewer. The primary difference between Levels 1 and 2 is that for Level 2, a pervious conveyance system (i.e., swales) is provided rather than storm sewer. Disconnection of roof drains and other lot-level impervious areas is essentially the same for both Levels 1 and 2.

Although CUHP allows the *D* and *R* values to be manually specified as overrides, the default is for CUHP to calculate these parameters based on the LID or MDCIA level using the following equations.

- Level 0 (Standard Practice)

$$D = \begin{cases} 2.0 * I, if 0\% \leq I < 40\% \\ 0.5 * I + 60\%, if 40\% \leq I < 60\% \\ 0.2 * I + 78\%, if 60\% \leq I < 90\% \\ 0.4 * I + 60\%, if 90\% \leq I < 100\% \end{cases} \quad \text{Eqn. B-5}$$

$$R = \begin{cases} 1.0 * I, if 0\% \leq I < 10\% \\ 0.3 * I + 7\%, if 10\% \leq I < 20\% \\ 0.4 * I + 5\%, if 20\% \leq I < 30\% \\ 0.3 * I + 8\%, if 30\% \leq I < 40\% \\ 0.3 * I + 8\%, if 40\% \leq I < 50\% \\ 0.4 * I + 3\%, if 50\% \leq I < 60\% \\ 0.3 * I + 9\%, if 60\% \leq I < 70\% \\ 0.3 * I + 9\%, if 70\% \leq I < 80\% \\ 0.4 * I + 1\%, if 80\% \leq I < 90\% \\ 0.3 * I + 10\%, if 90\% \leq I < 100\% \end{cases}$$

- Level 1

$$D = \begin{cases} 1.1 * I, if 0\% \leq I < 10\% \\ 1.2 * I - 1\%, if 10\% \leq I < 20\% \\ 1.4 * I - 5\%, if 20\% \leq I < 30\% \\ 1.3 * I - 2\%, if 30\% \leq I < 40\% \\ 1.1 * I + 6\%, if 40\% \leq I < 50\% \\ 0.9 * I + 16\%, if 50\% \leq I < 60\% \\ 0.7 * I + 28\%, if 60\% \leq I < 70\% \\ 0.8 * I + 21\%, if 70\% \leq I < 80\% \\ 0.7 * I + 29\%, if 80\% \leq I < 90\% \\ 0.8 * I + 20\%, if 90\% \leq I < 100\% \end{cases} \quad \text{Eqn. B-6}$$

$$R = \begin{cases} 2.0 * I, if 0\% \leq I < 10\% \\ 0.4 * I + 16\%, if 10\% \leq I < 20\% \\ 0.5 * I + 14\%, if 20\% \leq I < 30\% \\ 0.4 * I + 17\%, if 30\% \leq I < 40\% \\ 0.5 * I + 13\%, if 40\% \leq I < 50\% \\ 0.4 * I + 18\%, if 50\% \leq I < 60\% \\ 0.5 * I + 12\%, if 60\% \leq I < 70\% \\ 0.4 * I + 19\%, if 70\% \leq I < 80\% \\ 0.5 * I + 11\%, if 80\% \leq I < 90\% \\ 0.4 * I + 20\%, if 90\% \leq I < 100\% \end{cases}$$

- Level 2

$$D = \begin{cases} 0.5 * I, & \text{if } 0\% \leq I < 60\% \\ 1.0 * I - 30\%, & \text{if } 60\% \leq I < 70\% \\ 2.0 * I - 100\%, & \text{if } 70\% \leq I < 100\% \end{cases} \quad \text{Eqn. B-7}$$

$$R = \begin{cases} 3.0 * I, & \text{if } 0\% \leq I < 10\% \\ 0.6 * I + 24\%, & \text{if } 10\% \leq I < 20\% \\ 0.5 * I + 26\%, & \text{if } 20\% \leq I < 30\% \\ 0.6 * I + 23\%, & \text{if } 30\% \leq I < 40\% \\ 0.5 * I + 27\%, & \text{if } 40\% \leq I < 50\% \\ 0.6 * I + 22\%, & \text{if } 50\% \leq I < 60\% \\ 0.5 * I + 28\%, & \text{if } 60\% \leq I < 70\% \\ 0.6 * I + 21\%, & \text{if } 70\% \leq I < 80\% \\ 0.5 * I + 29\%, & \text{if } 80\% \leq I < 90\% \\ 0.6 * I + 20\%, & \text{if } 90\% \leq I < 100\% \end{cases}$$

If after these calculations D is greater than 100%, D is set to 100%. Similarly, if R is greater than 100%, R is set to 100%. After D and R have been determined, UIF and SPF can be determined using Equations B-2 and B-4. These relationships are presented graphically in Figures B-2 and B-3.

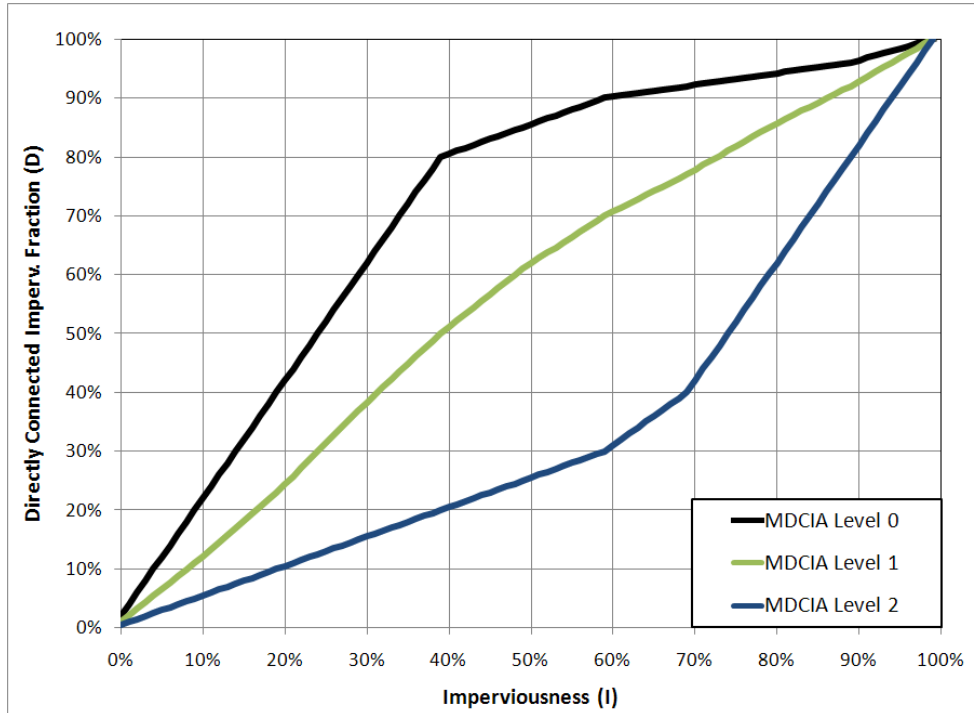


Figure B-2: D from Imperviousness

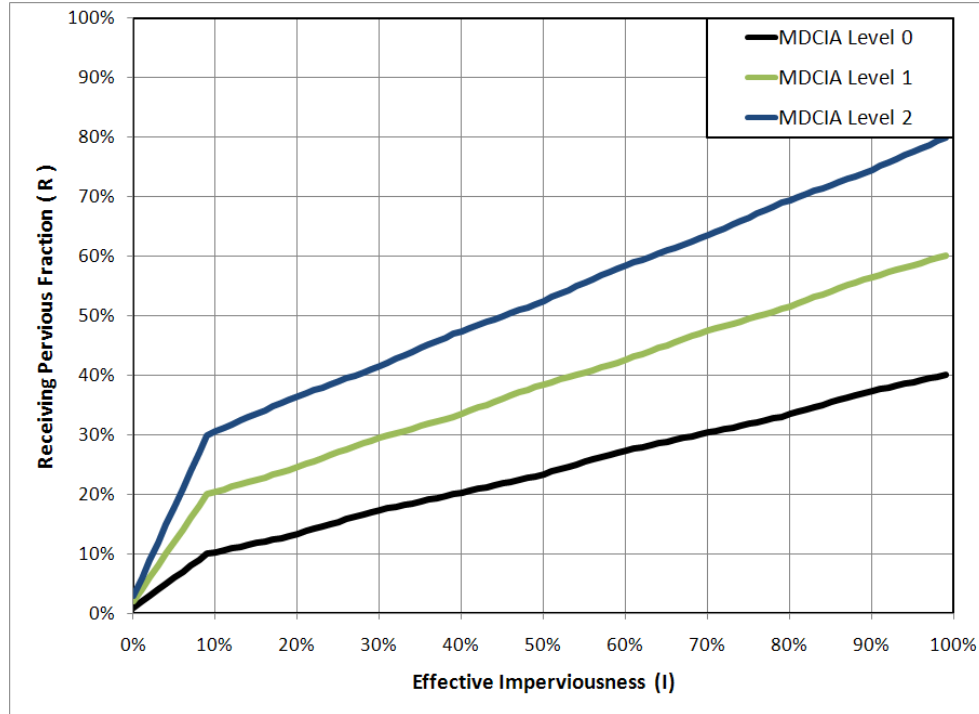


Figure B-3: R from Imperviousness

Losses

The portion of precipitation that does not reach a drainageway can include interception by vegetation, evaporation, infiltration, storage in all surface depressions, and long-term surface retention. CUHP lumps all losses into infiltration, depression losses, and other losses. Each of these is described below. Based on observations, CUHP always takes an additional 5% out of the total impervious area runoff (DCIA + UIA) to account for losses that cannot be attributed to infiltration or depression losses.

Infiltration Losses

The flow of water into the soil surface is called infiltration. For the purpose of infiltration, CUHP divides the total area into two types. Impervious areas (DCIA and UIA) do not experience infiltration, while pervious areas (RPA and SPA) experience infiltration according to Horton's equation (Equation B-8). In Horton's infiltration model, infiltration is high early in the storm and eventually decays to a steady state constant value as the pores in the soil become saturated.

$$f_t = f_o + (f_i - f_o)e^{-at} \quad \text{Eqn. B-8}$$

Where:

f_t = The infiltration rate at time t (in/hr)

f_i = The initial infiltration rate (in/hr)

f_o = The final infiltration rate (in/hr)

e = Natural logarithm base.

α = decay coefficient (1/second)

t = Time from f_i (seconds)

The coefficients and initial and final infiltration values are site specific and depend on the soil and vegetative cover complex. It is possible to develop these values for each site if sufficient rainfall-runoff observations are made. However, such an approach is rarely practical. Soil type is the most important factor in determining the infiltration rate. When the soil has a large percentage of well-graded fines, the infiltration rate is low. In some cases of extremely tight soil there may be, from a practical standpoint, essentially no infiltration. If the soil has several layers or horizons, the least permeable layer near the surface will control the maximum infiltration rate. The soil cover also plays an important role in determining the infiltration rate. Vegetation, lawn grass in particular, tends to increase infiltration by loosening the soil near the surface. Other factors affecting infiltration rates include slope of land, temperature, quality of water, age of lawn and soil compaction. Since 1977, the District has analyzed a considerable amount of rainfall-runoff data. Based on this analysis, the values in Table B-1 are recommended for use within the District with CUHP. The NRCS Hydrologic Soil Groups C and D occur most frequently within the District; however, areas of NRCS Group A and B soils are also common. Consult NRCS soil surveys for appropriate soil classifications. Urbanization can increase or decrease the total amount of infiltration.

Table B-1: Recommended Horton's Equation Parameters

NRCS Hydrologic Soil Group	Infiltration Rate (in/hr)		Decay Coefficient (α)
	Initial (f_i)	Final (f_o)	
A	5.0	1.0	0.0007
B	4.5	0.6	0.0018
C	3.0	0.5	0.0018
D	3.0	0.5	0.0018

Horton's equation gives an infiltration rate. This must be integrated over a length of time to get the total amount of infiltration. CUHP numerically integrates Horton's equation using the trapezoidal rule, as shown in Figure B-4. The amount infiltrated can never be greater than the total amount of rainfall. When the infiltration capacity is greater than the total available rainfall, infiltration should be limited to the total available rainfall and the excess infiltration capacity should be discarded.

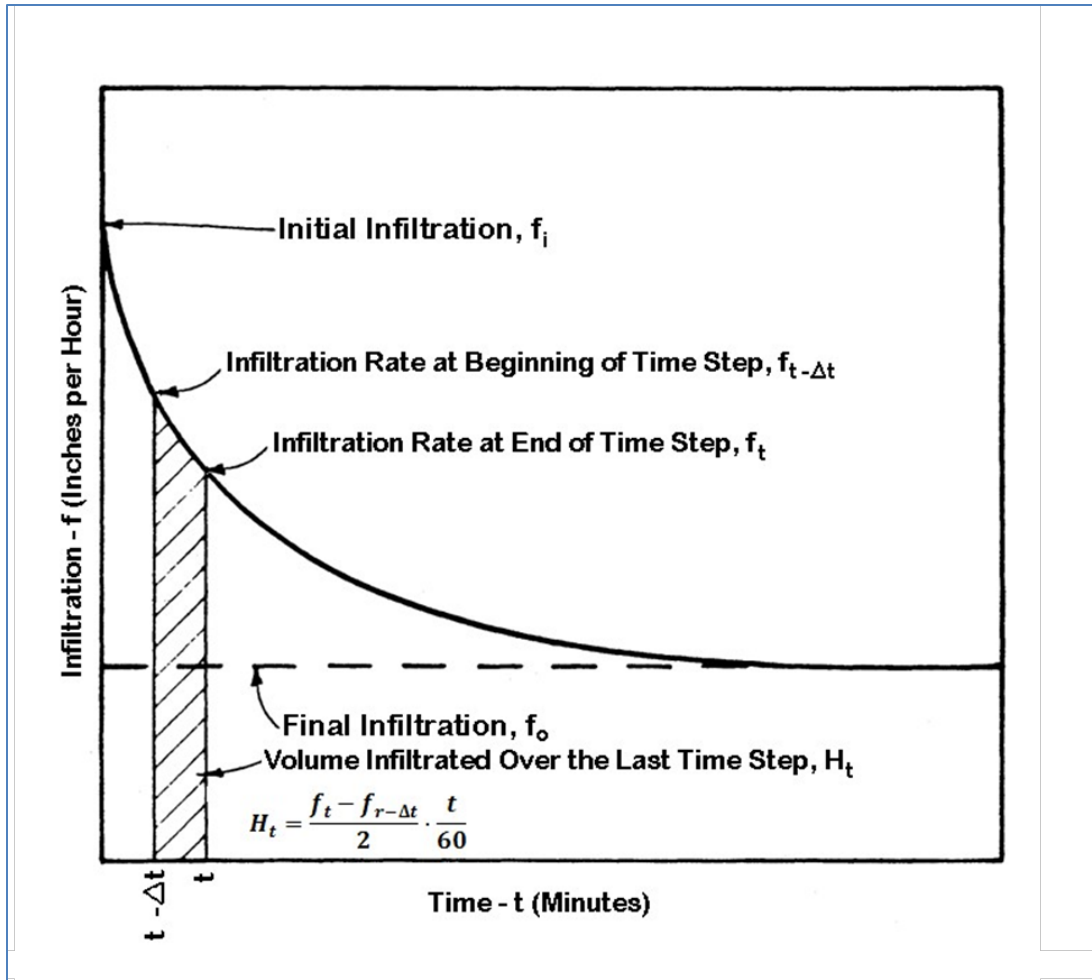


Figure B-4: Numerical Integration of Horton's Equation

Depression Losses

Depression or retention losses primarily refer to rainwater that is collected and held in small depressions and does not become part of the general surface runoff. However, depression losses can also include water intercepted by trees, bushes, other vegetation, and all other surfaces. In any case, most of this water eventually infiltrates or is evaporated. Table B-2 can be used as a guide in estimating the amount of depression losses to be used with CUHP. CUHP allows for different values of depression loss for the pervious and impervious areas.

Table B-2: Typical Depression Losses for Various Land Covers

Land Cover	Typical Range (in)	Recommended Value (in)
Impervious		
Large paved areas	0.05 – 0.15	0.1
Roofs, flat	0.1 – 0.3	0.1
Roofs, sloped	0.05 – 0.1	0.05
Pervious		
Lawn/Grass	0.2 – 0.5	0.35
Wooded Areas & Open Fields	0.2 – 0.6	0.40

Effective Precipitation Algorithm

The algorithm for determining effective precipitation is described below.

1. Determine the effective precipitation for the entire impervious area. This is done by determining the remaining impervious depression storage for the subcatchment, as shown in Equation B-9. The additional amount held in depression storage for the current time step is taken to be either the incremental precipitation for the current time step, or the remaining depression storage, whichever is less. This is mathematically described in Equation B-10. The effective precipitation is then calculated using Equation B-11.

$$D_{max,I,t} = D_{max,I,0} - \sum_{n=1}^{t-1} D_{I,n} \quad \text{Eqn. B-9}$$

$$D_{I,t} = \min \left\{ \begin{matrix} P_t \\ D_{max,I,t} \end{matrix} \right\} \quad \text{Eqn. B-10}$$

$$P_{eff,I,t} = 0.95 \left(\frac{I}{100\%} \right) (P_t - D_{I,t}) \quad \text{Eqn. B-11}$$

Where:

$D_{max,I,t}$ = The remaining capacity of the impervious depression storage for the current time step (in).

$D_{max,I,0}$ = The maximum impervious depression storage, as determined from Table B-2.

$D_{I,t}$ = The amount of water held in impervious depressions for the current time step (in).

P_t = The incremental precipitation of the time step (in).

I = The imperviousness of the subcatchment (percent)

$P_{eff,I,t}$ = The total effective precipitation for the impervious area for the time step (in).

2. Multiply the effective precipitation from Step 1 by the Directly Connected Impervious Fraction (D) obtained from Equation B-1, as shown in Equation B-12. This flow directly contributes to the runoff for the subcatchment. The remaining excess precipitation, calculated in Equation B-13, flows onto the Receiving Pervious Area.

$$P_{eff,DCIA,t} = D * P_{eff,I,t} \quad \text{Eqn. B-12}$$

$$P_{eff,UIA,t} = UIF * P_{eff,I,t} \quad \text{Eqn. B-13}$$

3. Determine the amount of water infiltrated over the time step. This is done by numerically integrating Horton's equation as shown in Figure B-4.
4. Determine the effective precipitation for the Separate Pervious Area. The remaining depression storage and depression storage for the current time step are calculated in the same way as in Step 1. However, the effective precipitation must account for the infiltration losses as shown in Equation B-16. The procedure for calculating effective precipitation for the Separate Pervious Fraction is described mathematically in Equations B-14 through B-16.

$$D_{max,SPA,t} = D_{max,SPA,0} - \sum_{n=1}^{t-1} D_{SPA,n} \quad \text{Eqn. B-14}$$

$$D_{SPA,t} = \min \left\{ \begin{matrix} P_t - H_t \\ D_{max,SPA,t} \end{matrix} \right\} \quad \text{Eqn. B-15}$$

$$P_{eff,SPA,t} = \max \left\{ \begin{matrix} 0 \\ SPF \left(\frac{100\% - I}{100\%} \right) * (P_t - D_{SPA,t} - H_t) \end{matrix} \right\} \quad \text{Eqn. B-16}$$

Where:

$D_{max,SPA,t}$ = The remaining capacity of the impervious depression storage for the current time step (in).

$D_{max,SPA,0}$ = The maximum pervious depression storage, as determined from Table B-2.

$D_{SPA,t}$ = The amount of water held in pervious depressions for the current time step (in).

P_t = The incremental precipitation of the time step (in).

H_t = The amount of water infiltrated over the current time step, from Figure B-4.

I = The unadjusted imperviousness of the subcatchment (percent)

$P_{eff,SPA,t}$ = The total effective precipitation for the impervious area for the time step (in).

5. Determine the effective precipitation for the Receiving Pervious Area. The method for this is similar to the method described for Separate Pervious Area in step 4, except that flow onto the RPA is equal to the incremental precipitation plus the runoff from the Unconnected Impervious Area. The procedure for calculating effective precipitation for

the Receiving Pervious Fraction is described mathematically in Equations B-17 through B-20.

$$P_{RPA} = P_t + \frac{P_{eff,UIA,t}}{(100\%-I)*R} \quad \text{Eqn. B-17}$$

$$D_{max,RPA,t} = D_{max,RPA,0} - \sum_{n=1}^{t-1} D_{RPA,n} \quad \text{Eqn. B-18}$$

$$D_{RPA,t} = \min \left\{ \begin{matrix} P_{RPA} - H_t \\ D_{max,RPA,t} \end{matrix} \right\} \quad \text{Eqn. B-19}$$

$$P_{eff,RPA,t} = \max \left\{ \begin{matrix} R \left(\frac{100\%-I}{100\%} \right) (P_{RPA} - D_{RPA,t} - H_t) \\ 0 \end{matrix} \right\} \quad \text{Eqn. B-20}$$

Where:

$D_{max,RPA,t}$ = The remaining capacity of the impervious depression storage for the current time step (in).

$D_{max,RPA,0}$ = The maximum pervious depression storage, as determined by Table B-2.

$D_{RPA,t}$ = The amount of water held in pervious depressions for the current time step (in).

P_{RPA} = The total incremental precipitation of the time step including the runoff depth from the UIA (in).

H_t = The amount of water infiltrated over the current time step, from Figure B-4.

I = The unadjusted imperviousness of the subcatchment (percent)

$P_{eff,RPA,t}$ = The total effective precipitation for the impervious area for the time step (in).

6. The effective precipitation for the subcatchment is the sum of the individual contributions from each area. Notice that the Unconnected Impervious Area does not directly contribute to the effective precipitation; all of its flow is routed through the Receiving Pervious Area where it is subject to infiltration and additional depression losses. The effective precipitation will always be less than the total rainfall.

$$P_{eff,t} = P_{eff,DCIA,t} + P_{eff,SPA,t} + P_{eff,RPA,t} \quad \text{Eqn. B-21}$$

Table B-3 shows an example layout for effective precipitation calculations, and sample results. While a one-minute time step is preferred, the calculations in Table B-3 have been performed with a five-minute time step for simplicity.

Table B-3: Example Effective Precipitation Calculations

One Hour Precipitation		2.58	Inches	Total Eff. Precip	2.132															
Return Period		100	years																	
NRCS Hydrologic Soil Ty		C or D																		
Final Infiltration Rate		0.5	in/hr																	
Initial Infiltration Rate		3.0	in/hr																	
Decay Coefficient		0.00180	1/sec																	
Impervious Fraction- IA		50.0%																		
Impervious Area Depression Loss		0.10	Inches																	
Directly Connected % of Total Impervious Area		50.0%																		
Unconnected % of Total Impervious Area (%)		50.0%																		
Pervious Fraction- PA		50.0%																		
Pervious Area Depression Loss		0.35	Inches																	
Receiving Pervious % of Total Pervious Area		50.0%																		
Separate Pervious % of Total Previous Area		50.0%																		
Impervious Area								Pervious Area												
								Horton's Infiltration		SPA- Separate Pervious Area				RPA- Receiving Pervious Area						
Time (minutes) (1)	Incremental Precipitation (2)	Depression Storage (3)	Five Percent Loss (4)	Effective Precipitation on (5)	Percent Effective Precipitation (6)	% DCI Effective Precipitation (7)	% UIA Effective Precipitation (8)	Value at Midpoint (9)	Incremental Infiltration Actual Depth (10)	SPA Infiltration (11)	Depression Storage (12)	Effective Precipitation (13)	% Effective Precipitation (14)	Adjusted UIA Precipitation (15)	Combined Precipitation Depth (16)	RPA Infiltration (17)	Depression Storage (18)	Effective Precipitation (19)	% Effective Precipitation (20)	Total Effective Precipitation (21)
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.026	0.026	0.000	0.000	0.000	0.000	0.000	1.957	0.207	0.026	0.000	0.000	0.000	0.000	0.026	0.026	0.000	0.000	0.000	0.000
10	0.077	0.074	0.000	0.003	0.002	0.001	0.001	1.349	0.138	0.077	0.000	0.000	0.000	0.003	0.080	0.080	0.000	0.000	0.000	0.001
15	0.119	0.000	0.006	0.113	0.056	0.028	0.028	0.995	0.098	0.098	0.021	0.000	0.000	0.113	0.231	0.098	0.134	0.000	0.000	0.028
20	0.206	0.000	0.010	0.196	0.098	0.049	0.049	0.788	0.074	0.074	0.132	0.000	0.000	0.196	0.402	0.074	0.216	0.112	0.028	0.077
25	0.361	0.000	0.018	0.343	0.172	0.086	0.086	0.668	0.061	0.061	0.197	0.104	0.026	0.343	0.704	0.061	0.000	0.644	0.161	0.273
30	0.645	0.000	0.032	0.613	0.306	0.153	0.153	0.598	0.053	0.053	0.000	0.592	0.148	0.613	1.258	0.053	0.000	1.205	0.301	0.603
35	0.361	0.000	0.018	0.343	0.172	0.086	0.086	0.557	0.048	0.048	0.000	0.313	0.078	0.343	0.704	0.048	0.000	0.656	0.164	0.328
40	0.206	0.000	0.010	0.196	0.098	0.049	0.049	0.533	0.045	0.045	0.000	0.161	0.040	0.196	0.402	0.045	0.000	0.357	0.089	0.179
45	0.160	0.000	0.008	0.152	0.076	0.038	0.038	0.519	0.044	0.044	0.000	0.116	0.029	0.152	0.312	0.044	0.000	0.268	0.067	0.134
50	0.129	0.000	0.006	0.123	0.061	0.031	0.031	0.511	0.043	0.043	0.000	0.086	0.022	0.123	0.252	0.043	0.000	0.209	0.052	0.104
55	0.103	0.000	0.005	0.098	0.049	0.025	0.025	0.507	0.042	0.042	0.000	0.061	0.015	0.098	0.201	0.042	0.000	0.159	0.040	0.079
60	0.103	0.000	0.005	0.098	0.049	0.025	0.025	0.504	0.042	0.042	0.000	0.061	0.015	0.098	0.201	0.042	0.000	0.159	0.040	0.080
65	0.103	0.000	0.005	0.098	0.049	0.025	0.025	0.502	0.042	0.042	0.000	0.061	0.015	0.098	0.201	0.042	0.000	0.159	0.040	0.080
70	0.052	0.000	0.003	0.049	0.025	0.012	0.012	0.501	0.042	0.042	0.000	0.010	0.002	0.049	0.101	0.042	0.000	0.059	0.015	0.029
75	0.052	0.000	0.003	0.049	0.025	0.012	0.012	0.501	0.042	0.042	0.000	0.010	0.002	0.049	0.101	0.042	0.000	0.059	0.015	0.029
80	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
85	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
90	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
95	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
100	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
105	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
110	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
115	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
120	0.031	0.000	0.002	0.029	0.015	0.007	0.007	0.500	0.042	0.031	0.000	0.000	0.000	0.029	0.060	0.042	0.000	0.019	0.005	0.012
Totals:	2.982	0.100	0.144	2.738	1.369	0.685	0.685	NA	1.395	1.058	0.350	1.575	0.394	2.738	5.721	1.157	0.350	4.214	1.053	2.132

Unit Hydrograph Generation

The unit hydrograph is defined as the hydrograph of one inch of direct runoff from the tributary area resulting from a unit storm. It is intended to consider subcatchment conditions (e.g. area, shape, and slope) independently from the actual rainfall on the subcatchment. The unit hydrograph method was originally developed by Sherman in 1932, and was further refined by Snyder in 1938 to apply in regions where no rainfall-runoff data is available. The unit hydrograph used by CUHP is an implementation of the Snyder unit hydrograph.

The shape of the unit hydrograph can be described by six parameters, the time to peak (T_p), the peak flow (Q_p), the width of the unit hydrograph at 50% and 75% of the peak flow (W_{50} and W_{75} , respectively), and the width of the unit hydrograph before the peak (K_{50} and K_{75} , respectively). These parameters are illustrated in Figure B-5.

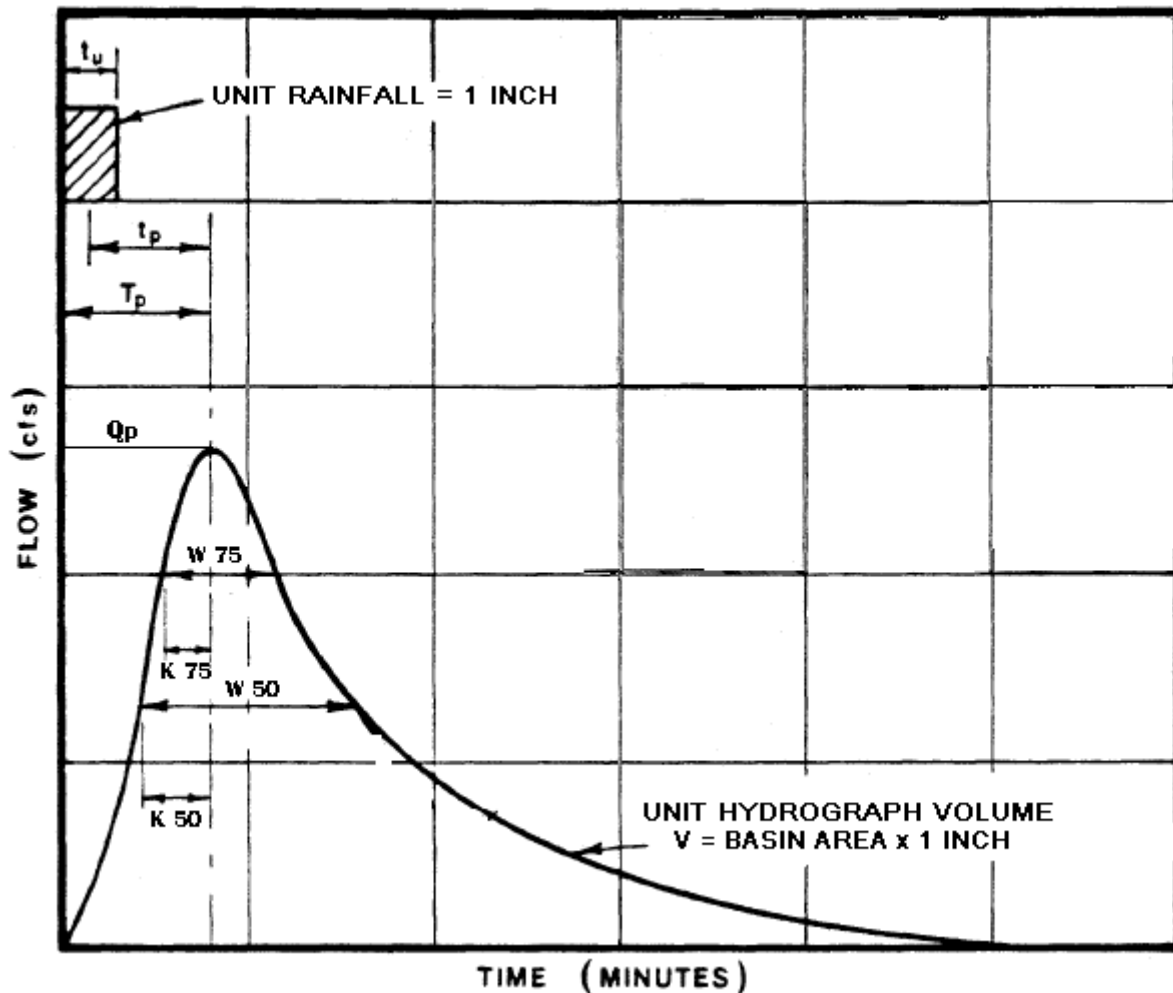


Figure B-5: Unit Hydrograph Parameters

Where:

T_p = The time from the start of the unit rainfall to the peak of the unit hydrograph (min).

t_u = The duration of the unit rainfall. In CUHP this is equal to the time step (min).

t_p = Time between the midpoint of the unit rainfall and the peak of the unit hydrograph (min).

Q_p = The peak flow of the unit hydrograph (cfs).

W_{50} = The width of the unit hydrograph at 50% of the peak flow (min).

W_{75} = The width of the unit hydrograph at 75% of the peak flow (min).

K_{50} = The fraction of the unit hydrograph before the peak at 50% of the peak flow.

K_{75} = The fraction of the unit hydrograph after the peak at 75% of the peak flow.

Effective Imperviousness

CUHP uses the volume-weighted imperviousness (I_v) in the unit hydrograph calculations. This value is used to adjust the shape of the unit hydrograph based on the DCIA, UIA, and RPA areas. The effective imperviousness value is calculated using Equations B-21 through B-27 and Figure B-6 as shown below:

$$UIA = (1 - D) * (A * I) \quad \text{Eqn. B-21}$$

$$RPA = R * ((1 - I) * A) \quad \text{Eqn. B-22}$$

$$I_a = \frac{UIA}{UIA + RPA} \quad \text{Eqn. B-23}$$

$$i = \frac{1.157 * P_1}{2} \quad \text{Eqn. B-24}$$

$$f_{avg} = f_o + \left(\frac{f_i - f_o}{7200 * \alpha} \right) * (1 - e^{-7200\alpha}) \quad \text{Eqn. B-25}$$

$$K = K_{slope} * I_a + K_{intercept} \quad \text{Eqn. B-26}$$

If $0 < I_a \leq 0.2$ Then (See Figure B-6 below)

$$K_{slope} = \left(-0.1895 * \left(\frac{f}{i} \right)^3 + 0.536 * \left(\frac{f}{i} \right)^2 - 1.6925 * \left(\frac{f}{i} \right) + 4.9141 \right)$$

$$K_{intercept} = 0$$

If $0.2 < I_a \leq 0.8$ Then (See Figure B-6 below)

$$K_{slope} = \left(0.0554 * \left(\frac{f}{i} \right)^3 - 0.1028 * \left(\frac{f}{i} \right)^2 + 0.2302 * \left(\frac{f}{i} \right) + 0.0776 \right)$$

$$K_{intercept} = \left(-0.0512 * \left(\frac{f}{i} \right)^3 + 0.143 * \left(\frac{f}{i} \right)^2 - 0.4085 * \left(\frac{f}{i} \right) + 0.9755 \right)$$

If $0.8 < I_a < 1.0$ Then

(See Figure B-6 below)

$$K_{slope} = \left(0.232 * \left(\frac{f}{i} \right)^3 - 0.2275 * \left(\frac{f}{i} \right)^2 + 1.0019 * \left(\frac{f}{i} \right) - 0.147 \right)$$

$$K_{intercept} = \left(-0.0235 * \left(\frac{f}{i} \right)^3 + 0.2286 * \left(\frac{f}{i} \right)^2 - 1.0032 * \left(\frac{f}{i} \right) + 1.1474 \right)$$

$$I_v = \frac{DCIA + (K * UIA)}{A}$$

Eqn. B-27

Where:

DCIA = Directly Connected Impervious Area (sq.mi.).

UIA = Unconnected Impervious Area (sq.mi.).

RPA = Receiving Pervious Area (sq.mi.).

D = Directly Connected Impervious Fraction from Eqn. B-1.

R = Receiving Pervious Fraction from Eqn. B-3.

A = Total subcatchment area (sq.mi.).

I = Unadjusted imperviousness value for subcatchment (%).

I_a = The cascading area-weighted imperviousness fraction.

i = The average rainfall intensity over a two hour duration (in/hr).

P_1 = The one-hour precipitation depth (in).

f_{avg} = Average Horton infiltration rate over a two hour duration (in/hr).

f_i = Initial Horton infiltration rate (in/hr).

f_o = Final Horton infiltration rate (in/hr).

e = Natural logarithm base.

α = Horton decay coefficient (1/sec).

K = Impervious Reduction Factor from Figure B-6 and *Figure 3-9 in Chapter 3 of the USDCM Vol. 3*.

K_{slope} = The slope of a line segment from Figure B-6.

$K_{intercept}$ = The y-axis intercept value of a line segment from Figure B-6.

I_v = The volume-weighted imperviousness

A more detailed discussion of effective imperviousness is provided in *Chapter 3 of the USDCM Volume 3*.

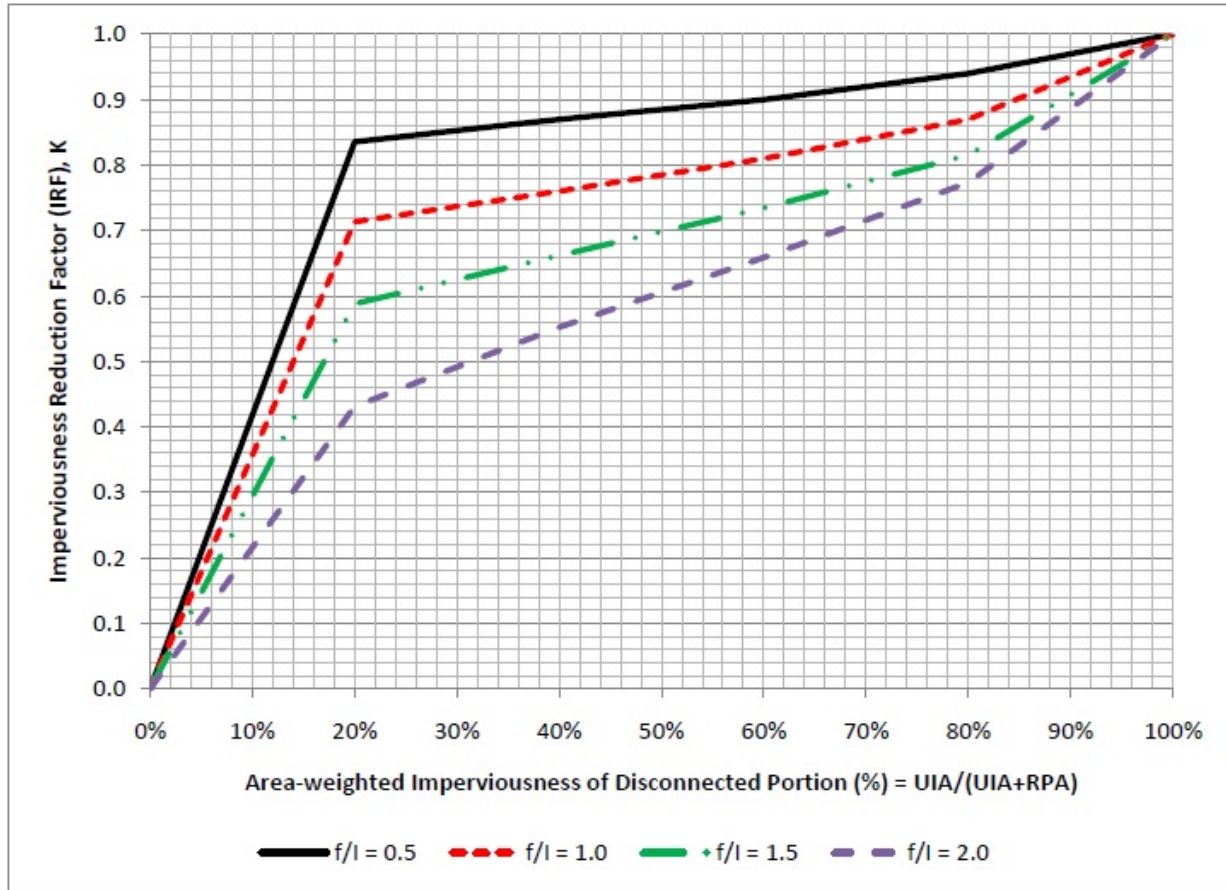


Figure B-6: Coveyance-Based Impervious Reduction Factor

C_T and C_p

To assist in the determination of the time to peak and peak runoff for the unit hydrograph, three quantities are defined: C_T , P and C_p .

C_T is a time to peak coefficient that relates the imperviousness of a subcatchment to the Time to Peak (T_p). C_T is determined using Figure B-7. In versions of CUHP prior to v2.0, a modified time to peak coefficient C_t , was obtained by applying an area correction to C_T . C_t is no longer included in CUHP v2.0.

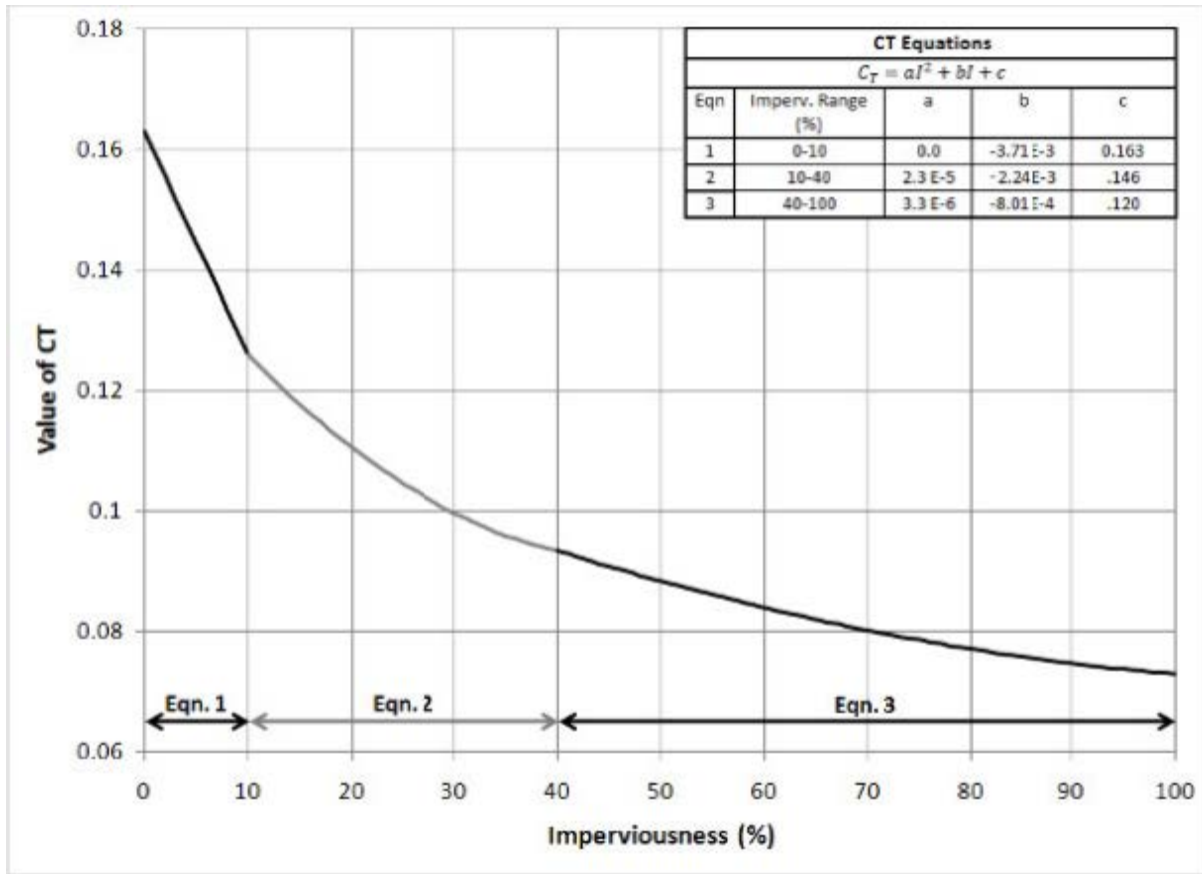


Figure B-7: C_T vs. Imperviousness

C_p relates imperviousness and area to Q_p . Once C_T has been determined, C_p can be determined from Area, C_T and the peaking parameter (P). Figure B-8 shows the relationship between the peaking parameter and the imperviousness of the subcatchment. Equation B-28 indicates the relationship between P , C_T , and C_p .

$$C_p = \begin{cases} 1.3 * P * C_T * A^{0.45}, & \text{if } A \leq 0.1875 \text{ sq.mi. (120 acres)} \\ P * C_T * A^{30}, & \text{if } A > 0.1875 \text{ sq.mi. (120 acres)} \end{cases} \quad \text{Eqn. B-28}$$

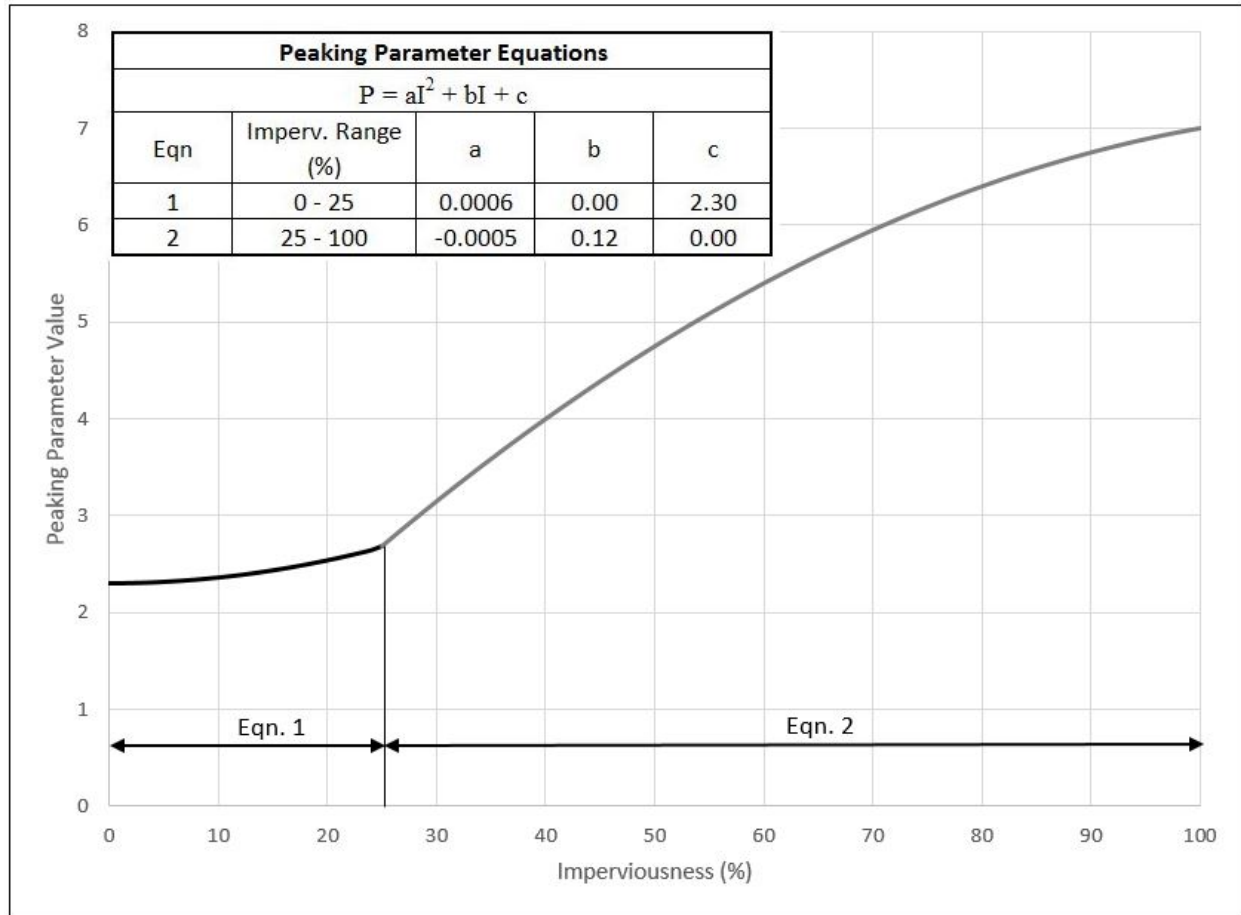


Figure B-8: Peaking Parameter vs. Imperviousness

Time to Peak (T_p)

The time to peak is defined as the time from the start of the unit storm to the peak of the unit hydrograph. This is defined using the relationships found in Equations B-29 and B-30.

$$t_p = C_T \left(\frac{L * L_{ca}}{\sqrt{S}} \right)^{0.48} \quad \text{Eqn. B-29}$$

$$T_p = 60t_p + 0.5t_u \quad \text{Eqn. B-30}$$

Where:

T_p = The time from the start of the unit storm to the peak of the unit hydrograph (minutes).

t_p = The time between the midpoint of the unit storm to the peak of the unity hydrograph (hours).

t_u = The unit storm duration, taken to be equal to the CUHP time step (minutes).

L = The length along the stream from the study point to the upstream limit of the subcatchment (miles).

L_{ca} = The length along the stream from the study point to a point along the stream adjacent to the centroid of the subcatchment (miles).

S = The corrected, length-weighted, average slope of the subcatchment as described in the next section (ft/ft).

C_T = The time to peak coefficient, as determined from Figure B-7.

Slope Weighting and Correction

When the slope varies along the flow-line, a weighted slope must be calculated for use with CUHP. This is done by segmenting the drainageway into reaches with similar longitudinal slopes. The slope correction described in Figure B-9 should be applied to each slope as appropriate, and the corrected, length-weighted slope should be calculated from the corrected longitudinal slopes using Equation B-31.

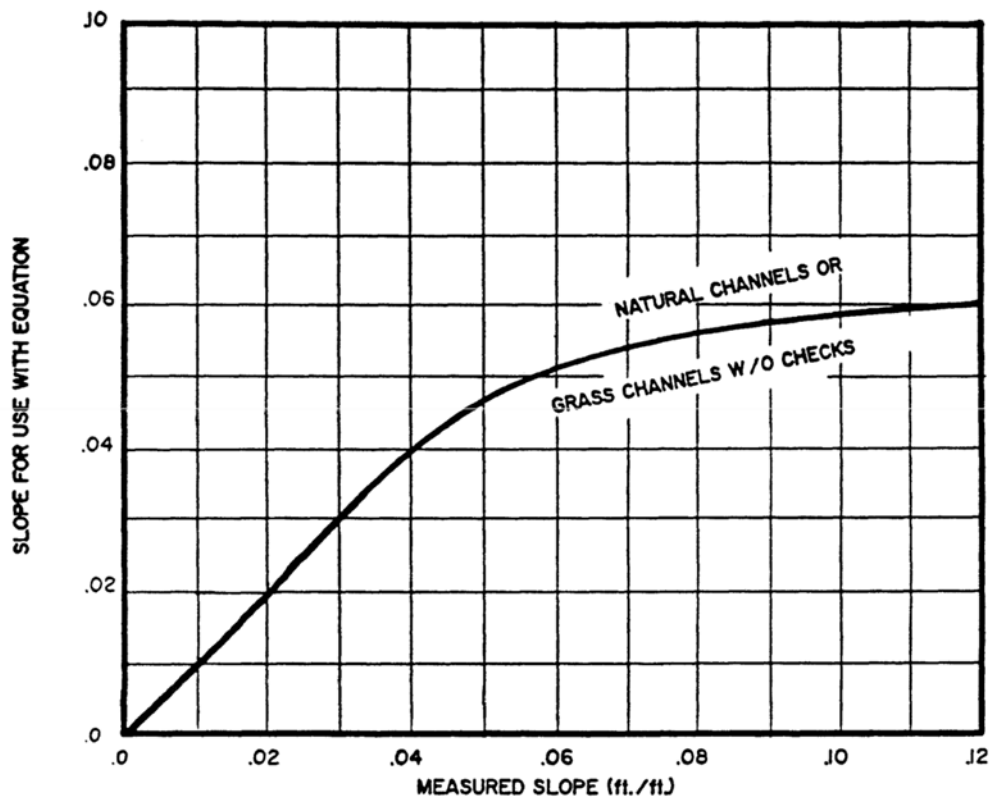


Figure B-9: Slope Correction Factor

$$S = \left(\frac{\sum_{i=1}^n L_i S_i^{0.24}}{\sum_{i=1}^n L_i} \right)^{4.17} = \left[\frac{L_1 S_1^{0.24} + \dots + L_n S_n^{0.24}}{L_1 + \dots + L_n} \right]^{4.17} \quad \text{Eqn. B-31}$$

Additional Slope Considerations

1. In natural and grass-lined drainageways, channels become unstable as the Froude number approaches 1.0. Additionally, there are natural processes at work that limit the time to peak of the unit hydrograph as the drainageway becomes steeper. To account for this phenomenon, it is recommended that the slope used in Equation B-31 for natural drainageways and existing manmade grass-lined channels be adjusted using Figure B-9.
2. Grass-lined channels designed and built using District Criteria have a slope that limits maximum flow velocities. A typical range in longitudinal slopes is between 0.003 and 0.006 ft/ft. It is recommended that for preliminary estimating purposes a longitudinal slope of 0.005 ft/ft should be used for grass-lined channels that are to be designed using UDFCD criteria.
3. The District's criteria limit the Froude Number to 0.8 or less for riprap-lined channels. For this reason it is suggested that, for preliminary estimating purposes where riprap channels are contemplated, a longitudinal slope of 0.01 ft/ft should be used. For existing riprap-lined channels, the average channel profile slope should be used.
4. For concrete-lined channels and buried conduits, the flow velocities can be very high. Therefore, it is recommended that the average ground slope (i.e., not flow-line slope) be used where concrete-lined channels and/or storm sewers dominate the catchment drainageways. There is no upper limit recommended to the slope for such catchments.

Unit Hydrograph Runoff (Q_p)

Once the time to peak has been determined, the peak runoff can be determined for the unit hydrograph. This depends on the peak rate of runoff, as calculated using Equation B-32.

$$q_p = \frac{640C_p}{t_p} \quad \text{Eqn. B-32}$$

The total runoff can then be determined by multiplying the runoff rate by the area of the subcatchment, as shown in Equation B-33.

$$Q_p = q_p * A \quad \text{Eqn. B-33}$$

Width of the Unit Hydrograph (W_{50} and W_{75})

In order to draw the unit hydrograph, the width of the hydrograph must be determined at two points: 50% of the peak flow and 75% of the peak flow. CUHP uses Equations B-34 and B-35 to determine these widths.

$$W_{50} = 60 * \left(\frac{500}{q_p} \right) \quad \text{Eqn. B-34}$$

$$W_{75} = 60 * \left(\frac{260}{q_p} \right) \quad \text{Eqn. B-35}$$

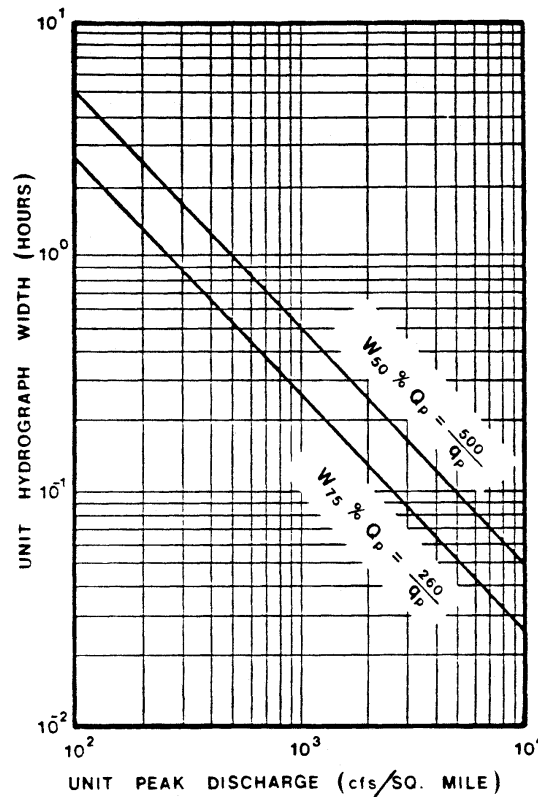


Figure B-10: Unit Hydrograph Widths

Peak Offset of the Unit Hydrograph (K_{50} and K_{75})

Since the unit hydrograph is typically not symmetrical, the width of the unit hydrograph must be distributed around the peak. A study of many unit hydrographs generated using recorded rainfall and runoff events indicates that, as a general rule, 0.35 of the width at 50% of peak is to the left of the peak and 0.65 of the width is to the right of the peak. At 75% of the peak, 0.45 of the width is left of the peak and 0.55 of the width is to the right of the peak. However, on some hydrographs this rule needs to be modified. Whenever the above rule results in the hydrograph at 50% of peak being left of the peak by more than $0.6T_p$ (T_p = the distance from zero to the peak

of the unit hydrograph); the x coordinate at 50% of peak should be placed at $0.6T_p$, and at 75% of the peak it should be placed at $0.424T_p$. The portion of the width before the peak at 50% and 75% of the peak flow (K_{50} and K_{75} , respectively) can be determined using Equations B-36 and B-37. Note that K_{50} and K_{75} are capped based on the value of T_p .

$$K_{50} = \min \left\{ \begin{array}{l} 0.35 \\ 0.6 \frac{T_p}{W_{50}} \end{array} \right\} \quad \text{Eqn. B-36}$$

$$K_{75} = \min \left\{ \begin{array}{l} 0.45, \text{ if } K_{50} = 0.35 \\ 0.424 \frac{T_p}{W_{75}}, \text{ if } K_{50} = 0.6 \frac{T_p}{W_{50}} \end{array} \right\} \quad \text{Eqn. B-37}$$

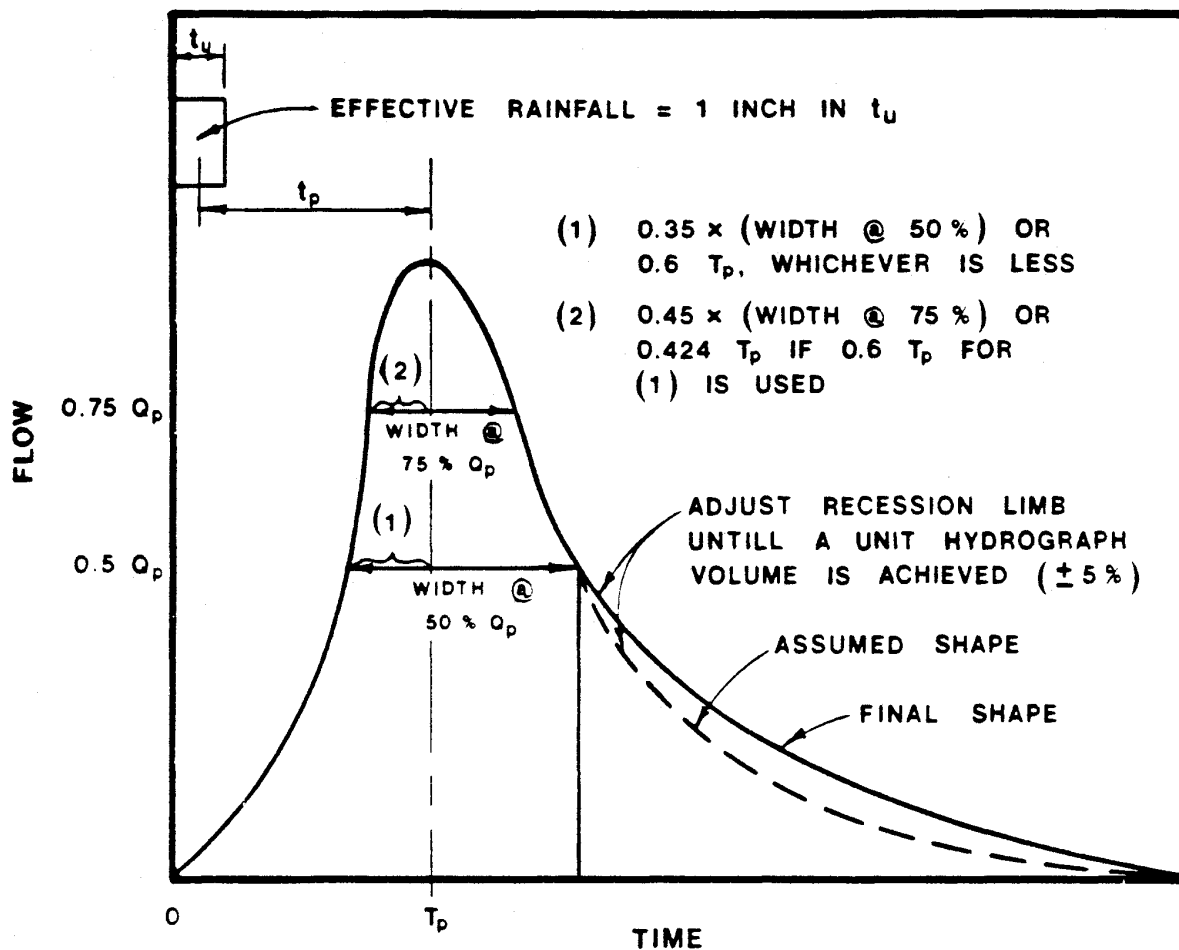


Figure B-11: Unit Hydrograph Shaping

Table B-4 shows the results of example calculations for Q_p , W_{50} , W_{75} , K_{50} and K_{75} using the equations provided above. While a one-minute time step is preferred, the calculations in Table B-4 have been performed with a five-minute time step for simplicity.

Table B-4: Example Unit Hydrograph Parameter Calculations

Input Parameters		
Area	0.23	sq.mi.
Imperviousness	50.00	%
CUHP Time Step (t_u)	5.00	min
Length (L)	0.48	mi
Centroid Length (L_{ca})	0.24	mi
Slope (S)	0.03	ft/ft
Calculation Results		
C_T (Figure B-7)	0.0882	--
Peaking Parameter, P (Figure B-8)	4.7500	--
Peaking Coefficient, C_p (Eqn. B-28)	0.2696	--
Time from Center of Unit Storm, t_p	0.0725	hrs
Time to Peak, T_p (Eqn. B-30)	6.85	min
Rate of Runoff, q_p (Eqn. B-32)	2,379	cfs/sq.mi.
Unit Peak Runoff, Q_p (Eqn. B-33)	547	cfs
Width at 50%, W_{50} (Eqn. B-34)	12.61	min
Width at 75%, W_{75} (Eqn. B-35)	6.56	min
K_{50} (Eqn. B-36)	0.33	--
K_{75} (Eqn. B-37)	0.44	--

CUHP Curve Fitting Algorithm

Since the Unit Hydrograph is not easily described by one equation, the CUHP uses a combination of first, second and third order polynomials to determine the shape of the hydrograph. The following discussion uses the notation defined in Figure B-10. For this section, the figures and calculations correspond to the numbers calculated in Table B-5. While a one-minute time step is preferred, the calculations in this section have been performed with a five-minute time step for simplicity. Table B-5 indicates results of calculations for t_0 through t_5 and V_{uh} using the equations from Figure B-10.

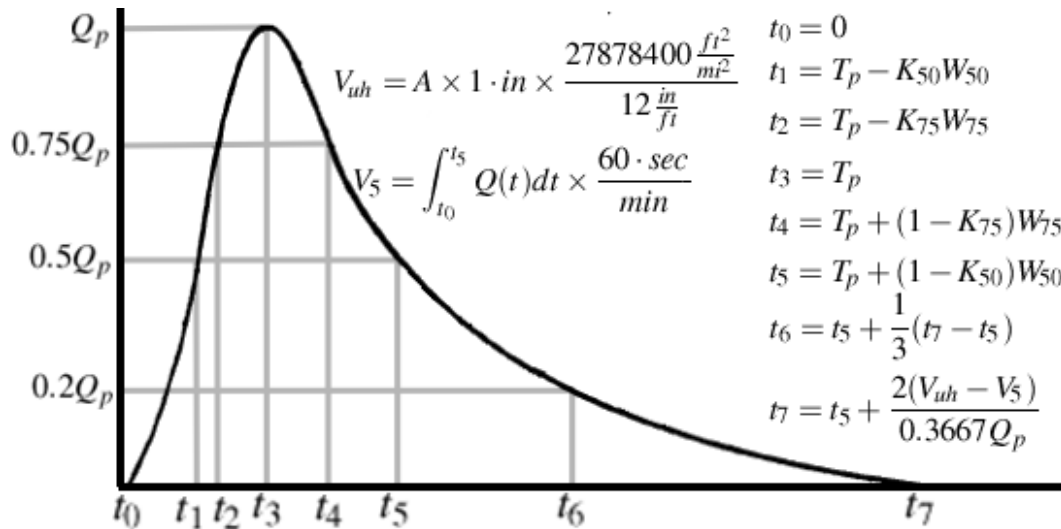


Figure B-12: Unit Hydrograph Times and Equations

Table B-5: Unit Hydrograph Times, Flows, and Volume

Parameter	Value	Parameter	Value
t_0	0.00	Q_0	0.00
t_1	4.53	Q_1	504.50
t_2	5.34	Q_2	756.76
t_3	6.97	Q_3	1009.01
t_4	8.96	Q_4	756.76
t_5	11.50	Q_5	504.50
		V_{uh}	544,500

Initially, the CUHP solves for a third order polynomial connecting t_0 and t_2 as shown in Figure B-11. If the polynomial is less than zero for any point between t_0 and t_2 , the method switches to a second order polynomial between t_0 and t_1 and a linear equation between t_1 and t_2 . The CUHP then attempts to fit a third order polynomial between t_2 and t_4 . If no suitable third order polynomial can be found between t_2 and t_4 , the CUHP attempts to fit two second order polynomials; one between t_2 and t_3 , and one between t_3 and t_4 as shown in Figure B-12. The CUHP always selects a linear equation between points t_4 and t_5 as shown in Figure B-13.

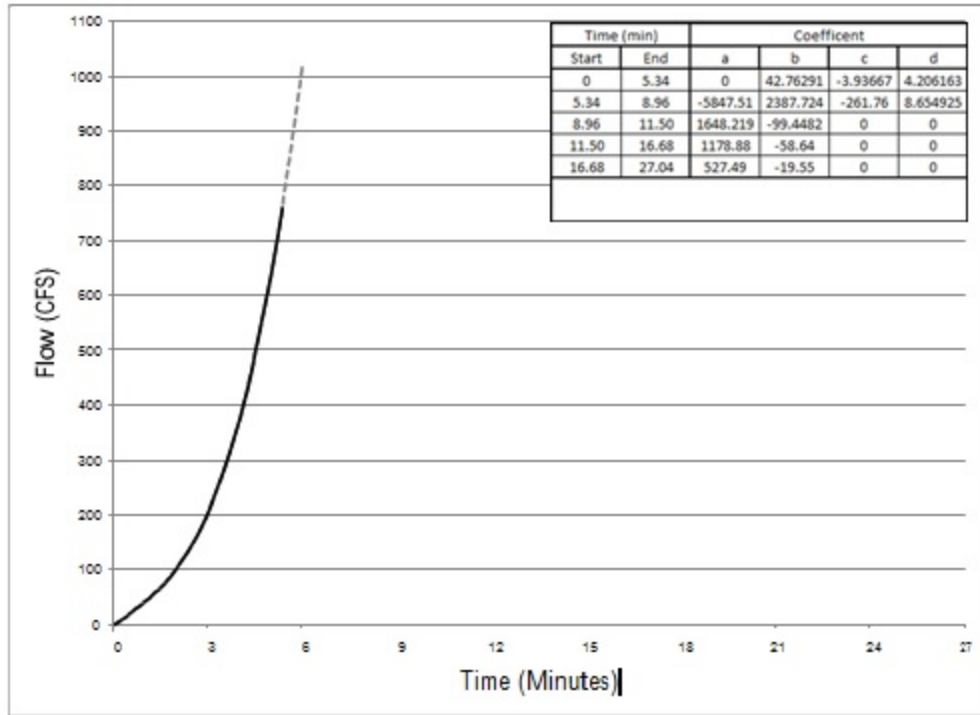


Figure B-13: Unit Hydrograph, Segment 1

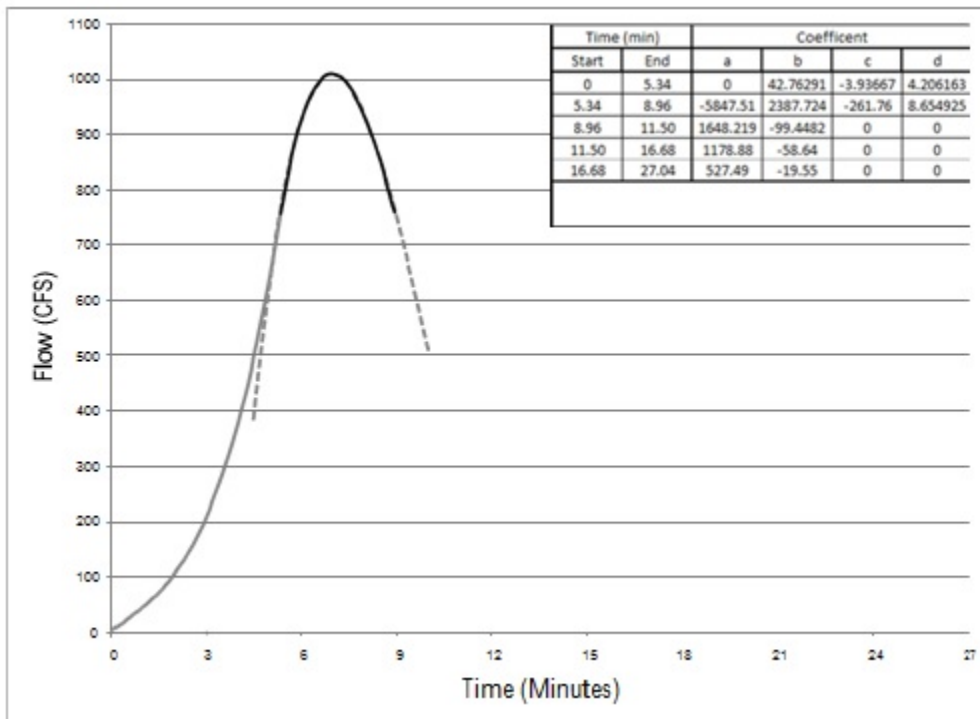


Figure B-14: Unit Hydrograph, Segment 2

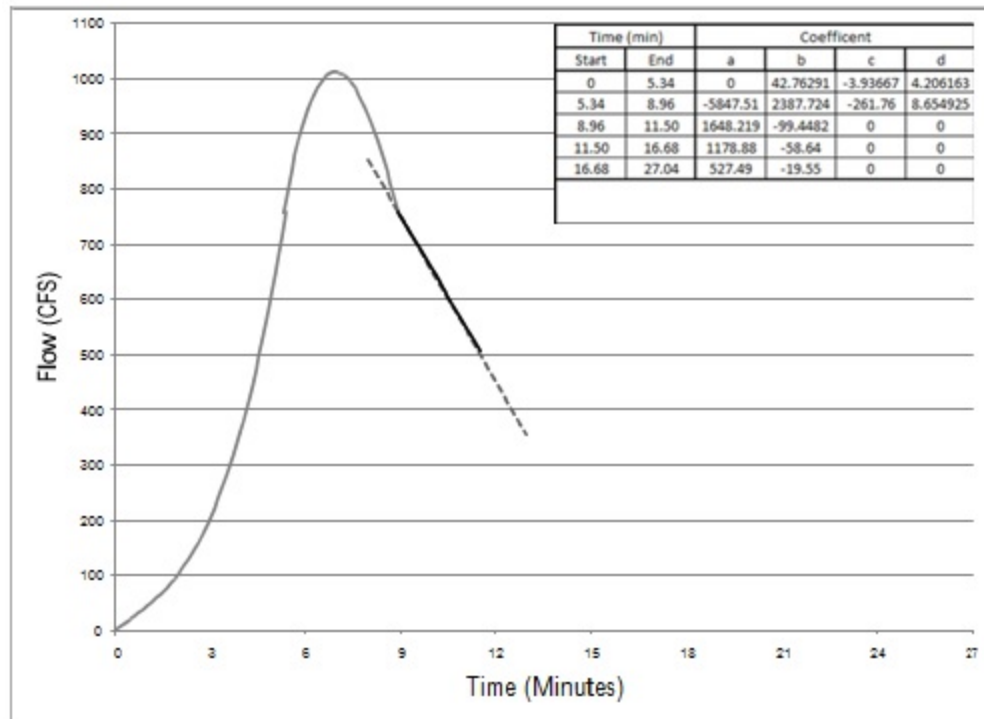


Figure B-15: Unit Hydrograph, Segment 3

To ensure that the Unit Hydrograph has the appropriate volume, CUHP integrates the existing unit hydrograph (from t_0 to t_5). This value is then used to determine t_6 and t_7 according to the equations given in Figure B-10. Example calculations are provided below in Figures B-14 and B-15.

$$\begin{aligned}
 V_{t_0-t_2} &= \int_{t_0}^{t_2} Q_{t_1-t_2} dt \\
 &= \int_0^{5.34 \text{ min}} (4.21t^3 - 3.94t^2 + 42.76t) dt \\
 &= \left. \frac{4.21}{4}t^4 - \frac{3.94}{3}t^3 + \frac{42.76}{2}t^2 \right|_0^{5.34 \text{ min}} \\
 &= 1265.51 \cdot \frac{ft^3}{sec} \cdot \frac{min}{60} \times \frac{60 \cdot sec}{min} \\
 \boxed{V_{t_0-t_2} &= 75930.43 \cdot ft^3}
 \end{aligned}
 \qquad
 \begin{aligned}
 V_{t_2-t_4} &= \int_{t_2}^{t_4} Q_{t_2-t_4} dt \\
 &= \int_{5.34 \text{ min}}^{8.96 \text{ min}} (8.65t^3 - 261.76t^2 + 2387.72t - 5847.51) dt \\
 &= \left. \frac{8.65}{4}t^4 - \frac{261.76}{3}t^3 + \frac{2387.72}{2}t^2 - 5847.51t \right|_{5.34 \text{ min}}^{8.96 \text{ min}} \\
 &= 3091.56 \cdot \frac{ft^3}{sec} \cdot \frac{min}{60} \times \frac{60 \cdot sec}{min} \\
 \boxed{V_{t_2-t_4} &= 185493.40 \cdot ft^3}
 \end{aligned}$$

$$\begin{aligned}
 V_{t_4-t_5} &= \int_{t_4}^{t_5} Q_{t_4-t_5} dt \\
 &= \int_{8.96 \text{ min}}^{11.50 \text{ min}} (-99.44t + 1648.22) dt \\
 &= \left. \frac{-99.44}{2}t^2 + 1648.22t \right|_{8.96 \text{ min}}^{11.50 \text{ min}} \\
 &= 1842.13 \cdot \frac{ft^3}{sec} \cdot \frac{min}{60} \times \frac{60 \cdot sec}{min} \\
 \boxed{V_{t_4-t_5} &= 110527.90 \cdot ft^3}
 \end{aligned}$$

$$\begin{aligned}
 V_{t_0-t_5} &= V_{t_0-t_2} + V_{t_2-t_4} + V_{t_4-t_5} \\
 &= 75930.43 + 185493.40 + 110527.90 \\
 \boxed{V_{t_0-t_5} &= 371951.80 \cdot ft^3}
 \end{aligned}$$

Figure B-16: Unit Hydrograph Curve Fitting Calculations

$$\begin{aligned}
 t_7 &= t_5 + \frac{2(V_{uh} - V_{t_0-t_5})}{0.3667Q_p} \\
 &= 11.50 \cdot min + \frac{2(544500 - 371951.8)}{0.3667 \cdot 1009} \\
 &= 11.50 \cdot min + 932.69 \cdot sec \\
 \boxed{t_7 &= 27.04 \cdot min} \\
 t_6 &= t_5 + \frac{1}{3}(t_7 - t_5) \\
 &= 11.50 + \frac{1}{3}(27.04 - 11.50) \\
 \boxed{t_6 &= 16.68 \cdot min}
 \end{aligned}$$

Figure B-17: Unit Hydrograph Curve Fitting Calculations (Continued)

Finally, CUHP fits linear equations between t_5 and t_6 as well as between t_6 and t_7 as shown in Figure B-16.

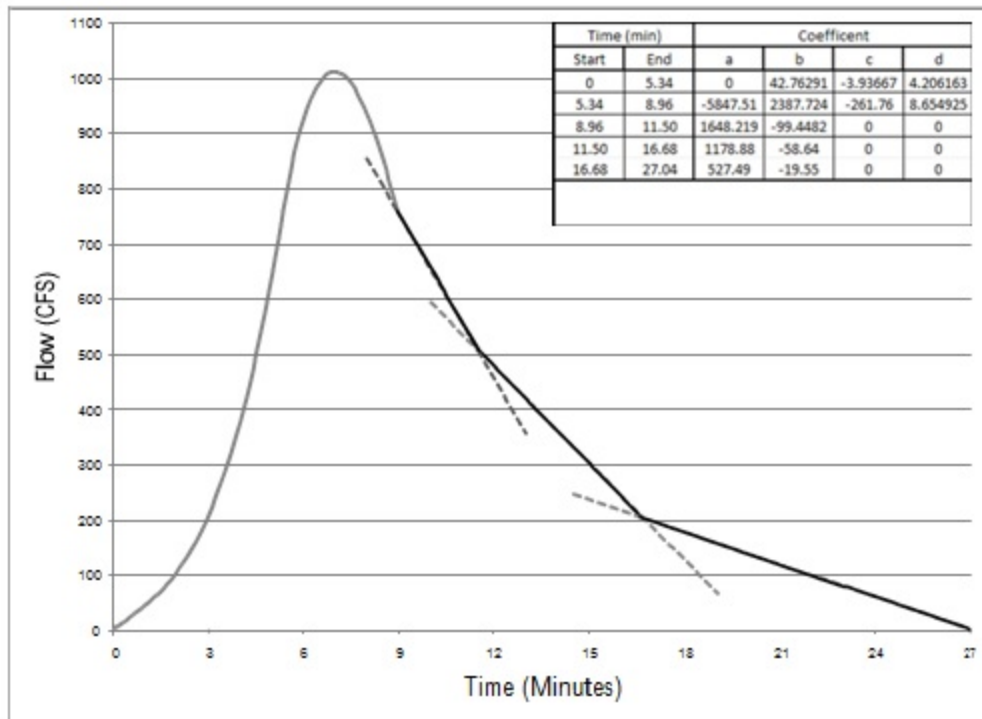


Figure B-18: Unit Hydrograph, Segments 4 and 5

The current CUHP is not able to generate a storm hydrograph with continuous functions. Therefore, the unit hydrograph must be discretized: points are pulled from these equations with spacing equal to the CUHP time step for use in generating the storm hydrograph, as shown in Table B-6. Users should note that due to the discretization process, the shape of the unit hydrograph formed by connecting lines between the points in Table B-6 will be different than the shape of the unit hydrograph calculated using this section. Additionally, if the CUHP time step is too great the points used for CUHP's calculations may miss the peak of the unit hydrograph. Both situations are illustrated in Figure B-17, which uses the calculations performed in this section. The errors associated with discretization can be minimized by reducing the CUHP time step. Figure B-18 shows the continuous and discrete unit hydrographs using a one-minute time step for the data in this section. Due to the poor correlation of the five-minute unit hydrograph, it is recommended to use a one-minute time step for all CUHP analyses.

Table B-6: Unit Hydrograph Values

Time (min)	Value (cfs)
0	0
5	632.6321
10	648.8007
15	287.7175
20	130.0612
25	28.9378
30	0

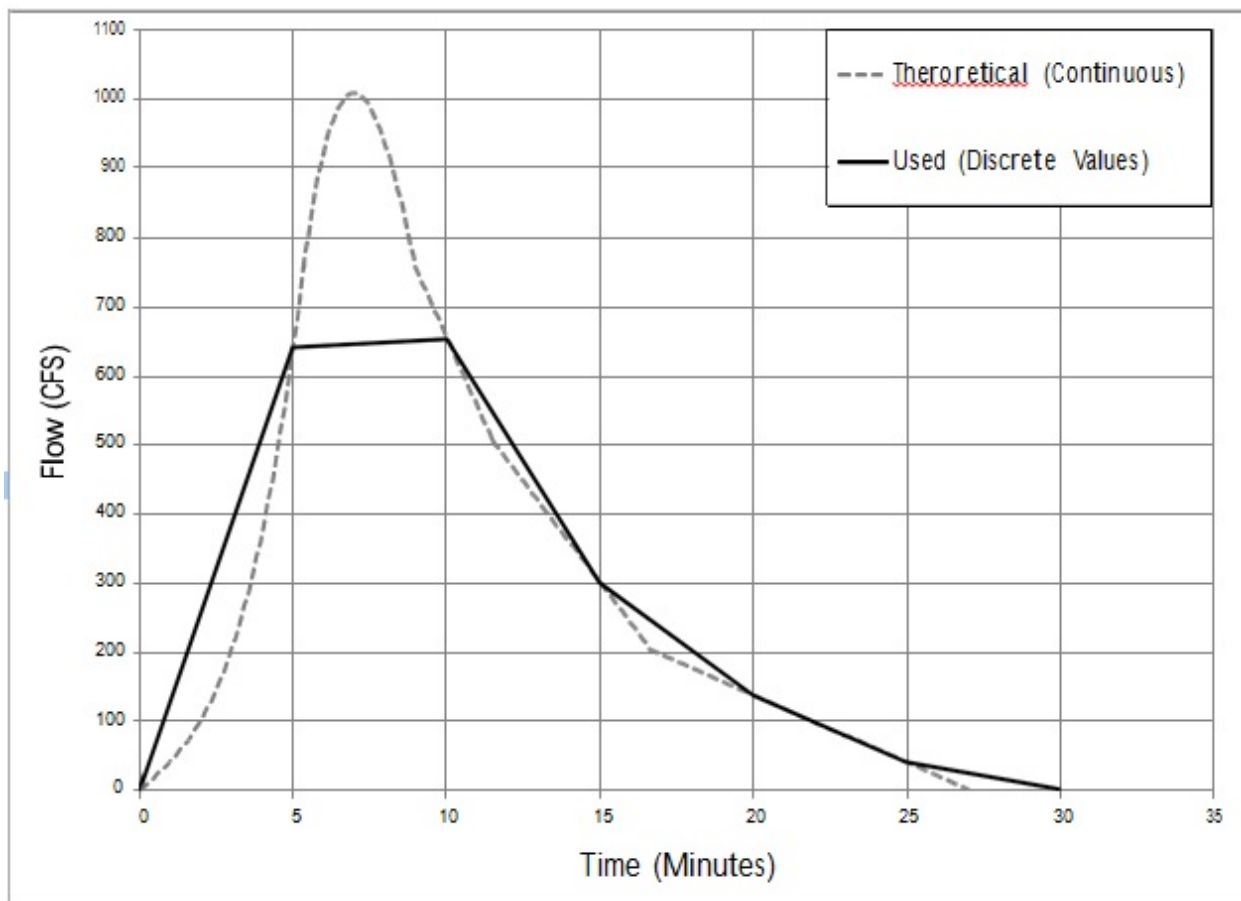


Figure B-19:
Superposition of Continuous and Discrete Unit Hydrographs for a 5-minute Time Step

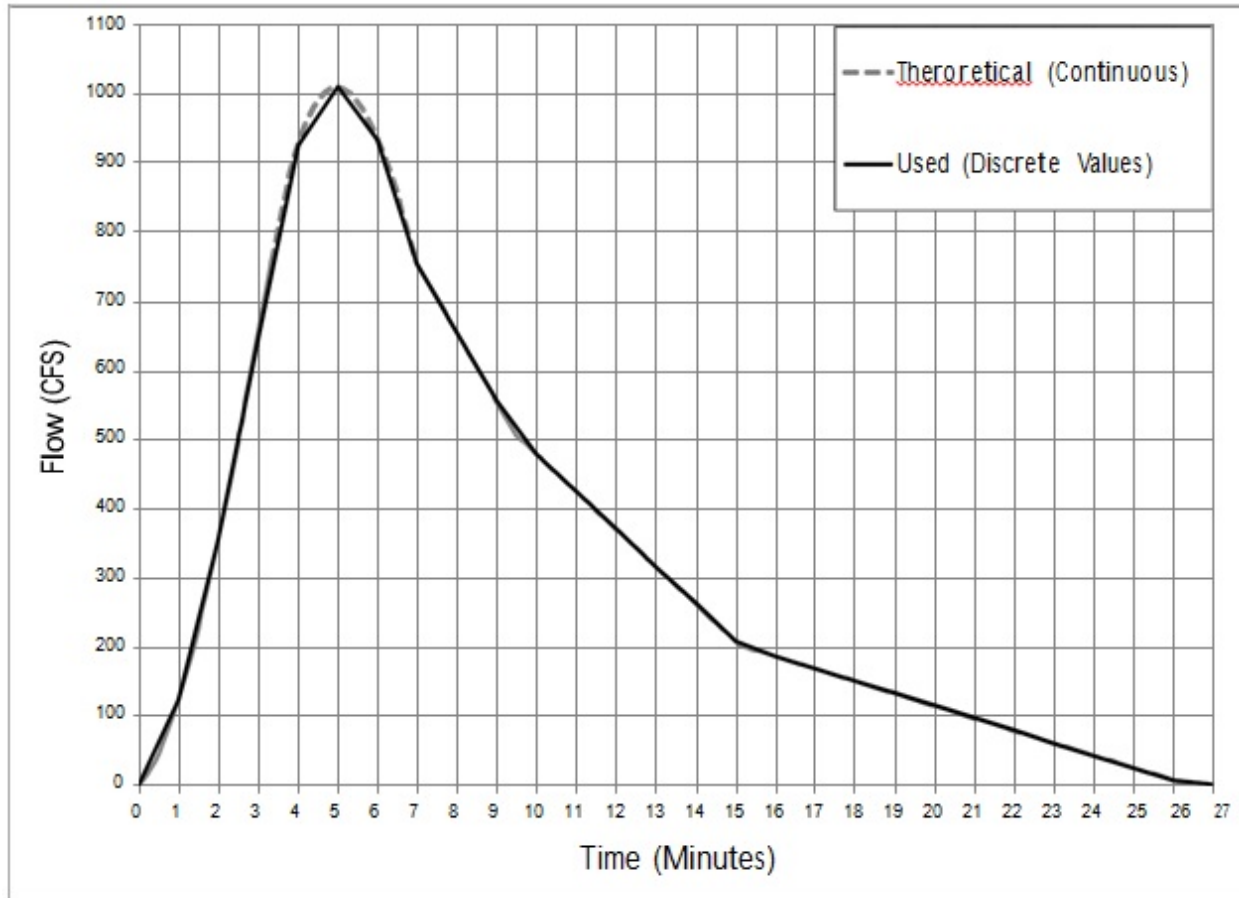


Figure B-20:
Superposition of Continuous and Discrete Unit Hydrographs for a 1-minute Time Step

Storm Hydrograph

To generate the storm hydrograph, a unit hydrograph is applied to each incremental depth from the effective precipitation calculations. This is done by shifting the unit hydrograph to the start time of the precipitation increment, then scaling the unit hydrograph by the incremental precipitation depth. This is shown in Figure B-19.

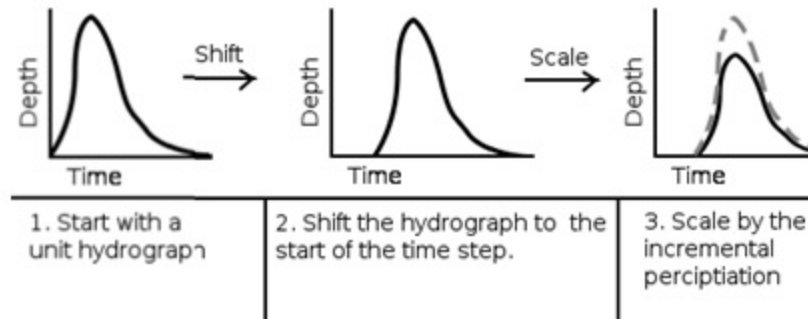


Figure B-21: Shifting and Scaling of a Unit Hydrograph

The scaled unit hydrographs are then added together to produce an output hydrograph as shown in Figure B-20. The suggested format for manually performing these calculations is shown in Table B-7.

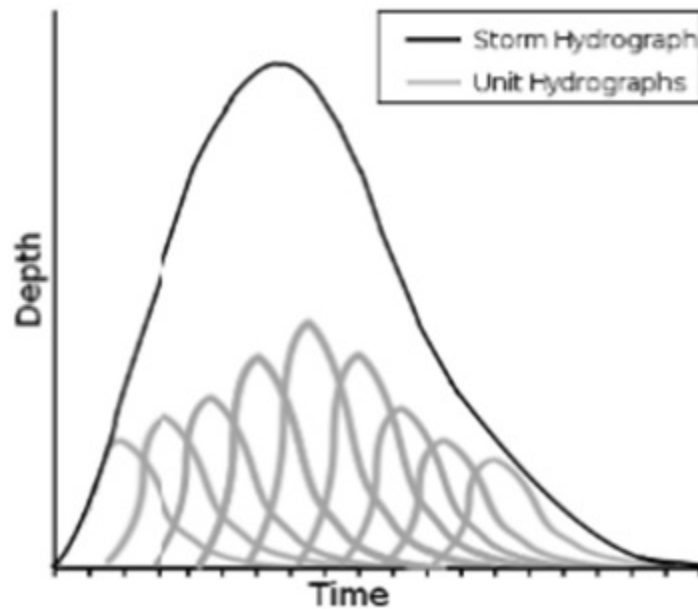


Figure B-22: Superposition of Scaled Unit Hydrographs

Table B-7: Storm Hydrograph Generation (cfs)

[illegible]

Appendix C - Basis of the Original CUHP Method

Basis for 1982 Version of CUHP

NOTE: The following was excepted from an earlier version of the Urban Storm Drainage Criteria Manual, Volume I, Runoff Section (revised 5-1-84). Any questions concerning this supplemental information should be directed to the Master Planning Program.

Rainfall and runoff data were collected by U.S. Geological Survey in the Denver metropolitan area since 1969 under a cooperative agreement with the Urban Drainage and Flood Control District. Analysis of this data by the District staff began in earnest in 1977. Of the original thirty gaging stations, data from only seven sites (nine different basin conditions) were used by the District to develop the 1982 version of the CUHP. Data from all other sites were evaluated and were determined not suitable for use due to various gaging problems and watershed definition problems. Because the metropolitan area data base lacked an undeveloped watershed, data from a small watershed (Kiowa Creek Tributary at Elbert) being gaged by USGS for the Colorado Highway Department was used to round out the mix of land uses in the data base.

Table 4.1 presents a summary of rainfall/runoff data base and includes the key watershed parameters for each site. For each of the dates that data were available, a complete rainfall depth record and concurrent flow measurements at 5-minute time increments served as the basis for the development of the revised CUHP. Peak flows from each recorded hydrograph are compared with the calculated peak flows using the 1982 version of CUHP in Figure 4-8. This comparison substantiates the validity of the new CUHP procedure.

Those wishing to compare the older version of the CUHP with the new version will find that often the new unit hydrograph will have a significantly shorter time to peak. This is particularly true for smaller urbanized basins. However, the new version will often produce peak flow results comparable to those obtained using the old version over a wide range of watershed conditions typically used in drainage studies in the Denver Metropolitan Area.

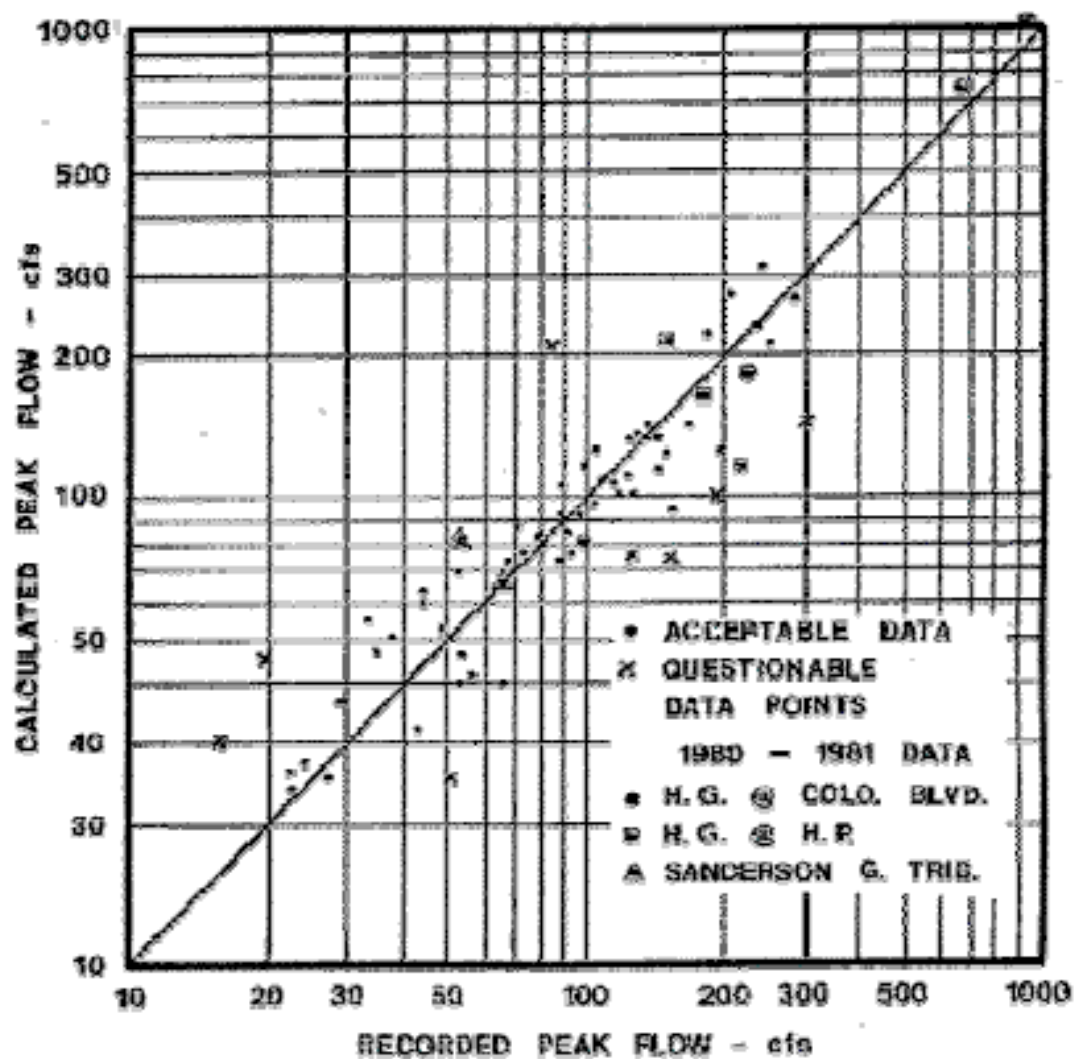


FIGURE 4 - 8. COMPARISON OF RECORDED
 PEAKS WITH CALCULATED PEAKS
 USING NEW C U H P
 (5-MINUTE UNIT
 HYDROGRAPHS)

Table 4.1: Basin and Ranfall/Runoff Data Used to Develop the 1982 CUHP Version

Basin Name	Area (sq.mi)	Imp. (%)	L (mi.)	L _{ca} (mi.)	Slope (ft/ft)	Soil Type	Date	Precip (in)	Peak Flow (CFS)
Sand Creek Trib. In Denver	0.29	32	0.84	0.21	0.0007	A	7-25-71	0.70	86.00
							6-4-72	0.50	52.00
							6-12-72	0.39	48.00
	0.29	40	0.84	0.21	0.0007	A	7-19-73	0.64	68.00
							7-24-73	0.95	104.00
							8-7-73	1.94	236.00
							9-11-73	0.56	143.00
							7-22-74	1.05	98.00
							7-30-74	1.38	25.00
	0.29	43	0.84	0.21	0.0007	A	8-13-75	0.68	53.00
							7-25-76	398.00	196.00
							8-1-76	1.34	85.00

Basin Name	Area (sq.mi)	Imp. (%)	L (mi.)	L _{ca} (mi.)	Slope (ft/ft)	Soil Type	Date	Precip (in)	Peak Flow (CFS)
							8-4-76	0.30	47.00
							7-5-77	0.36	23.00
							7-23-77	0.44	72.00
							7-25-77	0.76	87.00
							8-8-77	0.28	34.00
							8-8-77	0.18	16.00
S. Platte Trib. #2 at Northglenn	0.56	14	1.17	0.71	0.037	D	6-23-69	0.61	23.00
	0.56	20	1.17	0.71	0.037	D	7-25-71	0.39	51.00
	0.56	35	1.17	0.71	0.037	D	8-23-72	0.49	28.00
							7-19-73	0.30	29.00
							9-10-73	0.29	35.00
							5-21-76	0.75	78.00
	0.56	39	1.17	0.71	0.037	D	5-24-76	0.74	151.00
							6-23-77	0.35	69.00

Basin Name	Area (sq.mi)	Imp. (%)	L (mi.)	L _{ca} (mi.)	Slope (ft/ft)	Soil Type	Date	Precip (in)	Peak Flow (CFS)
							6-28-78	0.59	109.00
							7-6-78	0.68	71.00
							8-9-79	0.98	130.00
							8-10-79	0.61	135.00
							8-26-79	0.54	115.00
Concourse D at Stapleton	0.15	97	0.97	0.43	0.005	C	7-19-73	0.59	197.00
							7-24-79	0.66	123.00
							9-11-73	0.57	81.00
							6-23-75	0.70	126.00
							7-30-75	0.70	119.00
							7-21-76	0.45	92.00
							7-25-76	0.98	88.00
							8-1-76	2.00	285.00
							8-4-76	0.24	65.00

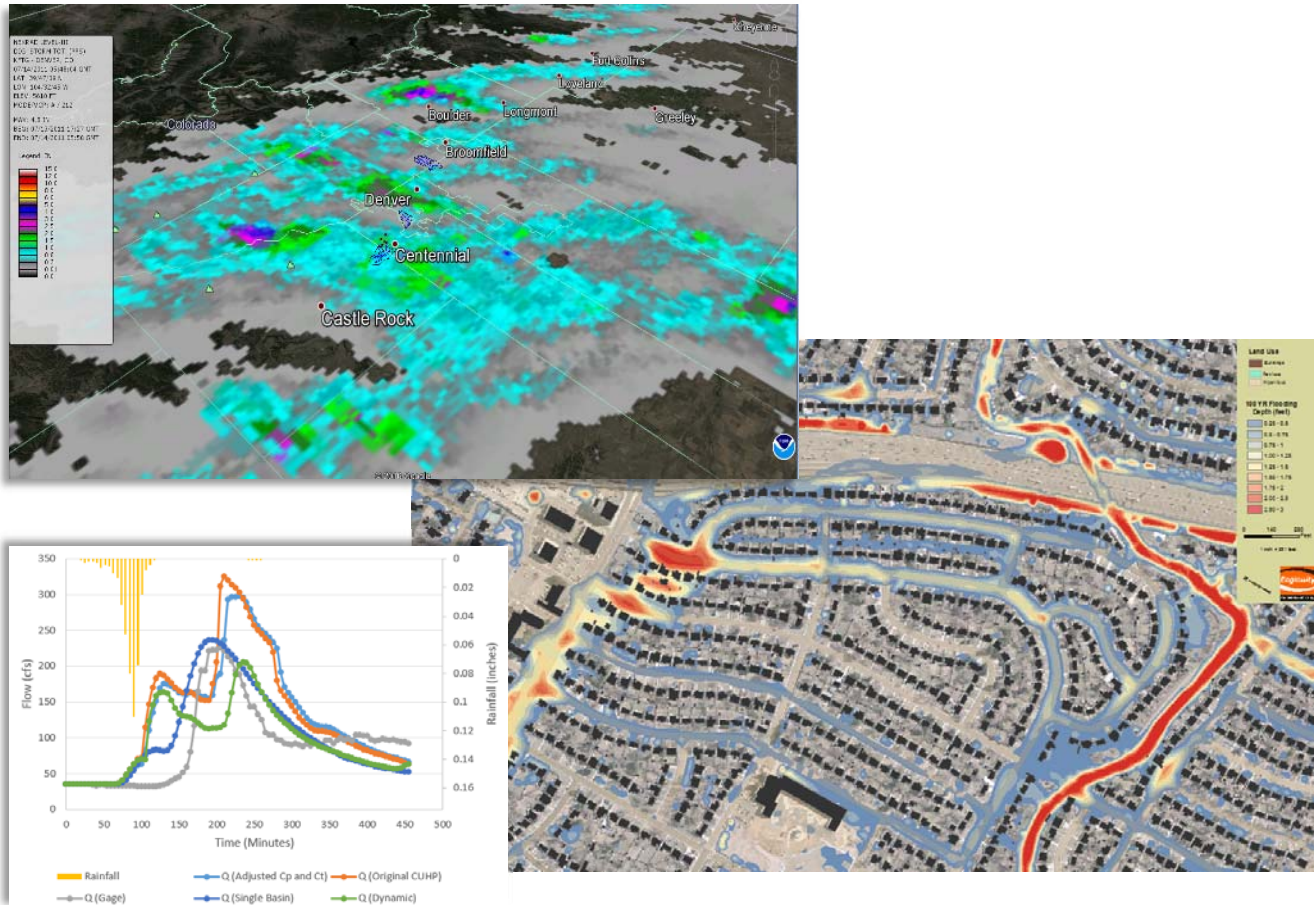
Basin Name	Area (sq.mi)	Imp. (%)	L (mi.)	L _{ca} (mi.)	Slope (ft/ft)	Soil Type	Date	Precip (in)	Peak Flow (CFS)
							7-5-77	0.32	24.00
							7-20-77	0.84	123.00
							7-24-77	0.29	55.00
							7-25-77	0.56	116.00
							8-22-77	0.26	56.00
Sanderson Gulch Trib. At Lakewood	0.38	44	1.28	0.52	0.0102	D	7-25-76	0.40	44.00
							3-13-76	0.60	94.00
							6-5-77	0.57	38.00
							6-6-77	0.91	299.00
							7-29-78	0.35	34.00
							7-4-79	1.10	176.00
							8-19-79	0.84	90.00
							8-26-79	0.27	42.00
							5-5-80	0.38	20.00
							8-14-80	0.42	45.00

Basin Name	Area (sq.mi)	Imp. (%)	L (mi.)	L _{ca} (mi.)	Slope (ft/ft)	Soil Type	Date	Precip (in)	Peak Flow (CFS)
Goose Creek at Boulder	0.66	34	1.48	0.51	0.006	B	4-20-81	0.73	54.00
							7-26-81	0.62	68.00
							6-5-72	1.32	185.00
							6-5-75	0.82	102.00
							7-25-76	0.76	137.00
Goose Creek at Boulder	0.66	34	1.48	0.51	0.006	B	9-19-76	0.62	102.00
							7-20-77	1.11	133.00
							5-28-81	1.01	672.00
							5-29-81	0.49	99.00
							7-12-81	0.69	225.00
Harvard Gulch at Harvard Park	3.08	39	3.26	1.61	0.0085	D	8-19-79	0.43	135.00
							5-1-80	0.27	112.00
							7-10-80	0.24	65.00

Basin Name	Area (sq.mi)	Imp. (%)	L (mi.)	L _{ca} (mi.)	Slope (ft/ft)	Soil Type	Date	Precip (in)	Peak Flow (CFS)
							8-14-80	0.72	277.00
							5-3-81	0.48	153.00
							5-28-81	1.14	914.00
							5-29-81	0.74	123.00
							7-12-81	0.51	186.00
Harvard Gulch at Colo. Blvd.	1.12	40	1.42	0.56	0.011	D	5-28-81	1.01	672.00
							5-29-81	0.49	99.00
							7-12-81	0.69	225.00

Appendix D - 2016 Re-Calibration of CUHP Method

A SUMMARY OF CUHP RE-CALIBRATION EFFORTS



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Appendix B – CUHP Sub-Catchment Parameters for Select Basins (Digital Appendix not Included in Report)

Appendix C – Addressed Comments from June 2016 Draft Summary Report

EXECUTIVE SUMMARY

This summary report highlights the efforts to re-calibrate the Colorado Urban Hydrograph Procedure (CUHP) in 2015 and 2016. This effort was commissioned by the Urban Drainage and Flood Control District (UDFCD) as a result of noting higher than anticipated peak flow values during the Major Drainageway Planning (MDP) and Outfall Systems Planning (OSP) hydrologic studies currently underway and also ones that were performed in the past. The CUHP had not been calibrated with gage data since its inception and peak flows developed in recent studies deviated from statistical gage analysis across the District.

The calibration effort utilized Gage Adjusted Radar Rainfall and recorded runoff from US Geological Survey (USGS) and Alert 5 Gages in addition to statistical gage analysis to adjust CUHP's timing and peaking coefficients to be more in line with the large gage record maintained by the District and the USGS. The iterative approach between matching recorded runoff and gage values developed the *Proposed Version of CUHP* presented within this report.

Changes to CUHP proposed within this report will lower peak flow rates for almost all studies across the District. However, as shown through comparison of gage frequency analysis, values produced with the proposed version of CUHP will still be conservative when compared to most gage frequency estimates. Work performed through calibration found that CUHP Version 1.4.4 is statistically within range of recorded rainfall and runoff. However, Version 1.4.4 more often produced results higher than the recorded flow when compared to the proposed version of CUHP. Additionally, the proposed version of CUHP will trend more closely with gage frequency estimates than Version 1.4.4. In order to match both recorded rainfall and runoff values and gage frequency estimates, the most recently published 1 hour precipitation depths found in NOAA's Atlas 14 Precipitation Frequency Estimates are recommended.

BACKGROUND AND INTRODUCTION

CUHP Background

The Colorado Urban Hydrograph Procedure (CUHP) was first developed by the Urban Drainage and Flood Control District (UDFCD) in 1971. CUHP is an evolution of the Snyder Unit Hydrograph (Snyder 1938) that has been modified to include imperviousness, making it an Urban Unit Hydrograph that accounts for a watershed's imperviousness percentage, slope, and size. CUHP translates a watershed's response from rainfall into a runoff hydrograph that reflects peak runoff rates, volumes, and timing. The complete history of CUHP is presented within the CUHP 2005 User Manual (UDFCD 2014). Many adjustments to CUHP have been made in the past. One of the more recent and influential adjustments that exist within CUHP are modifications of timing coefficients for basins less than 160 acres (Guo and Urbonas 2008). These modifications connected a disparity between 90 and 100 acres that occurred when CUHP 2005 was developed.

Hydrograph Routing

Hydrographs developed from CUHP are routed within the Storm Water Management Model (SWMM5)(EPA 2010) via the Kinematic Wave routing method. The Kinematic Wave is a shortened version of the St. Venant Equations, which are widely accepted as the governing equations in hydraulics to solve for momentum and continuity under shallow water approximations (Sturm 2010). The Kinematic Wave assumes that the flow is uniform and the friction slope of the water's surface is approximately equal to the channel slope. Under this assumption, Kinematic Wave hydraulics do not account for channel storage, flow attenuation, or backwater from downstream influences. The Kinematic Wave progresses a flood wave from upstream to downstream with no attenuation and only translates the wave in time. Some research has shown that the Kinematic Wave is accurate with Froude numbers as high as 2.0 (Woolhiser and Liggett 1967)(Liggett and Cunge 1975). Since natural channels do not flow supercritical¹ and that the Kinematic Wave velocity is less than the Dynamic Wave velocity, it has been suggested that the Kinematic Wave best represents a flood wave in natural channels. However, almost all research on Kinematic Wave velocity and applications is limited to shallow overland flow and generally does not address full channel hydraulics. Many publications recommend

¹ Supercritical flow is defined when the Froude Number is greater than 1.0

the full solution of momentum (i.e. Dynamic Wave) be applied whenever the lateral inflow is less than the main channel flow (USGS 1984)(Liggett and Cunge 1975)(Ferrick and Goodman 1998). In practice, all forms of the St. Venant Equations (Kinematic, Diffusive, and Dynamic) are considered acceptable for channel routing.

Unit Discharge for Large and Small Watersheds

As with many runoff simulation models, the unit discharge of peak flow per runoff area of smaller basins is higher than larger basins within CUHP (See Figure 1). This phenomenon is observed in physical runoff models, regression equations, and unit hydrographs and represents physical routing characteristics that occur as flow progresses through the watershed. Larger drainage areas have a longer flow path and consequently more flow attenuation occurs before the drainage outlet while smaller watersheds have a shorter flow path and less flow attenuation.

CUHP was originally calibrated to single basins ranging from 0.15 to 3.08 square miles with a majority of the basins being larger than 0.3 square miles (192 acres). This is because most stream gages are located lower in the watershed. Over the years, however, CUHP has more widely been applied by subdivided one large watershed into many catchments averaging 90-100 acres in size. Since CUHP's hydrographs are routed via the Kinematic Wave, there is no attenuation of the flood hydrographs as they progress downstream. This, among other factors, has resulted in excessively high peak flows at drainage outlets for many of UDFCD's studies.

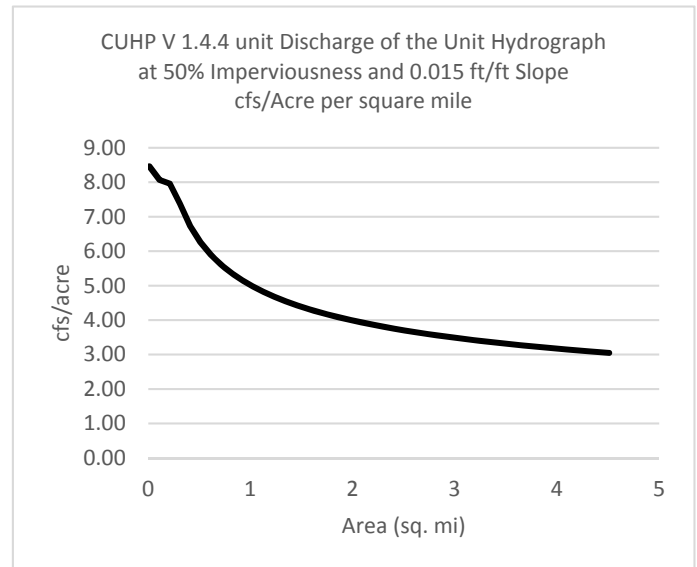


Figure 1 – Unit Discharge per Area of CUHP 1.4.4

The phenomenon of higher peaks from discretized drainage areas is not new and has been known for a long time (Dankenbring and Mays 2009). In 2014, Urbonas and Rapp (2014) published a report developing protocols for consistency in CUHP/SWMM hydrology for large discretized catchments. Recommendations within this report include modeling a more realistic drainage system that accounts for the channel slope between drop structures and higher channel roughness values. Essentially, the results of these recommendations are forcing the hydrographs from CUHP to be translated in time so they don't compound on each other. Since the Kinematic Wave does not attenuate flows (Sturm 2001, USGS 1984) or account for

channel storage, modifying the slope and roughness of a channel to change timing is the only option under the limited mathematics of the Kinematic Wave.

Basis for Re-Calibrating CUHP

Even with the modifications from Urbonas and Rapp (2014), the UDFCD was experiencing higher than anticipated peak flow values during the Major Drainageway Planning (MDP) and Outfall Systems Planning (OSP) processes that apply CUHP and SWMM5 for hydrologic studies. To remedy the high peak flows, each study had user-adjusted peaking and timing coefficients within CUHP to match either previous studies or to be more in line with a stream gage statistical frequency analysis. This created inconstancy across the District in how CUHP was applied and was also not consistent with the Federal Emergency Management Agency's (FEMA) acceptance of the CUHP method where CUHP is accepted under the default parameters in the model (FEMA 2016). The District began to investigate a wide range of published flows against the large stream gage network throughout the entire District and noticed that the published values in the MDP and OSP studies are not always consistent with the gage frequency analysis in the watersheds studied. UDFCD commissioned this calibration effort based on the following needs:

- CUHP had not been calibrated with gage data since its inception in the 1970's and adjustments in the 1980s.
- Current practice requires users to adjust C_p for almost all studies. This develops a *study specific* calibrated model and reduces consistency in hydrologic practice across the District.
- Peak flows developed in recent studies deviated from statistical gage analysis across the District and created uncertainty with CUHP model results for some studies.

Under this calibration effort the District considered many alternatives to address the differences noted between gage analysis and the MDP/OSP hydrologic studies. These alternatives included:

1. Keep CUHP in its current form and incorporate Depth Area Reduction Factors (DARFs) for smaller watersheds and adopt the new NOAA Rainfall Atlas No. 14 to determine 1 hour point precipitation depths.
2. Adopt the Stormwater Management Model (SWMM5) overland flow equations for hydrology and calibrate the smaller SWMM basins to larger CUHP basins for baseline hydrology (EPA 2010).
3. Accept 2D Rain on Grid Technology within FEMA Accepted 2D Hydrology models like the Gridded Surface and Subsurface Hydrologic Analysis Model (GSSHA) developed by the US Army Corps of Engineers (Downer et al 2006, Downer and Ogden 2004).

4. Apply the full and/or partial solutions of motion (Dynamic and Diffusive Wave) for routing CUHP flows hydrographs for all studies (USGS 1984) (USACE 2002).
5. develop larger sub basin area delineations for all major drainage studies to reduce the high unit discharge that is not attenuated when routed with the Kinematic Wave.
6. Recalibrate CUHP with updated rainfall and runoff data and frequency analysis from USGS and Alert 5 gage history. This alternative keeps the hydrologic practice within the District relatively the same.

This Summary Report only includes results of the alternative recommended and carried forward, which was to recalibrate CUHP with updated rainfall and runoff and then test the results against gage frequency and existing studies within the District.

CALIBRATION PROCESS

Adjustments to CUHP's peaking and timing coefficients were tested as part of the calibration effort. This calibration effort was separated into two phases: First, CUHP was re-tested with Gage Adjusted Radar Rainfall (GARR)² and recorded runoff from USGS and Alert 5 Gages. Secondly, those adjustments were then tested with frequency design storms and statistical gage analysis. An iterative approach between matching recorded runoff and gage values developed the *Proposed Version of CUHP (Proposed CUHP)*. This iterative approach first made an adjustment to the equations within CUHP that matched recorded runoff, then they were compared with frequency curves for gages that monitor clean³, developed basins that have little to no detention or storage. The equations were then calibrated until good agreements were achieved.

The proposed coefficients within this summary will reduce flows for almost all studies. However, some studies across the district currently report peak flow values that match well to the flow frequency analysis at the stream gage. Many of these studies have study specific adjusted parameters that were input into CUHP during the hydrology phase. To be cautious while moving forward, testing of those hydrologic models was

² Gage-adjusted radar rainfall (GARR) is gridded rainfall at high spatial and temporal resolution. GARR is a combination of radar and rain gage data, that leverages the strength of both sensor measurements (Vieux, 2013). It was produced by Vieux & Associates, Inc. for the Urban Drainage and Flood Control District for use in their flood warning program.

³ Clean basins are described as Basins that have little effects from detention, diversions, and other anthropologic influences that could affect the frequency curve.

important to ensure that new calibrated peaking and timing parameters did not produce results below acceptable gage analysis.

PROPOSED ADJUSTMENTS

Although many various alternatives were tested, compared, and considered during this calibration process, the simplest and most effective path forward was to modify CUHP to match gage data and make limited changes to many of the other parameters. The following bullets support this decision:

- **No change to infiltration parameters:** Based upon review of many studies, published literature (Alley and Veenhuis 1983)(Arnold and Gibbons 1996)(Booth and Jackson 1997), and nationwide hydrologic guidance, it was found that the infiltration parameters within CUHP fall within an acceptable range for developed soils when it is considered that CUHP applies the time dependent form of Horton's Equation opposed to the integrated form which is used within distributed models such as SWMM5 and many other hydrologic models (Blackler 2013)(Blackler and Guo 2010). This study also found a low correlation between rainfall and runoff from Mountain Basins. All tests on the Mountain Basins found that CUHP infiltrated more rainfall than what was recorded at the gage. This will require further investigation that will be completed under a different project.
- **No change to design storm:** At this time, no changes to the design storm are proposed. However, this calibration considers the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 point precipitation frequency estimates for Denver and the surrounding areas. This study applied the updated NOAA 14 Atlas to calibrate CUHP so that it matches closely to both recorded flow and gage frequency analysis. It is therefore recommended to use the updated Atlas for all future studies.
- **No change to methodology:** CUHP follows the Snyder Unit Hydrograph Procedure (Snyder 1938)(Sherman 1932). This procedure was developed in 1938 and CUHP follows its general form with the addition of imperviousness to handle peaking for urban catchments. This commonly applied unit hydrograph procedure does not leave a lot of room for variation, as such, the general form of CUHP was held for this study.

Below are the adjustments to the Proposed CUHP:

Adjust Peaking Parameter (P) to be modified as Equations (1) and (2):

$$\text{If } Ia < 25\%, \text{ then } P = 0.0006 * Ia^2 + 2.3 \quad (1)$$

$$\text{If } Ia > 25\% \text{ then } P = -0.0005 * Ia^2 + 0.12 * Ia \quad (2)$$

Where, Ia is the percent imperviousness of the basin. Adjust the coefficient of peaking (C_p) to be Equations (3) and (4):

If the area is less than or equal to 120 acres, then:

$$C_p = P * C_T * 1.3 * A^{0.45} \quad (3)$$

For basins greater than 120 acres apply the following:

$$C_p = P * C_T * A^{0.30} \quad (4)$$

It was recommended to keep the timing coefficient for larger basins (C_T) as it is within the current CUHP. This study found that the timing remained appropriate for a majority of the basins tested. The above equations were tested for consistency on small and large basins to ensure smooth transitions between the equations applied for smaller and larger basins that are currently within CUHP. Figures 2 and 3 below present snapshots of this testing.

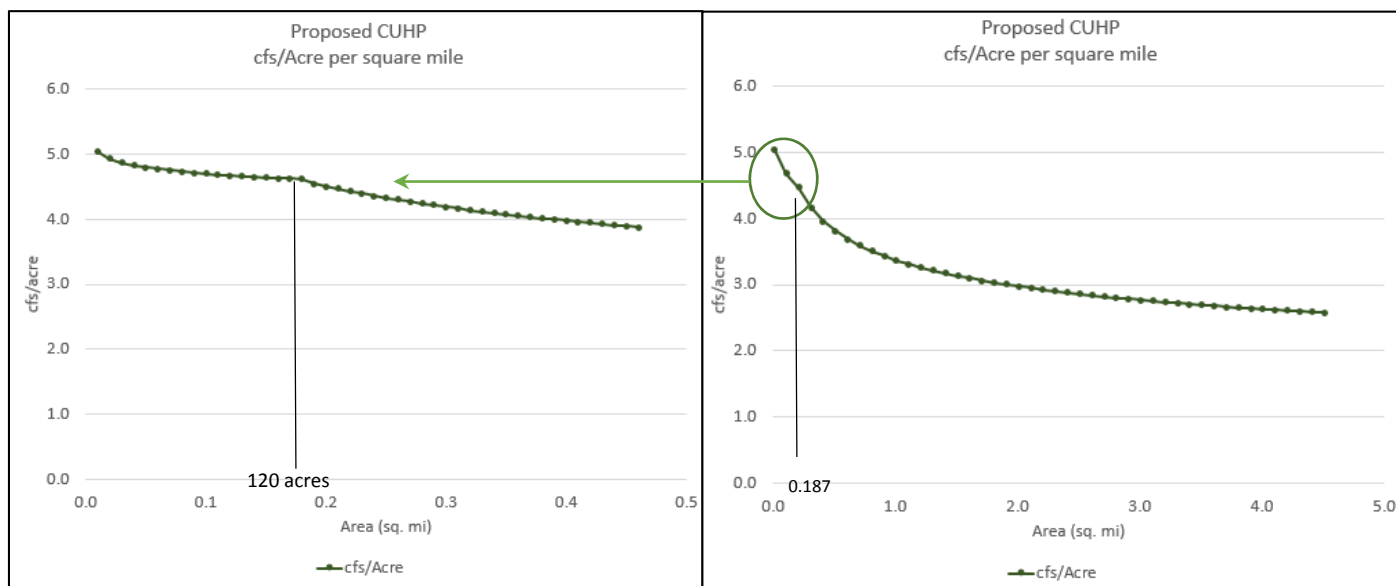


Figure 2 – Left: Proposed CUHP Unit Discharge for Basins 6 Acres up to 0.45 Square Miles, Right: Proposed CUHP Unit Discharge for Basins 6.4 acres to 4.5 square miles showing the smooth transition at 0.25 square miles.

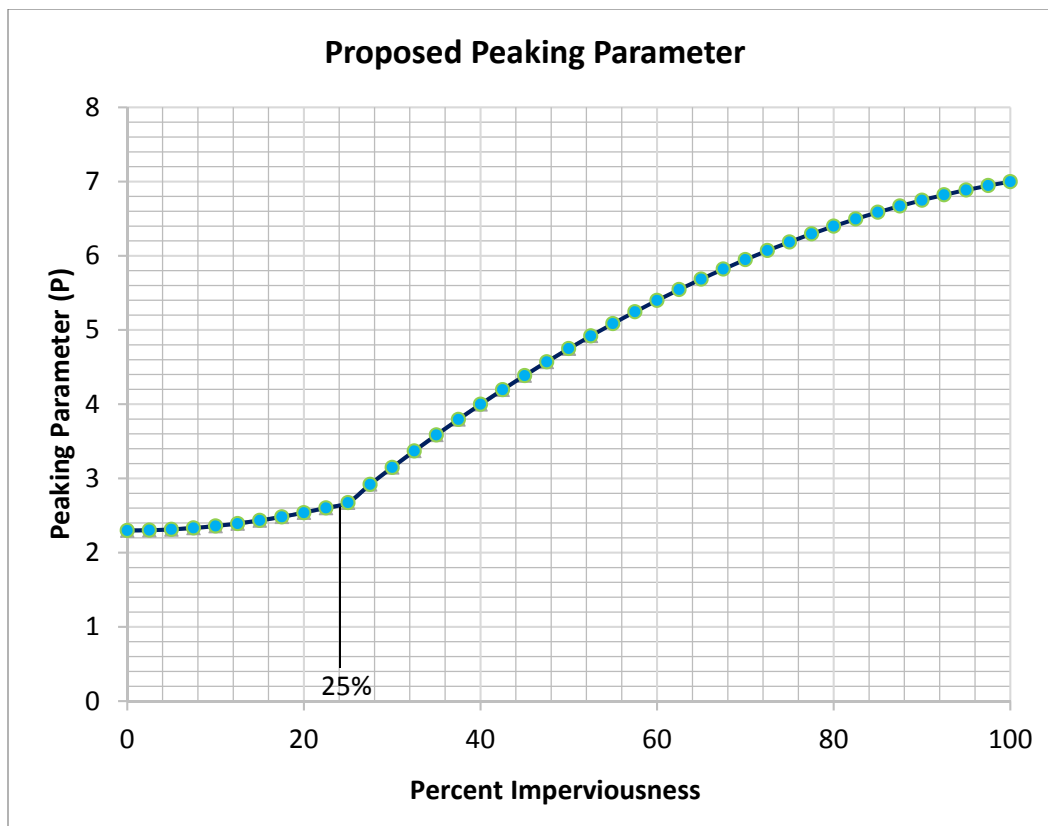


Figure 3 - Graph of the Peaking Parameter vs Imperviousness

COMPARISON OF RECORDED RAINFALL AND RUNOFF DATA

This analysis found that the Proposed CUHP has less error than CUHP 1.4.4 when compared to recorded rainfall from GARR and corresponding runoff from USGS and Alert 5 Gages for selected storms (See Table 2). Additionally, it found that CUHP 1.4.4 is more often higher than the Proposed CUHP (See Figure 5). Tables 1 and 2 below present a discussion of the basins tested during this analysis and the result of CUHP's performance when GARR storms were tested on select basins. Figure 4 below Tables 1 and 2 presents a graphical representation of the data sets.

Error testing followed guidance from the US Army Corps of Engineers Hydrologic Modeling System (HEC HMS) Manual, that defines error as

$$Z = 100 \left| \frac{q_s(\text{peak}) - q_o(\text{peak})}{q_o(\text{peak})} \right| \quad (5)$$

Where, Z is the absolute value of the difference between computed and observed flows expressed as a percentage, q_s is the computed peak flow from CUHP, q_o is the observed peak flow at the gage. This methodology treats overestimations and underestimations as equally undesirable. More discussion on error analysis for hydrologic systems is found within Chapter 9 of the HMS Technical Manual (Pages 97-100) (USACE 2000). It is also useful to know the average error being both above and below the gage results. At the bottom of Table 2 the row showing *Average (+/-)* includes the average of all error results when the absolute values in Equation 5 are ignored and error is both positive and negative. Numbers in this row that are positive indicate the average error is above the recorded values, or more simply put that the computed flows from CUHP are higher than the recorded flows at the gage.

Table 1 summarizes watershed and gage locations that were tested for calibration of the Proposed CUHP. Some gages did not have overlapping record with the GARR but did have a good length of annual peak flows that could be compared against the Proposed CUHP. These are described as gages "Tested for Frequency" in Table 1 below. An example would be North Sanderson Gulch, which did not have a gage record recent enough to compare with GARR storms, although results from the Proposed CUHP's 2- through 100-year results were compared with the gages prediction of the 2- through 100-year flows from a log Pearson III analysis.

Table 1 - Summary of Gages Tested as part of the Calibration Effort

Gage Description	Tested for Calibration Version 1 (Yes/No)	Kept in Calibration Data Set (Yes/No)	Tested for Proposed CUHP Calibration (Yes/No)	Tested for Frequency (Yes/No)	Notes
Dry Gulch	Yes	Yes	Yes	Yes	Updated MDP Model may have been completed while study was ongoing.
Dutch Creek	Yes	Yes	Yes	Yes	Storage in golf course upstream influences gage results. This storage is not accounted for in MDP model. Was added in calibration version 1 for testing.
Goldsmith	Yes	Yes	Yes	Yes	Good gage readings. Large watershed makes rainfall difficult to model. Upper and lower GARR storms created to better represent rainfall distribution.
Havana Pond	Yes	No	No	No	Calibrating to pond depths has less error for any storm due to the large change in volume over time compared to depth. Good agreement on calibration, but not viable to carry into data set.
Little Dry (Arapahoe County)	Yes	Yes	Yes	Yes	Good gage readings with little detention or piped systems since it is higher in the watershed.
Lena Gulch Upper	Yes	No	No	No	No success calibrating watersheds in the mountain basins during this phase.
Lena Gulch Lower	Yes	Yes	Yes	Yes	Reasonable gage. Upper Lena did not calibrate well but as it traveled through the developed areas more agreement was noted. Ponds immediately upstream have major influence on gage readings.
No Name at Quincy	Yes	No	No	*	Gage is located between pond and culvert, difficult to predict maintenance state and hydraulics.
North Sanderson Gulch at Lakewood	Yes	No	No	Yes	Gage record not current enough for GARR testing but a good gage for frequency testing as it represents a small, urbanized basin.

Gage Description	Tested for Calibration Version 1 (Yes/No)	Kept in Calibration Data Set (Yes/No)	Tested for Proposed CUHP Calibration (Yes/No)	Tested for Frequency (Yes/No)	Notes
Sanderson Gulch at Navajo	No	No	No	No	Gage record not long enough for frequency testing
Upper Harvard Gulch	Yes	Yes	Yes	Yes	Good gage with developed upper basin. 2D model shows Canal spilling, as such, canal spilling accounted for in runs.
Van Bibber at 93	Yes	No	No	*	No success calibrating watersheds in the mountain basins during this phase.
Harvard Gulch at Harvard Park	No	NA	NA	Yes	Good gage for frequency testing
Little Dry at Westminster	Considered	NA	NA	Yes	No time series available for GARR testing. Frequency testing only.
Weir Gulch	Considered	NA	NA	Yes	No time series available for GARR testing. Frequency testing only. Gage is un-reliable due to major leak in drop structure at gage.
Sloan's Lake Trib	Considered	NA	NA	No	Gage is in pond. See Havana Pond Comments.
Westerly Creek	Considered	NA	NA	*	Gage does not have current record for GARR
Willow Creek	No	No	No	Yes	Frequency testing since MDP data fell within Gage data.

*Pending but Viable

Table 2 – Summary of Recorded Rainfall and Runoff Testing between CUHP 1.4.4 and Proposed CUHP

Basin	Storm ID	Recorded Peak Flows	CUHP 1.4.4 Single Basin	CUHP 1.4.4 Small Basins	Proposed CUHP Single Basins	Proposed CUHP Small Basins	Total Depth (inches)	Peak 5 Minute Intensity (inch/hour)	Error (%) CUHP 1.4.4 Single Basin	Error (%) CUHP 1.4.4 Small Basins	Error (%) Proposed CUHP Single Basin	Error (%) Proposed CUHP Small Basins
Goldsmith	7/15/2013	1,303	1,192	1,181	973	911	0.93	2.64	9%	9%	25%	30%
Goldsmith	8/3/2013	235	499	424	417	338	0.63	2.36	112%	80%	77%	44%
Goldsmith	7/15/2014	765	1,413	1,257	1,343	982	0.93	3.27	85%	64%	76%	28%
Goldsmith	8/7/2014	221	264	170	244	131	0.26	0.90	19%	23%	10%	41%
Goldsmith	9/29/2014	500	1,424	1,386	1,146	1,042	1.22	3.55	185%	177%	129%	108%
Goldsmith	5/4/2015	249	426	269	363	227	0.52	1.23	71%	8%	46%	9%
Goldsmith	6/12/2015	1,412	1,960	1,642	1,702	1,343	1.80	2.00	39%	16%	21%	5%
Goldsmith	7/21/2015	359	760	565	630	705	0.65	1.79	112%	57%	76%	96%
Upper Harvard	7/13/2013	534	379	515	306	420	0.83	1.16	29%	4%	43%	21%
Upper Harvard	8/8/2013	511	650	929	492	696	0.75	2.30	27%	82%	4%	36%
Upper Harvard	5/20/2014	339	263	354	196	262	0.41	1.13	23%	4%	42%	23%
Upper Harvard	7/7/2014	449	388	607	340	462	0.58	1.98	14%	35%	24%	3%
Upper Harvard	9/29/2014	475	1,011	1,464	751	1,058	1.08	3.34	113%	208%	58%	123%
Upper Harvard	6/5/2015	367	519	149	92	120	0.74	0.80	41%	59%	75%	67%
Upper Harvard	6/11/2015	679	699	951	554	765	1.34	1.93	3%	40%	18%	13%
Upper Harvard	6/24/2015	583	625	889	514	679	0.53	1.77	7%	52%	12%	17%
Lena Gulch	7/13/2013	378	633	734	654	473	0.98	1.25	67%	94%	73%	25%
Lena Gulch	5/24/2014	455	372	490	394	314	0.71	1.22	18%	8%	13%	31%
Lena Gulch	7/30/2014	208	193	331	201	226	0.71	0.58	7%	59%	3%	9%
Lena Gulch	5/8/2015	302	145	214	155	102	0.73	0.60	52%	29%	49%	66%
Lena Gulch	6/11/2015	242	194	216	144	186	0.37	1.32	20%	11%	40%	23%
Dry Gulch	7/30/2014	127	221	213	178	201	0.80	0.46	74%	68%	40%	58%
Dry Gulch	5/7/2015	181	155	138	134	133	0.43	0.67	14%	24%	26%	26%
Dry Gulch	6/5/2015	208	152	131	133	130	0.40	1.97	27%	37%	36%	37%
Dry Gulch	6/12/2015	255	244	238	192	224	0.70	0.53	4%	7%	25%	12%
Dry Gulch	7/8/2015	102	105	104	88	97	0.37	0.31	3%	2%	14%	4%
Little Dry (arapahoe)	8/3/2013	327	323	379	249	300	0.55	1.39	1%	16%	24%	8%
Little Dry (arapahoe)	8/9/2013	283	351	420	278	342	0.59	1.30	24%	48%	2%	21%
Little Dry (arapahoe)	7/14/2014	442	993	1,189	726	885	0.84	3.43	125%	169%	64%	100%
Little Dry (arapahoe)	8/7/2014	285	324	365	236	276	0.42	2.23	14%	28%	17%	3%
Little Dry (arapahoe)	9/29/2014	369	237	246	168	186	0.35	1.57	36%	33%	54%	50%
Little Dry (arapahoe)	6/11/2015	605	484	922	398	775	1.39	1.37	20%	52%	34%	28%
Little Dry (arapahoe)	7/18/2015	122	183	193	135	150	0.33	1.33	50%	58%	11%	23%
Little Dry (arapahoe)	8/10/2015	487	707	799	568	669	0.90	1.69	45%	64%	17%	37%
Little Dry (arapahoe)	6/6/2016	317	559	630	445	529	0.80	1.43	76%	99%	40%	67%
Little Dry (arapahoe)	8/3/2016	160	267	307	203	242	0.41	1.20	67%	92%	27%	51%
Average of All Storms		412	536	584	437	461			30%	42%	6%	12%
Geometric Mean of All Error (%)									27%	33%	27%	26%
Standard Deviation of all Error (%)									43%	49%	28%	31%
This accounts for positive and negative error values. Average Error (%) (+ & -)									30%	40%	5%	12%

	CUHP 1.4.4		Proposed CUHP	
	Large Basins	Small Basins	Large Basins	Small Basins
Percent of Time Computed Values are Greater than Recorded Values	61%	72%	42%	53%

Notes: HEC HMS Manual Chapter 9 references Error in Peak is Found with:

$$Z = 100 \left| \frac{q_s(peak) - q_o(peak)}{q_o(peak)} \right|$$

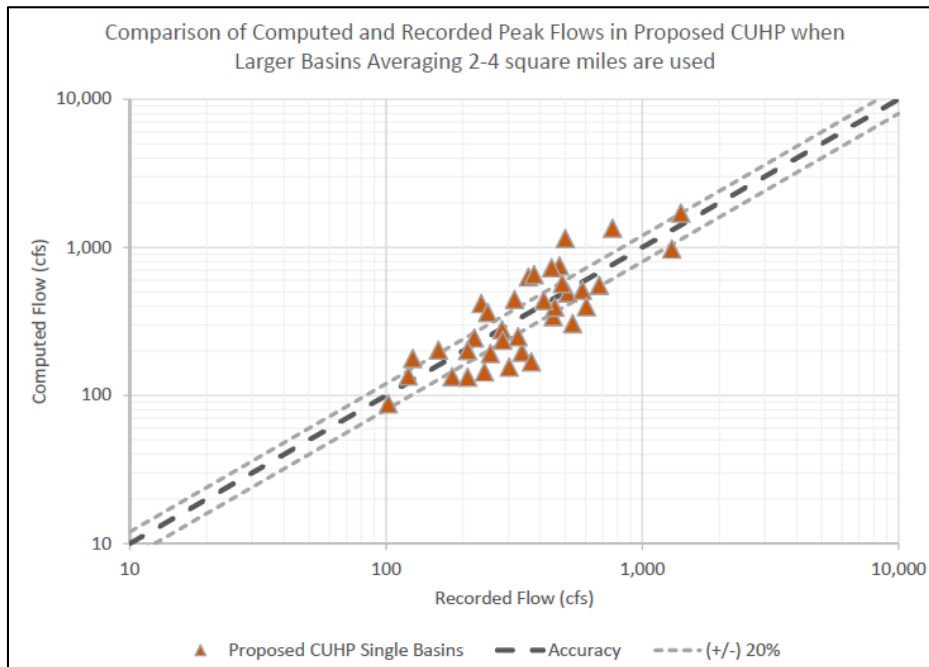
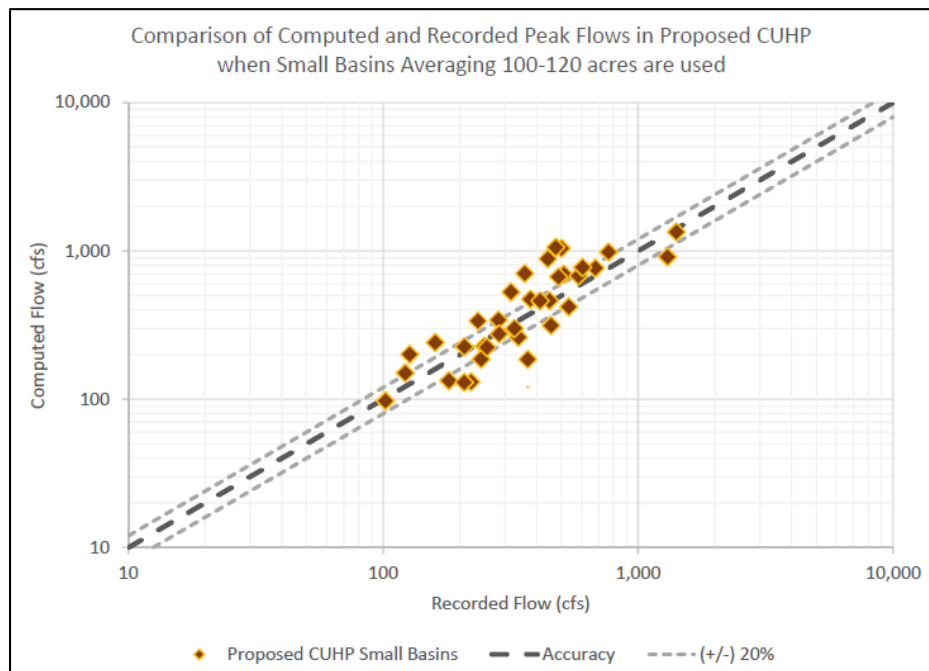


Figure 4 – Accuracy Plots of Proposed CUHP Calibration Testing for both smaller CUHP Basins Routed Via SWMM5’s Kinematic Wave Method (Top) and larger CUHP Basins ranging from 2 to 4 square miles. (+/- 20%) Bands are included to represent potential gage error that is innate with stream gage networks.

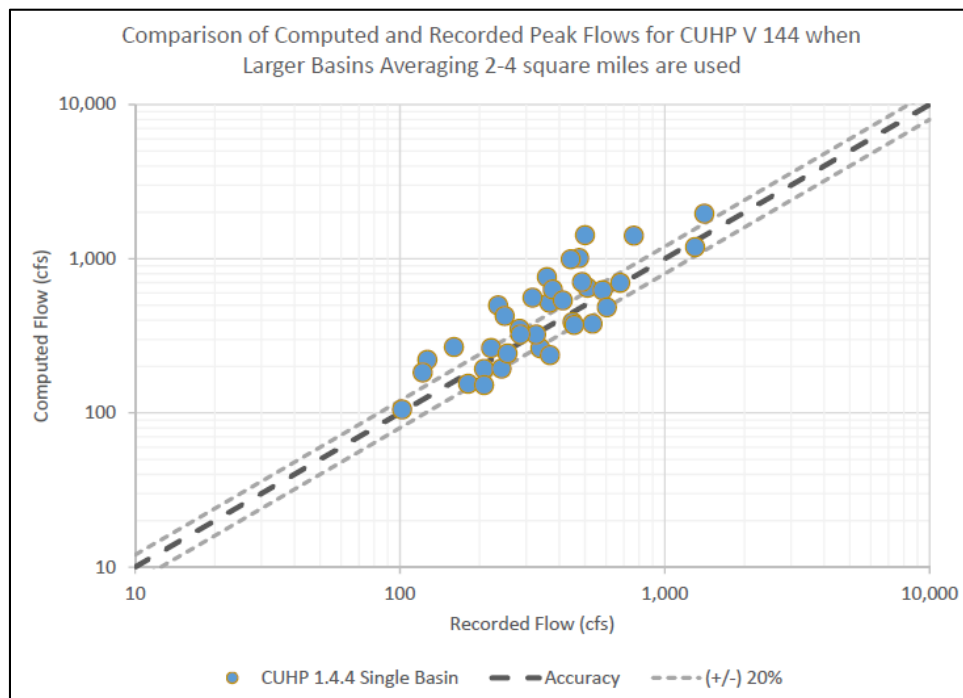
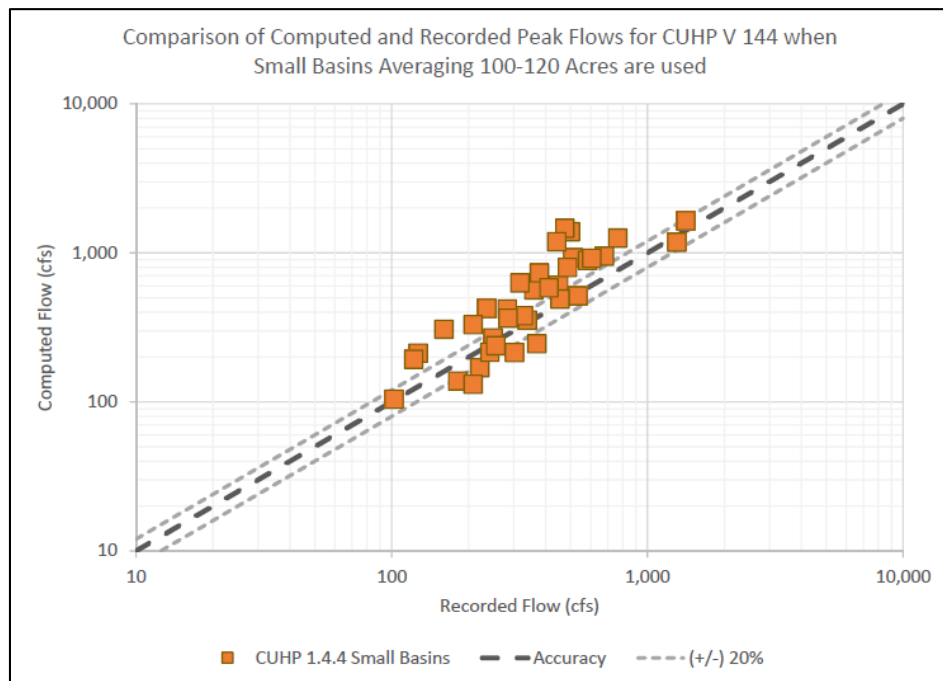


Figure 5 – Comparison of CUHP 1.4.4 with small basins (Top) and Large Basins (bottom). Note that almost all values sit at or above the line of accuracy.

COMPARISON OF DESIGN STORMS AND GAGE FREQUENCY

Goldsmith at Eastman

The below graph compares a Log Pearson III gage frequency analysis and the computed flow rates from CUHP 1.4.4 and Proposed CUHP.

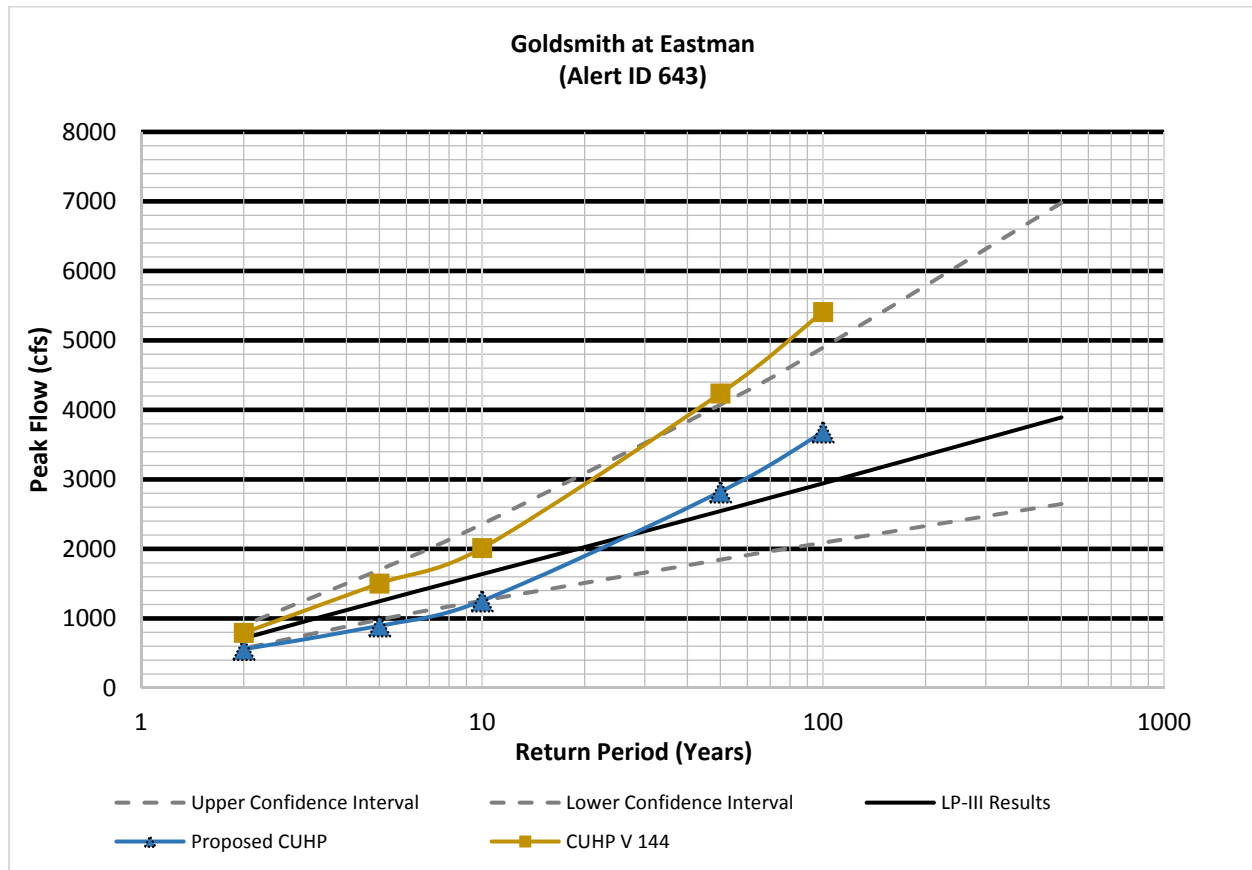


Figure 6 – Frequency Testing of Goldsmith Gulch Gage

Harvard Gulch

The 2015 Major Drainageway Planning (MDP) Model was used as a comparison for the small CUHP Basins and a larger, single basin model was developed for Upper Harvard Gulch. This study applied eight (8) GARR events in addition to the 2, 5, 10, 50, and 100-year storm frequency design events for testing. Multiple 2D hydraulic scenarios were performed using the most up to date LiDAR to determine the likelihood of the canal spilling during storm events. If the canal is running full during a storm, there is a possibility that some spilling occurs at a few locations in the upper Harvard gulch watershed.



Figure 7 - Image of 2D Rain on Grid Model of Upper Harvard Gulch at the Highline Canal

The below graph compares the values from the Proposed CUHP, CUHP Version 1.4.4, and the MDP CUHP model that included adjusted C_p values. All are compared with the Log Pearson III Statistical Gage Analysis for the USGS Stream Gage upstream of Jackson Street and also at Harvard Park.

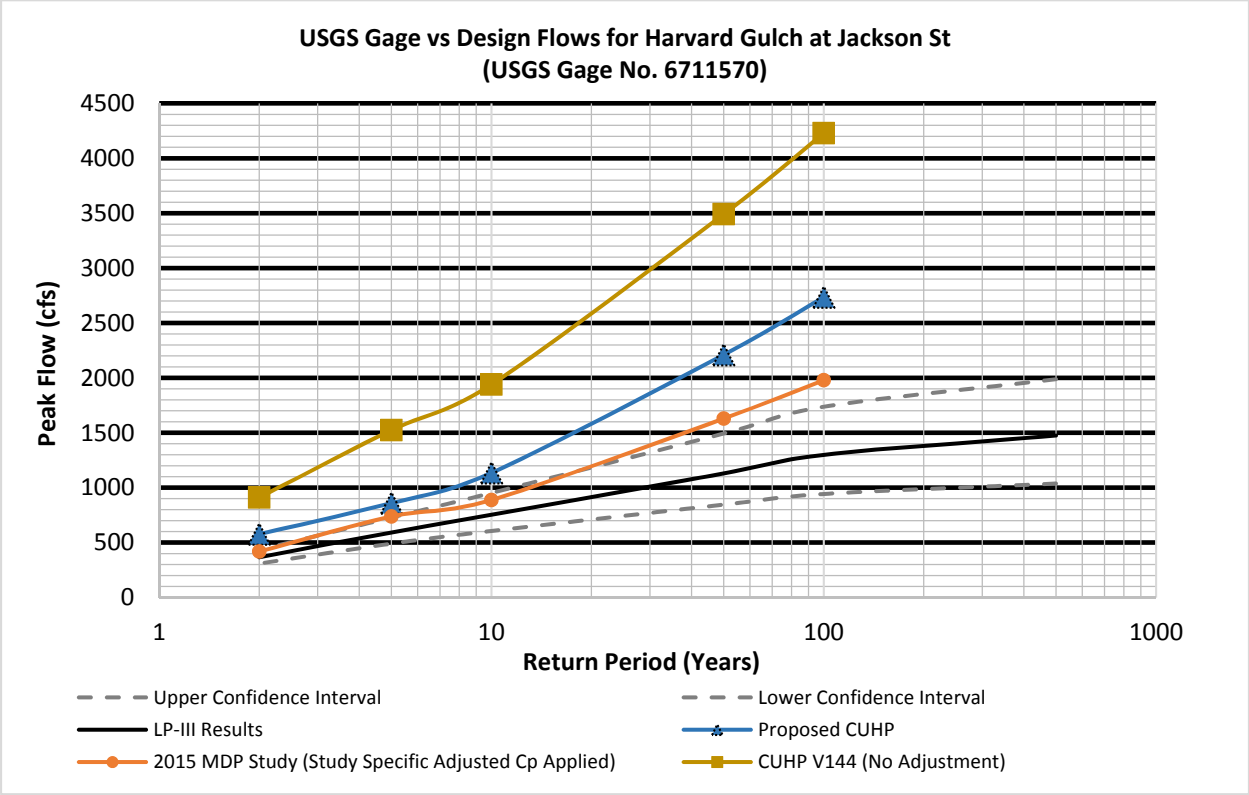


Figure 8 - Gage Frequency Comparison for Upper Harvard Gulch at Jackson St (Note 2015 MDP Has Study Specific Cp and Ct)

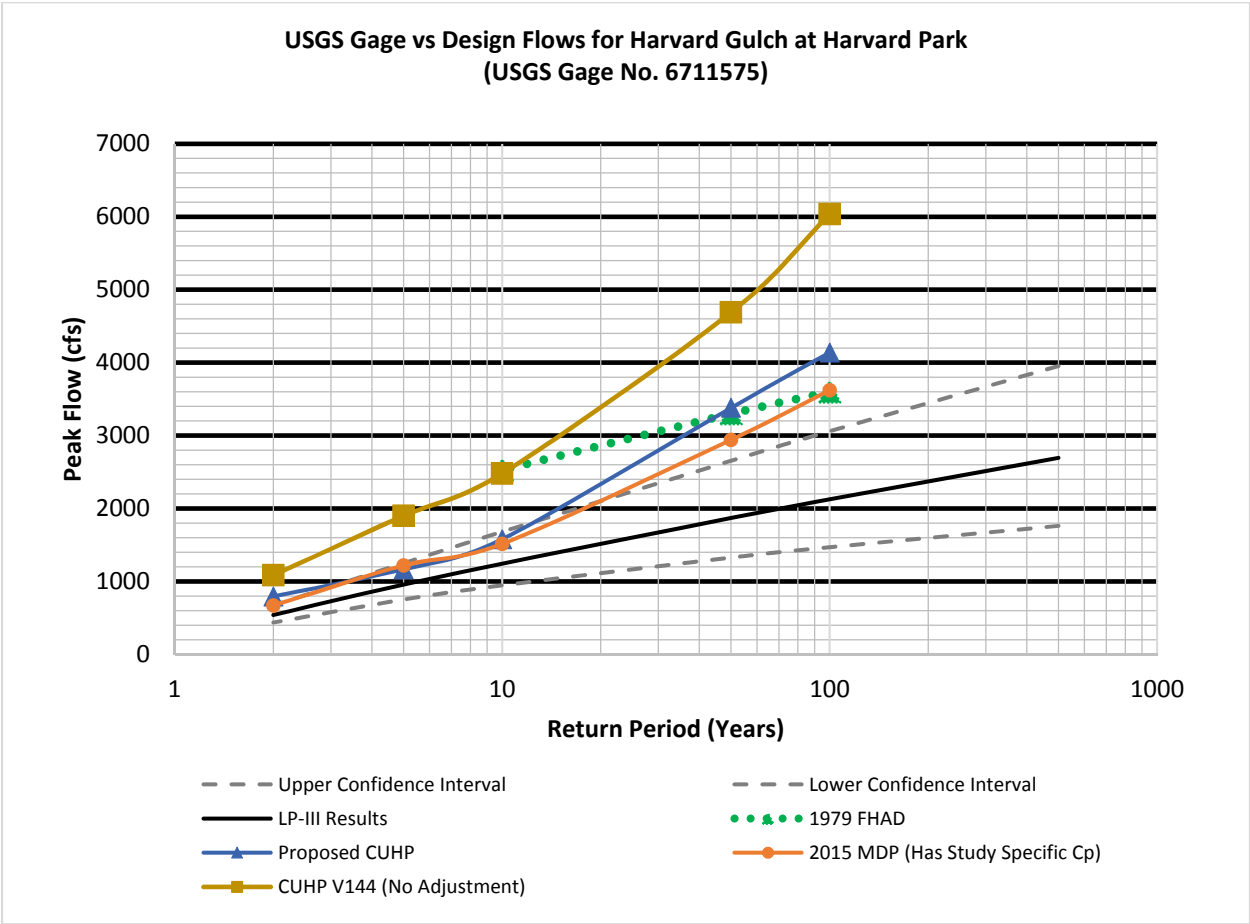


Figure 9 - Frequency Comparison for Harvard Gulch at Harvard Park

Willow Creek

The Willow Creek MDP adjusted the directly connected and receiving portions of CUHP's rainfall loss functions to adjust the reported peak flows. Additionally, the model modified Manning's n values to further refine the peak flows in the study. The resulting MDP flows fall within the bounds of a Log Pearson III statistical analysis. Presented below are the results from the 2008 MDP model, results from CUHP 1.4.4 without any calibration, and then the results of the Proposed CUHP version all compared to a Log Pearson III Statistical Distribution of the Willow Creek Stream Gage.

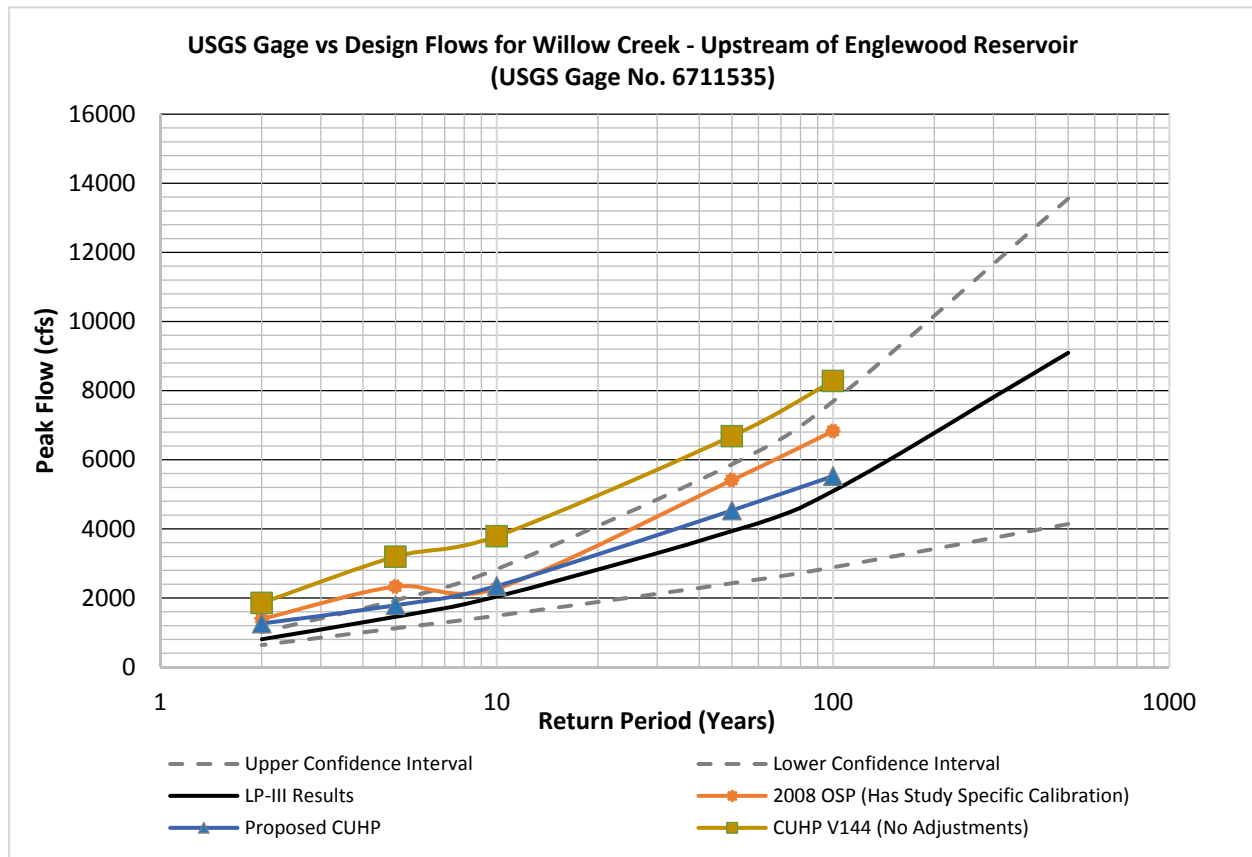


Figure 10 Frequency Testing for Willow Creek

Little Dry Creek near Arapahoe Rd

The gage at Little Dry Creek near Arapahoe Road was tested with many alternatives. This gage monitors flows from relatively dense development that consists of commercial and residential development. A hydrologic model was developed with sub-watersheds were to an average of 54 acres to test the performance of CUHP with small, developed basins. A 2D Diffusive wave and SWMM5 Overland Flow Kinematic Wave model was also developed, however, those results are not relevant for this report and are not discussed further. Figure 1 below is caption of the watershed above Little Dry Creek near Arapahoe Rd.

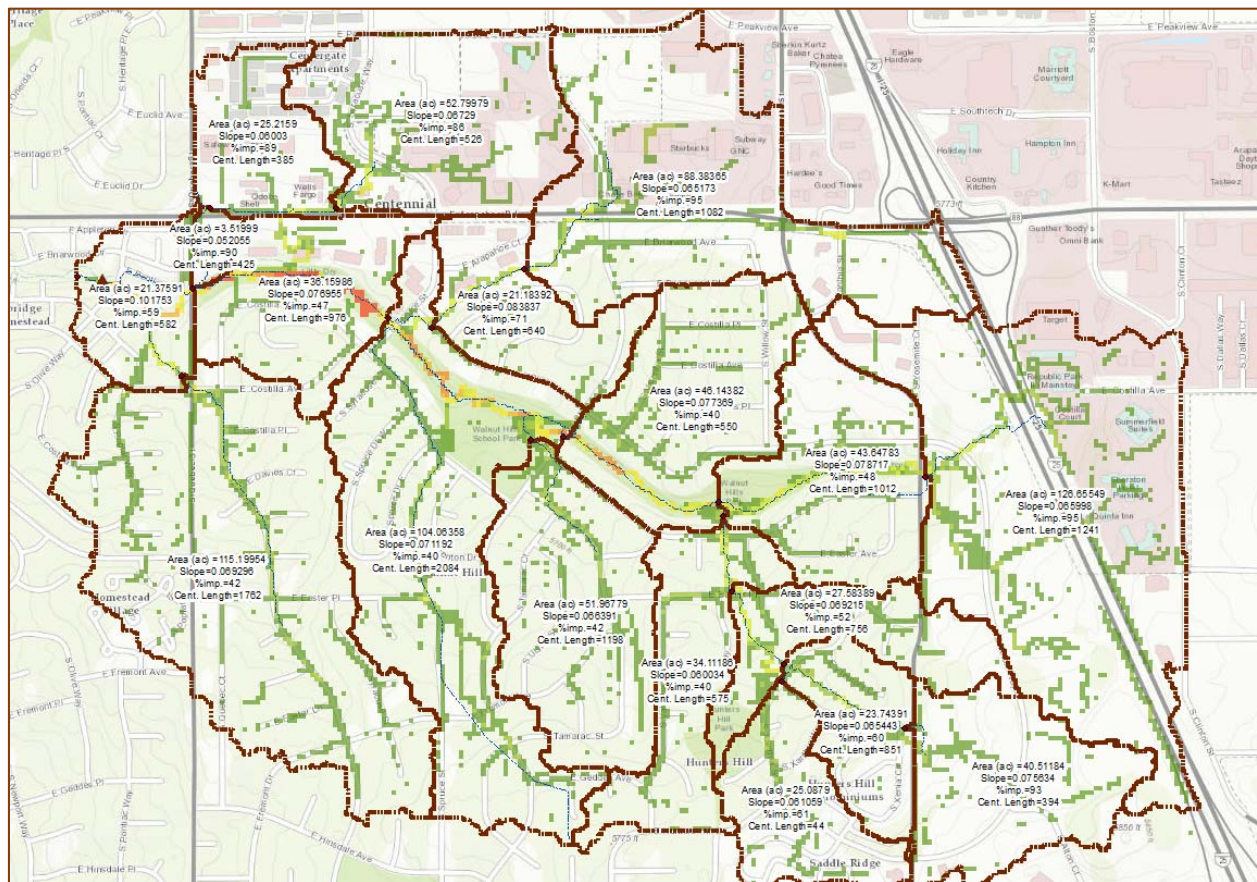


Figure 11 - Image of LDC Arapahoe Basins and 2D Flow Grid

The flow history of this gage goes back to 1985, and serves as a good gage for frequency testing since it is relatively un-influenced by major detention facilities, has a decent length of record, and is not influenced by

backwater at the gage location. As shown in the figure below, the Proposed Version of CUHP still sits above the gage frequency curve and provides a conservative estimate of design flows at this gage.

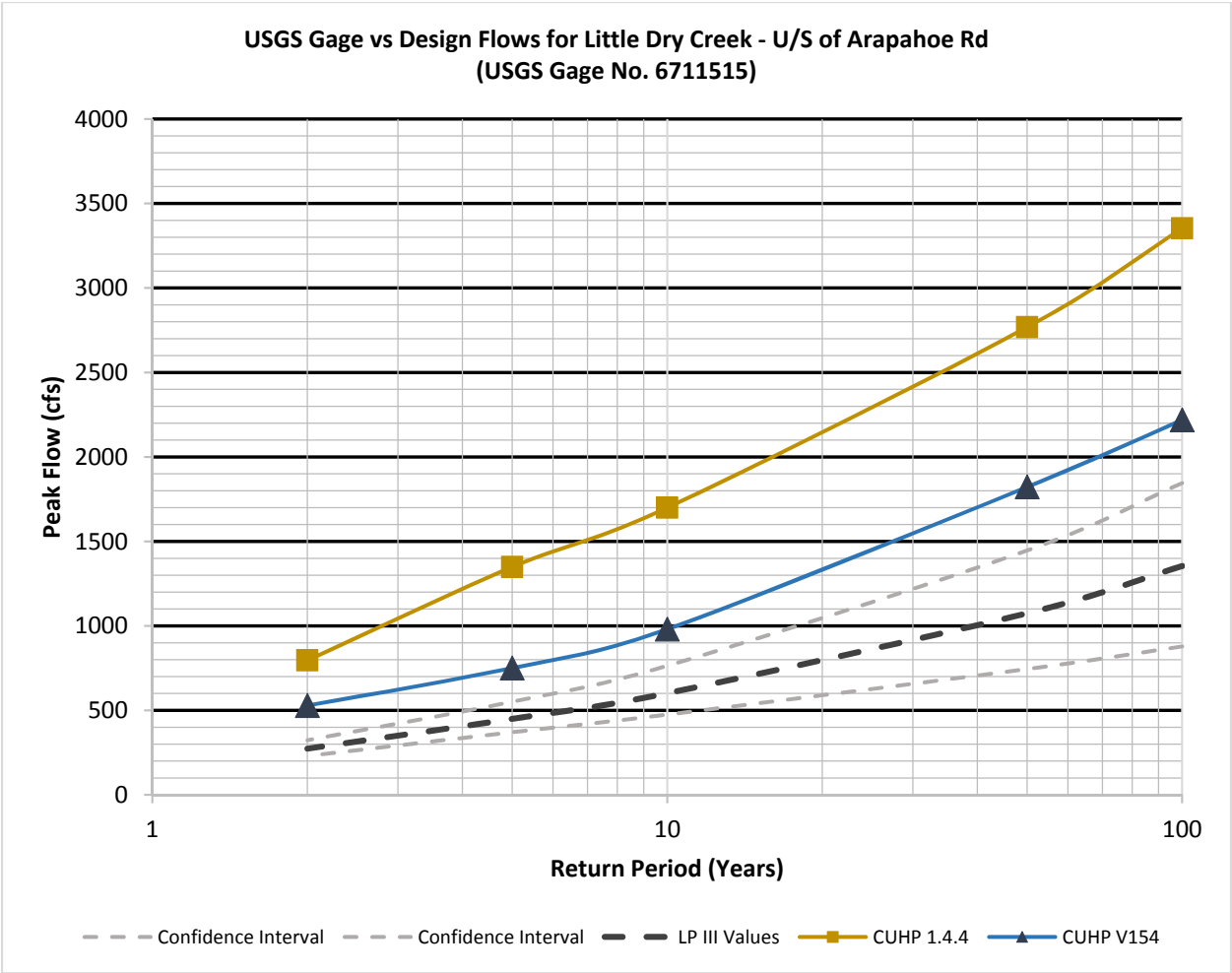


Figure 12 - Gage Frequency for Little Dry u/s of Holly Reservoir near Arapahoe Rd

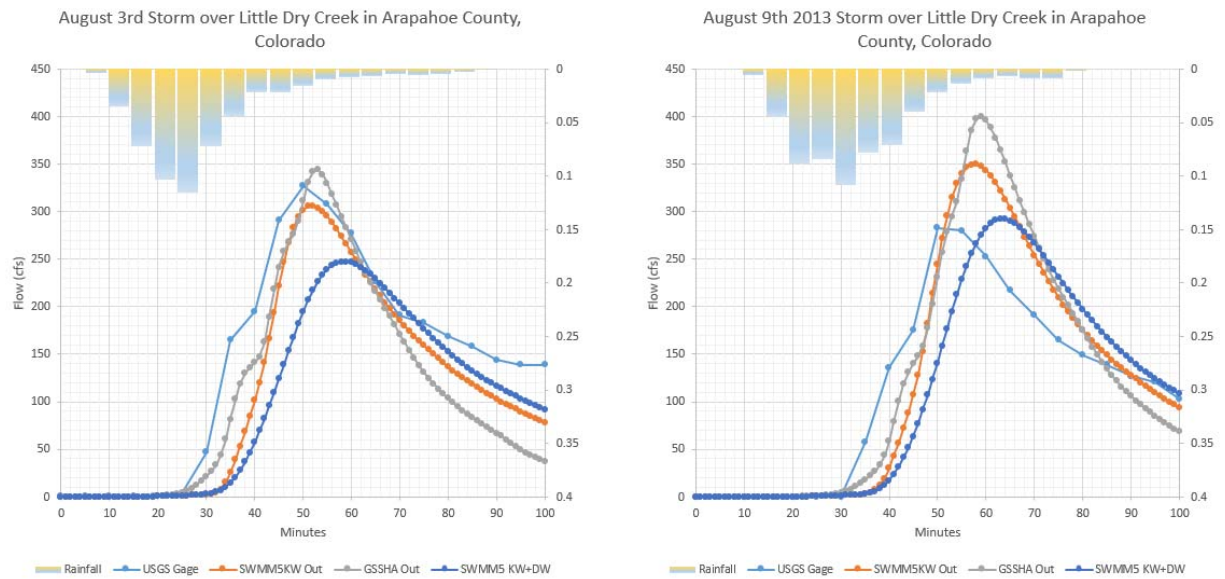
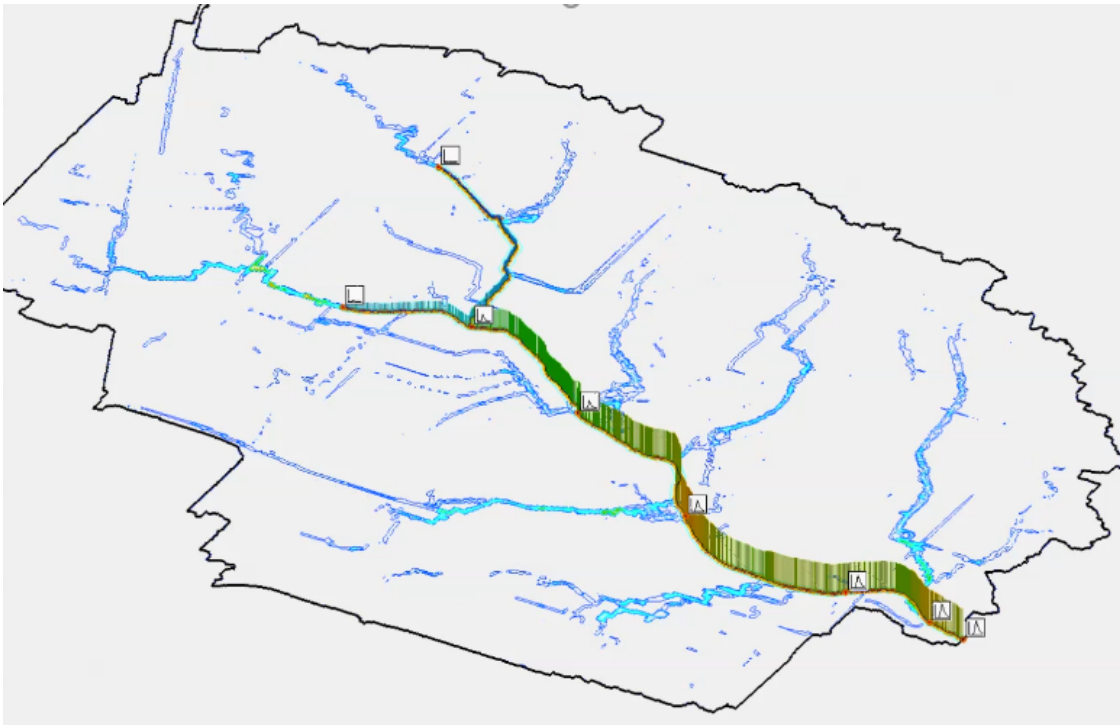


Figure 13 - Image of 2D Diffusive Wave, Kinematic Wave, and Dynamic Wave Testing on LDC near Arapahoe Rd

Dutch Creek at Platte Canyon Rd

Dutch Creek was compared due to the large difference between the existing major drainageway plan and the gage frequency curve. After analyzing the effects of routing in this basin, it was noted that there are a few locations that contain storage facilities that aren't qualified to be included in the regional hydrologic model since they're not formal detention. The image below highlights the Dutch Creek Watershed and the orange circles present the numerous formal and informal detention facilities that have a large effect on the gage's frequency analysis.

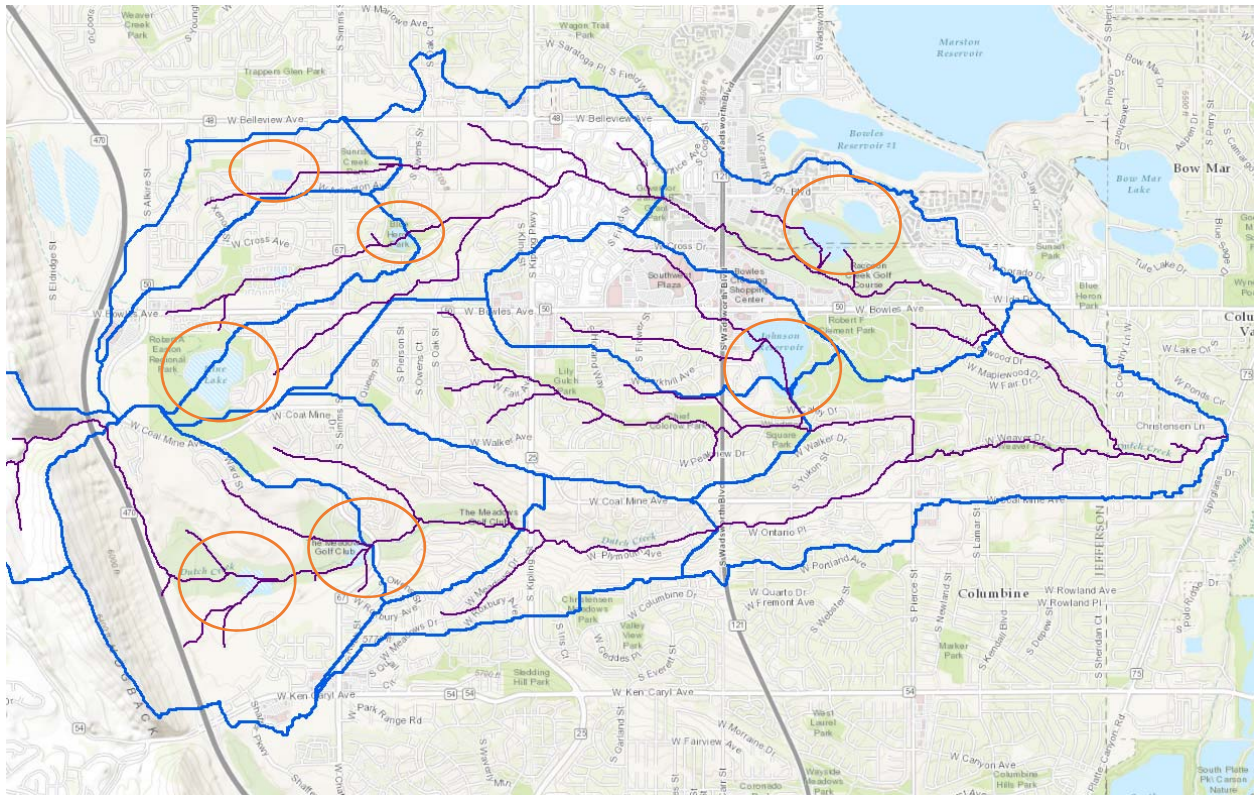


Figure 14 - Dutch Creek Watershed and Numerous Detention Locations

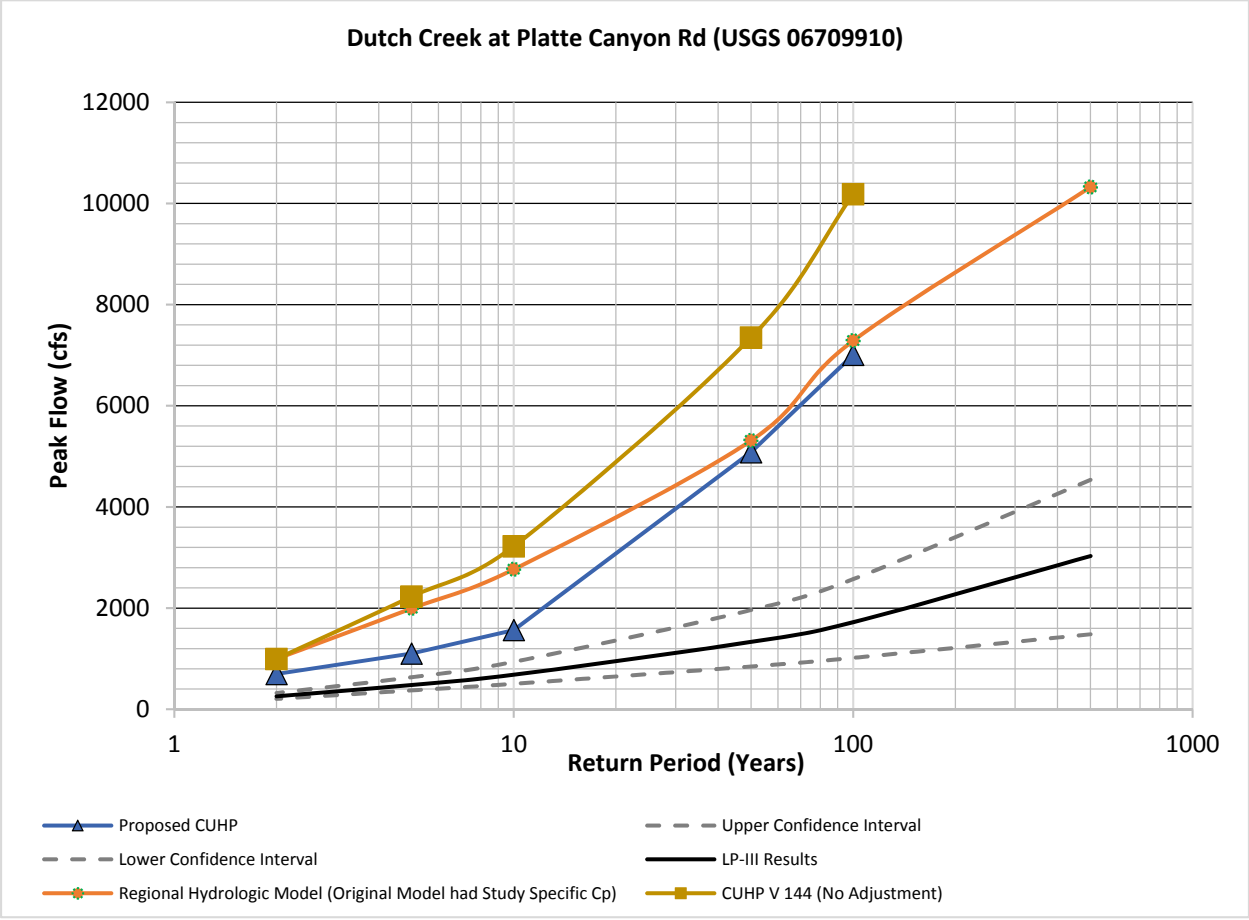


Figure 15 - Dutch Creek Frequency Curve

North Sanderson Gulch in Lakewood (Upstream of Wadsworth)

North Sanderson Gulch in Lakewood was originally selected for rainfall and runoff calibration but the gage record is not recent enough to compare with GARR rainfall. However, the basin is a good basin for frequency comparison because it is relatively small, has limited detention, and is mostly developed with residential neighborhoods and planned open spaces.

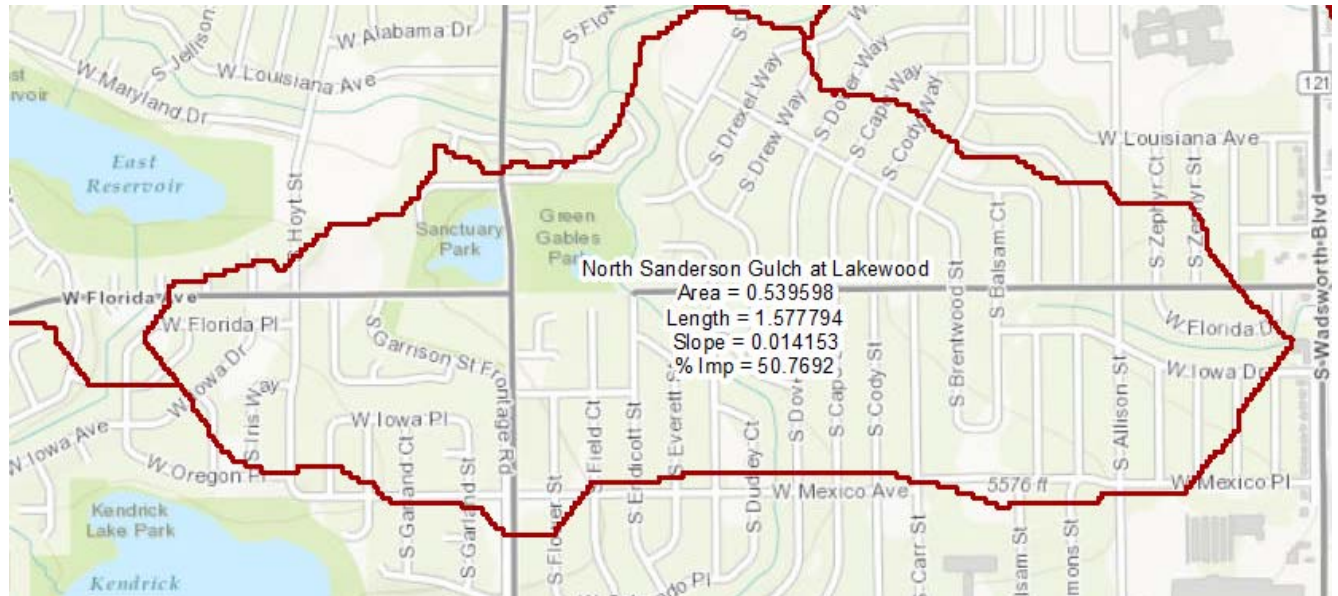


Figure 16 - Sanderson Gulch at Lakewood Upstream of Wadsworth

As presented below, the Proposed Version of CUHP sits near the upper confidence interval of the frequency analysis.

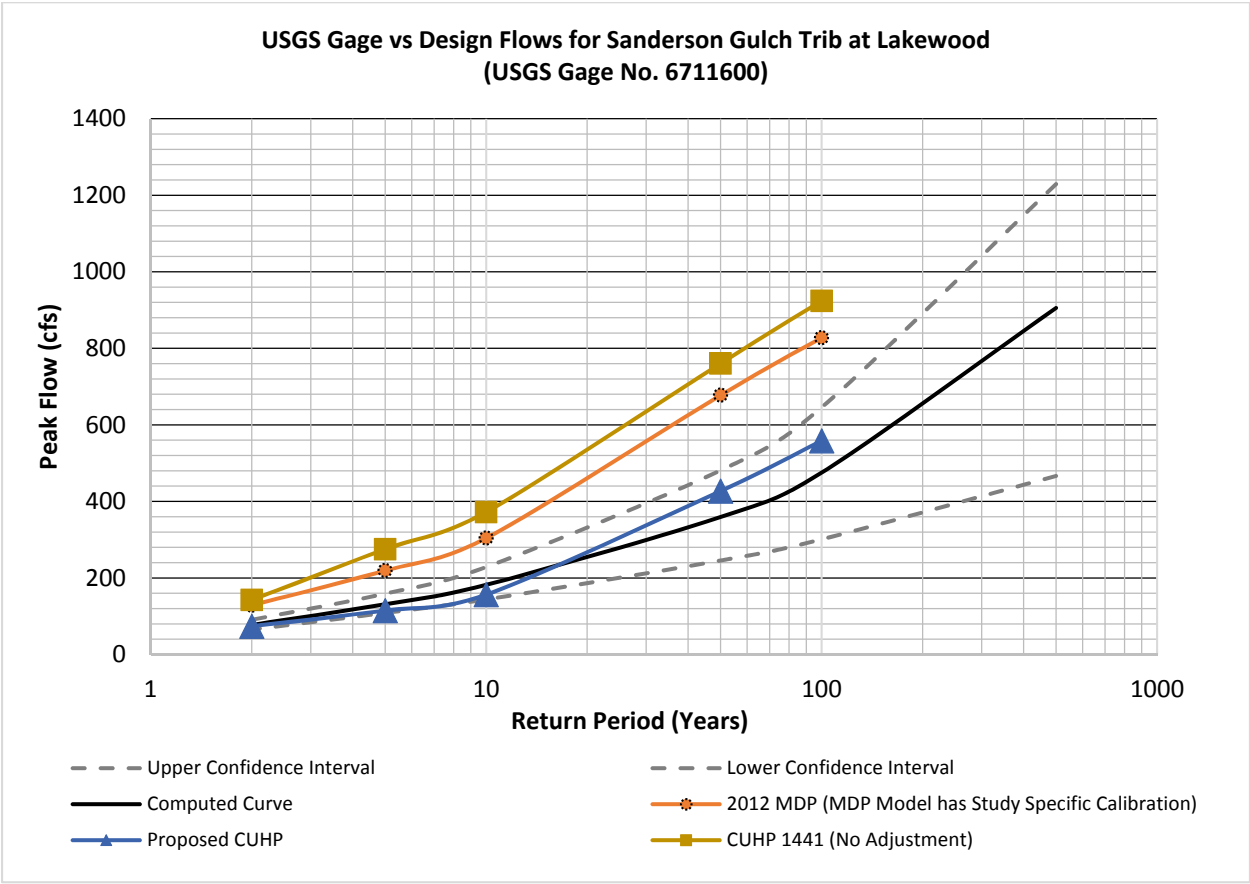


Figure 17 - Frequency Curve for North Sanderson Gulch above Wadsworth

Dry Gulch at Denver

Dry Gulch in Denver begins in Lakewood Colorado upstream of Colfax and Simms St and progresses through a series of urban, mostly residential drainages until the USGS gage at Perry Street just north of 10th Avenue in Denver, CO. The 1995 OSP Phase B had a design discharge of 2,200 cfs for the 100 year flow. There is an ongoing master plan update during the time of this study and the values in the graph below may vary from that update depending on modeling details.

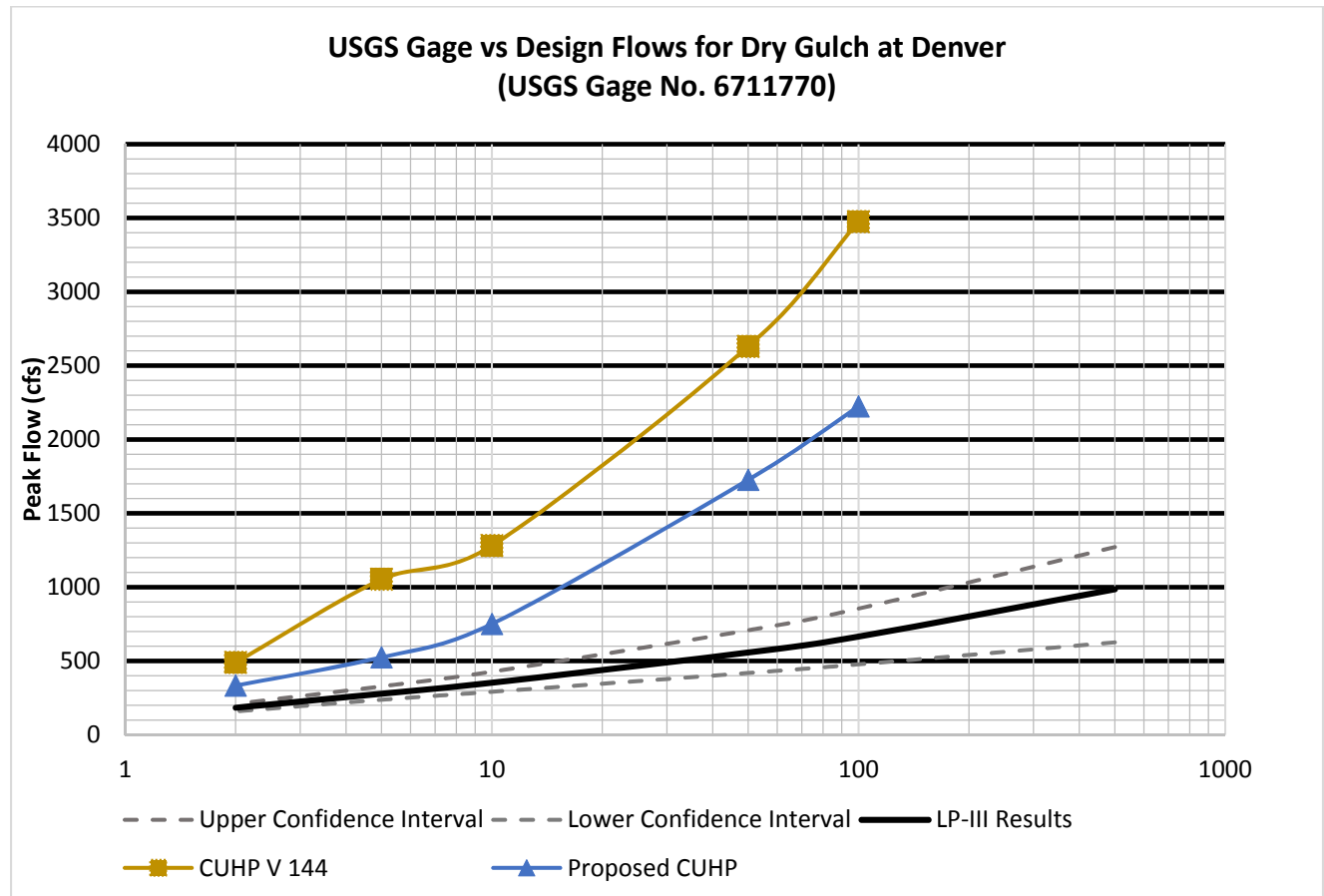


Figure 18 – Frequency Curve for Dry Gulch in Denver, CO at Perry St. North of 10th Ave.

HYDROGRAPH TIMING

This re-calibration effort made modifications to the timing coefficients for small sub-catchments and subsequently required testing of the hydrograph timing between rainfall and recorded flows at the stream gage. Table 3 and the Figures below present the hydrograph timing from the beginning of a recorded storm event to the peak of the flow hydrograph and the time to peak from the beginning of the hydrograph to the hydrograph peak.

Table 3 - Comparison of Hydrograph Timing at Little Dry Creek USGS Gage

Storm ID	Beginning of Storm	Total Depth	Proposed Version of CUHP		USGS Gage at Little Dry Creek above Arapahoe Rd	
			Time to Peak from beginning of Hydrograph (Minutes)	Time to Peak from Beginning of Storm (Minutes)	Time to Peak from beginning of Hydrograph (Minutes)	Time to Peak from Beginning of Storm (Minutes)
Storm 1	2013-08-03 19:15	0.551	36	51	35	50
Storm 2	2013-08-09 15:25	0.591	32	52	25	50
Storm 3	2014-07-14 21:30	0.835	27	82	30	80
Storm 4	2014-08-07 12:30	0.416	27	42	30	35
Storm 5	2014-09-29 14:10	0.349	24	50	25	40
Storm 6	2015-06-11 17:25	1.388	41	86	50	90
Storm 7	2015-07-18 16:10	0.326	32	62	35	65
Storm 8	2015-08-10 13:20	0.903	38	88	40	85
Storm 9	2016-08-03 18:20	0.405	24	99	25	95

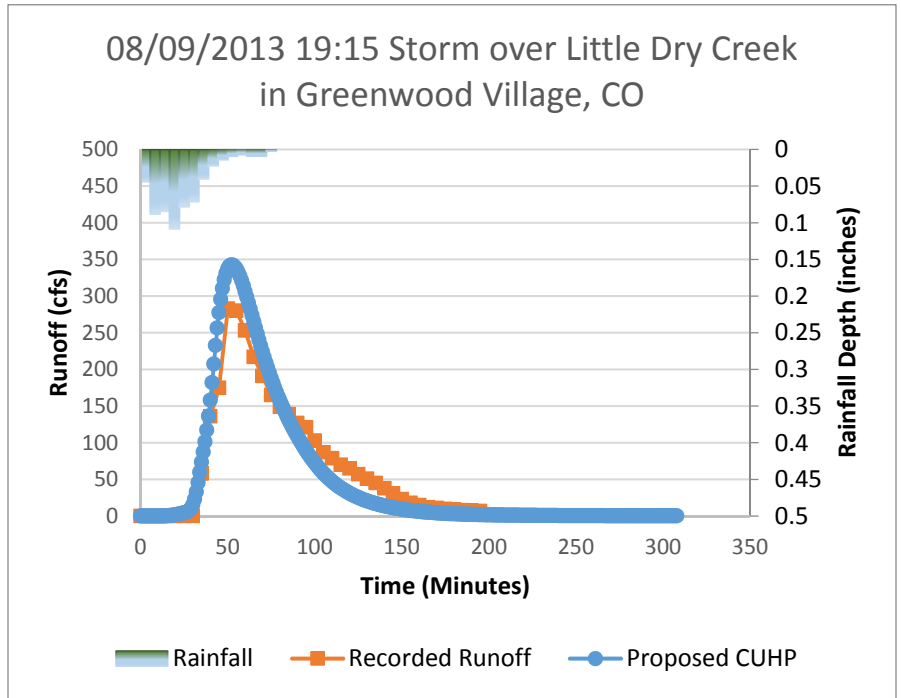
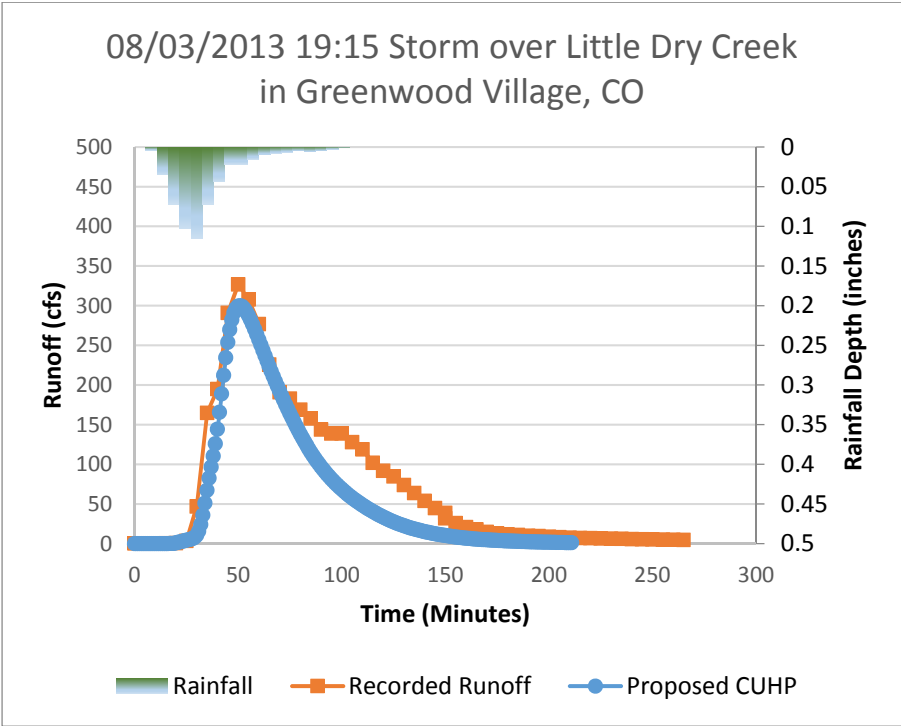


Figure 19 – Recorded and Predicted Hydrographs showing Hydrograph Timing

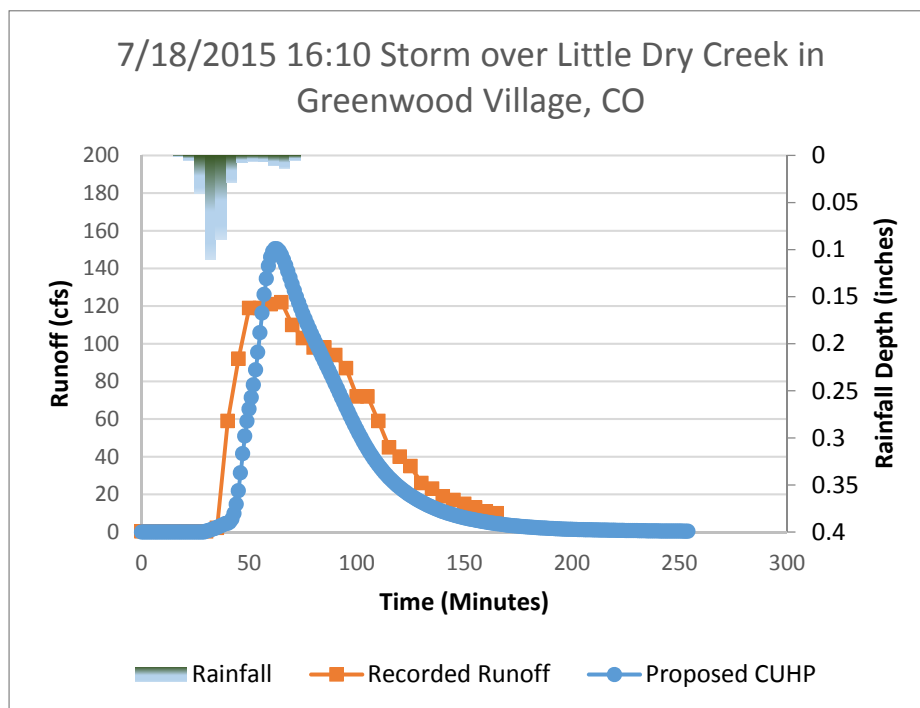
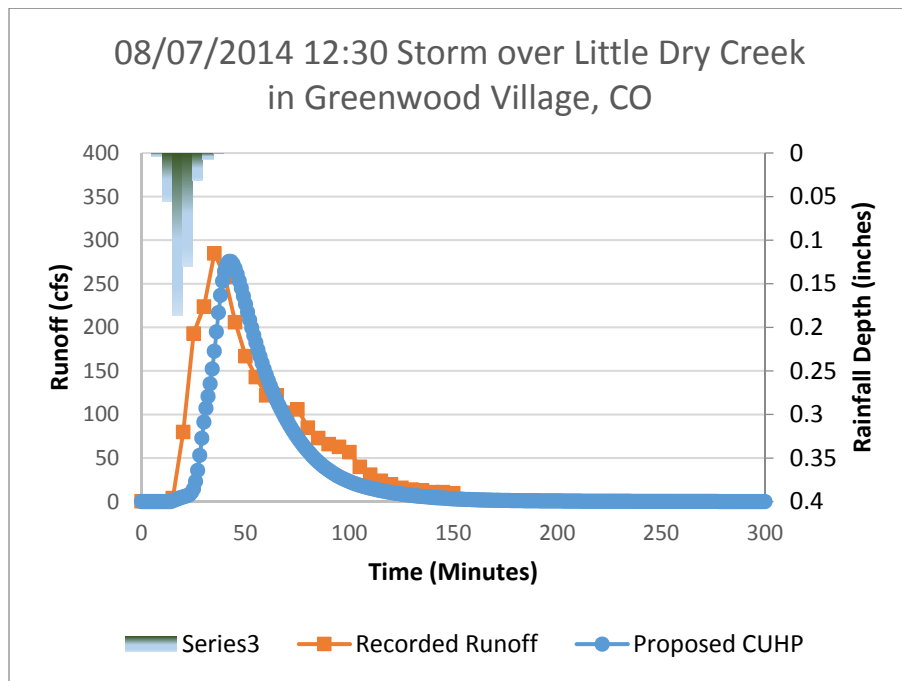


Figure 20 - Recorded and Predicted Hydrographs showing Hydrograph Timing

TESTING BETWEEN THE PROPOSED CUHP AND RATIONAL METHOD

Modifications to CUHP within this summary report adjusted how CUHP computes the peak flows for urban drainage basins. A comparison between the commonly applied Rational Method was tested to ensure that the peaking within the proposed changes did not dramatically alter the expected flows between the Rational Method described within the District's Criteria Manual and the proposed version of CUHP. Preliminary testing between the two methods considered a hypothetical basin that is twice as long as it is wide. Overland and channel flow times were developed based on equations within the UDFCD Manual. The figure below is a layout of the hypothetical basin used for this comparison.

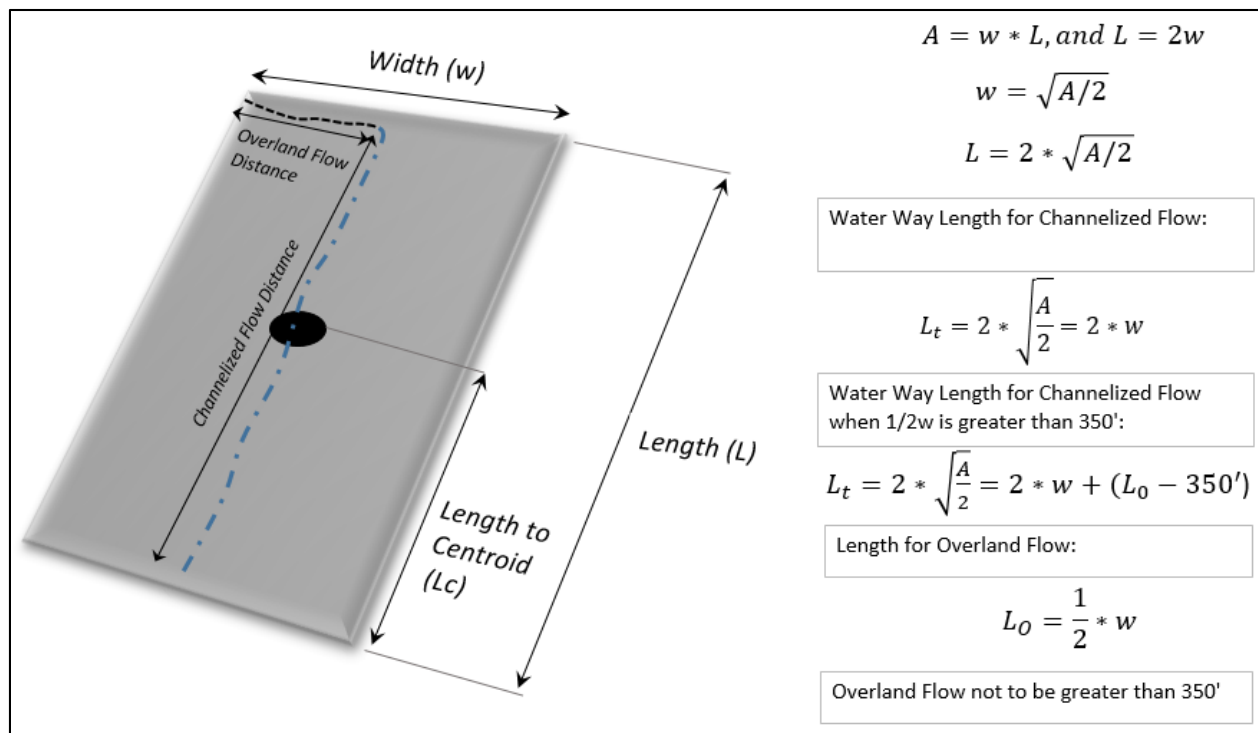


Figure 21 – Characteristic Watershed for Rational Method Testing

The time of concentration for the rational method was developed by computing overland flow and channel flow times as presented in the Equations below:

Time of concentration (t_c) is found with,

$$t_c = t_i + t_t \quad (6)$$

Where (t_i) is the overland flow time computed by,

$$t_i = \frac{0.395(1.1 - C_5)\sqrt{L}}{S_o^{0.33}} \quad (7)$$

Where C_5 is the 5 year runoff coefficient, S_o is the flow slope, and L is the overland flow length not to exceed 350 feet (Guo 2006). Travel time in the main flow path was computed by,

$$t_t = \frac{L_t}{60K\sqrt{S_o}} = \frac{L_t}{60V_t} \quad (8)$$

Where, K is the conveyance coefficient, V is the approximate flow velocity, and S_o is the channel slope. In the figure below, peak flow rates between the Proposed CUHP and the District's Rational Method are compared. As shown, the Rational Method trends a bit higher than the Proposed CUHP, however, the differences are not large. Further testing between the two methods may be warranted. Additionally, adjustments to the Rational Method that were made to match previous versions of CUHP may need to be revisited.

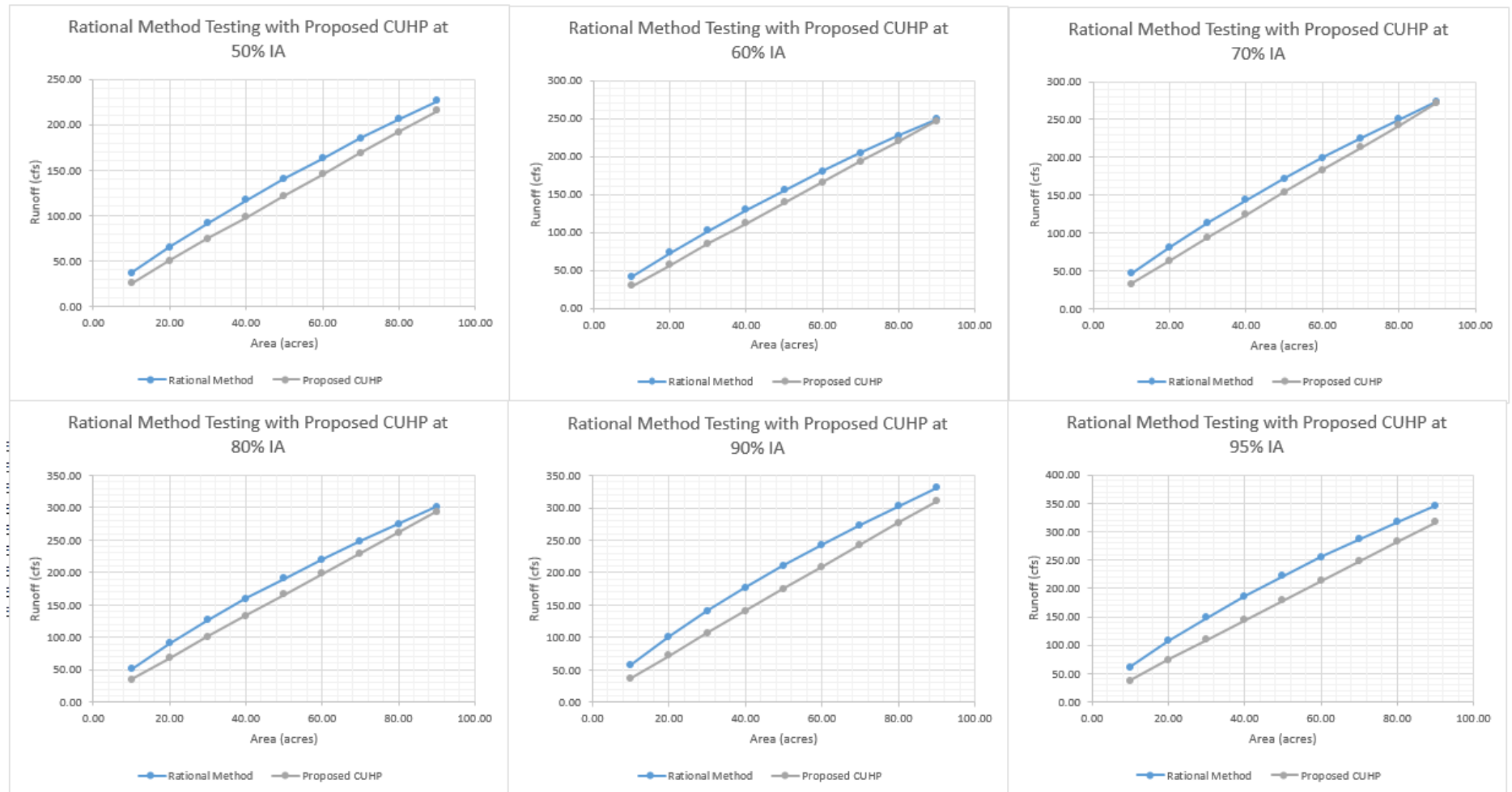


Figure 22 – Comparison of the Rational Method as Described in UDFCD’s Criteria Manual with the Proposed CUHP for Imperviousness Values between 50% and 95%

RECOMMENDATIONS AND CONCLUSIONS

Changes to CUHP proposed within this report will lower peak flow rates for almost all studies across the District. However, as shown through comparison of gage frequency analysis, values produced with the proposed version of CUHP will still be conservative in most cases when compared to gage frequency estimates. Work performed through calibration found that CUHP Version 1.4.4 is statistically within range of recorded rainfall and runoff. However, Version 1.4.4 more often produced results higher than the recorded flow when compared to the proposed version of CUHP. Additionally, the proposed version of CUHP will trend more closely with gage frequency estimates than Version 1.4.4. In order to match both recorded rainfall and runoff values and gage frequency estimates, the most recently published 1 hour precipitation depths found in NOAA's Atlas 14 Precipitation Frequency Estimates are recommended. Adopting the most recently published rainfall depths to trend CUHP more in line with gage frequency estimates was recommended over adjustments to the temporal distribution of the UDFCD design storm.

In summary, recommendations from this project are for the District to adopt the following changes:

- Modify the equations within CUHP to be more in line with the recorded rainfall and runoff record analyzed through this study. Additionally, these modifications place design frequency closer to gage frequency analysis for clean, developed basins with a good gage record.
- Adopt NOAA's rainfall atlas Volume 14 for point precipitation depths within the District. Without this adoption, CUHP will remain higher when compared to frequency analysis at trusted gages.

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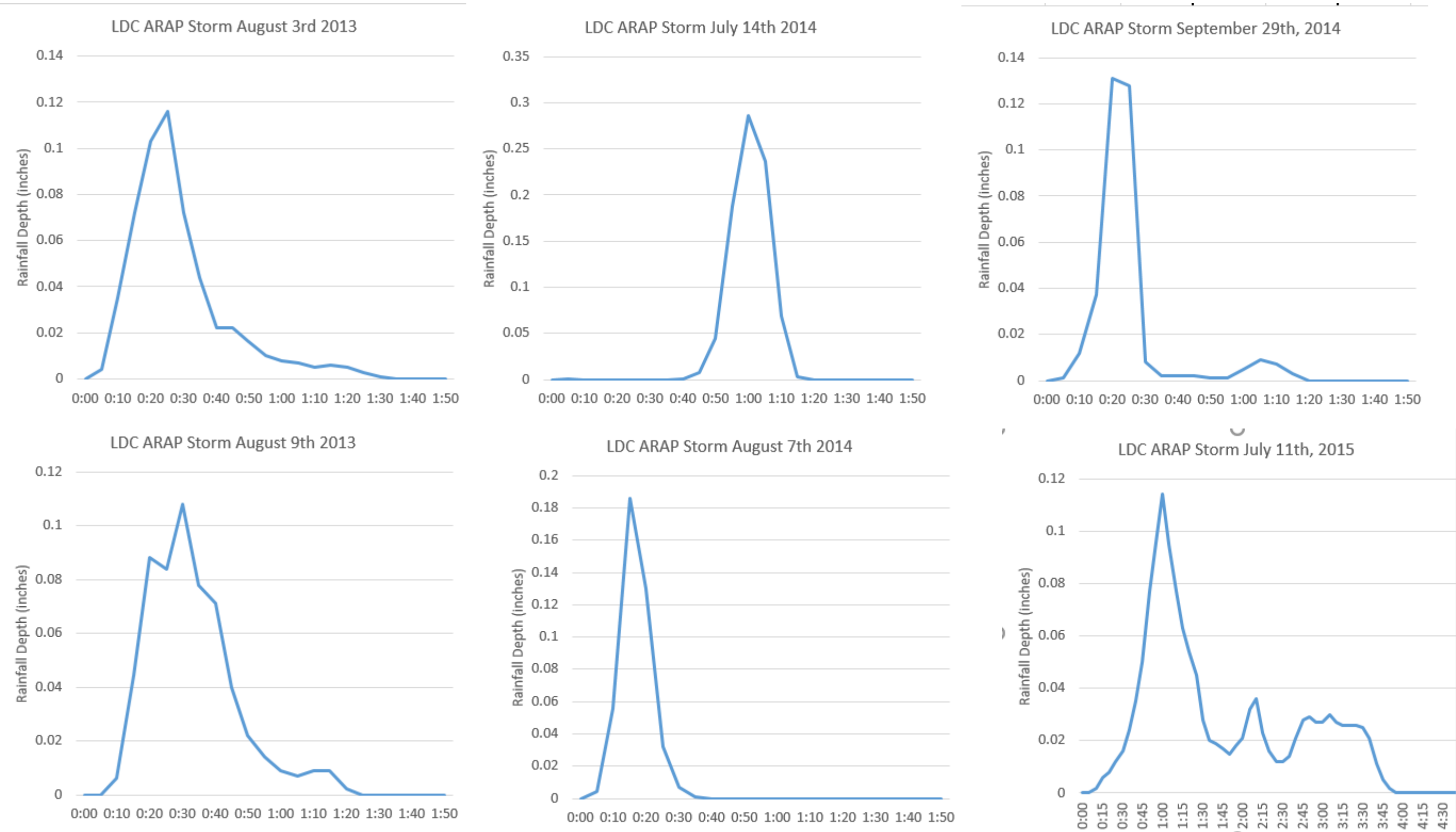
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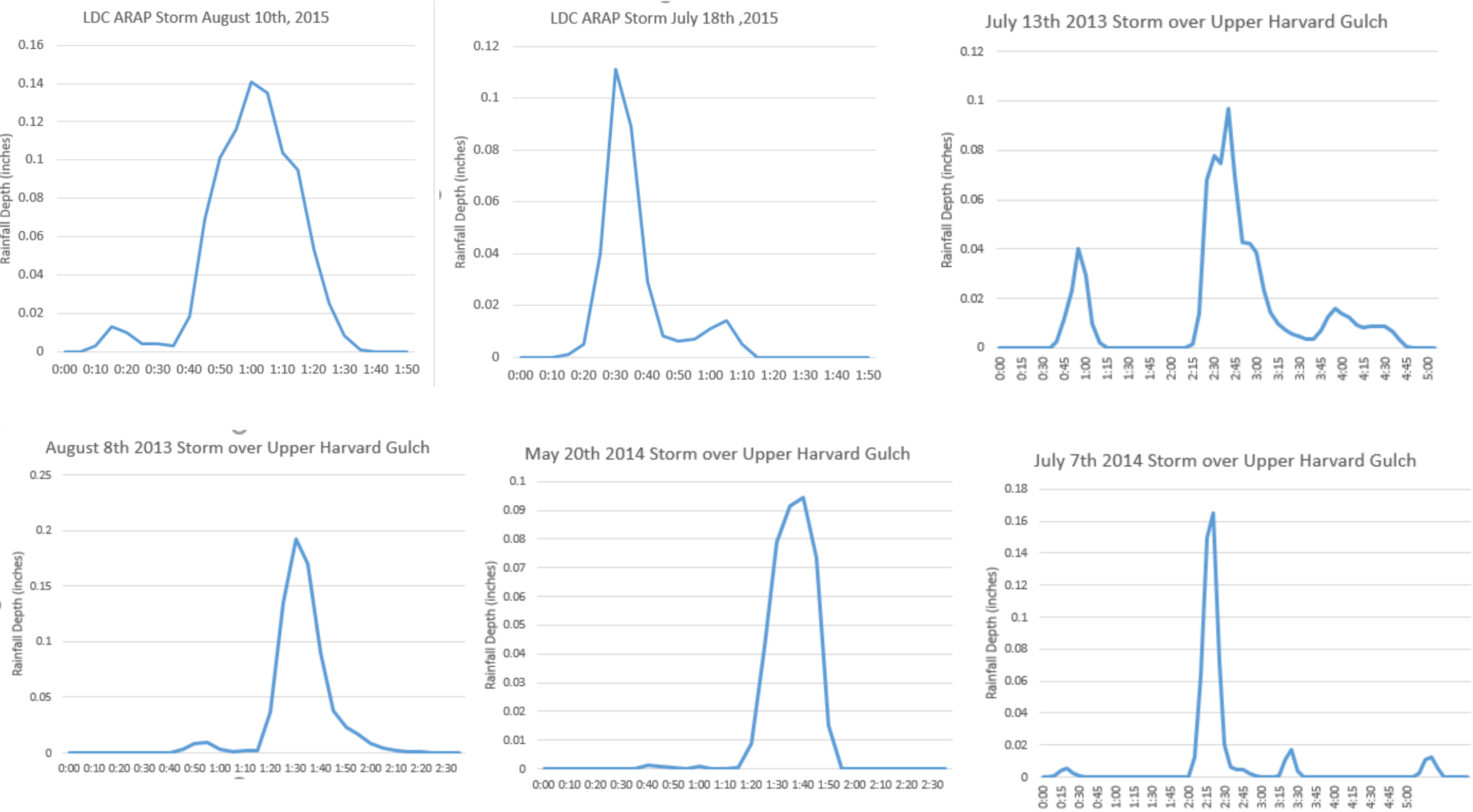
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Appendix A – GARR Rainfall Hyetographs

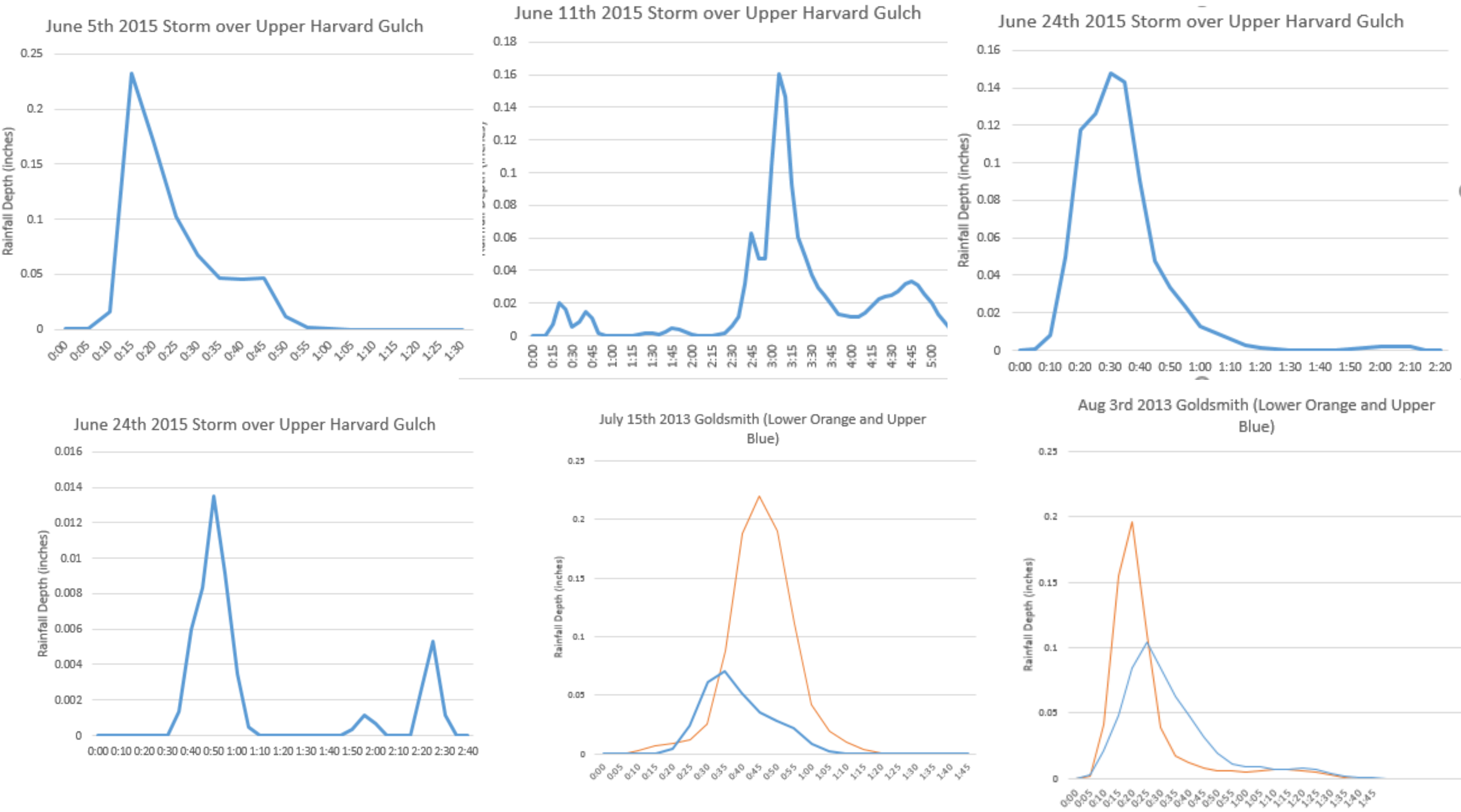
This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis



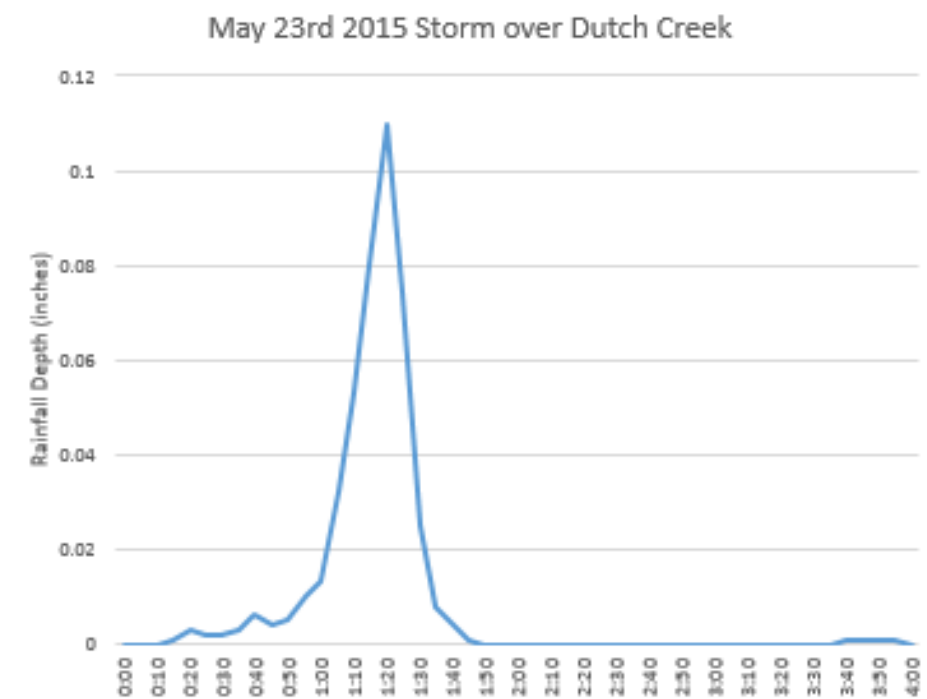
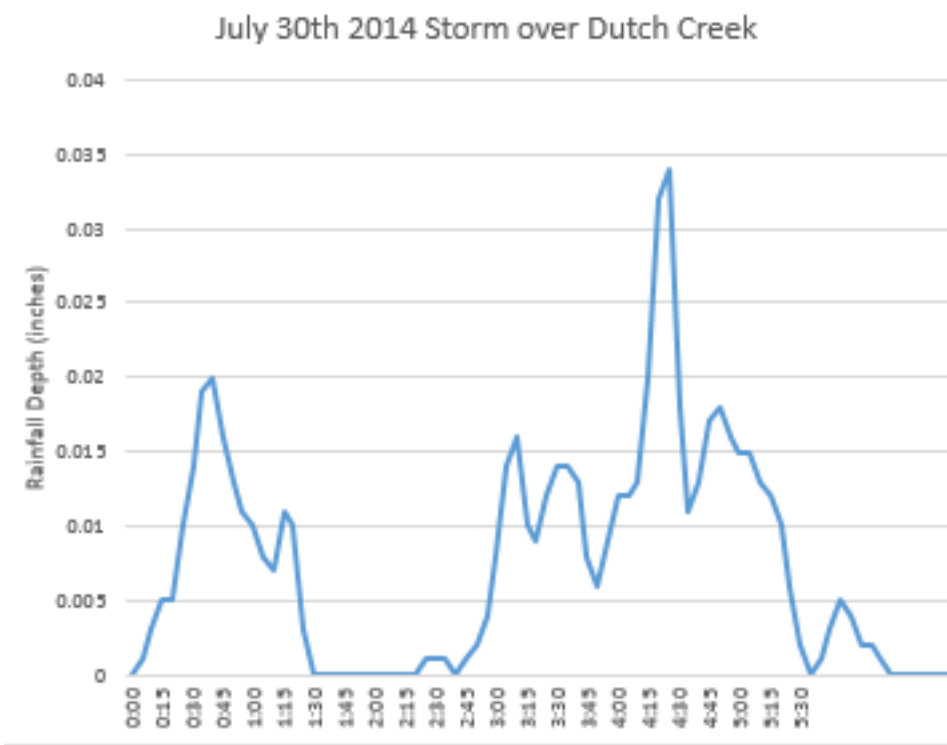
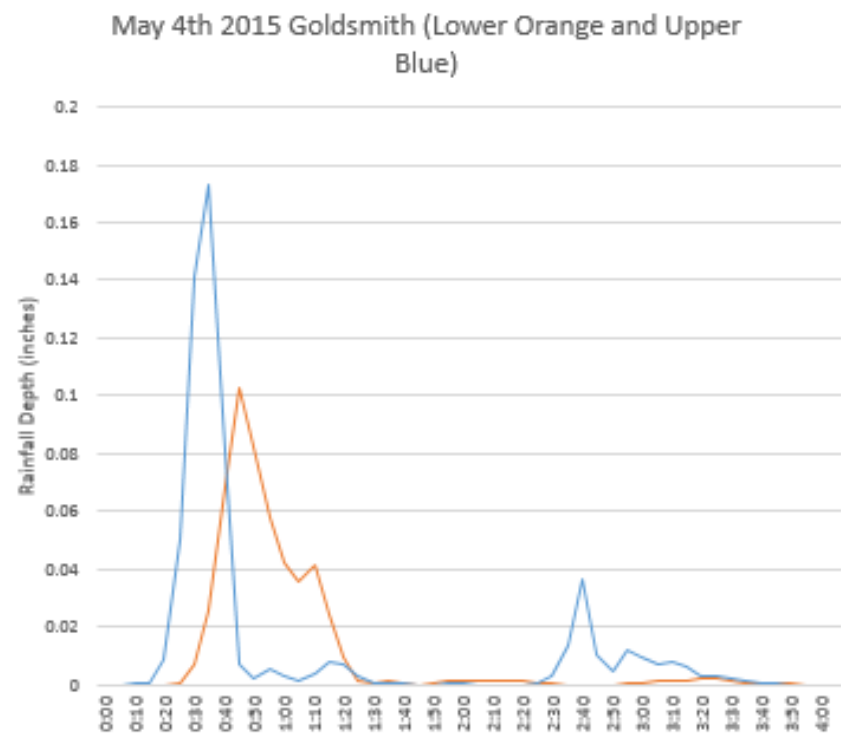
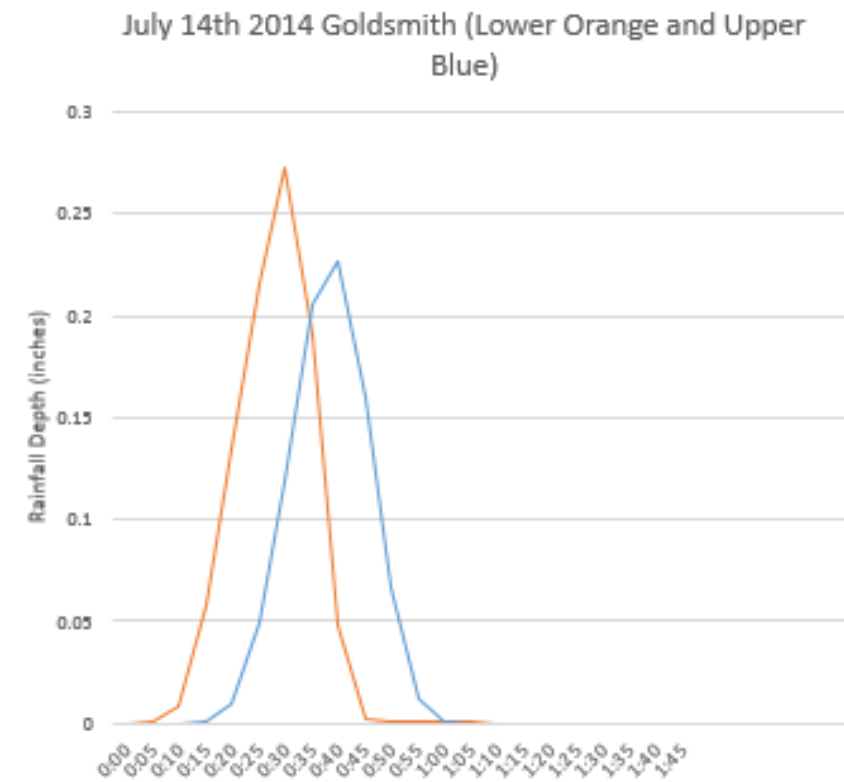
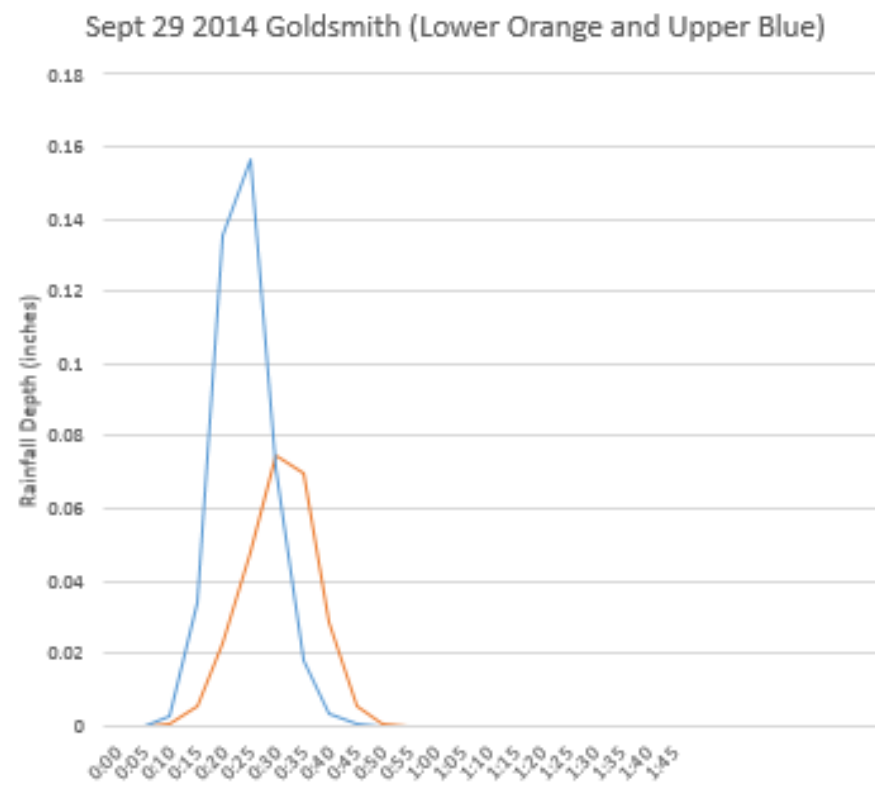
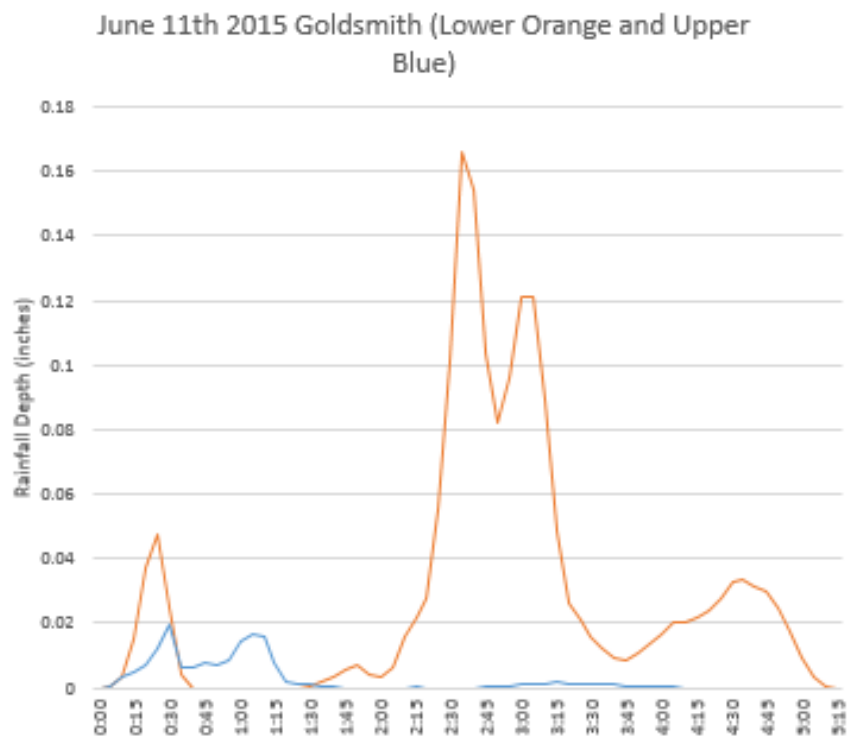
This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis



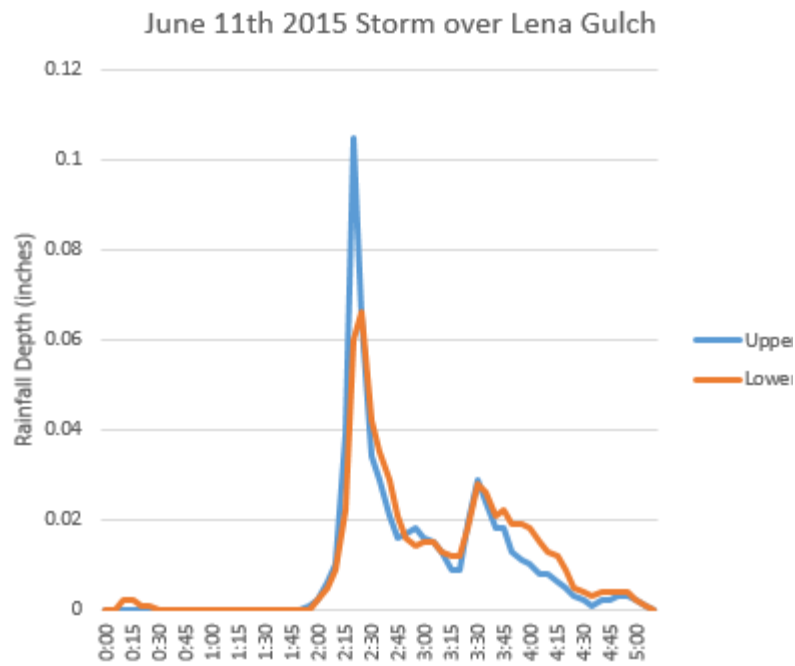
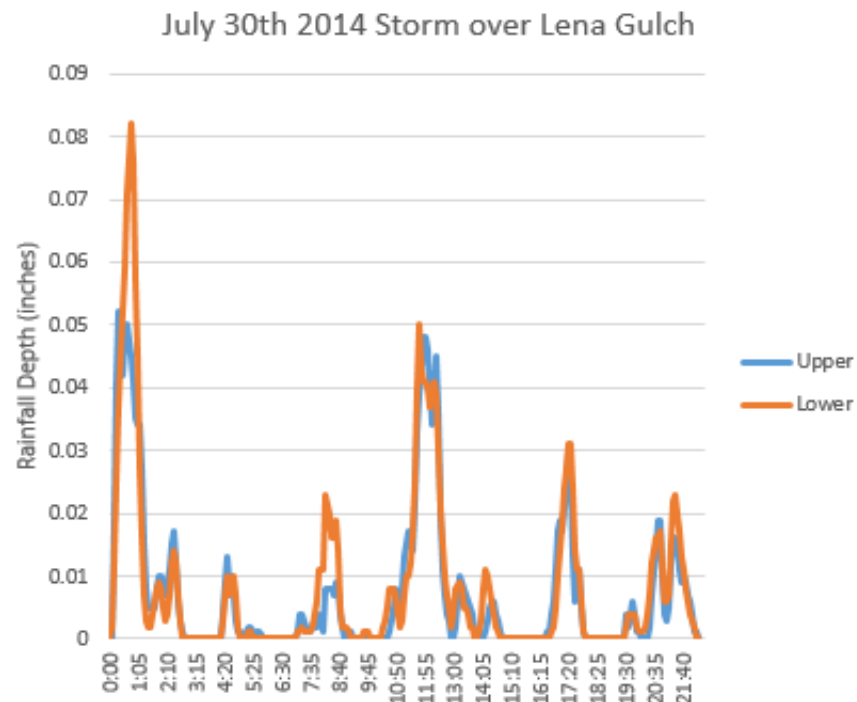
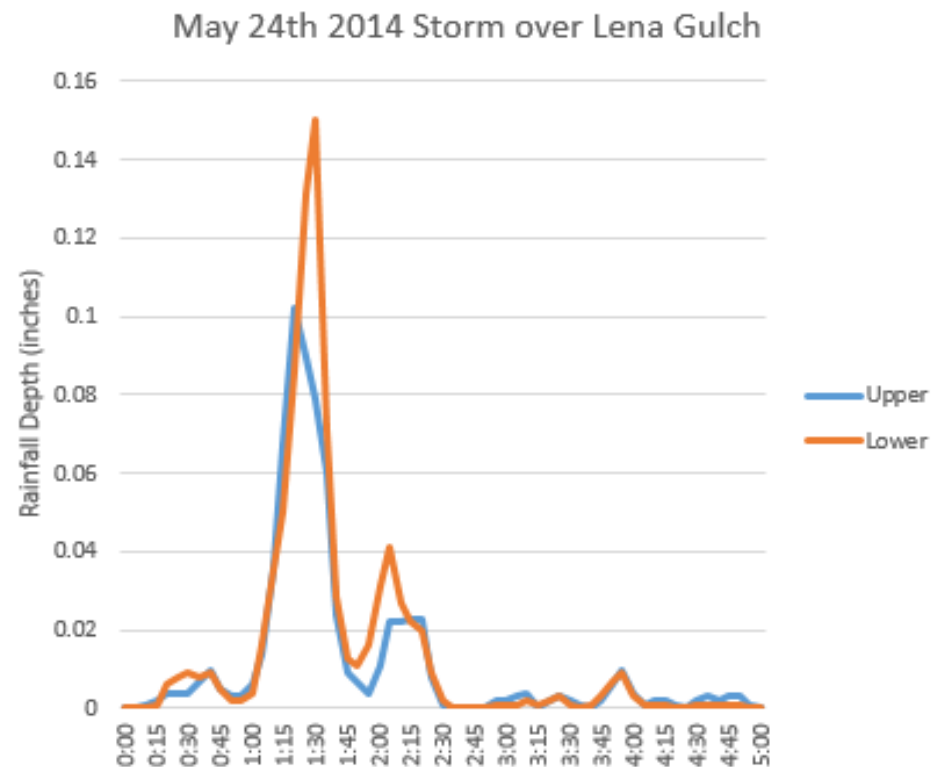
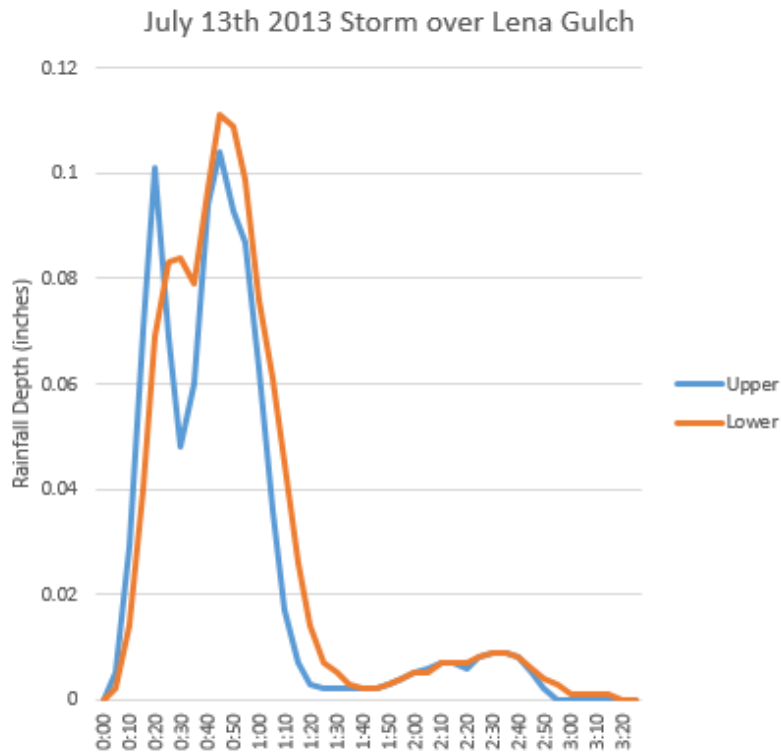
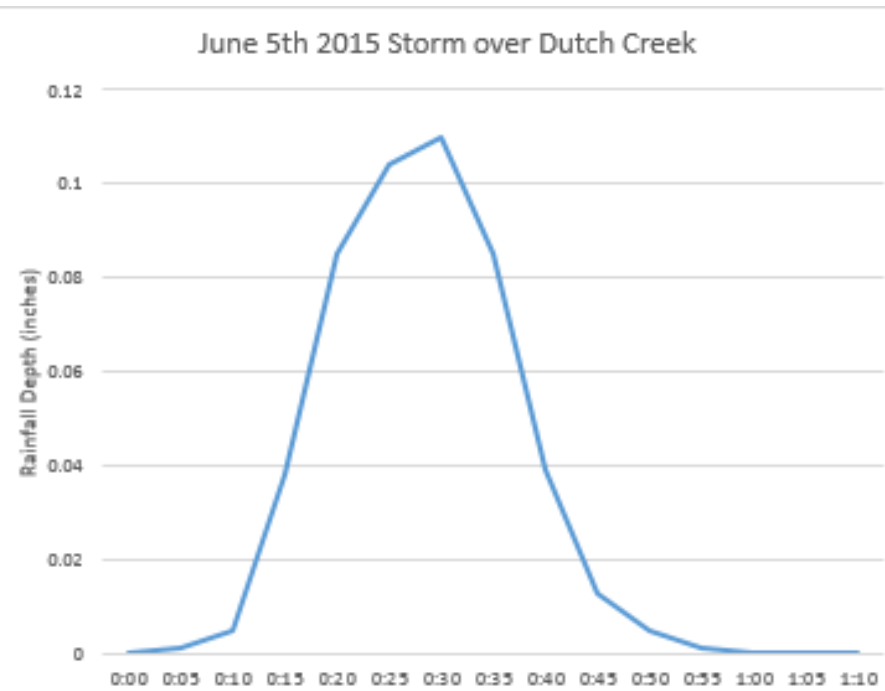
This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis



This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis



This Study Developed 60 GARR Storms over 10 Basins. Below are Selected Storms that were kept in the Analysis



Appendix B – CUHP Sub-Catchment Parameters for Select Basins

Summary of CUHP Input Parameters for Harvard Gulch (Version 1.5.1)

Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			Percent Eff. Imperv.
								Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in./hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con't Imperv. Fraction	Receiv. Perv. Fraction	
10	JUNCT_10	STORM1	0.030	0.057	0.161	0.012	32.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.66	0.18	28.26
20	JUNCT_20	STORM1	0.023	0.133	0.246	0.012	63.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	61.13
30	JUNCT_30	STORM1	0.016	0.114	0.246	0.012	41.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	38.30
40	JUNCT_40	STORM1	0.050	0.123	0.341	0.008	85.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.95	0.35	84.16
50	JUNCT_50	STORM1	0.020	0.133	0.265	0.010	62.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.28	59.60
60	JUNCT_60	STORM1	0.123	0.625	0.871	0.014	62.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	59.90
71	JUNCT_71	STORM1	0.038	0.203	0.365	0.021	74.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	72.00
72	JUNCT_72	STORM1	0.056	0.190	0.496	0.012	34.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.69	0.18	30.00
73	JUNCT_73	STORM1	0.034	0.189	0.354	0.022	62.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	60.00
80	JUNCT_80	STORM1	0.054	0.142	0.256	0.034	5.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.26
90	JUNCT_90	STORM1	0.038	0.152	0.331	0.015	19.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.39	0.13	15.14
95	JUNCT_95	STORM1	0.018	0.193	0.252	0.010	75.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	73.47
100	JUNCT_100	STORM1	0.019	0.152	0.256	0.007	75.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	73.16
110	JUNCT_110	STORM1	0.065	0.294	0.515	0.006	54.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.25	51.71
120	JUNCT_120	STORM1	0.060	0.152	0.398	0.014	51.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.23	47.73
130	JUNCT_130	STORM1	0.015	0.180	0.360	0.006	40.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.99
140	JUNCT_140	STORM1	0.110	0.265	0.549	0.007	72.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	70.44
150	JUNCT_150	STORM1	0.076	0.303	0.530	0.015	63.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	60.62
160	JUNCT_160	STORM1	0.031	0.170	0.360	0.006	68.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	66.28
170	JUNCT_170	STORM1	0.061	0.237	0.436	0.005	77.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.94	0.32	75.68
180	JUNCT_180	STORM1	0.104	0.246	0.540	0.012	57.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	54.36
190	JUNCT_190	STORM1	0.015	0.133	0.265	0.023	50.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.90
200	JUNCT_200	STORM1	0.082	0.246	0.492	0.017	60.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.06
210	JUNCT_210	STORM1	0.034	0.189	0.341	0.010	49.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.08
220	JUNCT_220	STORM1	0.017	0.133	0.246	0.017	50.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.80
230	JUNCT_230	STORM1	0.045	0.057	0.208	0.013	49.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.28
240	JUNCT_240	STORM1	0.071	0.208	0.454	0.011	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
250	JUNCT_250	STORM1	0.047	0.142	0.227	0.025	49.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	45.56
255	JUNCT_255	STORM1	0.033	0.189	0.445	0.014	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
260	JUNCT_260	STORM1	0.033	0.170	0.322	0.026	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
270	JUNCT_270	STORM1	0.123	0.313	0.530	0.014	49.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	45.76
280	JUNCT_280	STORM1	0.074	0.152	0.379	0.012	67.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.29	65.14
290	JUNCT_290	STORM1	0.028	0.180	0.303	0.021	67.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	64.52
300	JUNCT_300	STORM1	0.071	0.208	0.483	0.021	69.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	66.39
310	JUNCT_310	STORM1	0.036	0.227	0.464	0.016	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
320	JUNCT_320	STORM1	0.122	0.237	0.625	0.014	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
330	JUNCT_330	STORM1	0.118	0.398	0.606	0.013	73.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	70.96
340	JUNCT_340	STORM1	0.090	0.133	0.303	0.015	22.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.46	0.14	18.24
350	JUNCT_350	STORM1	0.091	0.265	0.597	0.020	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
360	JUNCT_360	STORM1	0.091	0.208	0.644	0.020	50.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	47.01
370	JUNCT_370	STORM1	0.107	0.227	0.398	0.018	29.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	24.26
380	JUNCT_380	STORM1	0.087	0.170	0.417	0.014	21.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.42	0.13	16.63
390	JUNCT_390	STORM1	0.094	0.246	0.454	0.030	7.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.16	0.08	5.12
400	JUNCT_400	STORM1	0.200	0.379	0.663	0.015	25.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.52	0.15	21.05
410	JUNCT_410	STORM1	0.135	0.331	0.814	0.026	33.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.66	0.18	28.69
420	JUNCT_420	STORM1	0.124	0.227	0.407	0.025	22.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.45	0.14	18.04
430	JUNCT_430	STORM1	0.072	0.095	0.275	0.021	25.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.50	0.15	20.26
440	JUNCT_440	STORM1	0.162	0.218	1.022	0.016	34.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.68	0.18	29.56
450	JUNCT_450	STORM1	0.025	0.256	0.492	0.012	72.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.31	69.92
460	JUNCT_460	STORM1	0.015	0.133	0.227	0.012	49.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.49
470	JUNCT_470	STORM1	0.046	0.246	0.483	0.014	51.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.23	47.84

820	JUNCT_820	STORM1	0.069	0.161	0.430	0.028	60.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.35
821	JUNCT_821	STORM1	0.029	0.231	0.398	0.015	75.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	73.16
831	JUNCT_831	STORM1	0.053	0.143	0.362	0.030	50.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.70
832	JUNCT_832	STORM1	0.066	0.212	0.543	0.032	48.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.23	45.25
840	JUNCT_840	STORM1	0.091	0.265	0.502	0.023	45.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	42.26
860	JUNCT_860	STORM1	0.122	0.227	0.511	0.010	59.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	56.61
870	JUNCT_870	STORM1	0.062	0.095	0.364	0.006	49.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.18
871	JUNCT_871	STORM1	0.039	0.180	0.360	0.015	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
872	JUNCT_872	STORM1	0.014	0.104	0.237	0.026	50.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	46.59
880	JUNCT_880	STORM1	0.146	0.474	0.758	0.017	50.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.85	0.23	47.42
881	JUNCT_881	STORM1	0.062	0.538	0.711	0.027	61.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.28	58.88

Summary of CUHP Input Parameters for LDC ARAP (Version 1.5.1)

Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			Percent Eff. Imperv.
								Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in./hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con't Imperv. Fraction	Receiv. Perv. Fraction	
B1	1	STORM1	0.180	0.370	0.807	0.031	42.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	38.40
B2	2	STORM1	0.033	0.116	0.306	0.026	59.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	56.56
B3	3	STORM1	0.039	0.171	0.379	0.026	88.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.96	0.37	87.24
B5	5	STORM1	0.111	0.219	0.493	0.023	46.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.15
B6	6	STORM1	0.082	0.202	0.500	0.030	86.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.95	0.35	84.27
B7	7	STORM1	0.163	0.457	0.802	0.030	40.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.39
B8	8	STORM1	0.033	0.145	0.297	0.035	71.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	68.94
B9	9	STORM1	0.081	0.319	0.538	0.029	41.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	37.90
B10	10	STORM1	0.138	0.326	0.646	0.030	95.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.98	0.39	94.54
B11	11	STORM1	0.072	0.243	0.506	0.027	40.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.39
B12	12	STORM1	0.053	0.243	0.580	0.023	40.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	36.39
B13	13	STORM1	0.043	0.246	0.440	0.040	52.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.24	48.67
B14	14	STORM1	0.039	0.188	0.366	0.028	60.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.82
B15	15	STORM1	0.068	0.199	0.468	0.031	48.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	44.52
B16	16	STORM1	0.037	0.187	0.380	0.033	60.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.15
B17	17	STORM1	0.198	0.349	0.773	0.027	95.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.98	0.39	94.25
B18	18	STORM1	0.063	0.191	0.501	0.030	93.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.97	0.38	91.97

Summary of CUHP Input Parameters for Lena Gulch (Version 1.5.1)

Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			Percent Eff. Imperv.
								Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in./hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con't Imperv. Fraction	Receiv. Perv. Fraction	
1	JUNCT_1	UPPERSTORM1	0.119	0.208	0.455	0.060	10.0	0.40	0.10	6.00	2.70	0.0009	0.00	0.20	0.10	6.68
2	JUNCT_1	UPPERSTORM1	0.054	0.303	0.417	0.060	8.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.16	0.08	5.30
3	JUNCT_2	UPPERSTORM1	0.065	0.189	0.511	0.060	6.1	0.40	0.10	6.00	2.70	0.0009	0.00	0.12	0.06	3.91
4	JUNCT_3	UPPERSTORM1	0.098	0.360	0.663	0.060	1.3	0.40	0.10	3.00	1.08	0.0009	0.00	0.03	0.01	0.80
5	JUNCT_3	UPPERSTORM1	0.169	0.265	0.587	0.060	1.6	0.40	0.10	6.00	2.70	0.0009	0.00	0.03	0.02	0.96
6	JUNCT_4	UPPERSTORM1	0.156	0.341	0.795	0.060	3.5	0.40	0.10	3.00	1.08	0.0009	0.00	0.07	0.03	2.19
7	JUNCT_5	UPPERSTORM1	0.117	0.170	0.568	0.060	10.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.20	0.10	6.71
8	JUNCT_5	UPPERSTORM1	0.161	0.265	0.852	0.060	0.0	0.40	0.10	6.00	2.70	0.0009	0.00	0.00	0.00	0.02
9	JUNCT_6	UPPERSTORM1	0.127	0.417	0.758	0.060	10.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.20	0.10	6.71
10	JUNCT_6	UPPERSTORM1	0.151	0.417	0.890	0.060	10.0	0.40	0.10	6.00	2.70	0.0009	0.00	0.20	0.10	6.71
11	JUNCT_106	UPPERSTORM1	0.137	0.379	0.833	0.060	12.5	0.40	0.10	3.00	1.08	0.0009	0.00	0.25	0.11	8.78
12	JUNCT_7	UPPERSTORM1	0.103	0.246	0.720	0.060	0.7	0.40	0.10	3.00	1.08	0.0009	0.00	0.00	0.01	0.42
13	JUNCT_112	UPPERSTORM1	0.121	0.322	0.663	0.060	35.9	0.40	0.10	3.00	1.08	0.0009	0.00	0.72	0.19	31.62
14	JUNCT_8	UPPERSTORM1	0.140	0.303	0.701	0.060	0.3	0.40	0.10	3.00	1.08	0.0009	0.00	0.00	0.00	0.17
15	JUNCT_9	UPPERSTORM1	0.145	0.473	0.852	0.060	0.2	0.40	0.10	3.00	1.08	0.0009	0.00	0.00	0.00	0.11
16	JUNCT_12	UPPERSTORM1	0.106	0.322	0.587	0.060	4.6	0.40	0.10	3.00	1.08	0.0009	0.00	0.09	0.05	2.90
17	JUNCT_11	UPPERSTORM1	0.165	0.322	0.909	0.060	2.8	0.40	0.10	3.00	1.08	0.0009	0.00	0.06	0.03	1.75
18	JUNCT_10	UPPERSTORM1	0.109	0.511	0.966	0.060	20.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.40	0.13	15.52
19	JUNCT_10	UPPERSTORM1	0.144	0.470	0.852	0.060	1.0	0.40	0.10	3.00	1.08	0.0009	0.00	0.02	0.01	0.64
20	JUNCT_10	UPPERSTORM1	0.086	0.246	0.606	0.060	30.8	0.40	0.10	3.00	1.08	0.0009	0.00	0.62	0.17	26.07
21	JUNCT_14	UPPERSTORM1	0.153	0.170	0.682	0.044	8.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.17	0.09	5.72
22	JUNCT_15	UPPERSTORM1	0.152	0.189	0.720	0.042	15.2	0.40	0.10	7.80	2.40	0.0009	0.00	0.30	0.12	11.11
23	JUNCT_17	UPPERSTORM1	0.098	0.360	0.720	0.053	41.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.81	0.20	38.02
24	JUNCT_16	UPPERSTORM1	0.186	0.303	0.606	0.060	9.1	0.40	0.10	7.80	2.40	0.0009	0.00	0.18	0.09	6.09
25	JUNCT_17	UPPERSTORM1	0.166	0.436	0.833	0.045	35.7	0.40	0.10	7.80	2.40	0.0009	0.00	0.71	0.19	31.44
26	JUNCT_20A	UPPERSTORM1	0.138	0.379	0.795	0.038	64.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.91	0.28	61.85
27	JUNCT_18	UPPERSTORM1	0.085	0.379	0.644	0.060	5.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.11	0.05	3.49
28	JUNCT_19	UPPERSTORM1	0.125	0.284	0.663	0.060	57.8	0.40	0.10	7.80	2.40	0.0009	0.00	0.89	0.26	54.83
29	JUNCT_20	UPPERSTORM1	0.122	0.246	0.625	0.048	62.2	0.40	0.10	7.80	2.40	0.0009	0.00	0.90	0.28	59.39
30	JUNCT_21	LOWERSTORM1	0.227	0.511	0.947	0.060	7.0	0.40	0.10	5.10	1.30	0.0009	0.00	0.14	0.07	4.56
31	JUNCT_21	LOWERSTORM1	0.131	0.455	0.795	0.060	0.1	0.40	0.10	5.10	1.30	0.0009	0.00	0.00	0.00	0.04
32	JUNCT_23	LOWERSTORM1	0.168	0.436	0.890	0.060	7.1	0.40	0.10	5.10	1.30	0.0009	0.00	0.14	0.07	4.60
33	JUNCT_22	LOWERSTORM1	0.116	0.398	0.814	0.060	7.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.16	0.08	5.17
34	JUNCT_22	LOWERSTORM1	0.138	0.379	0.871	0.060	13.5	0.40	0.10	5.10	1.30	0.0009	0.00	0.27	0.11	9.68
35	JUNCT_23	LOWERSTORM1	0.048	0.227	0.511	0.060	27.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.56	0.16	23.16
36	JUNCT_24	LOWERSTORM1	0.146	0.265	0.568	0.060	30.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.62	0.17	26.27
37	JUNCT_26	LOWERSTORM1	0.098	0.265	0.663	0.060	17.6	0.40	0.10	5.10	1.30	0.0009	0.00	0.35	0.12	13.32
38	JUNCT_26	LOWERSTORM1	0.092	0.303	0.777	0.060	13.0	0.40	0.10	5.10	1.30	0.0009	0.00	0.26	0.11	9.26
39	JUNCT_27	LOWERSTORM1	0.149	0.436	0.777	0.060	43.9	0.40	0.10	5.10	1.30	0.0009	0.00	0.82	0.21	40.36
40	JUNCT_25	LOWERSTORM1	0.102	0.189	0.436	0.060	30.0	0.40	0.10	5.10	1.30	0.0009	0.00	0.60	0.17	25.31
41	JUNCT_28	LOWERSTORM1	0.144	0.303	0.511	0.044	41.7	0.40	0.10	5.10	1.30	0.0009	0.00	0.81	0.21	38.11
42	JUNCT_29	LOWERSTORM1	0.114	0.398	0.852	0.060	37.3	0.40	0.10	5.10	1.30	0.0009	0.00	0.75	0.19	33.25
43	JUNCT_29	LOWERSTORM1	0.116	0.208	0.625	0.061	41.9	0.40	0.10	7.80	2.40	0.0009	0.00	0.81	0.21	38.35
44	JUNCT_30	LOWERSTORM1	0.086	0.189	0.530	0.029	46.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.83	0.22	42.86
45	JUNCT_31	LOWERSTORM1	0.152	0.322	0.814	0.037	52.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.86	0.24	49.35
46	JUNCT_32	LOWERSTORM1	0.135	0.189	0.530	0.036	35.5	0.40	0.10	7.80	2.40	0.0009	0.00	0.71	0.19	31.24
47	JUNCT_40	LOWERSTORM1	0.150	0.625	0.928	0.029	46.9	0.40	0.10	7.80	2.40	0.0009	0.00	0.83	0.22	43.43
48	JUNCT_42	LOWERSTORM1	0.119	0.436	0.871	0.026	48.5	0.40	0.10	7.80	2.40	0.0009	0.00	0.84	0.23	45.08
49	JUNCT_42	LOWERSTORM1	0.069	0.322	0.606	0.025	47.6	0.40	0.10	7.80	2.40	0.0009	0.00	0.84	0.22	44.14
50	JUNCT_33	LOWERSTORM1	0.155	0.379	0.852	0.036	31.1	0.40	0.10	7.80	2.40	0.0009	0.00	0.62	0.17	26.48
51	JUNCT_36	LOWERSTORM1	0.139	0.492	0.871	0.022	36.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.73	0.19	32.23

52	JUNCT_35	LOWERSTORM1	0.147	0.436	0.777	0.034	33.4	0.40	0.10	7.80	2.40	0.0009	0.00	0.67	0.18	28.91
53	JUNCT_34	LOWERSTORM1	0.095	0.133	0.473	0.032	26.2	0.40	0.10	7.80	2.40	0.0009	0.00	0.52	0.15	21.47
54	JUNCT_36	LOWERSTORM1	0.114	0.549	0.852	0.044	30.9	0.40	0.10	7.80	2.40	0.0009	0.00	0.62	0.17	26.21
55	JUNCT_37	LOWERSTORM1	0.160	0.227	0.625	0.060	0.4	0.40	0.10	3.66	0.84	0.0009	0.00	0.00	0.00	0.25
56	JUNCT_38	LOWERSTORM1	0.093	0.303	0.625	0.048	8.7	0.40	0.10	3.66	0.84	0.0009	0.00	0.17	0.09	5.77
57	JUNCT_39	LOWERSTORM1	0.140	0.417	0.852	0.053	17.4	0.40	0.10	3.66	0.84	0.0009	0.00	0.35	0.12	13.08
58	JUNCT_41	LOWERSTORM1	0.117	0.265	0.625	0.048	1.0	0.40	0.10	3.66	0.84	0.0009	0.00	0.02	0.01	0.64
59	JUNCT_139	LOWERSTORM1	0.074	0.284	0.625	0.060	11.8	0.40	0.10	3.66	0.84	0.0009	0.00	0.24	0.11	8.19
60	JUNCT_42	LOWERSTORM1	0.122	0.549	0.795	0.048	22.4	0.40	0.10	3.66	0.84	0.0009	0.00	0.45	0.14	17.72
61	JUNCT_43	LOWERSTORM1	0.101	0.189	0.455	0.033	10.0	0.40	0.10	3.66	0.84	0.0009	0.00	0.20	0.10	6.71
62	JUNCT_45	LOWERSTORM1	0.182	0.511	0.852	0.044	26.9	0.40	0.10	3.66	0.84	0.0009	0.00	0.54	0.16	22.17
63	JUNCT_44	LOWERSTORM1	0.047	0.208	0.417	0.036	10.0	0.40	0.10	3.66	0.84	0.0009	0.00	0.20	0.10	6.71
64	JUNCT_45	LOWERSTORM1	0.195	0.417	0.777	0.049	41.3	0.40	0.10	3.66	0.84	0.0009	0.00	0.81	0.20	37.68
65	JUNCT_46	LOWERSTORM1	0.153	0.492	0.966	0.055	34.8	0.40	0.10	3.18	0.72	0.0009	0.00	0.70	0.18	30.48
66	JUNCT_141	LOWERSTORM1	0.115	0.189	0.568	0.053	49.2	0.40	0.10	4.68	1.26	0.0009	0.00	0.85	0.23	45.78
67	JUNCT_42	LOWERSTORM1	0.137	0.492	0.890	0.026	57.8	0.40	0.10	4.68	1.26	0.0009	0.00	0.89	0.26	54.81
68	JUNCT_46	LOWERSTORM1	0.176	0.606	0.966	0.035	60.1	0.40	0.10	4.68	1.26	0.0009	0.00	0.90	0.27	57.25
69	JUNCT_47	LOWERSTORM1	0.123	0.246	0.663	0.034	50.1	0.40	0.10	4.68	1.26	0.0009	0.00	0.85	0.23	46.69
70	JUNCT_48	LOWERSTORM1	0.168	0.379	0.758	0.025	37.2	0.40	0.10	4.68	1.26	0.0009	0.00	0.74	0.19	33.17
71	JUNCT_49	LOWERSTORM1	0.109	0.170	0.568	0.040	22.4	0.40	0.10	4.68	1.26	0.0009	0.00	0.45	0.14	17.73
73	JUNCT_46	LOWERSTORM1	0.126	0.284	0.682	0.028	64.6	0.40	0.10	4.68	1.26	0.0009	0.00	0.91	0.28	61.87
74	JUNCT_49	LOWERSTORM1	0.125	0.303	0.492	0.023	27.4	0.40	0.10	4.68	1.26	0.0009	0.00	0.55	0.16	22.60

Summary of CUHP Input Parameters for Goldsmith Gulch (Version 1.5.1)

Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			Percent Eff. Imperv.
								Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in./hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con't Imperv. Fraction	Receiv. Perv. Fraction	
1	101	STORM1	0.089	0.318	0.817	0.012	70.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	68.89
2	102	STORM1	0.139	0.683	0.975	0.013	60.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.26
3	103	STORM1	0.240	0.232	0.606	0.014	28.8	0.35	0.06	3.00	0.50	0.0018	0.00	0.58	0.17	25.56
4	104	STORM1	0.157	0.445	0.846	0.013	33.6	0.35	0.05	3.00	0.50	0.0018	0.00	0.67	0.18	30.56
5	105	STORM1	0.155	0.369	0.631	0.023	48.4	0.35	0.07	3.00	0.50	0.0018	0.00	0.84	0.23	46.09
6	106	STORM1	0.085	0.151	0.361	0.011	25.9	0.35	0.07	3.00	0.50	0.0018	0.00	0.52	0.15	22.57
7	107	STORM1	0.142	0.202	0.449	0.011	34.7	0.35	0.07	3.00	0.50	0.0018	0.00	0.69	0.18	31.76
8	108	STORM1	0.137	0.216	0.964	0.008	30.6	0.35	0.07	3.00	0.50	0.0018	0.00	0.61	0.17	27.36
9	109	STORM1	0.225	0.521	0.928	0.020	33.7	0.35	0.06	3.00	0.50	0.0018	0.00	0.67	0.18	30.60
10	110	STORM1	0.180	0.240	0.696	0.012	34.5	0.35	0.07	3.00	0.50	0.0018	0.00	0.69	0.18	31.54
11	111	STORM1	0.067	0.320	0.428	0.009	53.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.24	51.26
12	112	STORM1	0.119	0.285	0.467	0.014	61.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	59.18
13	113	STORM1	0.050	0.302	0.763	0.003	51.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.23	48.82
14	114	STORM1	0.155	0.399	0.748	0.004	57.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	55.56
15	115	STORM1	0.120	0.261	0.601	0.007	46.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	44.30
16	116	STORM1	0.132	0.214	0.547	0.009	58.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	56.45
17	117	STORM1	0.153	0.206	0.914	0.013	34.1	0.35	0.05	3.00	0.50	0.0018	0.00	0.68	0.18	31.09
18	118	STORM1	0.089	0.208	0.639	0.014	35.2	0.35	0.07	3.00	0.50	0.0018	0.00	0.70	0.19	32.31
19	119	STORM1	0.060	0.173	0.361	0.004	61.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.28	59.80
20	120	STORM1	0.163	0.217	0.593	0.016	61.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	59.41
21	121	STORM1	0.209	0.533	0.856	0.006	45.8	0.35	0.08	3.00	0.50	0.0018	0.00	0.83	0.22	43.47
22	122	STORM1	0.172	0.136	0.768	0.011	51.4	0.35	0.08	3.00	0.50	0.0018	0.00	0.86	0.24	49.14
23	123	STORM1U	0.215	0.438	0.975	0.011	61.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.42
24	124	STORM1U	0.163	0.479	0.656	0.004	59.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	56.91
25	125	STORM1U	0.129	0.432	1.133	0.004	55.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.88	0.25	52.36
26	126	STORM1U	0.153	0.530	0.814	0.011	45.1	0.35	0.07	3.00	0.50	0.0018	0.00	0.83	0.22	41.58
27	127	STORM1U	0.159	0.475	0.979	0.010	54.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.25	50.90
28	128	STORM1U	0.166	0.193	0.636	0.016	25.2	0.35	0.05	3.00	0.50	0.0018	0.00	0.50	0.15	20.45
29	129	STORM1U	0.060	0.154	0.441	0.006	29.2	0.35	0.05	3.00	0.50	0.0018	0.00	0.58	0.17	24.45
30	130	STORM1U	0.183	0.396	0.709	0.011	22.4	0.35	0.05	3.00	0.50	0.0018	0.00	0.45	0.14	17.78
31	131	STORM1U	0.057	0.196	0.518	0.021	30.1	0.35	0.05	3.00	0.50	0.0018	0.00	0.60	0.17	25.42
32	132	STORM1U	0.103	0.367	0.625	0.007	57.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	54.55
33	133	STORM1U	0.217	0.246	0.786	0.007	32.7	0.35	0.05	3.00	0.50	0.0018	0.00	0.65	0.18	28.13
34	134	STORM1U	0.069	0.283	0.599	0.016	37.4	0.35	0.05	3.00	0.50	0.0018	0.00	0.75	0.19	33.35
35	135	STORM1U	0.113	0.194	0.669	0.020	38.3	0.35	0.05	3.00	0.50	0.0018	0.00	0.77	0.19	34.42
36	136	STORM1U	0.101	0.300	0.687	0.001	34.7	0.35	0.07	3.00	0.50	0.0018	0.00	0.69	0.18	30.30
37	137	STORM1U	0.158	0.292	0.724	0.003	34.1	0.35	0.07	3.00	0.50	0.0018	0.00	0.68	0.18	29.65
38	138	STORM1U	0.044	0.210	0.334	0.022	76.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.32	74.36
39	139	STORM1U	0.029	0.257	0.534	0.008	57.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	54.55
40	140	STORM1U	0.135	0.452	0.777	0.011	62.2	0.35	0.08	3.00	0.50	0.0018	0.00	0.90	0.28	59.41
41	141	STORM1U	0.171	0.441	0.986	0.032	66.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	63.68
42	142	STORM1U	0.075	0.045	0.364	0.020	73.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	71.21

Summary of CUHP Input Parameters for Dutch Creek (Version 1.5.1)

Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			
								Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in./hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con't Imperv. Fraction	Receiv. Perv. Fraction	Percent Eff. Imperv.
CC1	CC1	STORM1	0.166	0.440	0.622	0.019	42.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	39.99
CC2	CC2	STORM1	0.260	0.198	0.751	0.019	45.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.60
CC3	CC3	STORM1	0.364	0.310	0.777	0.019	34.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.69	0.18	32.23
CC4	CC4	STORM1	0.233	0.352	0.551	0.029	31.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.62	0.17	28.29
CC5	CC5	STORM1	0.496	0.414	1.418	0.015	59.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.27	57.34
CC6	CC6	STORM1	0.151	0.387	0.852	0.009	59.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	57.49
CC7	CC7	STORM1	0.123	0.230	0.640	0.015	65.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	63.53
CC8	CC8	STORM1	0.216	0.476	0.965	0.020	48.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.23	46.61
CC9	CC9	STORM1	0.234	0.426	0.902	0.021	42.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	40.30
CC10	CC10	STORM1	0.252	0.533	0.994	0.019	59.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.04
CC11	CC11	STORM1	0.343	0.415	1.019	0.020	41.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.49
CC12	CC12	STORM1	0.435	0.506	1.090	0.021	39.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.78	0.20	36.94
CC13	CC13	STORM1	0.355	0.297	1.218	0.026	39.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.78	0.20	37.03
CCN1	CCN1	STORM1	0.015	0.079	0.185	0.031	58.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.89	0.26	56.69
CCN2	CCN2	STORM1	0.117	0.366	0.802	0.026	43.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.82	0.21	41.68
CCN3	CCN3	STORM1	0.279	0.463	0.930	0.017	47.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	45.28
CCN4	CCN4	STORM1	0.279	0.285	0.812	0.019	45.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.71
CCN5	CCN5	STORM1	0.046	0.220	0.431	0.025	37.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.74	0.19	34.68
DC1	DC1	STORM1	0.299	0.626	1.434	0.011	28.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.56	0.16	25.19
DC2	DC2	STORM1	0.255	0.451	0.877	0.018	35.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.71	0.19	33.03
DC3	DC3	STORM1	0.343	0.421	1.008	0.015	41.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.29
DC4	DC4	STORM1	0.134	0.299	0.712	0.023	42.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	40.19
DC5	DC5	STORM1	0.172	0.281	0.771	0.012	41.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.46
DC6	DC6	STORM1	0.131	0.315	0.387	0.020	53.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.87	0.24	51.71
DC7	DC7	STORM1	0.166	0.205	0.620	0.016	52.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.24	51.06
DC8	DC8	STORM1	0.274	0.406	1.104	0.022	47.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	45.28
DC9	DC9	STORM1	0.257	0.289	0.820	0.025	35.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.71	0.19	33.25
DC10	DC10	STORM1	0.166	0.202	0.546	0.041	31.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.63	0.17	28.60
DC11	DC11	STORM1	0.113	0.150	0.504	0.032	32.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.65	0.18	29.83
DC12	DC12	STORM1	0.131	0.299	0.488	0.038	18.2	0.35	0.10	4.00	0.55	0.0018	0.00	0.36	0.12	15.27
DC13	DC13	STORM1	0.155	0.532	1.167	0.028	41.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.20	39.28
DC14	DC14	STORM1	0.349	0.639	1.486	0.034	12.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.24	0.11	10.09
DC15	DC15	STORM1	0.363	0.472	0.984	0.036	34.2	0.35	0.10	4.50	0.60	0.0018	0.00	0.68	0.18	30.95
DC16	DC16	STORM1	0.467	0.870	1.669	0.025	9.9	0.35	0.10	4.00	0.55	0.0018	0.00	0.20	0.10	7.77
DC17	DC17	STORM1	0.281	0.598	1.027	0.039	21.7	0.35	0.10	4.00	0.55	0.0018	0.00	0.43	0.14	18.59
DC18	DC18	STORM1	0.227	0.330	0.836	0.054	5.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.95
DC19	DC19	STORM1	0.272	0.364	0.908	0.038	5.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.95
DC20	DC20	STORM1	0.089	0.170	0.459	0.038	17.0	0.35	0.10	4.00	0.55	0.0018	0.00	0.34	0.12	14.20
DC21	DC21	STORM1	0.169	0.295	0.568	0.056	12.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.25	0.11	10.15
DC22	DC22	STORM1	0.180	0.479	0.771	0.046	5.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.10	0.05	3.95
DC23	DC23	STORM1	0.546	0.796	1.805	0.051	31.7	0.35	0.10	4.00	0.55	0.0018	0.00	0.63	0.18	28.63
DC24	DC24	STORM1	0.211	0.604	1.206	0.049	19.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.38	0.13	16.56
DC25	DC25	STORM1	0.355	0.758	1.419	0.058	16.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.32	0.12	13.74
DC26	DC26	STORM1	0.364	0.724	1.384	0.061	6.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.12	0.06	4.82
DC27	DC27	STORM1	0.509	0.845	1.611	0.061	9.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.19	0.09	7.62
DCN1	DCN1	STORM1	0.221	0.463	0.913	0.034	29.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	26.39
DCN2	DCN2	STORM1	0.231	0.392	0.985	0.039	23.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.46	0.14	20.34
DCT1	DCT1	STORM1	0.157	0.484	1.015	0.032	30.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.61	0.17	27.89
LG1	LG1	STORM1	0.045	0.210	0.389	0.022	41.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	39.65
LG2	LG2	STORM1	0.045	0.190	0.396	0.032	37.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.75	0.19	35.29
LG3	LG3	STORM1	0.194	0.410	0.726	0.015	29.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	26.47

LG4	LG4	STORM1	0.118	0.305	0.555	0.017	35.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.70	0.19	32.51
LG5	LG5	STORM1	0.104	0.205	0.538	0.022	45.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	43.05
LG6	LG6	STORM1	0.317	0.490	1.009	0.019	42.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	40.10
LG7	LG7	STORM1	0.258	0.520	0.974	0.026	40.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	38.17
LG8	LG8	STORM1	0.411	0.560	1.176	0.029	37.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.76	0.19	35.53
LG9	LG9	STORM1	0.045	0.070	0.224	0.017	47.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	45.13
LG10	LG10	STORM1	0.280	0.518	1.196	0.023	46.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	44.63
LG11	LG11	STORM1	0.191	0.364	0.771	0.026	37.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.74	0.19	34.66
LG12	LG12	STORM1	0.204	0.327	0.886	0.026	39.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.79	0.20	37.29
LGN1	LGN1	STORM1	0.316	0.313	0.882	0.020	73.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.93	0.31	72.26
LGN2	LGN2	STORM1	0.335	0.625	1.282	0.024	65.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	63.54
LGN3	LGN3	STORM1	0.314	0.527	1.090	0.023	46.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	44.62
LGN4	LGN4	STORM1	0.188	0.372	0.634	0.035	68.6	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.30	67.09
TL1	TL1	STORM1	0.200	0.533	0.975	0.018	40.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.80	0.20	38.47
TL2	TL2	STORM1	0.142	0.238	0.668	0.018	44.8	0.35	0.10	4.00	0.55	0.0018	0.00	0.82	0.21	42.43
TL3	TL3	STORM1	0.271	0.569	1.088	0.016	40.0	0.35	0.10	4.00	0.55	0.0018	0.00	0.80	0.20	37.60

Summary of CUHP Input Parameters for Dry Gulch (Version 1.4.4 and Version 1.5.4)

Catchment Name/ID	SWMM Node/ID	Raingage Name/ID	Area (sq.mi.)	Dist. to Centroid (miles)	Length (miles)	Slope (ft./ft.)	Percent Imperv.	Depression Storage		Horton's Infiltration Parameters			DCIA Level and Fractions			Percent Eff. Imperv.
								Pervious (inches)	Imperv. (inches)	Initial Rate (in./hr.)	Final Rate (in./hr.)	Decay Coeff. (1/sec.)	DCIA Level	Dir. Con't Imperv. Fraction	Receiv. Perv. Fraction	
8B	8B	100	0.172	0.251	0.974	0.021	55.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.88	0.25	54.35
7B	7B	100	0.059	0.315	0.775	0.013	60.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	60.02
1B	1B	100	0.163	0.117	0.768	0.018	42.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	41.70
6B	6B	100	0.141	0.308	1.031	0.013	64.3	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	63.55
5B	5B	100	0.213	0.298	1.032	0.017	65.4	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	64.70
3B	3B	100	0.147	0.428	0.814	0.015	48.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.84	0.22	47.27
14B	14B	100	0.266	0.347	1.142	0.018	45.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.83	0.22	45.00
12B	12B	100	0.164	0.557	1.121	0.021	51.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.86	0.24	50.83
10B	10B	100	0.084	0.192	0.604	0.030	62.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	61.90
2B	2B	100	0.278	0.435	1.350	0.018	24.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.48	0.15	22.98
4B	4B	100	0.168	0.409	1.152	0.022	29.1	0.35	0.10	3.00	0.50	0.0018	0.00	0.58	0.17	27.89
18B	18B	100	0.152	0.391	0.935	0.016	43.8	0.35	0.10	3.00	0.50	0.0018	0.00	0.82	0.21	42.81
17B	17B	100	0.185	0.377	1.284	0.015	42.2	0.35	0.10	3.00	0.50	0.0018	0.00	0.81	0.21	41.26
9B	9B	100	0.255	0.353	0.865	0.012	62.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.28	61.93
13B	13B	100	0.117	0.187	0.917	0.014	59.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.90	0.27	58.23
11B	11B	100	0.184	0.480	0.989	0.013	71.9	0.35	0.10	3.00	0.50	0.0018	0.00	0.92	0.31	71.23
16B	16B	100	0.235	0.448	0.941	0.014	43.5	0.35	0.10	3.00	0.50	0.0018	0.00	0.82	0.21	42.53
15B	15B	100	0.140	0.282	0.922	0.010	38.7	0.35	0.10	3.00	0.50	0.0018	0.00	0.77	0.20	37.63
19B	19B	100	0.073	0.308	0.636	0.015	66.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.91	0.29	65.32
21B	21B	100	0.145	0.308	0.715	0.015	30.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.60	0.17	28.76
20B	20B	100	0.122	0.198	0.649	0.026	32.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.64	0.18	30.79
22B	22B	100	0.151	0.276	0.786	0.023	35.0	0.35	0.10	3.00	0.50	0.0018	0.00	0.70	0.19	33.85

Appendix C – Addressed Comments from June 2016 Draft Summary Report

RESPONSE TO COMMENTS FROM CUHP RECALIBRATION SUMMARY REPORT SENT IN JUNE OF 2016

MAJOR COMMENTS AND RESPONSES:

Urbonas: Looking at the comparisons I see much overlap with the SWMM routing analysis Derek and I did for you for the peak flow comparisons.

a. I am not convinced that the gage data used, especially in the few cases where there are significant differences, are always credible.

b. There is no discussion in the report that the timing and proper routing of the sub-hydrographs from individual sub-catchments was considered, or used, in the SWMM model.

c. In the report's tables, many of the peaks increase when going from a single large catchment to many small sub-catchments. This is exactly what was explored earlier and, at least to me, implies that the routing protocols used with the current CUHP model is still the reason for the increases in downstream peaks.

Response: The previous report prepared by Rapp and Urbonas (2014) was reviewed as part of this study. Models used in this report were from the MDP models developed for the District by the District's consultants and were assumed to be developed per the District's standards. Additionally, one of the first recommendations from this project was to apply routing methods that would not compound the peak flows as they move downstream, i.e. applying the Dynamic Wave for routing. This recommendation was not carried forward but was considered viable.

The Sept Version of the report has been updated to include more discussion on the proper routing and timing of hydrographs.

Baxter: The origin and characteristics of this rainfall product should be given, especially since it is not generally available in the public domain. Suggested wording is as follows:

Gage-adjusted radar rainfall (GARR) is gridded rainfall at high spatial and temporal resolution. GARR is a combination of radar and rain gage data, that leverages the strength of both sensor measurements (Vieux, 2013). It was produced by Vieux & Associates, Inc. for the Urban Drainage and Flood Control District for use in their flood warning program. The GARR period of record extends from June 2013

Reference:

Vieux, 2013. Chapter 11 in *Hydrology and Floodplain Analysis*. by Bedient, Huber, and Vieux, Fifth Edition, Prentice-Hall, Inc., One Lake St., Upper Saddle River, NJ 07458. ISBN 0-13-256796-2.

Response: Thank you for the additional wording and reference, they will be incorporated into the report. If there is any more detail you feel should be added about the GARR derivation process, we will happily add it into our final report.

Baxter: When you calibrated the equations, are those the C_t and C_p coefficients in the Snyder method? Please clarify. Also, when running frequency storms and comparing to stream gage flow frequencies, there are several assumptions that must (should) be made such as duration and antecedent soil moisture. Was this done? Please improve the description of the calibration and which factors were considered.

Response: Yes, these peaking parameters are based on the Snyder Method, which is referenced later in the report on Page 4.

Antecedent storms were tested as part of this study. It was found that little to no difference in the CUHP results were produced. This is because CUHP applies a time dependent form of Horton's equation and infiltration capacity from the beginning of the storm is not carried forward in the model. As such, most storms experienced their peak by the time the decay curve was flattening out and becoming constant. As such, when storms earlier in the day, or week were considered, there was no difference between the two CUHP models. However, there was not a significant effort on analyzing the peak years from the gages and estimating the antecedent moisture conditions for those annual peaks. Within the Semi Arid Environment of Denver, CO, it is a relatively safe assumption that the soil capacity has regained itself over a short time in the summer months when our flash floods occur.

Rapp: It would be nice to see a side-by-side comparison of the results (peak flows and hydrographs) for the existing model, an adjusted model to remove the study specific adjustments, and the proposed model. This would demonstrate whether the proposed model can adequately replace the need for study specific adjustments to C_p and C_t .

Response: Agreed. Hydrograph comparisons have been added and the frequency gages no include V 1.4.4 without adjusted C_p .

Rogers: I assume this includes both rainfall and stream gage data. How is gage data compared/related to storm frequency, especially the stream gage data? In other words, how do you know you are measuring a certain frequency storm event (eg. 10-year)?

Response: Gage data and flood frequency are related statistically based on annual exceedance probabilities which are most commonly estimated by the Log Pearson III method recommended in Bulletin 17B. The methodology does not include rainfall. Conversely, the Unit Hydrograph Method is calibrated from an array of storms, backed into a unit runoff and shape, then applied design rainfall storms that contain rainfall *depths* that are determined statically and distributed according to a design rainfall curve. The other option for calibration would have been to make smaller adjustments to the peaking parameters of CUHP and then modify the UDFCD design storm distribution. This route was not taken, but was considered and could have been equally justified.

Rapp: Will this investigation be done before releasing a new version of CUHP? The additional investigation may produce results that conflict with the approach being proposed in this report.

Response: It is my recommendation to apply a separate method or unit graph for the mountains and not use CUHP in the mountain regions, or have a Mountain CUHP... at that point it would be wiser to have guidance for applying SWMM5 or Snyder in HMS for those regions than developing another specific model. This will likely not be completed under this study.

Rapp: The re-calibration study uses the NOAA Atlas 14 precipitation values which are known to be lower than the previous values used by the District. However, it is not clear if the NOAA Atlas 14 precipitation values were used for both the existing CUHP version results (existing MDP models) and the proposed CUHP results. Assuming they

both were, it would be nice to compare how much of the reduction in peak flow is related to the reduced rainfall and how much is a result of the proposed adjustment to CUHP.

Response: These comparisons were made but not presented to keep it brief. The plots presented are from the published MDP models which used the UDFCD Rainfall. One of the original recommendations was to adopt new NOAA rainfall and apply Dynamic Wave Routing for attenuation, and make limited changes to CUHP. This recommendation was not carried forward, but still may be valid.

Rapp: There is a very slight discontinuity in the Peaking Parameter Equation at the 5% cutoff threshold. This can be seen in the attached spreadsheet. The equation produces values below 0.5 for imperviousness between 5% and 5.1%. Therefore, it is recommended that in the CUHP code, the threshold be set so that for Imperviousness $\leq 5.1\%$, $P = 0.5$. Above this threshold the equation can be used. I don't think it is necessary to show this level of precision in the report or user manual, but in the model it is probably best to avoid the discontinuity since these types of issues always seem to come up later for a very specific scenario.

Response: Thank you for checking, this has been corrected within the Sept. Version of the Summary Report.

Rapp: The attached spreadsheet provides a comparison between the old and new equations for P, C_p , C_t , and C_t .

a. As shown in the plots, the Peaking Parameter (P) decreases in the proposed model. This is as expected since the overall goal was to reduce peak flows.

b. The coefficient of Peaking (C_p) also decreases in the proposed model as expected.

c. The timing coefficient (C_t) for subcatchments less than 0.25 square miles also decreased in the proposed model. However, this was unexpected since smaller C_t values result in a shorter Time to Peak (T_p). This means that the resulting hydrograph will have a smaller peak but will also occur more quickly and have a long drawn out receding limb to conserve volume. This seems counterintuitive because it has the potential to further exacerbate the problem of hydrographs stacking up on each other in the routing process. In order to validate the adjustment to the timing coefficient, it is necessary to compare the resulting hydrograph shapes and peak timing at the recorded stream gages instead of just the peak flow values. Although this may have been done, as the report stands now there are no results presented to compare outflow hydrographs at the gages and to justify the smaller C_t values.

Response: Thank you for checking, this has been corrected in the Sept 2016 Version of the report and CUHP.

Rogers: It would be helpful to better explain the reasons for adjusting the C_p and C_t factors. It appears that adjustment to the C_p factor is being recommended. Why? Is this for both large and small basins? Adjustment to the C_t factor is being recommended only for small drainage basins and not large basins. An explanation and/or clarification would be helpful as to why an adjustment is needed for small basins.

Response: The peaking parameter adjustments effects basins of all sizes. Adjustments to timing for the small basins is necessary to avoid a major discontinuity at 0.25 sq miles. These have been adjusted in the Sept 2016 Version per other comments.

Morrisey: What Imperviousness was used to produce these curves? Is 5.6 cfs/ac valid, nothing less than 4 cfs/ac?

Response: 50%, the unit curve for a unit rainfall excess does not go lower than 4 cfs/ac until 0.5 sq miles, yes, that is correct.

Rapp: In most locations throughout the report, CUHP v1.4.1 is referred to as the current version of CUHP. However, the current version is 1.4.4 and it has been since September 2014, well before this recalibration study was even started. Is there a reason the study was done using v1.4.1 as opposed to 1.4.4, or is this simply a typographical error throughout the report?

Response: This is a typo, we updated all the models from the MDP planning studies to version 1.4.4 at the beginning of this study.

Anderson: Do you mean the row labeled "Average of All Storms"?

Also, I don't see any + or - signs in Table 2

Response: Table 2 column that says *this accounts for positive and negative values* shows this.

Rogers: Very few, if any, gage data is available, or was used, from tributaries west of the S. Platte River. Many of these tributaries that have had hydrology studies done in the recent past have shown higher runoff flows. Are we comfortable that this re-calibration effort will take into account the physical differences (long, narrow, steep basins) of these tributaries as opposed to the tributaries east of the S. Platte River?

Response: Out of the entire gage record, very few gages were available, however, gages west of the South Platte river were tested with frequency testing and one of the calibrated basins is West of the S Platte. We expect that the proposed version will trend better with gage frequency analysis for gages west of the S. Platte as well as across the District. Care should be taken when applying CUHP to Mountain Basins.

Urbonas: Comparing Log-Pearson analysis to current and proposed CUHP results, I do not see that the differences justify making this change in CUHP. The Enginuity report did not show confidence bands for the two CUHP models, only for the Log-Pearson analysis. But, if you give consideration to the fact that both CUHP analyses also have confidence band, you will find that all results overlap. In other words, the proposed changes are not statistically significant.

Response: There is not a method to generate 5 and 95% confidence intervals with the Unit Hydrograph Method. It is shown that the current version of CUHP mostly sits within the +/- 20% gage error that could be expected but that almost all the data sit at or above the middle line. It is agreed that this could be statistically insignificant. During the beginning of this study it was presented to the District that if our goal was to justify the current version of CUHP it could be done as the spread of the data was large, and many times the current version of CUHP was applicable, although it sits on the higher end, especially when discretized into smaller basins and routed via kinematic wave. As previously noted, this is not a new problem and many studies have been funded by the district to dampen these effects, and to date, none seemed to produce results that are having that effect in the master planning process. The do nothing alternative was not considered an option since very study is requiring the consultant to manually (and sometimes randomly) adjust the peaking and timing parameters to get different results. It was not felt that this is a good path to continue forward.

Rapp: In reviewing Table 2, and looking at the individual storms as opposed to the summary average, the proposed single basin model does not appear any better than the existing single basin model (geometric mean of Error is 24% vs. 25%). Whereas, for small basins, the proposed model does seem to provide better results. This raises concerns that the proposed model may actually underestimate peak flows in larger basins (it underestimates half of the recorded peak flows in Table 2).

Response: Yes, when modifying the curves my attempt was to make little change for the larger basins. This was based on the initial findings that large basin CUHP were producing reasonable results and the compounding of hydrographs via KW is the real problem. As such, the dampening for smaller basins was needed if attenuation and natural processes in the watershed are to be ignored. However, I was unable to generate a curve that didn't affect the larger basins and still produced results from smaller basins that sat closer to our gage analysis. This has also been adjusted in the Sept 2016 Version.

Rapp: In Figures 4 and 5, I would agree that the proposed model peak flows more closely straddle the recorded flows than the existing model. However, the proposed model also more commonly underestimates the peak flows which could be viewed as a bad thing in regard to public safety. For Goldsmith Gulch, the proposed model is below the lower confidence interval indicating that it underestimates peak flows for the 2-, 5-, and 10-year events.

Response: Yes, based on other comments, this is indeed a concern. The drop below the confidence intervals for goldsmith is due to the larger differences in NOAAs new atlas at those intervals. The lower frequency's trend very nice when the 2, 5, 10 old rainfall depths were used, however, the recent NOAA atlas drops these values more significantly than the differences at the larger interval (less frequent storms.). This has been updated in the Sept 2016 Version.

Baxter: what is the basis for separation between upper/lower storms, and why was this done?

Response: It was separated by area into an upper and lower basin, than those grids were taken and averaged to make a hyetograph for upper and lower basins. It was done because of the geographic variability and size of basin. The entire Goldsmith basin rarely sees a storm covering the entire basin as it is long, narrow, and sloping south to north.

Piza: When comparing design storms to stream gage, why not use the dynamic wave method? Wouldn't this be more accurate?

Response: Yes, I feel it would be. However, we were trying to make comparisons that reflect how the model would be applied. As such, our calibration models needed to be built and applied in the same manner that they would for a drainageway study.

Baxter: these two computed curves are clear, but what is the line labeled as "Computed Curve" ?

Response: The result from the Log Pearson III analysis that includes all outliers.

Urbonas: The Harvard Gulch at Harvard Park example illustrates something I been harping about for years, namely that the CUHP model used was misapplied and not properly routed. Especially the 1997 FHAD. Regardless, the new and the old CUHP virtually produce identical results in that example for all return periods.

Response: Thank you for your comment and highlighting the effects of the Canal. The Sept. 2016 Report has updated language and figures.

Anderson: Please explain possible reasons that both the blue and orange lines are outside the confidence limits, applicability of this to the overall study and why/whether it should be included or disregarded.

Response: Many anthropologic development effects the gage readings, the canal, the culvert backwater downstream of the gage, differences in vegetation development, and also the large stormsewer down Yale.

Knowing this, our goal was to reach the higher confidence intervals for trusted gages to maintain a level of conservatism in hydrologic practice across the District.

Morrisey: Would it be worth checking an uncalibrated CUHP 1.4.4 for the sake of comparison to the Proposed CUHP? The MDP results represent better correlation with gage data. The Proposed CUHP results are substantially higher than gage data.

Response: We have made that comparison, and included it within the most recent report.

Morrisey: Are the flows presented in the graph unaltered from WC MDP, or modified per steps listed below?

Response: That particular graph is the original flows from the WC MDP that includes all the alteration they applied for calibration.

Rogers: Does this mean that actual flow at this gage was not measured, or that gage data is not available? What is the difference between the "Predicted Flow from Gage Analysis" and "Computed Curve"?

Response: It is the same as computed curve, will modify to be consistent. Thank you for the catch.

Urbonas: What I like to point out is that the North Sanderson Gulch data are very suspect. When we analyzed the data many years back, we found that it did not follow typical unit peak discharge trends. Upon field investigations, we found that the major storm sewer upstream of the gage had no stormwater inlets and that the flows at the upstream end of the catchment were greatly restricted by a culvert under a highway and detention storage. I do not know if any of these physical conditions were modified since, but these physical anomalies were there when data were taken.

Response: Thank you for pointing that out. I did not know that.

RESPONSE TO SOME OF THE CONCLUSION REMARKS:

Urbonas: My bottom line recommendation is to not modify the current CUHP Ct and Cp protocols. Instead, I recommend UDFCD focus on guiding its consultants (and ones working for developers and local governments) in setting up routing models (i.e., SWMM) properly to do a more credible job in routing small sub-catchment hydrographs through the systems. One aspect of this that needs attention is the tendency of SWMM users to not account for the effective longitudinal slopes of channels (sometimes pipes) in most reaches and merely to enter the starting and ending invert elevations at the junctures. This we found to result in excessively high peaks when small sub-catchments are used and routed using SWMM. Another, is to use very simplified cross-sections, sometimes ones that have much less flow storage that would be available if more representative ones were used. Also, I observed that many of the routings in the past ignored the recommendations in the USDCM to increase the Manning's n by around 25% in order to reduce the tendency to over-accelerate the flows in the system, something that contributes to higher peaks downstream. Mathematically defined routing elements, do not have the imperfections that real-works routing elements have and users of SWMM need to compensate for this, namely by increasing their roughness.

As to changes in the NOAA rainfall used, they too will have a ripple effect on all past studies. Although, the changes are not significant in most places within UDFCD, personally I am not convinced the end result of this change is fully justified for UDFC.

Response: We fully understand the routing concern and made updates to the Sept Version of the Report. We also considered many different alternatives during this study. Currently, every study requires the user to adjust C_p and C_t in addition to the routing you discuss above. It sounds like you feel this is acceptable as a permanent path forward and the District requested a different option than status quo. Discussing comments and cross sections and flow storage: The math in the kinematic wave does not account for flow storage or attenuation and as such will have minimal impact.

Rapp: The biggest concern with the re-calibration approach is that there does not appear to be any comparison of peak timing with the gage results. The modifications to the equations are changing the timing of the hydrograph peaks as well as the peak value. Plots should be created to show the outflow hydrographs from the existing and proposed CUHP/SWMM models and then compare those with the recorded stream gauge data to see how well the timing matches up. This will show what effect the reduced time to peak has in combination with the SWMM routing network.

Response: We have compared the timing and they match well. The Sept 2016 Version Addresses these comments.

Rapp: There also does not appear to be any evaluation of the effects of the SWMM model on the overall results. This may have been performed but is not discussed or presented in the report. As shown in Table 2, the proposed model still has a noticeable increase in peak discharges for Upper Harvard Gulch and Little Dry Creek when going from a single large basin to several small basins. This indicates that the routing network results in increased flows using the shorter time to peak from the individual subcatchments. However, the flows decrease for Goldsmith Gulch and remain relatively constant for Dutch Creek. This indicates that the SWMM routing does play a significant role in the overall peak flows and unit discharges for a watershed. The timing of the individual hydrographs and how quickly they are routed and combined in the drainage network are significant when comparing to a recorded gage downstream. To ignore the time to peak of the hydrograph and the interconnectivity of the subcatchments within the routing network and simply reduce all subcatchment peak discharges so that the net effect at the downstream end of a few watersheds have an average peak flow closer to the recorded gages does not seem sufficient. On the other hand, if these factors were considered in the re-calibration then the results should be presented in the report.

Response: The Sept 2016 Report has been adjusted based on these comments.