CALIBRATION OF CUHP2005/SWMM5 COMPUTER MODELS FOR FLOOD FLOW PREDICTIONS

Submitted to Urban Drainage & Flood Control District

Submitted by

AMEC Earth & Environmental, Inc.

2000 S. Colorado Blvd., Suite 2-1000

Denver, Colorado 80222

Phone: 303.935.6505

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Prepared for

UDFCD
2480 West 26th Avenue, Suite 156-B
Denver, CO 80211

Prepared by

AMEC Earth & Environmental, Inc.
2000 S. Colorado Blvd., Suite 2-1000
Denver, CO 80222

And

Stormwater Computer Software Library, Inc.
Dr. James C.Y. Guo

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TABLE OF CONTENTS

1.0 HARVARD GULCH WATERSHED **1**

2.0 FLOOD FLOW MONITORING SYSTEMS **3**

3.0 HYDROLOGIC CONDITION AT STREAM GAGES **4**

3.1 Stream Gage 06711570 at Colorado Blvd. 4

3.2 Stream Gage 06711575 at Harvard Park 4

3.3 Review of Flood History 6

3.4 Annual Flood Flow Frequency Analysis 9

4.0 COMPUTER MODELS DEVELOPED FOR STORMWATER SIMULATION **11**

4.1 Colorado Urban Hydrograph Procedure (CUHP) 11

4.2 Kinematic Wave Hydrograph Procedure (KWHP) 13

5.0 DESIGN EVENTS AND ANNUAL FLOW-FREQUENCY CURVE **16**

5.1 Design Events Predicted by CUHP and KWHP Methods 19

6.0 MODEL CALIBRATION WITH OBSERVED EVENTS **20**

6.1 Event on 07/08/2001 21

6.2 Event on 06/18/2003 24

6.3 Event on 09/12/2002 25

6.4 Event on 08/17/2000 28

6.5 Event on 07/25/1998 29

6.6 Event 09/18/1993 Event 31

6.7 Event 07/20/1991 Event 33

7.0 KINEMATIC WAVE MODEL FOR PRE-DEVELOPMENT CONDITION **37**

8.0 CONCLUSION **40**

9.0 REFERENCES **41**

APPENDIX A – EVENT STUDY AND COMPARISON

APPENDIX B – DATA FILES AND MODELS CD

LIST OF FIGURES

FIGURE 1-1 WATERSHED MAP FOR HARVARD GULCH 2
FIGURE 2-1 RAINFALL GAGES OPERATED IN HARVARD GULCH WATERSHED 3
FIGURE 3-1 GAGE 06711570 AT COLORADO BLVD 4
FIGURE 3-2 GAGE 06711575 AT HARVARD PARK 5
FIGURE 3-3 CROSSING BOX CULVERT UNDER S. LOGAN STREET 6
FIGURE 3-4 ANNUAL MAXIMUM FLOW-FREQUENCY ANALYSIS FOR GAGE 06711570 AT COLORADO BLVD 10
FIGURE 3-5 ANNUAL MAXIMUM FLOW-FREQUENCY ANALYSIS FOR GAGE 06711575 AT HARVARD PARK 10
FIGURE 4-1 WATERSHED DISCRETIZATION FOR BASE CUHP MODEL 11
FIGURE 4-2 ENTRANCE INLET AT COLORADO BLVD AND YALE STREET 13
FIGURE 4-3 ILLUSTRATION OF AREA SKEWNESS 14
FIGURE 4-4 WATERSHED DISCRETIZATION FOR BASE SWMM MODEL 16
FIGURE 5-1 DESIGN PEAK FLOWS PREDICTED AT GAGE AT COLORADO BLVD 18
FIGURE 5-2 DESIGN PEAK FLOWS PREDICTED AT GAGE AT HARVARD PARK 18
FIGURE 5-3 DESIGN EVENTS PREDICTED BY CUHP AND KWHP METHODS 19
FIGURE 6-2 COMPARISON OF HYDROGRAPHS FOR 06/18/2003 EVENT 25
FIGURE 6-3 COMPARISON OF HYDROGRAPHS FOR 09/12/2002 EVENT 27
FIGURE 6-4 COMPARISON OF HYDROGRAPHS FOR 08/17/2000 EVENT 29
FIGURE 6-5 COMPARISON OF HYDROGRAPHS FOR 07/25/1998 EVENT 31
FIGURE 6-6 COMPARISON OF HYDROGRAPHS FOR 09/18/1993 EVENT 32
FIGURE 6-7 COMPARISON OF HYDROGRAPHS FOR 07/20/1991 EVENT 34
FIGURE 6-8 COMPARISON BETWEEN OBSERVED AND PREDICTED PEAK FLOWS 36
FIGURE 7-1 DETENTION EFFECT ON EXTREME EVENTS IN HARVARD GULCH 39

LIST OF TABLES

TABLE 2-1 RAINFALL GAGES INSTALLED IN HARVARD GULCH WATERSHED 3
TABLE 3-1 HYDROLOGIC CONDITION AT STREAM GAGES 5
TABLE 3-2 ANNUAL PEAK FLOWS RECORDED AT GAGE 06711570 AT COLORADO BLVD 7
TABLE 3-3 ANNUAL PEAK FLOWS RECORDED AT GAGE 06711575 AT HARVARD PARK 8
TABLE 3-4 STATION STATISTICS FOR LOG VALUES OF ANNUAL MAXIMUM PEAK FLOWS 9
TABLE 4-1 HYDROLOGIC PARAMETERS USED IN BASE CUHP MODEL 12

TABLE 4-2 KW PLANE WIDTHS FOR KWHP METHOD 15
TABLE 5-1 COMPARISON AMONG PREDICTED PEAK FLOWS FOR DESIGN EVENTS..................... 17
TABLE 6-1 SELECTED RAINFALL EVENTS FOR HARVARD GULCH STUDY 21
TABLE 6-2 RAINFALL DEPTHS AT FIVE RAIN GAGES ON JULY 8, 2001 22
TABLE 6-3 USGS REPORT AT GAGE 06711570 AT COLORADO BLVD FOR 07/08/2001 EVENT 22
TABLE 6-4 HYDROLOGIC PARAMETERS USED IN 07/08/2001 EVENT SIMULATION 23
TABLE 6-5 HYDROLOGIC PARAMETERS USED IN 06/18/2003 EVENT SIMULATION 24
TABLE 6-6 HYDROLOGIC PARAMETERS USED IN 09/12/2002 EVENT SIMULATION 26
TABLE 6-7 HYDROLOGIC PARAMETERS USED IN 08/17/2000 EVENT SIMULATION 28
TABLE 6-8 HYDROLOGIC PARAMETERS USED IN 07/25/1998 EVENT SIMULATION 30
TABLE 6-10 HYDROLOGIC PARAMETERS USED IN 09/18/1993 EVENT SIMULATION 32
TABLE 6-10 HYDROLOGIC PARAMETERS USED IN 07/20/1991 EVENT SIMULATION 33
TABLE 6-11 SUMMARY FOR OBSERVED AND PREDICTED PEAK FLOWS 35
TABLE 7-1 EXISTING UNDERGROUND CONDUITS ALONG HARVARD GULCH................................. 37
TABLE 7-2 COMPARISON AMONG PREDICTED FLOWS USING VARIOUS METHODS 38

CALIBRATION OF CUHP2005/SWMM5 COMPUTER MODELS FOR FLOOD FLOW PREDICTIONS

Jeffrey Y. Cheng, P.E.
Dr. James C.Y. Guo, P.E., PhD

The AMEC Team was authorized to work on this project in April 2010. The main purpose for this project is to calibrate CUHP/SWMM5 computer models using the recorded data in Harvard Gulch Watershed and then to refine the protocol to apply the CUHP/SWMM5 software package to stormwater modeling and flood predictions.

The original version of CUHP ran on a computer mainframe. It was revised in 1977 by Ben Urbonas to account for variable infiltration rates, to override the default unit hydrograph parameters, and to generate output for flood frequency analysis. In 1984, it was revised again to work on a personal computer and to route hydrographs using UDSWM2-PC, which is a modified Runoff Block module in the Environmental Protection Agency's (EPA) Storm Water Management Model (SWMM4 1988).

In 2000, the program's interface was changed to operate under Microsoft™ Windows 95® or later version operating systems. New features were added to account for Directly Connected Impervious Area (DCIA) and water quality capture volume (WQCV). In 2004 the program was translated to C programming language for faster workbook execution and the correction of certain bugs in the output files. The most recent version (CUHP 2005) utilizes an EXCEL spreadsheet frontend to interface with the C version of the math engine. CUHP2005 also ended the support for DCIA level 3 and removed user input for the time of concentration. The converter was also developed to automate the transfer of a CUHP2000 input file into CUHP2005 and interface with EPA SWMM Version 5 (SWMM5 2005) for flow routing. More recent changes to CUHP2005 are noted by numbered versions and are discussed below.

CUHP2005 Version 1.1.4

This version was released on July 26th, 2007. Within this version the rainfall distribution with area correction was adjusted to more closely match the values presented in UDFCD 2004. This was accomplished with exponential decay functions that are fitted to the curves presented in UDFCD 2004, which closely approximate the Area Depth Adjustment Curves (ADAC) for 2-, 3-, and 6- hour storm durations.

CUHP2005 Version 1.2.1

This version was released on February 20th, 2008. Within this version a review of the effective rainfall calculations was performed and adjustments within the model were made to produce expected values. The effective rainfall table in the criteria manual was also updated to reflect any changes. Values for the peaking (C_p) and timing (C_t) coefficients were also adjusted.

CUHP2005 Version 1.3.1

This version was released shortly after the previous version on August 11th, 2008. Major review of the CUHP Excel work book was conducted by a selected team. The new functions for the peaking coefficient (C_p) and time to peak coefficient (C_t) were derived by Dr. James Guo at the University of Colorado Denver to reach good agreement to the Rational method for drainage basins less than 90 acres.

CUHP2005 Version 1.3.2

CUHP 1.3.2 was never released to the public because of the inconsistent predictions among DCIA Levels 0, 1, and 2. Dr. James Guo proposed the concept of effective imperviousness that should be weighted by the runoff volumes produced from the cascading flows associated with different DCIA Levels. A set of new design curves of effective imperviousness was developed and implemented into CUHP2005 Version 1.3.2. (Guo et, al 2010).

CUHP2005 Version 1.3.3

CUHP 1.3.3 is the compilation of all changes discussed above. A new user interface is also added into the operation. Version tracking has been added and the mathematic engine is referenced differently than the previous versions to prevent users from downloading a new version and continuing to use a mathematic engine from a previous version.

This version also introduces the 'CUHP Power tools' installer. This package is targeted at developers and power-users that want to study changes across different versions of CUHP, or need to work with large numbers of CUHP files (CH2MHill 2009).

The original algorithm used in CUHP was calibrated against Denver's urban watershed data. With the latest changes, it is important to confirm the integrity and reliability of the latest version of CUHP/SWMM's performance. The main purpose of this project is to apply the software package CUHP/SWMM to the Harvard Gulch Watershed and then compare the predicted flood flows with the 30-years of stream flow records collected from five (5) rain gages and two (2) stream gages operated in the watershed. This study involves numerical calibration of CUHP/SWMM5 models for design events, observed events, and evaluation of the operations of two stream gages and five rain gages.

1.0 HARVARD GULCH WATERSHED

The tributary area to Harvard Gulch has been recognized as one of the two urban areas that have been well monitored with a long term record (Zarriello 1998). Harvard Gulch flows westerly through the southern part of Denver for a length of 5.6 miles to reach the confluence with the South Platte River at Wesley Avenue. The total watershed area is approximately 7.7 square miles. Since the Highline Canal meanders through the southeast portion of the watershed and intercepts storm runoff flow, the effective tributary area is reduced to 3.1 square miles. The Harvard Gulch Flood Control project, completed in 1966, was designed to convey the 10-year flood using storm sewers, grass-lined swales, and concrete channels from Colorado Boulevard to Harvard Park. Downstream of S. Logan Street to the South Platte River, an underground box culvert was constructed through Logan Park, which also serves as an outlet to the detention pond, built in Harvard Park Golf Course. The intent of this underground box culvert was to pass up to the 25-year peak flood flows. A larger flood event would result in uncontrolled flooding of the neighborhood and with no identifiable surface flow path to the river. The existing railroad, light rail and arterial roadways block surface flows from reaching the South Platte River. The existing infrastructure was determined to be incapable of conveying the 100-year design peak flow of 3600 cfs as predicted in the 1979 Flood Hazard Area Delineation Study (FHAD 1979). Therefore, storm runoff in excess of the existing capacity of the underground box culvert is anticipated to flood neighborhood streets and buildings (Matrix Group 2010).

Highway I-25 and the T-REX construction project bisect the upper portion of Harvard Gulch. Drainage improvements for the T-REX project through the Holly Hills area include several detention/water quality basins as well as a new storm sewer system. The T-REX storm sewer is connected to Denver's existing storm sewer system at two locations along the west side of I-25. They are: (1) the T-REX storm sewer system to the south outfalls to the Highline Canal; and (2) the storm sewer system to the north outfalls to the existing 36-inch storm sewer within Yale Avenue. As a result, only the downstream area of the Highline Canal, or a total of 3.10 square miles, is the effective tributary area to the stream gage installed at Harvard Park. This tributary area is about twice as long as it is wide and is drained by a combination of storm sewers and open channels. The base flow ranges from 2.1 and 5.6 ft3/s. The topographic relief is about 150 feet with slopes ranging from approximately 2.0 to 0.5 percent (MacKenzie et. al. 2007)

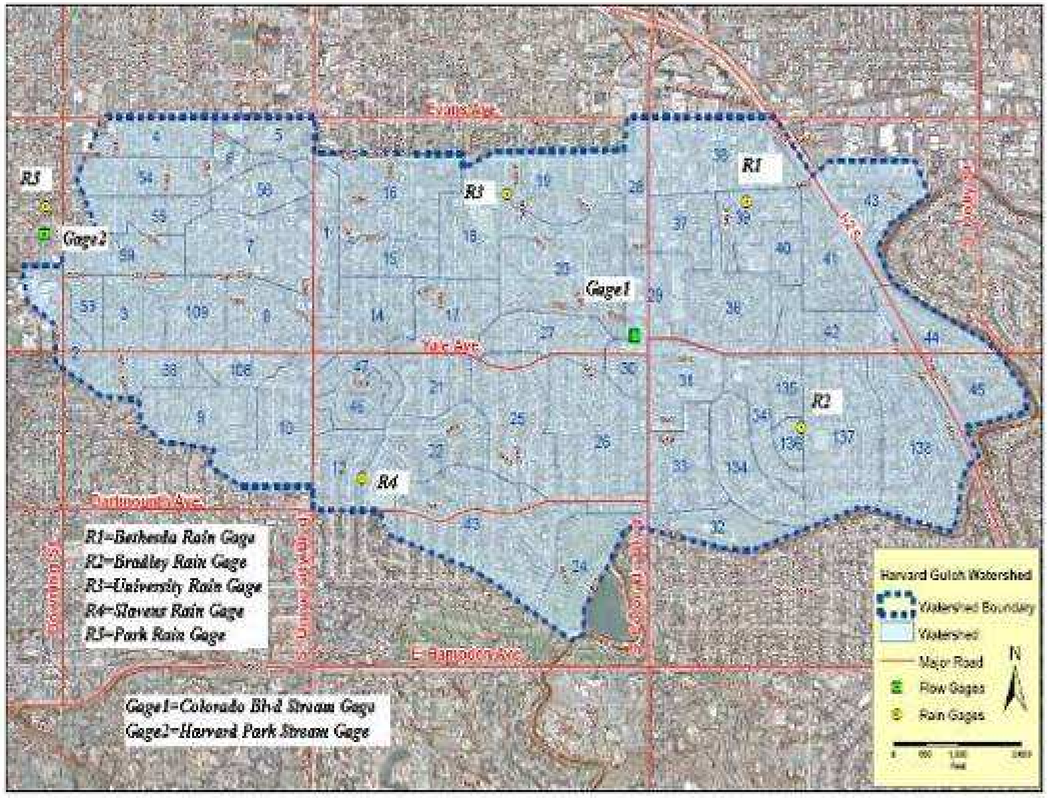

Figure 1-1 Watershed Map for Harvard Gulch

As illustrated in Figure 1-1, this study area is confined by Evans Avenue to the north, Dartmouth Avenue to the south, I-25 to the east, and S. Logan Street to the west. This area has been developed into mixed land uses, including commercial development along Colorado Boulevard and Broadway Boulevard. The residential areas in the watershed are dense single-family housing with small lots. The average imperviousness percent is approximately 40 percent of watershed's surface area. Encroachments into the floodplains occurred prior to the City and County of Denver zoning regulations to protect the floodplain from neighboring developments.

2.0 FLOOD FLOW MONITORING SYSTEMS

As illustrated in Figure 1-1, Harvard Gulch Watershed downstream of the Highline Canal is monitored by five (5) rain gages and two (2) USGS stream gages. As summarized in Table 2-1, these five rain gages are evenly installed to cover the tributary area, but the operational details and possible vegetal canopy effects are not clear.

Table 2-1 Rainfall Gages Installed in Harvard Gulch Watershed

Station	Height to Top of Rain Gage	Wind gage
1. Harvard Gulch @ University Park	7.6 ft	No
2. Harvard Gulch @ Denver Academy	7.9 ft	No
3. Harvard Gulch @ Bradley School	7.6 ft	No
4. Harvard Gulch @ Slavens Elementary	7.6 ft	No
5. Harvard Gulch @ Harvard Gulch Park	7.5 ft	No

Figure 2-1 Rainfall Gages Operated in Harvard Gulch Watershed

Operational errors at a rain gage are introduced by evaporation due to adhesion on the funnel surface, and raindrop splash. In addition, interference errors are directly related to wind and vegetal canopy effects at a rate of 1% rain under-catch per every one mile per hour of wind speed (Guo, Urbonas, and Stewart, 2001). For instance, during the January 9-10, 1995 rain storm in Sacramento, California, winds were ranged from 20 to 45 miles per hour for several hours. The rain under-catch at several gages was approximately 20 to 45% (Curtis and Humphrey 1995). Figure 2-1 shows three of the rain gage installations. These are representative of all five rain gage installations in that the gages are not protected by gage shields. Consequently, their operations have been subject to wind effects.

3.0 HYDROLOGIC CONDITION AT STREAM GAGES

3.1 Stream Gage 06711570 at Colorado Boulevard

The headwater of Harvard Gulch begins at Colorado Boulevard. Street flows on Colorado Boulevard are collected into an entrance box inlet that directly drains into the underground 10-ft by 14-ft concrete conduit. As illustrated in Figure 3-1, Stream Gage 06711570 is located between the exit of the underground conduit and the entrance of a low-cord bridge under Jackson Street. At this location, a noticeable sediment deposit is accumulated upstream of the bridge and extended to the location of the stream gage. Throughout the summer, the low-flow channel and overbank areas grow with willows, cattails, and grass. The low flow channel (thalweg) has meandered toward the right bank about 1 foot in the past 4 to 7 years (USGS Memo 2011). Deposits of fine silt/sand tend to be along the low flow channel while sand bars are developed at the bridge just downstream from the gage. It seems many of the deposits along the outer edges become vegetated and do not scour out of the channel. The operation of this stream gage is affected by the stream bed scour at the conduit exit and the backwater/sediment effect from the downstream bridge. All these factors affect the reliability of the stage-discharge rating curve previously established at this gage. During an extreme event, these deposits may be eroded. However, during low flow events, the operation at Stream Gage 06711575 tends to overestimate the flow rate in the channel due to the sediment build-up.

Figure 3-1 Stream Gage 06711570 at Colorado Boulevard

3.2 Stream Gage 06711575 at Harvard Park

Stream Gage 06711575 is located at Latitude 39.67 and Longitude 104.98 between the exit of the underground 9-ft by 14.5-ft concrete conduit and the drop structure upstream of S. Logan Street (see Fig. 3-2). The floodplain of this reach usually remains clear with leaves, tree limbs, and urban debris flowing into the channel from neighboring streets. The bottom at this stream gage is protected with gravel and fine sand. During an extreme event, the operation at Stream Gage 06711575 tends to underestimate high flows due to the erosion potential or to overestimate low flows due to the sediment deposit potential.

Figure 3-2 Stream Gage 06711575 at Harvard Park

The box culvert upstream of Gage 06711575 has an overflow steel grate that can divert excessive storm water into Harvard Park located at the north-west corner of S. Downing Street and W. Harvard Avenue. The park serves as an off-line detention basin that releases the stored flood volume back to Harvard Gulch immediately upstream of S. Logan Street. Review of several previous studies revealed that this off-line detention capacity was not included in the any of previous computer models (FHDA 1979, and Matrix Group 2010).

Table 3-1 is the evaluation of the hydrologic conditions at these two stream gages.

Table 3-1 Hydrologic Conditions at Stream Gages

Hydrologic parameters	Gage 1 at Colorado Blvd	Gage 2 at Harvard Park
Tributary Area	730 acres	2058 acres
Watershed Average Imperviousness Percent	60%	40%
Gage Station Condition	Tall grass and healthy vegetation, widened floodplain, significant sediment deposit	Well-maintained grass-lining, widened floodplain, high-stage flow diversion overtopping the north bank into the park
Upstream Condition	Exit of underground culvert with significant scour.	Exit of underground culvert with erosion potential and flow diversion into the park
Downstream Condition	Low bridge with significant sediment deposit and backwater effect	Sediment deposit for low flows and possible erosion for extreme flows.

The computer model calibration procedure involves selection of input parameters to minimize the discrepancy between model predictions and observed data. It is critically important that the operations at stream gages be reliable and consistent. Therefore, the calibration process in this study begins with a statistical analysis using the 30-year stream flow records at the two stream gages. The annual flow frequency curve will serve as the basis to evaluate the dynamic wave model developed for the existing watershed condition.

3.3 Review of Flood History

Both stream gages installed in the Harvard Gulch Watershed have been operated since 1981. As summarized in Tables 3-2 and 3-3, the annual peak flows generated from this watershed have been affected by the continuous urbanization process. Both stream gages have a record of 30 years with no zero-flow years. Gage 06711570 at Colorado Boulevard has missing data for two separate years.

There were three large flooding events recorded at the stream gages in 1996, 2001, and 2010. On July 8, 2001, serious street and stream flooding hit Denver between 4 and 6 p.m. The storm was accompanied by high winds and small hail. Damage to the Cherry Creek Arts Festival was a major news story where one person was taken to the hospital after being struck by blowing debris from street displays. Flash flooding was observed on Harvard Gulch, Goldsmith Gulch, Cherry Creek, the South Platte River, and along I-25 where the infamous “Lake Logan” (Logan Street/I-25 underpass) once again stopped traffic. The Harvard Gulch at Jackson Street rain gage measured the heaviest rainfall of 0.67” in 5 minutes and 2.48” in an hour (Flash Flood Prediction 2001). The peak stage at the crossing culvert (see Figure 3-3) under S. Logan Street is approximately 6 inches below the road surface or a peak flow of 2120 cfs was estimated by the culvert hydraulics.

Figure 3-3 Crossing Box Culvert under S. Logan Street

Table 3-2 Annual Peak Flows Recorded at Gage 06711570 at Colorado Blvd

Gage 06711570 at Colorado Blvd Hydrologic Unit Code 10190002 Latitude 39°40'09.13", Longitude 104°56'33.03" NAD83 Gage datum 5,400 feet above sea level NGVD29	**Output formats** Table Graph Tab-separated file peakfq (watstore) format Reselect output format

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)	Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1981	1981	12.55	395[C]	1996	Jul. 12, 1996	13.34	673[C]
1982	1982	11.86	210[C]	1997	Sep. 04, 1997	12.97	488[C]
1983	1983	12.40	410[C]	1998	Jul. 25, 1998	12.91	462[C]
1984	1984	11.62	200[C]	1999	May 20, 1999	13.06	529[C]
1985	1985	12.34	392[C]	2000	May 17, 2000	12.86	441[C]
1986	1986	11.32	139[C]	2001	Jul. 08, 2001	13.98	1,100[C]
1987	1987	12.15	335[C]	2002	Sep. 12, 2002	13.66	870[C]
1988	Aug. 04, 1988	14.02	597[C]	2003	Jun. 18, 2003	13.16	578[C]
1989	May 15, 1989	11.56	187[C]	2004	2004		[B,C]
1990	Aug. 15, 1990	12.28	[C]	2005	Jun. 03, 2005	12.10	210[C]
1991	Jul. 20, 1991	12.50	309[C]	2006	Jul. 07, 2006	12.05	201[C]
1992	Jul. 20, 1992	13.50	750[C]	2007	Jul. 04, 2007	11.58	119[C]
1993	Sep. 18, 1993	12.57	332[C]	2008	Aug. 09, 2008	11.72	126[B,C]
1994	Aug. 13, 1994	12.71	382[C]	2009	Jul. 03, 2009	12.50	309[C]
1995	Jun. 04, 1995	12.67	367[C]	2010	Jun. 12, 2010	12.14	208[C]

- B -- Month or Day of occurrence is unknown or not exact
- C -- All or part of the record affected by Urbanization, Mining, Agricultural changes, Channelization, or other

Table 3-3 Annual Peak Flows Recorded at Gage 06711575 at Harvard Park

Gage 06711575 at Harvard Park
Hydrologic Unit Code 10190002
Latitude 39°40'18.20", Longitude 104°58'37.30" NAD83
Gage datum 5,320 feet above sea level NGVD29

Output formats
Table
Graph
Tab-separated file
peakfq (watstore) format
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Water Year	Date	Gage Height (feet)	Stream-flow (cfs)	Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1981	1981	15.61	785[C]	1996	Jul. 12, 1996	16.25	1,100[C]
1982	1982	13.59	214[C]	1997	Jul. 31, 1997	15.49	776[C]
1983	1983	14.81	488[C]	1998	Jul. 25, 1998	14.90	573[C]
1984	1984	13.44	191[C]	1999	Jul. 19, 1999	13.60	257[C]
1985	1985	12.38	81.0[C]	2000	Aug. 17, 2000	14.06	350[C]
1986	1986	12.67	104[C]	2001	Jul. 08, 2001	17.44	2,120[C]
1987	1987	14.39	372[C]	2002	Sep. 12, 2002	14.41	434[C]
1988	Aug. 04, 1988	14.02	597[C]	2003	Jun. 18, 2003	15.42	750[C]
1989	May 15, 1989	12.84	181[C]	2004	Jun. 18, 2004	13.56	249[C]
1990	Aug. 15, 1990	13.40	222[C]	2005	Jun. 03, 2005	15.92	951[C]
1991	Jul. 20, 1991	14.55	471[C]	2006	Aug. 13, 2006	15.48	772[C]
1992	Jul. 20, 1992	15.57	807[C]	2007	May 14, 2007	14.73	522[C]
1993	Sep. 18, 1993	14.37	424[C]	2008	Aug. 09, 2008	14.93	583[C]
1994	Jun. 21, 1994	15.41	746[C]	2009	Jul. 03, 2009	16.02	995[C]
1995	Jun. 04, 1995	14.95	589[C]	2010	Jul. 05, 2010	16.54	1,240[C]

3.4 Annual Flood Flow Frequency Analysis

As recommended in Bulletin 17B (1980), the annual maximum series (AMS) is formulated by the highest peak flow from each year. In this study, the computer model, HEC-SSP (2010), is employed to provide statistical analyses using the Log-Pearson Type III distribution (Bulletin 17B 1980). The AMS derived from both gage stations were examined to confirm that no high and low outliers exist in the data array. According to the recommended procedure, the skewness coefficient at each station was weighted between the system and the general skewness coefficients. Table 3-4 presents the statistics derived for logarithmic values from each station's AMS. Figures 3-4 and 3-5 are the flood-frequency curves extended from the record of 30 years to a span of 500 years.

In comparing the results from the two gages, the AMS at Gage 06711570 (Colorado Boulevard) shows a more normally distributed curve because of its low skewness. As a result, the plot in Figure 3-4 is a straight line rather than a curve line as shown in Figure 3-5. Both Figures 3-4 and 3-5 provide the predicted peak flows ranging from 1- to 500-year events.

Table 3-4 Station Statistics for Log Values of Annual Maximum Peak Flows

Station	Mean (cfs) Log-10 Value	Standard Deviation (SD) (cfs)	Skewness Coefficient
Gage 06711570 at Colorado Blvd	2.515	0.261	-0.091
Gage 06711575 at Harvard Park	2.675	0.321	-0.517

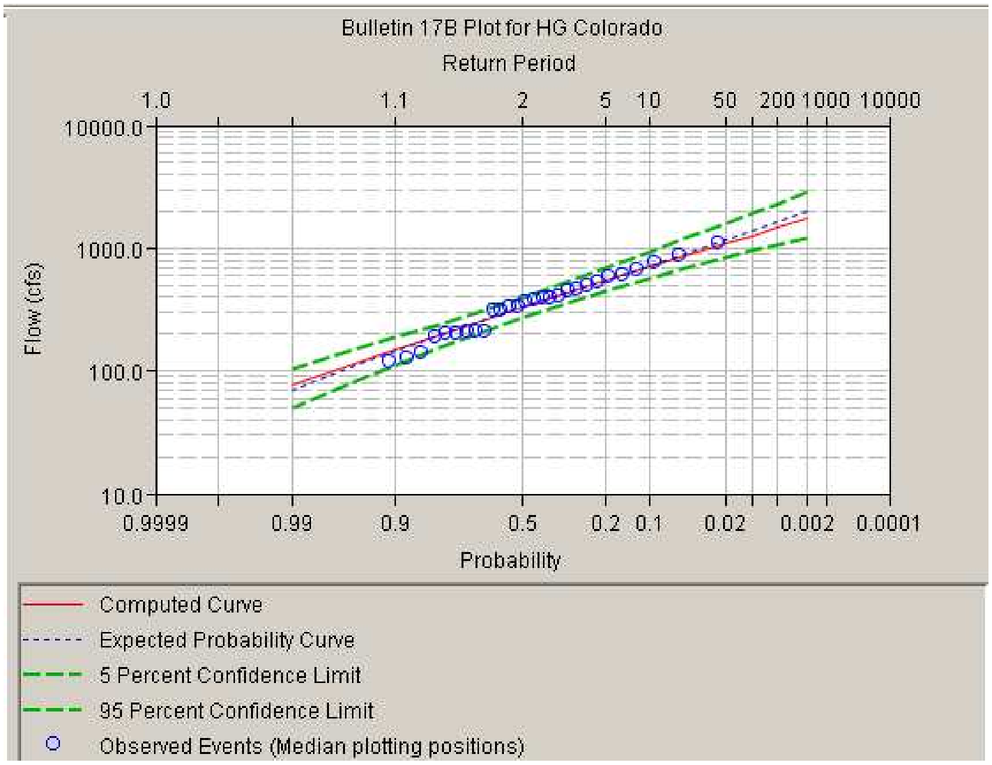


Figure 3-4 Annual Maximum Flow-Frequency Analysis for Gage 06711570 at Colorado Blvd

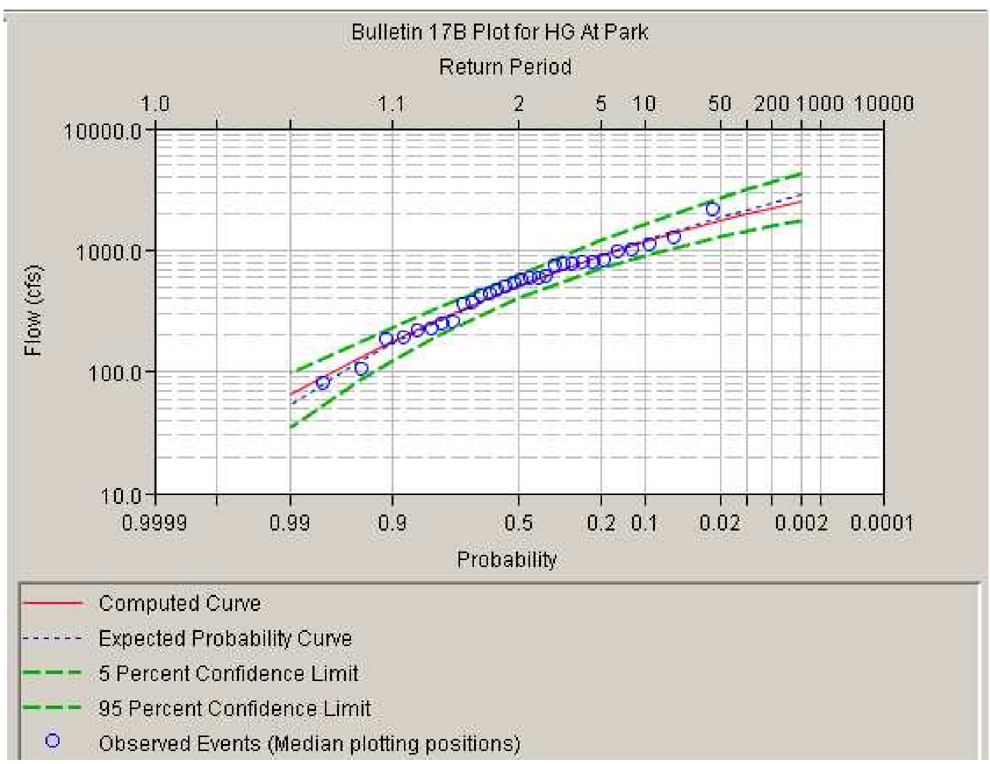


Figure 3-5 Annual Maximum Flow-Frequency Analysis for Gage 06711575 at Harvard Park

4.0 COMPUTER MODELS DEVELOPED FOR STORMWATER SIMULATION

4.1 Colorado Urban Hydrograph Procedure (CUHP)

As illustrated in Figure 4-1, the baseline CUHP computer model, HGCuhp.xls as shown in Appendix B, is developed to study the total tributary area of 3.19 square miles (2048 acres). The tributary area is divided into 26 sub-areas as listed in Table 4-1. This baseline model will be used for different applications. The average size of these subareas is approximately 80 acres with a maximum of 157 acres and a minimum of 13 acres. The average area imperviousness percent for the entire watershed is approximately 41% on an average slope of 0.0144 ft/ft. The standard recommended depression losses are used in the model, including 0.1 inch/watershed for impervious area and 0.4 inch/watershed for pervious area. The Level 1 MDCIA (minimizing directly connected impervious area) was adopted because the cascading flow pattern draining from roofs onto grass yard prevails in the watershed.

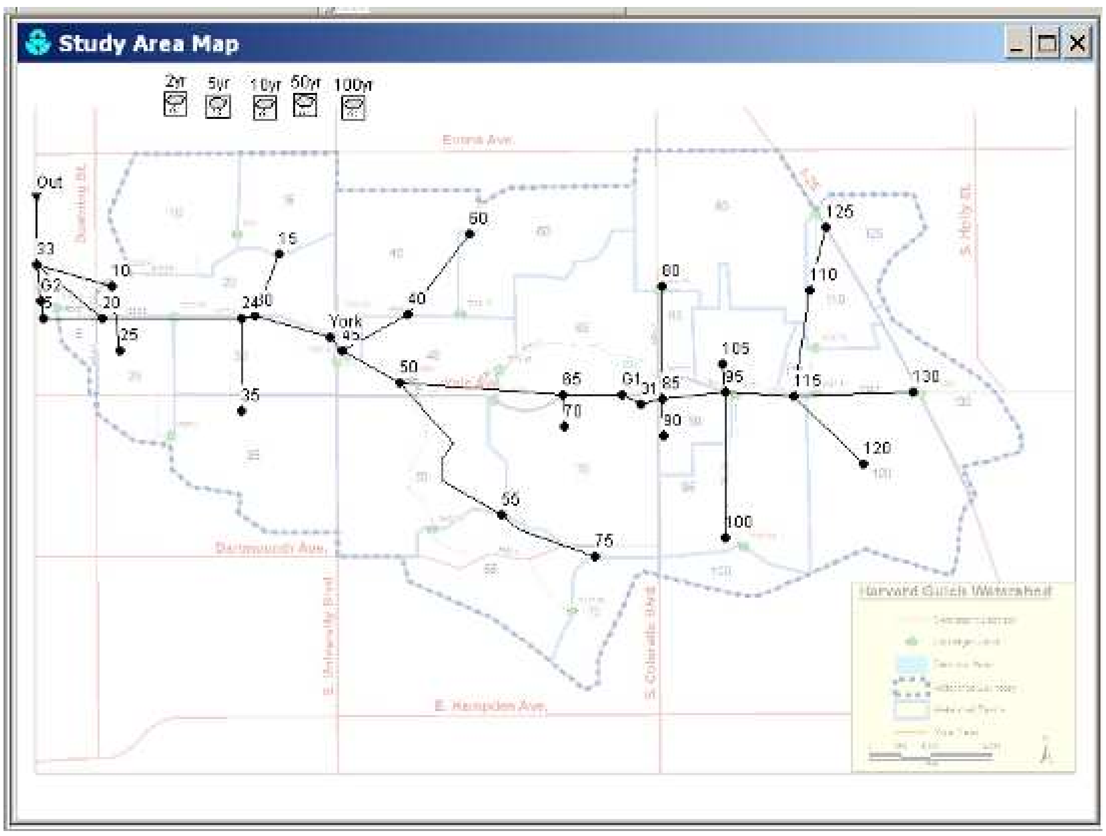


Figure 4-1 Watershed Discretization for Base CUHP Model

Table 4-1 Hydrologic Parameters Used in BASE CUHP Model

						Maximum Depression Storage (Watershed in)	
Catchment Name	Area (mi^2)	Distance to Centroid (mi)	Length (mi)	Slope (ft/ft)	Percent Imperviousness	Pervious	Impervious
5	0.020	0.076	0.354	0.0135	34.30	0.40	0.10
10	0.133	0.227	0.570	0.0071	34.30	0.40	0.10
15	0.089	0.181	0.542	0.0155	35.00	0.40	0.10
20	0.132	0.379	0.920	0.0135	43.40	0.40	0.10
25	0.089	0.206	0.602	0.0108	34.30	0.40	0.10
30	0.118	0.277	0.554	0.0153	34.30	0.40	0.10
35	0.186	0.248	0.752	0.0111	34.48	0.40	0.10
40	0.167	0.384	0.873	0.0095	34.07	0.40	0.10
45	0.121	0.272	0.608	0.0114	34.30	0.40	0.10
50	0.220	0.206	0.708	0.0202	42.98	0.40	0.10
55	0.152	0.252	0.556	0.0228	31.50	0.40	0.10
60	0.146	0.359	0.888	0.0072	34.30	0.40	0.10
65	0.191	0.201	0.711	0.0109	29.40	0.40	0.10
70	0.222	0.344	0.776	0.0237	34.53	0.40	0.10
75	0.063	0.104	0.327	0.0246	3.50	0.40	0.10
80	0.242	0.332	0.992	0.0093	58.40	0.40	0.10
85	0.032	0.150	0.363	0.0074	85.00	0.40	0.10
90	0.052	0.146	0.366	0.0194	85.00	0.40	0.10
95	0.191	0.231	0.674	0.0177	48.17	0.40	0.10
100	0.041	0.076	0.304	0.0141	8.00	0.40	0.10
105	0.076	0.164	0.433	0.0133	56.00	0.40	0.10
110	0.063	0.164	0.379	0.0161	37.00	0.40	0.10
115	0.061	0.229	0.432	0.0217	68.00	0.40	0.10
120	0.234	0.334	0.942	0.0113	43.00	0.40	0.10
125	0.065	0.211	0.384	0.0124	49.00	0.40	0.10
130	0.087	0.077	0.446	0.0143	38.00	0.40	0.10
Sum	3.1909	Sq Miles					

For flow routing, the baseline model, HGCuhp-DW.inp, is developed using EPA SWMM5 computer model (SWMM5 2005). The 26 pre-processed CUHP storm hydrographs can be transported into 26 nodes implemented in the flow routing model. In this study, the drainage network through the watershed was developed based on the previous studies (FHAD 1979, Matrix Group 2001), and then verified by field visitations. Harvard Gulch drains a matured urban watershed. Floodplains have been channelized. Many bridges and underground conduits are built across the encroached floodplains. For instance, the gulch collects the street flows from the entrance inlet located at Colorado Boulevard and Yale Street. This inlet is tied into the 9-ft x14-ft underground conduit between Colorado Boulevard and Jackson Street. As shown in Figure 4-2, the height of this entrance inlet is approximately 1.5 feet. To take the potential storage effect into consideration, the maximum water depth at this node used in the computer model is set to be no more than 1.5 feet for the street flow routing.

Figure 4-2 Entrance Inlet at Colorado Blvd and Yale Street

The gulch passes under University Boulevard through a multi-span bridge with a height of 5' and an overall span of 70'. From Downing Street to Harvard Park, the concrete channel is converted into the 7-ft by 14-ft underground box conduit underneath W. Harvard Avenue. The storage volumes associated with the headwater depths at the entrance of each conduit and bridge can result in a significant attenuation on peak flows. As a result, the routing model developed in this study uses the specified elevations and sizes at nodes and links. Flow detention and diversion along the channel network are automated according to the energy and hydraulic grade lines at each time step. This baseline model, HGCuhp-DW.inp, can be operated using the dynamic wave (DW) method when conducting a comparison study for the observed event under the existing condition or using the kinematic wave (KW) method when conducting conservative predictions for a planning or alternative condition.

4.2 Kinematic Wave Hydrograph Procedure (KWHP)

KWHP is the hydrograph generation process recommended by EPA SWMM5. In comparison, CUHP is a lumped method while KWHP is a discrete method that integrates unit-width overland flows into the storm hydrograph at the watershed outlet. A unit-width approach requires the conversion of an irregular watershed into its equivalent rectangular sloping plane. In current practice, there are two methods developed for this watershed shape conversion:

(1) The maximum overland flow length (ML) method (Bedient and Huber 1992) suggests that the average "maximal overland flow lengths" be identified and then averaged along the major sewer lines and channels through the watershed. The KW plane width is then calculated as:

$$L_w = \frac{A}{L_{max}} \quad (4\text{-}1)$$

where A = watershed area, L_{max}= longest length for overland flow, and L_w= KW plane width

(2) The KW watershed shape function (SF) method (Guo and Urbonas 2009) suggests that the watershed shape, A/L^2, be preserved during the shape conversion. The KW plane width is calculated as:

$$L_w = L[(1.5 - \frac{A_m}{A})(2.286\frac{A}{L^2} - 0.286(\frac{A}{L^2})^2] \text{ where } A/L^2<4 \quad (4\text{-}2)$$

where A_m = larger half area when the waterway divides the watershed into two halves. As illustrated in Figure 4-3, the value of A_m is between 0.5 for central channel and 1.0 for side channel.

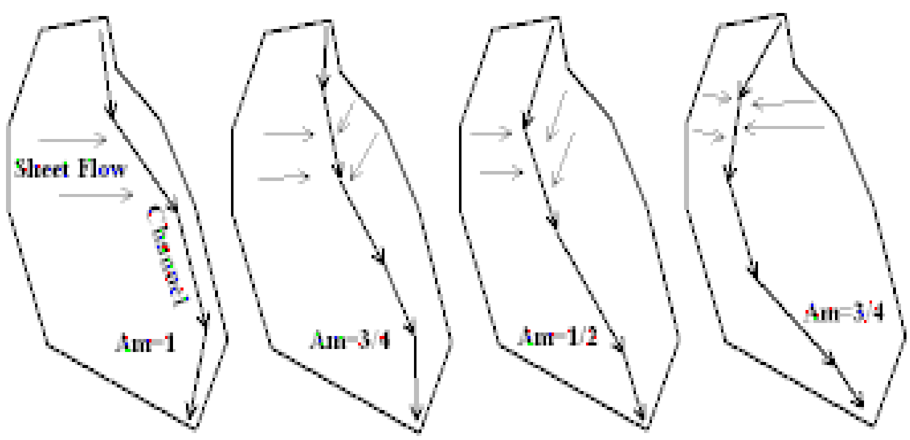


Figure 4-3 Illustration of Area Skewness

The ML method was tested for watershed less than 20 acres while the SF method was recommended for watershed less than 70 to 90 acres. Both methods give similar KW plane widths when the watershed is as small as 10 to 20 acres. Table 4-2 presents the shape conversion for the baseline model, HGSwmm-DW.inp, developed for the Harvard Gulch Watershed.

Table 4-2 KW Plane Widths for KWHP Method

Subarea	Area	L	So	Z=Am/A	X=A/L^2	Y=Lw/L	So/Sw	Sw	Lw
ID	acre	ft	%					%	ft
5	12.8	1869.1	0.01	0.67	0.16	0.30	0.83	**0.02**	**554.7**
10	85.6	3011.8	0.71	0.67	0.41	0.74	1.30	**0.55**	**2228.6**
15	57.4	2863.0	1.55	1.00	0.30	0.34	1.24	**1.24**	**959.6**
20	84.9	4858.2	1.35	0.85	0.16	0.23	0.91	**1.47**	**1108.9**
25	57.4	3176.7	1.08	0.75	0.25	0.41	1.01	**1.07**	**1307.4**
30	75.8	2923.0	1.53	1.00	0.39	0.42	1.34	**1.14**	**1228.9**
35	119.8	3972.3	1.11	0.50	0.33	0.72	1.18	**0.94**	**2879.2**
40	107.7	4607.5	0.95	0.85	0.22	0.32	1.01	**0.94**	**1470.9**
45	78.2	3211.9	1.14	0.85	0.33	0.47	1.17	**0.97**	**1510.7**
50	141.7	3736.9	2.02	0.50	0.44	0.95	1.42	**1.42**	**3566.9**
55	97.9	2936.6	2.28	0.50	0.49	1.06	1.53	**1.49**	**3114.7**
60	94.3	4688.5	0.72	0.50	0.19	0.42	0.86	**0.83**	**1955.0**
65	122.9	3751.6	1.09	0.50	0.38	0.83	1.29	**0.84**	**3106.7**
70	143.2	4096.3	2.37	0.70	0.37	0.65	1.22	**1.94**	**2655.8**
75	40.6	1728.5	2.46	0.67	0.59	1.04	1.61	**1.53**	**1796.4**
80	156.0	5238.7	0.93	0.90	0.25	0.33	1.08	**0.86**	**1724.6**
85	20.4	1915.7	0.74	1.00	0.24	0.27	1.17	**0.63**	**513.7**
90	33.8	1935.0	1.94	1.00	0.39	0.43	1.35	**1.44**	**826.2**
95	123.0	3560.8	1.77	0.60	0.42	0.82	1.34	**1.32**	**2933.1**
100	26.7	1602.8	1.41	1.00	0.45	0.49	1.41	**0.99**	**781.4**
105	49.3	2287.6	1.33	0.50	0.41	0.89	1.35	**0.99**	**2036.3**
110	40.4	2000.8	1.61	1.00	0.44	0.48	1.40	**1.15**	**951.0**
115	39.6	2282.8	2.17	1.00	0.33	0.36	1.28	**1.70**	**827.5**
120	150.7	4971.8	1.13	1.00	0.27	0.29	1.20	**0.94**	**1459.3**
125	42.0	2024.9	1.24	1.00	0.45	0.48	1.41	**0.88**	**975.3**
130	55.8	2355.3	1.43	1.00	0.44	0.47	1.40	**1.02**	**1115.2**

Aided by Table 4-2, a total of 26 sub-areas are incorporated into the baseline models, HGSwmm-DW.inp, HGCuhp.xls, and HGCuhp-DW.inp, developed for Harvard Gulch. Storm hydrographs generated under the design rainfall are placed at the sub-basin's outlets as shown in Figure 4-4. Both baseline models, HGSwmm-DW.inp and HGCuhp-DW.inp, share the same flow routing network that can be operated with DW or KW, depending on the applications.

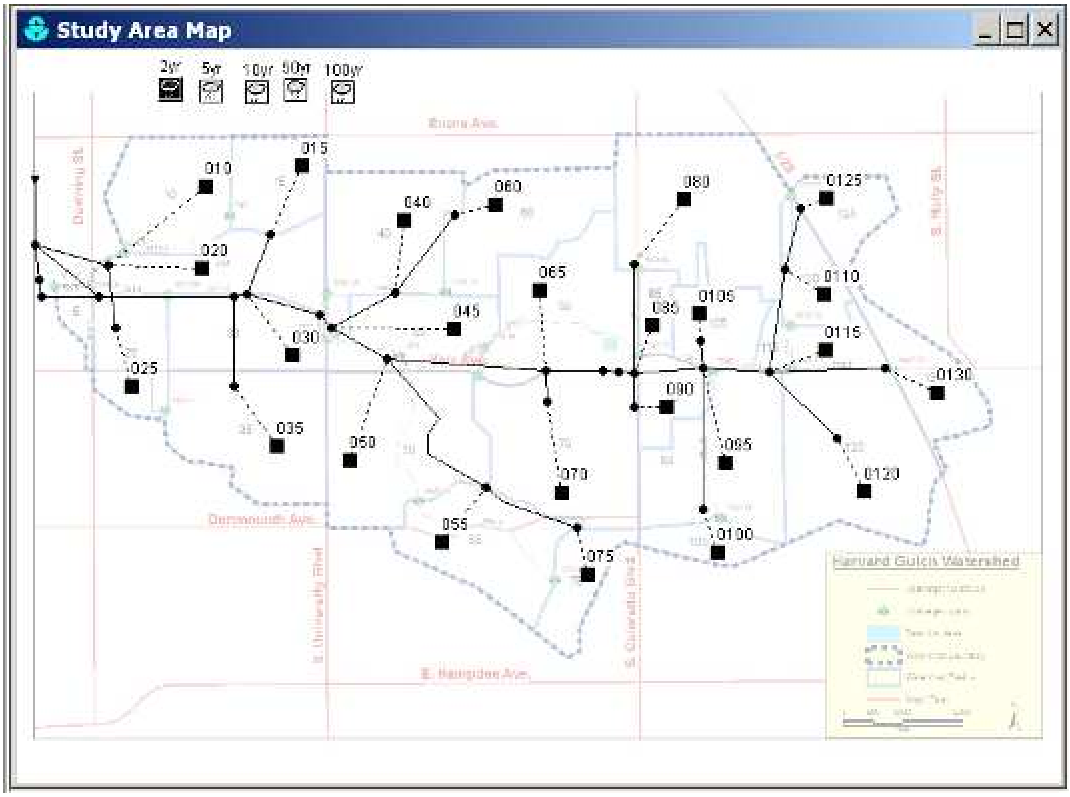


Figure 4-4 Watershed Discretization for Base SWMM Model

5.0 DESIGN EVENTS AND ANNUAL FLOW-FREQUENCY CURVE

Design events are defined as the flood flows simulated under the recommended 2-, 5-, 10-, 50-, and 100-year one-hour precipitation depths distributed on the 2-hr design rainfall curves (USWDCM 2001). The recommended depression losses are set to be 0.1 inch for impervious area and 0.4 inch for pervious (grass) area. The soil infiltration follows the Horton's formula developed for Type B/C soils. The Level 1 MDCIA (minimizing directly connected impervious area) is selected to model the stormwater cascading flow paths. Using the above design parameters, the baseline model, HGCuhp.xsl, was converted into a design-event model to predict design storm hydrographs. The baseline routing model, HGCuhp-DW.inp, was also revised to route the pre-processed CUHP hydrographs through the gulch.

Similarly, the baseline model, HGSwmm-DW.inp, was revised with subareas, flow widths, and slopes listed in Table 4-2, and Manning's roughness coefficient of 0.016 for impervious surface and 0.035 for pervious (grass) area. Using the same design rainfalls and hydrologic losses as those used in the model, HGCuhp-DW.inp, the baseline model, HGSwmm-DW.inp, is then converted into a design-event model.

Table 5-1 summarizes the predicted design peak flows for 2- through 100-yr events. The Log-Pearson Type-3 (statistical) method was adopted to analyze the continuous record of 30 years. The 5% and 95% confidence intervals were calculated to define the upper and lower limits for the 90% chance of the predicted value. In general, the predicted peak flows, Q-cuhp from the CUHP method and Q-kwhp from the KWHP method, give reasonably good agreement to the statistical predictions, Q-LP3.

As expected, due to the build-up of sediment deposit around the two gage stations, the stage-flow rating curve tends to overestimate frequent low flows. As shown in Table 5-1, the statistical prediction of 2-yr peak flow is consistently 50% higher than both computer models, but this difference diminishes for 50- to 100-yr events (Figures 5-1 and 5-2). Nevertheless, the differences among these three methods are within the confidence limits. The predicted peak flows for the 50- to 100-yr events are comparable to the magnitude observed during the July 8, 2001 event.

Table 5-1 Comparison among Predicted Peak Flows for Design Events

GAGE at HARVARD PARK							
Return	Non-Exceed	LP-3	Statistic	Upper	Lower	CUHP	KWHP
Period		Freq F	Peak Flow	Limit	Limit		
Tr	p(Q<q)	Z	Q-LP3	95%	5%	Q-cuhp	Q-kwhp
year			cfs	cfs	cfs	cfs	cfs
2	0.5	-0.329	**503**	634	402	**264**	**274**
5	0.8	0.539	**905**	1203	702	**673**	**464**
10	0.9	1.242	**1194**	1645	893	**998**	**677**
50	0.98	2.987	**1861**	2706	1283	**2132**	**1536**
100	0.99	3.781	**2153**	3175	1435	**2866**	**2362**
GAGE at COLORADO BLVD							
Return	Non-Exceed	LP-3	Statistic	Upper	Lower	CUHP	KWHP
Period		Freq F	Peak Flow	Limit	Limit		
Tr	p(Q<q)	Z	Q-LP3	95%	5%	Q-cuhp	Q-kwhp
year			cfs	cfs	cfs	cfs	cfs
2	0.5	-0.329	**330**	397	275	**176**	**185**
5	0.8	0.539	**543**	693	448	**377**	**309**
10	0.9	1.242	**702**	939	565	**519**	**410**
50	0.98	2.987	**1090**	1607	832	**1040**	**871**
100	0.99	3.781	**1270**	1942	948	**1196**	**1156**

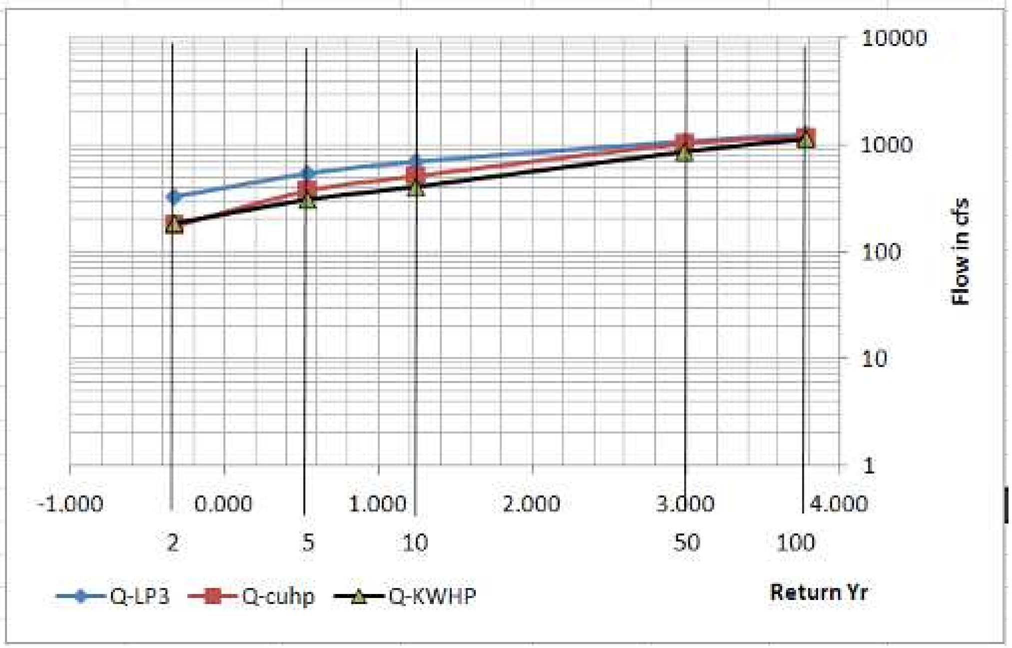


Figure 5-1 Design Peak Flows Predicted at Gage 06711570 at Colorado Boulevard

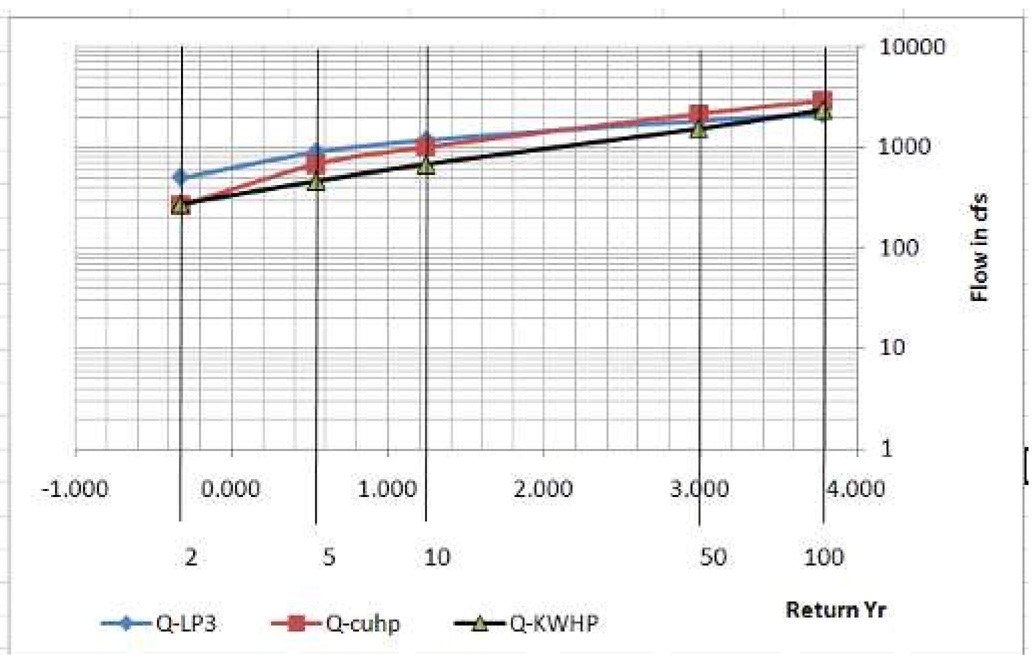


Figure 5-2 Design Peak Flows Predicted at Gage 06711575 at Harvard Park

5.1 Design Events Predicted by CUHP and KWHP Methods

CUHP was developed for urban watersheds up to 3 square miles with a dendritic drainage network while KWHP is recommended for micro scale urban catchments with a single collector channel that does not have any major incoming laterals. The ideal catchment for KWHP is a sloping street block that drains into the central street. Harvard Gulch serves as the collector channel from the neighboring streets. In comparison, the models developed for this watershed produce good agreement for 2- and 100-yr events, but a significant gap for the 10-yr event. A further investigation may be needed to examine the modeling consistency among flood events.

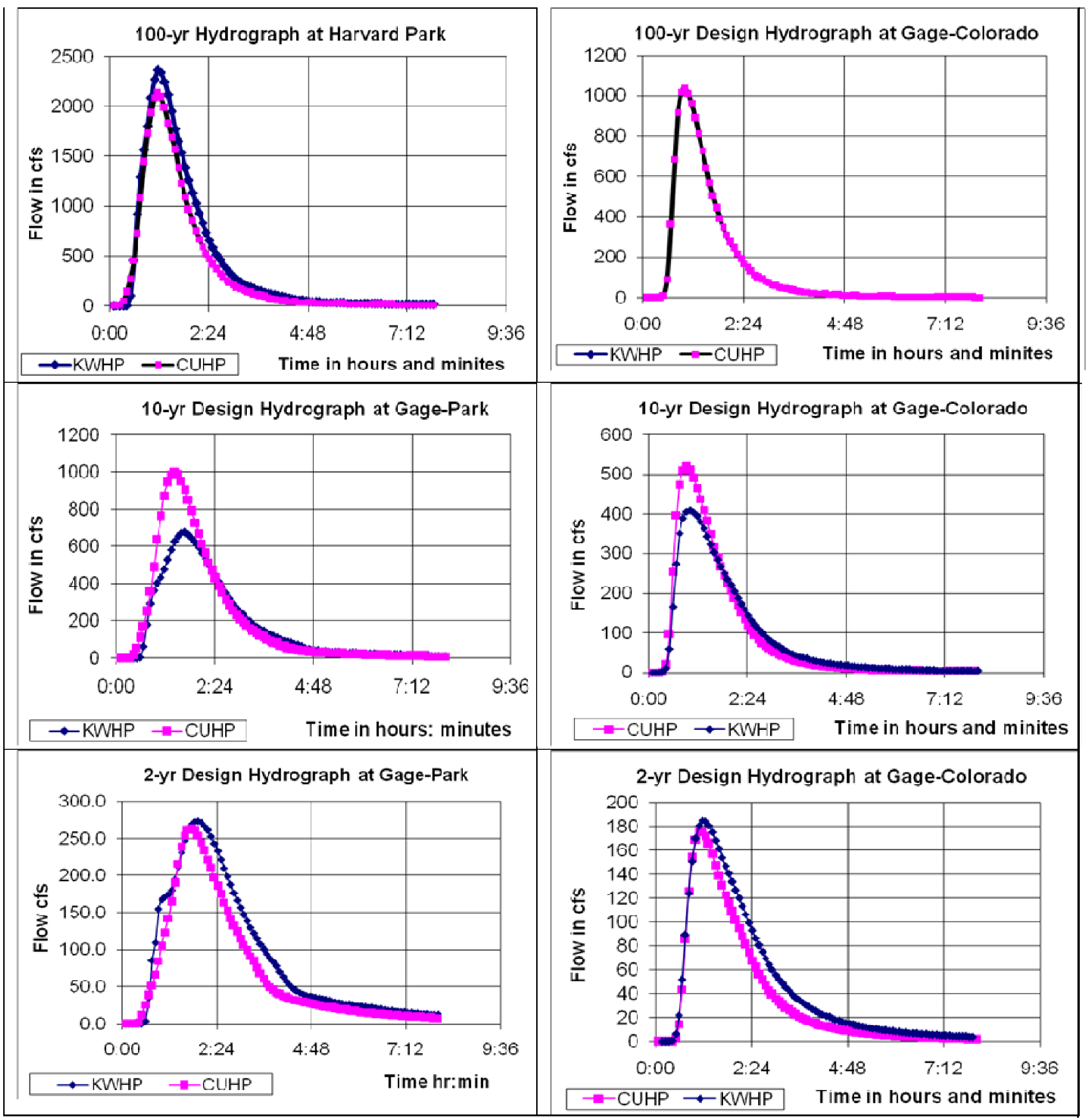


Figure 5-3 Design Events predicted by CUHP and KWHP Methods

6.0 MODEL CALIBRATION WITH OBSERVED EVENTS

The five (5) rain gages and two (2) stream gages operated in this watershed provide a continuous rainfall-runoff record since 1981. After an extensive review of more than 50 events, it was found that most of the recorded events were incomplete or failed to satisfy the basic principle of volume balance. For each case, the runoff volume under the direct runoff hydrograph must be greater than the rainfall volume under the recorded hyetograph. If not, the volumetric discrepancy was caused by either the rain under-catch at the rain gages due to wind and vegetation canopy effects or instrumental errors at the stream gages due to sediment deposit or high flows.

As recommended in the EPA SWMM User's manual (SWMM5 2005), four major water volumes in storm water simulation shall satisfy the principle of continuity as:

$$D_v = V_P - V_F - V_R \tag{6-1}$$

In which D_v = depression volume in [L], V_P = rainfall volume in [L], V_F = infiltration volume in [L], and V_R = direct runoff volume in [L]. All these volumes are computed as water depth per watershed area. The infiltration volume can be estimated by the Horton formula for Type B/C soils for this watershed. The unknown depression volume is set to vary between 0.05 and 0.5 inch. All observed runoff hydrographs were converted into equivalent volume in inch/watershed area. After a lengthy review of the published USGS data record from 1990 to 2005, there are nine events identified to satisfy the basic criteria of volume balance among rainfall, runoff, infiltration, and depression. The event rainfall depths for these selected events vary between 1.0 to 2.5 inches for the most intense 60 minute or shorter portion of the event. According to NOAA Atlas Volume 3 for Colorado (1973), this range of rainfall depths covers the return periods between 2- to 50- years for the Denver metropolitan area. Table 6-1 summarizes these nine events identified in this study.

To simulate the observed events, both baseline models, HGCuhp.xls and HGSwmm.DW.inp, were modified to incorporate the observed hyetograph into the climate data as the source of runoff. A range of hydrologic losses was tested in each model, for each case, in order to produce predicted hydrographs as similar to observed hydrographs as the model can be. In this study, it is an attempt to examine the best-fit condition based on both peak flow rate and water volume.

Table 6-1 Selected Rainfall Events for Harvard Gulch Study

		Incremental		Rainfall	Depth	(inch)			
Time	8/4/1988	7/20/1991	7/23/1992	9/18/1993	7/25/1998	8/17/2000	7/8/2001	9/12/2002	6/18/2003
min	inch	inch	inch	inch	inch	inch	inch	inch	inch
0	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.09	0.00	0.01	0.14	0.03	0.06	0.03	0.00	0.06
10	0.08	0.00	0.02	0.12	0.15	0.08	0.08	0.16	0.31
15	0.15	0.07	0.09	0.07	0.09	0.03	0.33	0.27	0.26
20	0.09	0.16	0.31	0.05	0.11	0.03	0.32	0.36	0.07
25	0.05	0.18	0.16	0.03	0.10	0.07	0.46	0.15	0.11
30	0.04	0.18	0.06	0.07	0.14	0.08	0.30	0.06	0.15
35	0.07	0.20	0.01	0.25	0.11	0.10	0.17	0.03	0.12
40	0.11	0.13	0.01	0.13	0.15	0.08	0.18	0.04	0.05
45	0.08	0.05	0.00	0.04	0.19	0.06	0.13	0.02	0.02
50	0.06	0.09	0.00	0.15	0.09	0.04	0.04	0.02	0.01
55	0.08	0.04	0.00	0.02	0.05	0.03	0.02	0.00	0.00
60	0.06	0.02	0.00	0.00	0.05	0.02	0.06	0.00	0.00
65	0.06	0.01	0.00	0.01	0.04	0.01	0.10	0.00	0.00
70	0.02	0.00	0.00	0.00	0.02	0.01	0.02	0.00	0.00
75	0.02	0.01	0.00	0.00	0.02	0.01	0.01	0.00	0.00
80	0.02	0.00	0.00	0.00	0.03	0.01	0.01	0.00	0.00
85	0.02	0.01	0.00	0.00	0.01	0.01	0.05	0.00	0.00
90	0.01	0.01	0.00	0.00	0.01	0.01	0.03	0.00	0.00
95	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00
100	0	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00
105	0.01	0.00	0.00	0.00	0.04	0.01	0.01	0.00	0.00
110	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
115	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
120	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Sum	1.24	1.19	0.68	1.09	1.47	0.83	2.37	1.14	1.16

6.1 Event on 07/08/2001

During the July 8, 2001 event, the rainfall depths were recorded at the five rain gages as shown in Table 6-2. The reading difference among the rain gages might reflect the decay of the storm intensity along Harvard Gulch or the possible operational errors due to the wind effect around the rain gages.

Table 6-2 Rainfall Depths at Five Rain Gages on July 8, 2001

Rain Gage	Rain Depth (inches)
Bethesda	2.97
Bradley	2.37
University	3.55
Slavens	1.35
Harvard Park	1.2

Applying Theissen's area-weighting method to this event, the area-averaged rainfall depth was determined to be approximately 2.41 inches or close to a 50 to100-yr event in the Denver area. Table 6-3 presents the USGS record of stream flows downstream of Colorado Boulevard during this event. The hydrograph sharply rises from the base flow of 2.4 cfs to the peak flow of 1100 cfs over a period of 30 minutes and then reduced to a dry bed condition over the next 30 minutes. These sharp changes in the hydrograph imply that the stream gage was malfunctioned. The reported peak flow of 1100 cfs is the best information available to represent the event.

Table 6-3 USGS Report at Gage 06711570 at Colorado Blvd for 07/08/2001 Event

Year-Month-Date	Hour:Min:Sec		Q (cfs)
20010708	161500	MDT	2.4
20010708	163000	MDT	2.4
20010708	164500	MDT	2.4
20010708	170000	MDT	157
20010708	171500	MDT	1100
20010708	174500	MDT	0
20010708	180000	MDT	0
20010708	181500	MDT	0

Although both stream gages failed to record the entire runoff hydrographs, the USGS annual peak flow records indicate that a peak flow of 1100 cfs occurred at the gage next to Colorado Boulevard, and 2120 cfs was estimated at the gage next to Park. As illustrated in Figure 6-1, the missing runoff hydrographs were estimated by the linear rising and falling hydrographs. For this case, it was found that using the recommended hydrologic losses listed in Table 6-4, both CUHP and KWHP methods can match with the observed peak flows well.

Table 6-4 Hydrologic parameters used in 07/08/2001 Event Simulation

Total precipitation depth	2.41	inch
Rain gage	All Gages	
Imp Depression Loss	0.10	inch
Perv Depression Loss	0.40	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

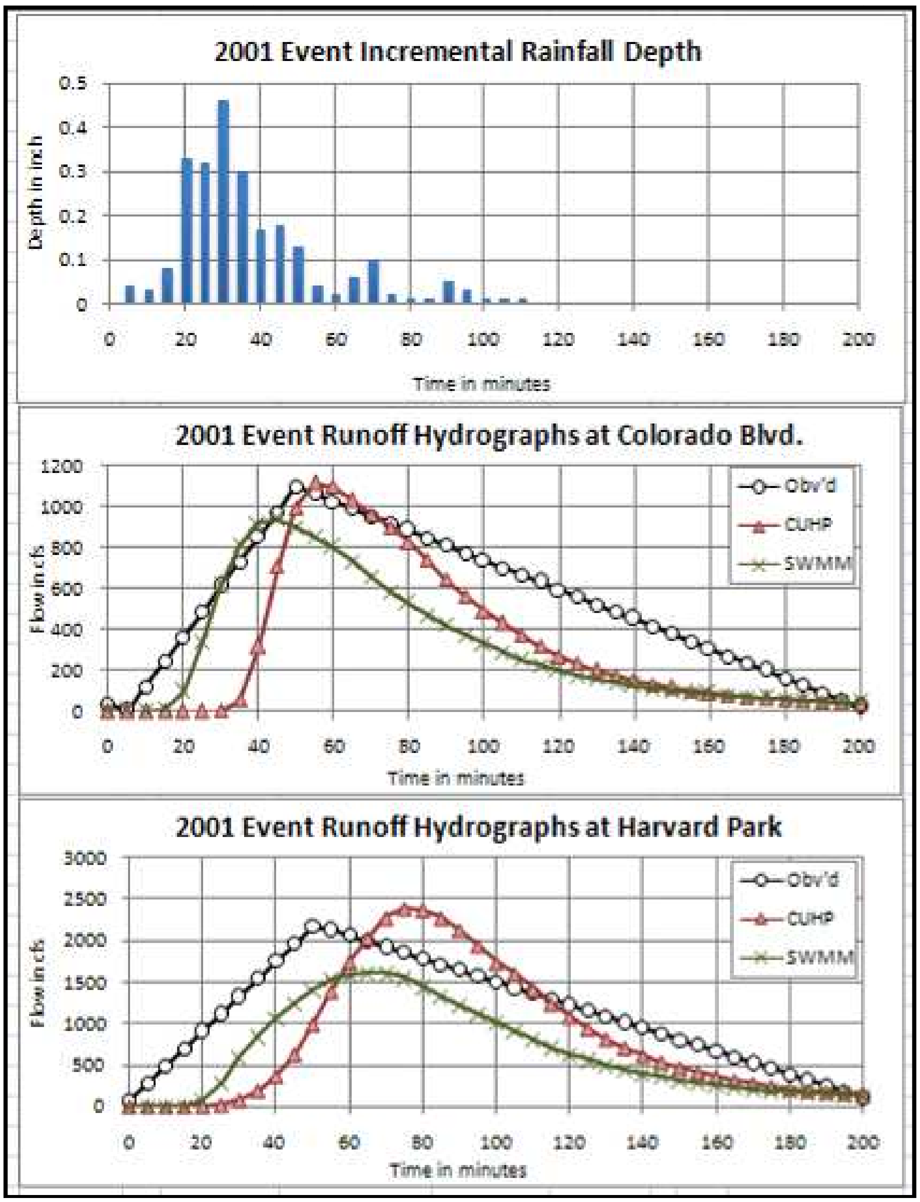


Figure 6-1 Comparison of Hydrographs for 07/08/2001 Event
(The linear rising and falling hydrograph was estimated in this study.)

6.2 Event on 06/18/2003

This event produced a total of rainfall depth of 1.16 inches over a period of 60 minutes as recorded at Rain Gage-University. The other four rainfall gages recorded much less rainfall amount. This rainfall amount is equivalent to a 4-yr event. A peak flow of 502 cfs was reported at the gage next to Colorado Boulevard, and 750 cfs was observed at the gage next to the park. Table 6-5 presents the estimated hydrologic losses. For this case, the KWHP method using the model, HGSwmm.inp, tends to underestimate the peak flows at both gage locations. As shown in Figure 6-2, the differences between the predicted and observed peak flows are within a reasonable tolerance. However, the observed hydrograph at Gage-Park seems too short to carry sufficient runoff volume.

Table 6-5 Hydrologic parameters used in 06/18/2003 Event Simulation

Total precipitation depth	1.16	inch
Rain gage	University	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

	Gage-Colorado			Gage-Park	
Obv'd	CUHP	SWMM	Obv'd	CUHP	SWMM
Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG
acre-ft	acre-ft	acre-ft	acre-ft	acre-ft	acre-ft
36.85	37.64	34.73	53.28	84.01	66.31

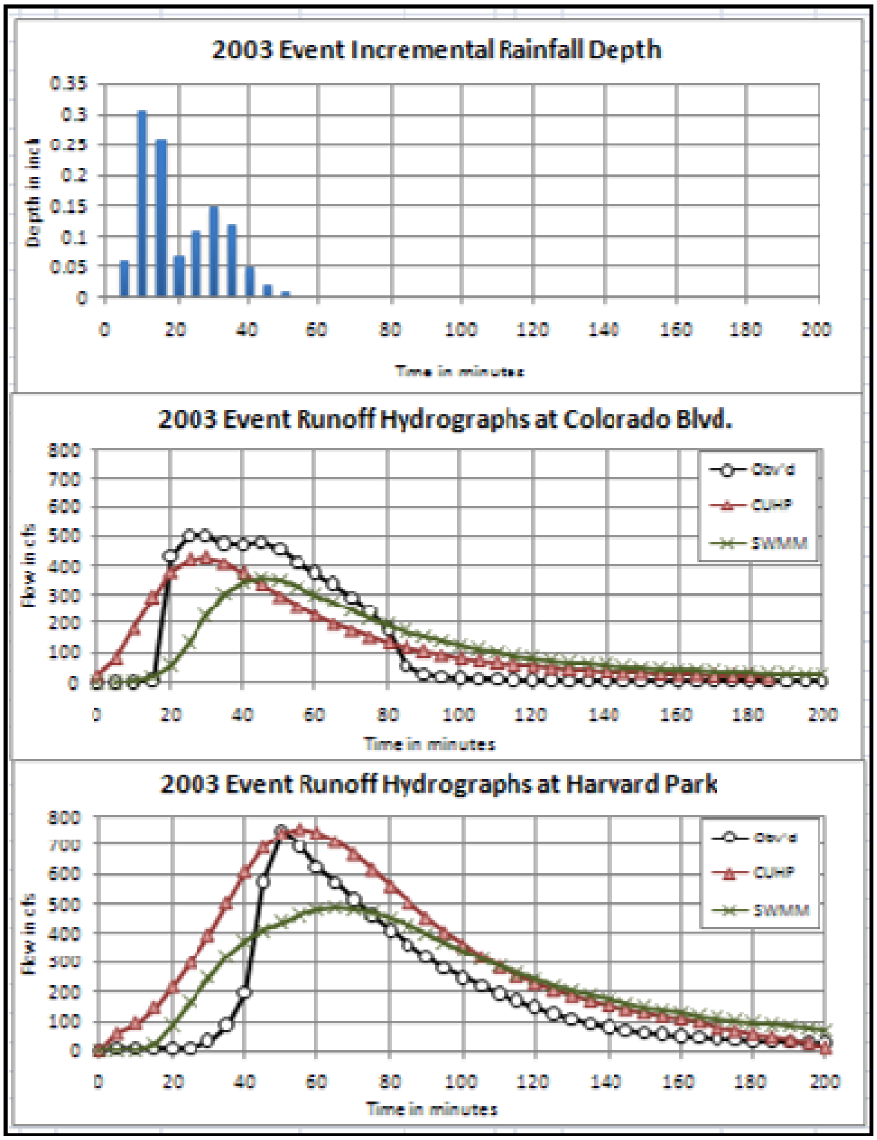


Figure 6-2 Comparison of Hydrographs for 06/18/2003 Event

6.3 Event on 09/12/2002

This event was similar to 06/18/2003 event. It produced a total of rainfall depth of 1.14 inches over 60 minutes as recorded at Rain Gage-Bethesda. This rainfall amount is equivalent to a 4-yr event. A peak flow of 450 cfs was reported at the gage next to Colorado Boulevard, and 750 cfs was observed at the gage next to the park. Table 6-6 presents the estimated hydrologic losses. For this case, the KWHP method tends to underestimate the peak flows at both gage locations. As shown in Figure 6-3, good agreement is achieved among the hydrographs at Stream Gage-Colorado. In comparison with the computed hydrographs, Stream Gage-Park was too slow to react to the incoming flood wave, but it had no problem with the low flows on the recession hydrograph. This case revealed that the instrument at Gage-Park was dried up between events, and then became fully activated until the peak flow arrived. As expected, the volume comparison for this case is very scattered.

Table 6-6 Hydrologic parameters used in 09/12/2002 Event Simulation

Total precipitation depth	1.14	inch
Rain gage	Bethesda	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

	Gage-Colorado			Gage-Park	
Obv'd	CUHP	SWMM	Obv'd	CUHP	SWMM
Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG
acre-ft	acre-ft	acre-ft	acre-ft	acre-ft	acre-ft
28.99	36.37	33.97	53.28	81.16	66.33

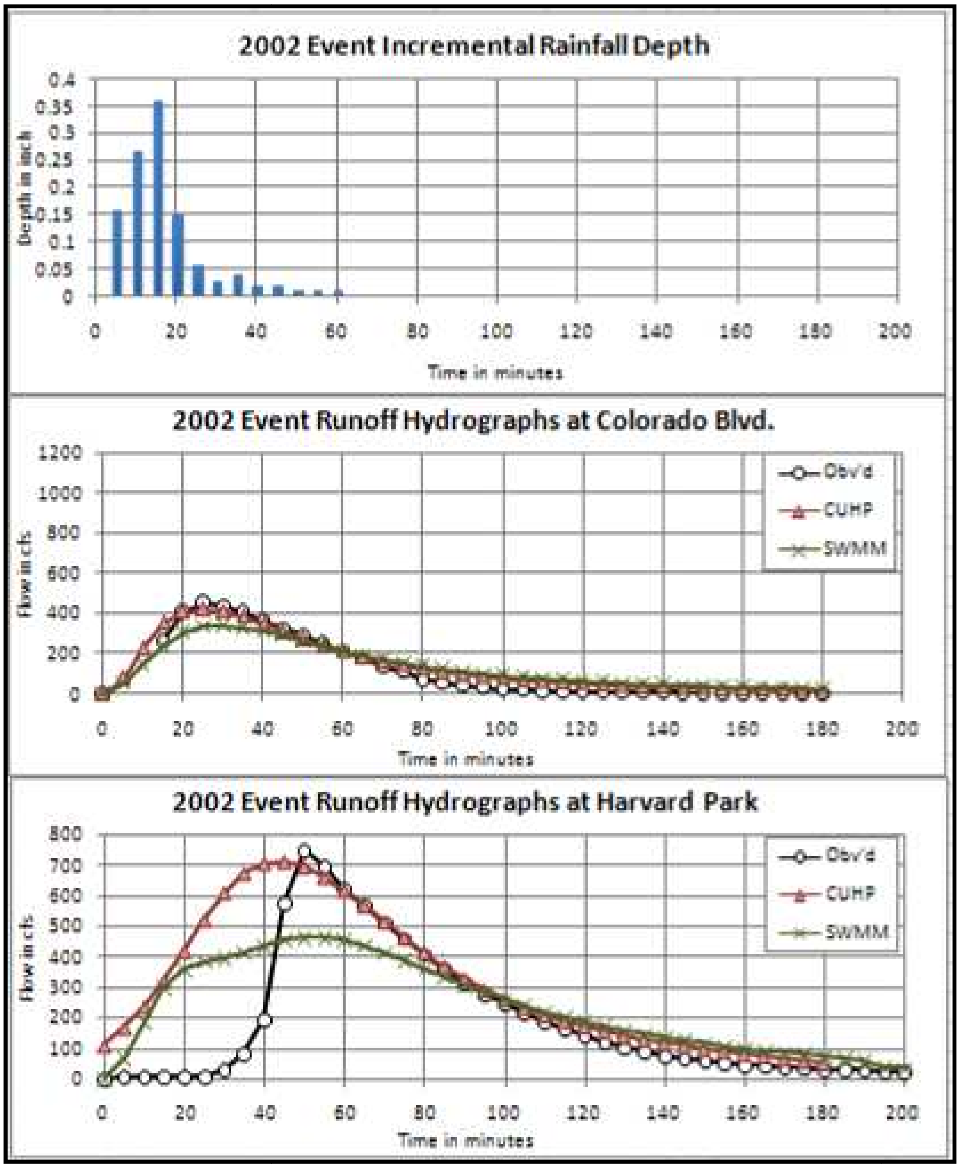


Figure 6-3 Comparison of Hydrographs for 09/12/2002 Event

6.4 Event on 08/17/2000

Although this event occurred in the summer, its distribution was a long, mild, double-peak. Over two-hour duration, this event produced a total rainfall amount of 1.22 inch as recorded at Rain Gage-Slavens. A peak flow of 409 cfs was reported at the gage next to Colorado Boulevard, and 350 cfs was observed at the gage next to Harvard Park. Obviously, the consistency between these two peak flows could imply that either the upstream gage overestimated the peak flow or the downstream gage underestimated the peak flow. Table 6-7 presents the estimated hydrologic losses. In comparison, the predicted and observed hydrographs at Gage-Colorado follow the same trend. As a result, It is determined that the flow record at Stream Gage-Park carries errors. As expected, the comparison among flows and water volumes at the downstream gage are very scattered.

Owning to the default numerical procedure for calculating the hydrologic losses, both CUHP and SWMM could not produce dual peaks on the computed hydrographs at Gage-Colorado. The CUHP's hydrologic loss function is to treat the soil column as a pipe. As soon as the incremental rainfall depth exceeds the soil infiltration loss, the model will generate overland flows. On the contrary, the SWMM's loss function is to treat the soil column as a sponge. It takes a ponding time to fill up the storage volume in the soil column before the surface runoff can occur. Numerically, the initial rainfall depth has to fill up the depression and soil infiltration losses before overland flows can be calculated. By nature, the rainfall and runoff process can be a quick response from impervious surfaces or a slow response from pervious surfaces. The dual-peak hydrograph is a good example of directly and indirectly flow connections in an urban setting. These details in storm water modeling require on-site information about flow paths and land uses. Both CUHP and SWMM5 at a scale of 80 acres per sub-area do not have an adequate resolution to repeat the dual peaks.

Table 6-7 Hydrologic parameters used in 08/17/2000 Event Simulation

Total precipitation depth	1.22	inch
Rain gage	Slavens	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

	Gage-Colorado			Gage-Park	
Obv'd	CUHP	SWMM	Obv'd	CUHP	SWMM
Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG
acre-ft	acre-ft	acre-ft	acre-ft	acre-ft	acre-ft
38.04	40.47	35.97	31.95	86.43	64.54

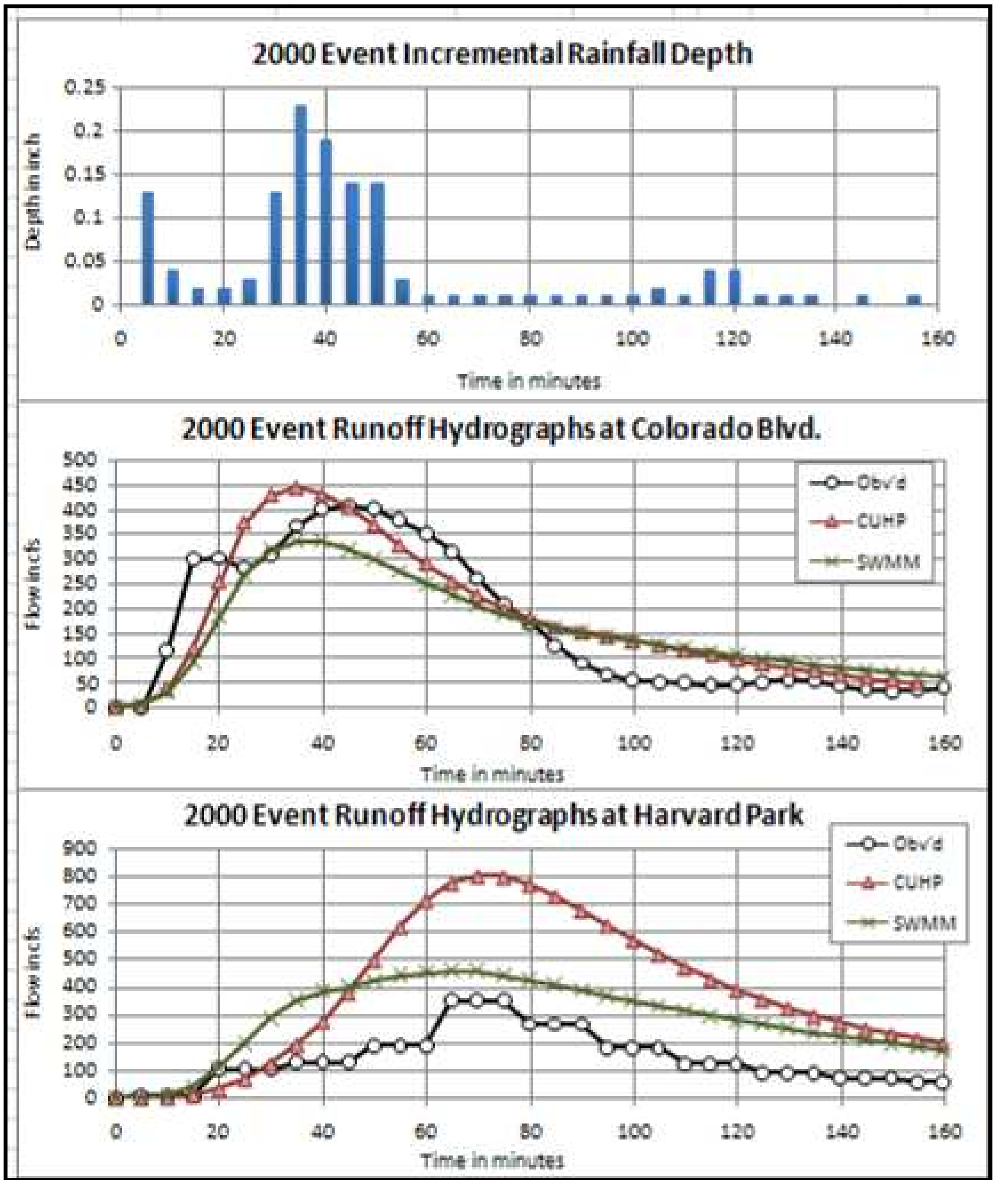


Figure 6-4 Comparison of Hydrographs for 08/17/2000 Event

6.5 Event on 07/25/1998

This event was long and intermitting for three hours. It produced a total rainfall amount of 1.39 inch. As shown in Table 6-8, a peak flow of 417 cfs was reported at the gage next to Colorado Boulevard, and 573 cfs was observed at the gage next to the park. Relatively, the magnitudes of these two peak flows reflect the sizes of their tributary areas.

The temporal rainfall distribution for this case shows a dual-peak nature. A total of 0.4 inch of rain occurred in the first 20 minutes and then followed with 0.95 inch of rainfall over the last 160 minutes. Although this rainfall pattern is similar to the 08/17/2000 event, it produced no twin peaks at all. As illustrated in Figure 6-5. The CUHP model gives good agreement with the observed peak flow at Stream Gage-Park, but underestimates the observed flow at Stream Gage-Colorado. It is necessary to investigate the sediment deposition and vegetation effect at this gage site.

Table 6-8 Hydrologic parameters used in 07/25/1998 Event Simulation

Total precipitation depth	1.39	inch
Rain gage		
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

	Gage-Colorado			Gage-Park	
Obv'd	CUHP	SWMM	Obv'd	CUHP	SWMM
Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG
acre-ft	acre-ft	acre-ft	acre-ft	acre-ft	acre-ft
32.19	32.41	34.71	60.59	71.78	65.16

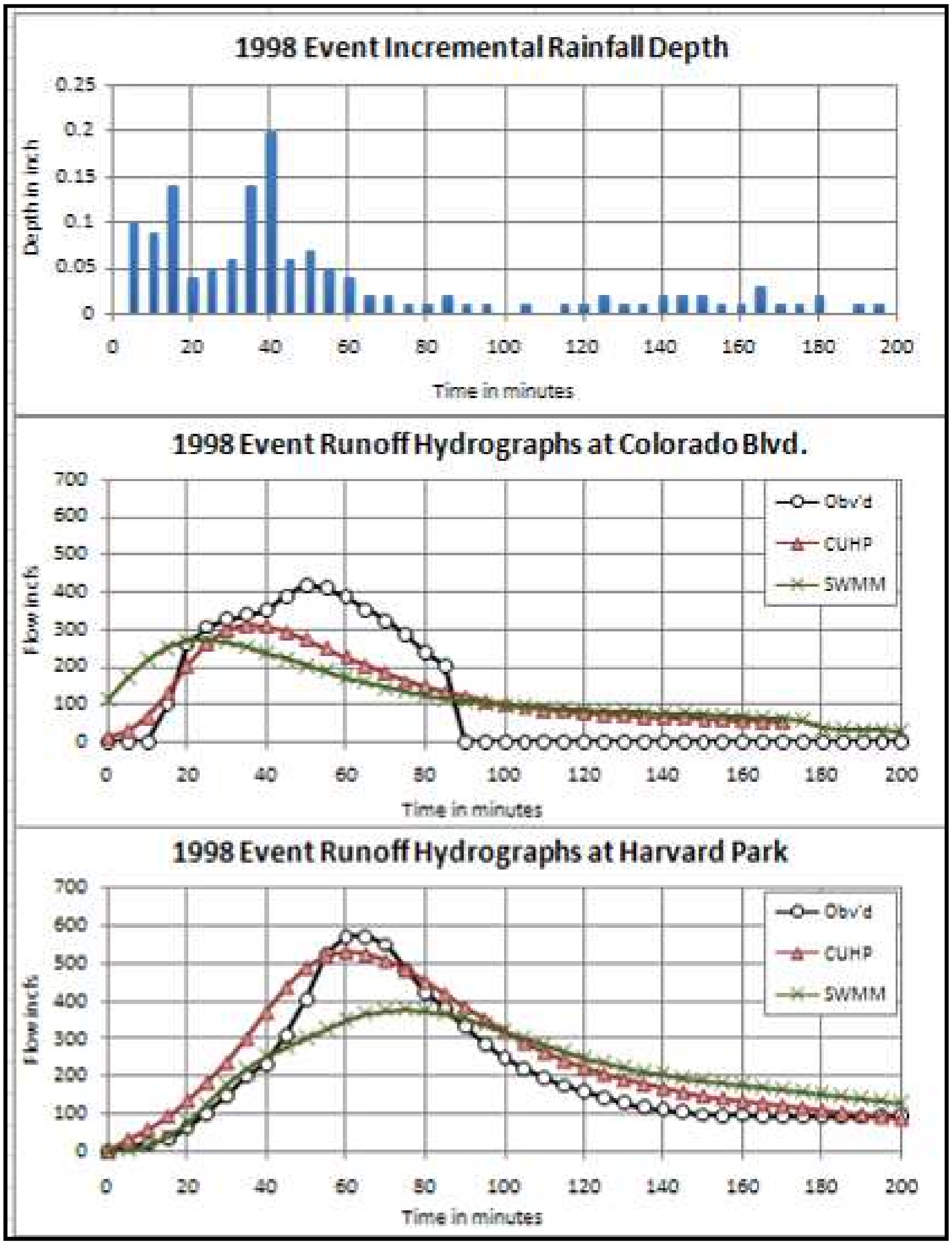


Figure 6-5 Comparison of Hydrographs for 07/25/1998 Event

6.6 Event 09/18/1993 Event

Th0 09/18/1993 event produced a total of 1.05 inch of rainfall from a dual-peak distribution over 60 minutes. The leading rainfall produced a rainfall amount of 0.3 inch in the first 20 minutes. The peak rainfall occurred after the soil depression was filled up already. Table 6-10 is the summary of hydrologic parameter used in the models, HGCuhp.xls and HGSwmm-DW.inp. Both models match with the observed well. As shown in Table 6-10, the computed water volumes deviate from the observed by approximately10%.

Table 6-10 Hydrologic parameters used in 09/18/1993 Event Simulation

Total precipitation depth	1.05	inch
Rain gage		
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.10	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

	Observed	CUHP	SWMM5
Peak (cfs)	424.00	384.75	350.02
Vol (a-f)	31.35	34.39	34.48

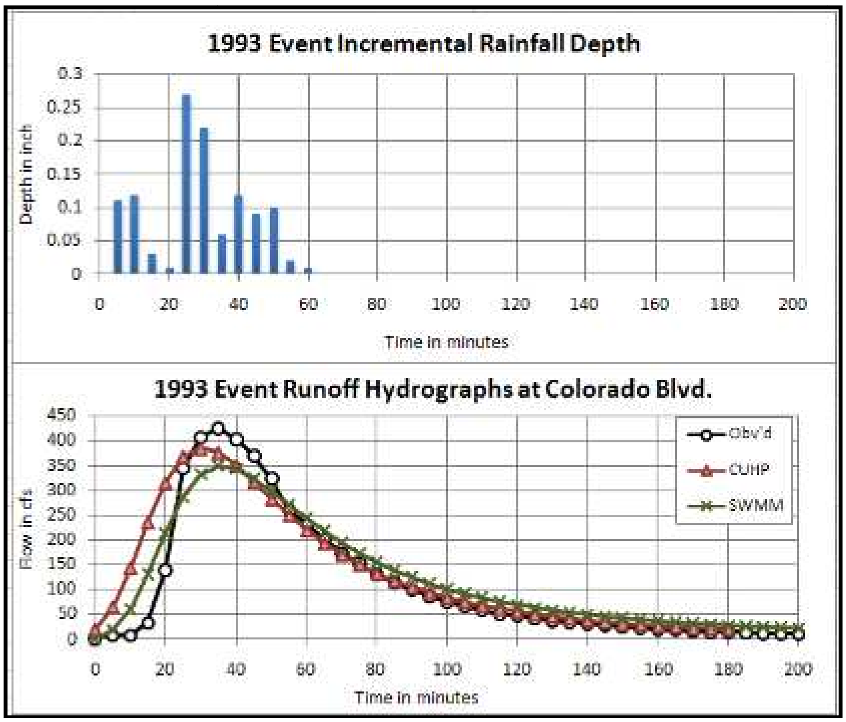


Figure 6-6 Comparison of Hydrographs for 09/18/1993 Event

6.7 Event 07/20/1991 Event

The07/20/1991 event produced a total of 1.13 inch of rainfall from a single peak distribution over 60 minutes. This is a case very similar to the recommended design rainfall curve with a leading nature through the first 20 minutes of the event. A peak flow of 309 cfs was recorded at Stream Gage-Colorado while a peak flow of 471 cfs occurred at Stream Gage-Park. This case is comparable to an event between 2 and 5-year design events. Table 6-10 presents the hydrologic parameters used in the numerical simulations. As expected, the computed hydrographs presented in Figure 6-7 at both gage sites closely agree with the observed. Again, the dip on the observed hydrograph at Stream Gage-Park was obviously caused by instrument errors.

It is noted that both computer models applied low depression losses, 0.05 inch for impervious area and 0.1 inch for pervious area, for this case and the KWHP method produced higher peak flows than those from the CUHP method.

Table 6-10 Hydrologic parameters used in 07/20/1991 Event Simulation

Total precipitation depth	1.13	inch
Rain gage	Bradley	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.10	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

	Gage-Colorado			Gage-Park	
Obv'd	CUHP	SWMM	Obv'd	CUHP	SWMM
Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG	Runoff HG
acre-ft	acre-ft	acre-ft	acre-ft	acre-ft	acre-ft
21.02	22.95	33.32	43.90	51.02	62.70

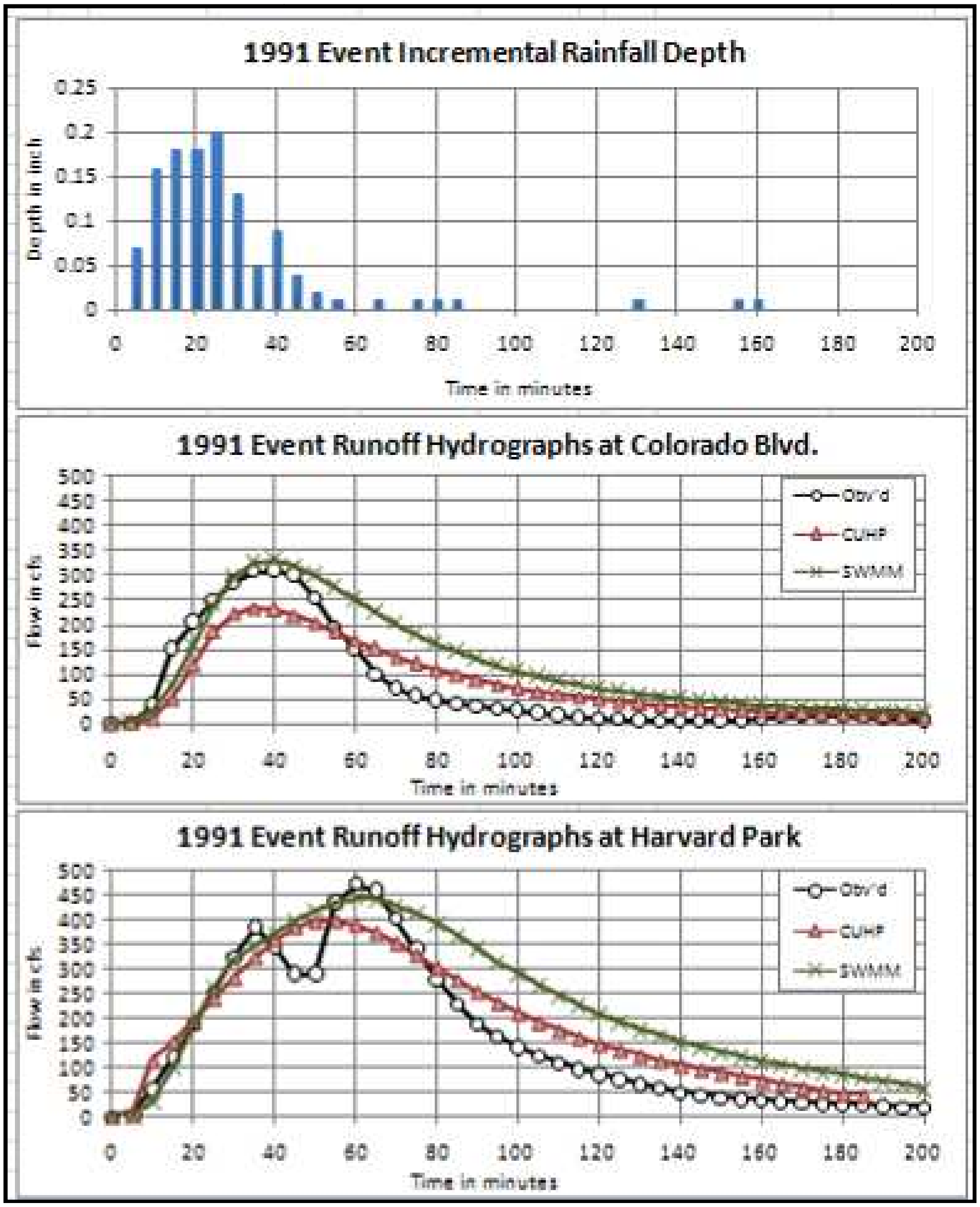


Figure 6-7 Comparison of Hydrographs for 07/20/1991 Event

Using the peak flow as the basis, Table 6-11 presents an evaluation of the CUHP and KWHP methods. Figure 6-8 summarizes the comparison between the observed and the predicted peak flood flows at Stream Gage-Park from1990 through 2010. Although both CUHP and KWHP methods provide reasonably good predictions for a wide range of peak flows, both models, as shown in Table 6-11, underestimate the peak flows 10 out of 14 cases.

As aforementioned, although there are five rain gages operated in the watershed, all of them are under the wind and vegetal canopy effects. As expected, the recorded hyetographs did not truly represent the spatial and temporal variations of storm movement. In this study, Theissen's area-weighting method was tested for several events. The 07/08/2001 event was the only one that had sufficient recorded rainfall amounts for application of Theissen's method. In order to satisfy the water volume balance, the highest recorded rainfall amount among these five rain gages was adopted for numerical simulations using the CUHP and KWHP method. Table 6-11 indicates that the CUHP method carried an average of 9% underestimation. Considering that rain under-catch is at a rate of 1% per one mile/hr of wind speed, an underestimation of 9% in flood peaks may imply that the operation of these rain gages was interferenced under an average wind speed at 9 mile/hour.

Table 6-11 Summaries for Observed and Predicted Peak Flows

Observed Peak Flow Q-obs cfs	Predcited Peak Flow Q-cuhp cfs	Predcited Peak Flow Q-kwhp cfs	CUHP Error (Qcuhp-Qobs)/Qobs percent	SWMM Error (Qkwhp-Qobs)/Qobs percent
293	221	131	-0.25	-0.55
309	233	329	-0.25	0.06
409	445	338	0.09	-0.17
417	310	272	-0.26	-0.35
424	385	350	-0.09	-0.17
458	422	343	-0.08	-0.25
471	397	444	-0.16	-0.06
502	430	360	-0.14	-0.28
573	531	361	-0.07	-0.37
750	757	890	0.01	0.19
750	711	666	-0.05	-0.11
1100	1115	936	0.01	-0.15
2120	2375	1604	0.12	-0.24
Average			-0.09	-0.19

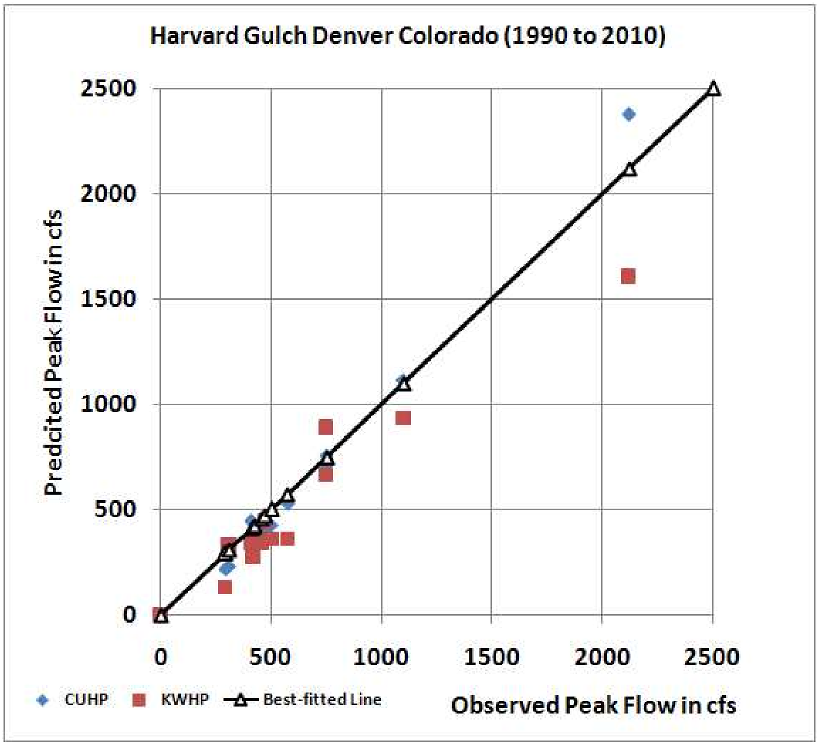


Figure 6-8 Comparison between Observed and Predicted Peak Flows

(Harvard Gulch Watershed in Denver, Colorado from 1990 to 2010)

7.0 KINEMATIC WAVE MODEL FOR PRE-DEVELOPMENT CONDITION

As a common practice, a master drainage study is conducted before the development of the watershed. To be conservative, the kinematic wave (KW) model is often recommended for master drainage studies. Harvard Gulch Watershed is one of the core areas in the development of the City of Denver. There were several master drainage studies that have been conducted for the Harvard Gulch Watershed. The 100-yr peak flow at Harvard Park has been predicted to be approximately 3600 cfs (FHAD 1979). It is interesting to investigate if the KW model developed in this study can repeat such a high flow prediction at Harvard Park.

Kinematic wave is a simplified flood wave routing method. The forward finite difference scheme used in KW routing does not take the downstream flow condition into computations. As a result, the backwater effect is ignored from the numerical process. Kinematic wave propagation takes an instantaneous uniform depth to propagate the flood flow as described in Manning's formula.

For this case, switching the numerical operation from the DW to its KW does not produce any significant difference in peak flow attenuation. For a matured urban area, significant flow attenuation is often associated with the backwater effects immediately upstream of closed conduits. Before Harvard Gulch Watershed was developed, several alternative KW models should have been developed using open channels as the major conveyance to carry the flood flows. Therefore, for this case, the DW model, HGCuhp-DW.inp, that portrays the after-development condition, could be converted into its equivalent KW model, HGCuhp-KW.inp, only if the three closed box conduits were replaced with the historic waterway. Table 7-1 is the default historic grass waterway throughout the current gulch alignment.

Table 7-1 Existing Underground Conduits along Harvard Gulch

Location	Existing Condition (DW)	Historic Condition (KW)
Colorado Blvd/Jackson Street	9-ft by 14-ft Concrete Box	10-ft Grass Channel 4H:1V
University	5-ft by 6.5-ft Concrete Box	10-ft Grass Channel 4H:1V
Downing Street to Park	10-ft by 14.5-ft Concrete Box	10-ft Grass Channel 4H:1V
Colorado and Yale Street	Curbs and Gutters	10-ft Grass Channel 4H:1V

The baseline DW model is then converted into its equivalent KW model using the historic waterway along the existing gulch alignment. The channel roughness coefficient is set to be 0.035 for grass linings. The 2- to 100-yr KW peak flows are predicted and summarized in Table 7-2. As expected, the KW approach repeated the 1979 FHAD study results and gives the highest prediction in comparison with other methods.

Table 7-2 Comparison among Predicted Flows using Various Methods

GAGE at HARVARD PARK								
Return Period Tr year	Non-Exceed p(Q<q)	LP-3 Freq F Z	Statistic Peak Flow Q-LP3 cfs	Upper Limit 95% cfs	Lower Limit 5% cfs	CUHP DW Q-cuhp cfs	KWHP DW Q-kwhp cfs	CUHP KW Q-cuhp
2	0.5	-0.329	**503**	634	402	**264**	**274**	**520**
5	0.8	0.539	**905**	1203	702	**673**	**464**	**1100**
10	0.9	1.242	**1194**	1645	893	**998**	**677**	**1515**
50	0.98	2.987	**1861**	2706	1283	**2132**	**1536**	**3052**
100	0.99	3.781	**2153**	3175	1435	**2866**	**2362**	**4046**
GAGE at COLORADO BLVD								
Return Period Tr year	Non-Exceed p(Q<q)	LP-3 Freq F Z	Statistic Peak Flow Q-LP3 cfs	Upper Limit 95% cfs	Lower Limit 5% cfs	CUHP DW Q-cuhp cfs	KWHP DW Q-kwhp cfs	CUHP KW Q-cuhp
2	0.5	-0.329	**330**	397	275	**176**	**185**	**287**
5	0.8	0.539	**543**	693	448	**377**	**309**	**551**
10	0.9	1.242	**702**	939	565	**519**	**410**	**735**
50	0.98	2.987	**1090**	1607	832	**1040**	**871**	**1380**
100	0.99	3.781	**1270**	1942	948	**1196**	**1156**	**1758**

Over the years, Harvard Gulch has been channelized with concrete linings, high banks, and sufficient headwater walls. All these improvements have increased the gulch's conveyance capacity to pass frequent events, and added "brimful" detention capacity to store extreme events. Such an efficient channel system will pass low flows like a kinematic wave, and high flows like a dynamic wave. This fact is clearly revealed in the flow-frequency relationship derived at Stream Gage-Park. As shown in Figure 7-1, the flow-frequency relationship represents a statistical distribution that can be described as

$$Q(Tr) = Q_m + SD \times Z(Tr) = 598.13 + 416.51\ Z(Tr) \qquad (7\text{-}1)$$

Where Q(Tr) = peak flow for a selected return period, Tr, Q_m = mean of flow data, SD= standard deviation of flow data. For the record of 30 years, Q_m = 598.13 cfs and SD= 416.51 cfs. Eq 7-1 should be a linear line on the Pearson-Type 3 graphic paper. Following the trend line of low flows (KW flows), the 100-yr KW peak flow at the location of Stream Gage-Park should be approximately 4000 cfs. In fact, the observed peaks (DW flows) bend down to 2200 cfs. The difference between the linear straight line and the concave curve is due to the detention effect in the system. Figure 7-1 reveals that the detention effect begins with a 10-yr event. In this study, the pronounced detention effects begin in the 50-yr event in both baseline models.

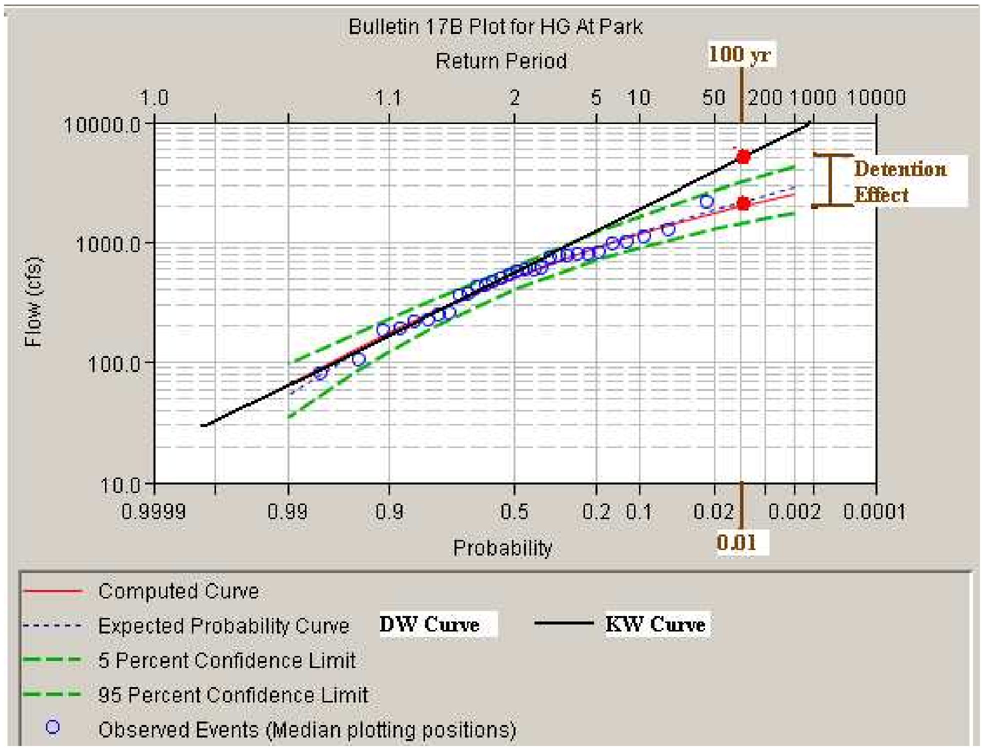


Figure 7-1 Detention Effect on Extreme Events in Harvard Gulch

In closing, Figure 7-1 provides convincing evidence to verify the KW and DW analyses for low and high flows through the historic and existing Harvard Gulch.

8.0 CONCLUSION

1. Based on the comparison with the 30-yr annual peak flows recorded at two stream gages in Harvard Gulch, the CUHP method is verified to be able to re-produce the flow-frequency curve using the 2-hr design rainfall distributions for 2- to 100-yr events. In this study, the entrance inlet at Colorado Boulevard and Yale Street is a critical element that provides an upstream detention effect on flood flows as soon as the gutter flow depth exceeds 18 inches. The dynamic wave model developed in this study indicates that this structure only attenuates 50- to 100-yr flood peaks. The underground culverts underneath Colorado Boulevard, University Boulevard, and W. Harvard Avenue also provide significant storage effects to attenuate the extreme events. This fact is verified by the concave flow-frequency relationship. This study confirms that the existing drainage system is capable of passing the 100-yr peak flow to S. Logan Street.

2. The dynamic wave (DW) routing scheme is recommended to model the existing conditions while the kinematic wave (KW) routing scheme is more suitable for master planning studies under a projected future condition. A KW model is a simplified approach that works best with an open-channel flow system. When the drainage system consists of culverts and closed conduits, a DW model should be selected. Since a DW flow is dictated by the energy grade line, it is critically important to apply the true elevations and sizes at a node.

3. The KW watershed shape function is a good approach to convert an irregular watershed into its KW sloping plan. However, the KWHP seems sensitive to the watershed size. From the preliminary findings in this study, the KWHP method is recommended for watersheds less than 50 to 70 acres. In comparison, KWHP consistently produces lower peak flows than CUHP when the watershed is greater than 90 acres. For this study, both CUHP and KWHP methods produce good agreement for 2- and 100-yr design hydrographs. This difference in peak flow increases from the 2-yr event toward the 10-yr event and then decreases to the 100-year event. This phenomenon may reflect the possible inconsistency in the prediction method among various events within each model. A further investigation is needed.

4. In this study, extensive data mining revealed that most recorded hyetographs had less water volume than the corresponding runoff hydrographs. Even though the numerical simulations of the selected nine events had to adopt an impervious depression loss as low as 0.05 inch and a pervious depression as low as 0.1 inch in order to produce good agreement, both CUHP and KWHP methods underestimate the peak flows for 10 out of 14 cases. All these facts imply that the operations of the five rain gages are under-catch due to wind effect. It is recommended that shields be built around the gage orifices or that a wind gage be added to record the wind speed for data corrections.

5. Based on the comparison between the predicted and observed annual peak flows, it is suggested that the performance of Gage-Colorado be examined for possible influence from sediment deposit, and Gage-Park be examined for a possible instrumental problem that becomes pronounced at the beginning of a large event and fails during the 50 to 100-yr peak flows.

9.0 REFERENCES

Bedient, P. B. and Huber, W (1992). Hydrology and Floodplain Analysis, 2nd edition, Addison Wesley Book Company, New York.

Bulletin 17B (1980), Guidelines for Determining Flood Frequency, USGS, Office of Water Data Coordination, Reston, Virginia

CH2MHill (2009), Summary Report for CUHP Program Support Services, submitted to UDFCD.

Curtis, David, C., and Humphrey, John H., (1995) "Use of Radar-Rainfall Estimates to Model the January 9-10, 1995 Floods in Sacramento, CA", the 1995 Southwest Association of ALERT Systems Conference held in Tulsa, OK, Oct 25-27

FHAD (1979), Flood Hazard Area Delineation Study for Harvard Gulch, West Harvard Gulch and Dry Gulch, UDFCD, prepared by Gingery Associates, Inc., December.

Flash Flood Prediction (2010), QUANTITATIVE PRECIPITATION FORECAST, issued at 2:33 PM Sun July 8, 2010, UDFCD.

Guo, James C.Y., Urbonas, Ben and Stewart, Kevin. (2001) "Rain Catch under Wind and Vegetal Effects", ASCE J. of Hydrologic Engineering, Vol 6, No.1, January, 2001.

Guo, James C.Y. and Urbonas, B. (2009) "Conversion of Natural Watershed to Kinematic Wave Cascading Plane", ASCE J. of Hydrologic Engineering, Vol 14, No. 8, August, 2009.

Guo, James C.Y., Blackler, E G., Earles, A., and MacKenzie, K. (2010) "Effective Imperviousness as Incentive Index for Stormwater LID Designs" ASCE J. of Irrigation and Drainage Engineering, Vol 136, No12, Dec, 2010.

HEC-SSP (2010), Statistical Software Package, Hydrologic Engineering Center, Corp of Engineers, Davis, California.

MacKenzie, Ken, Urbonas, Ben, Jansekok, K, and Guo, James C.Y. (2007), Effect of Rain Gage Density on Runoff Simulation Modeling, ASCE World Environmental and Water Resources Congress 2007.

Matrix Group (2010), Outfall Study (2010), Harvard Gulch Outfall Alternatives Analysis and Feasibility Study, Preliminary Engineering Report, UDFCD, prepared by Matrix Design Group, March.

NOAA Atlas Volume 3 for Colorado (1973), Current NWS Precipitation Frequency (PF) Documents , NOAA National Weather Service, Washington D.C.

SWMM4 (1988), Storm Water Management Model Version 4, Center for Exposure Assessment Modeling (CEAM), National Exposure Research Laboratory, Office of Research and Development (ORD), U.S. Environmental Protection Agency (U.S. EPA), Athens, Georgia, Web: http://www.epa.gov/ceampubl/

SWMM5 (2005), Storm Water Management Model Version 5, Water Supply and Water Resources Division of the U.S. EPA's National Risk Management Research Laboratory, Cincinnati, Ohio.

USGS Memo (2011), Information Sheet for Rain and Stream Gages in Harvard Gulch Watershed Urban, UDFCD.

USWDCM (2001), Urban Storm Water Drainage Criteria Manual, Volume 1, UDFCD

Zarriello, Phillip J. (1998), Comparison of Nine Uncalibrated Runoff Models to Observed Flows in Two Small Urban Watersheds, presented in the First Federal Interagency Hydrologic Modeling Conference, held in Las Vegas on April 19-23, 1998.

Appendix A – Event Study and Comparison

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case	**6/18/2003**					
Station	Stream Gage at Colorado Blvd					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check			X			used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20030618	190500	0.06	0.04	0.23	0.3
20030618	191000	0.31	0.04	4.25	3.49
20030618	191500	0.26	6.3	25.4	17.43
20030618	192000	0.07	433	93.41	57.45
20030618	192500	0.11	502	182.81	133.83
20030618	193000	0.15	502	294.92	227.32
20030618	193500	0.12	475	382.39	303.37
20030618	194000	0.05	471	423.7	346.42
20030618	194500	0.02	479	430.01	358.38
20030618	195000	0.01	458	411.29	350.9
20030618	195500		413	378.93	328.77
20030618	200000		378	339.39	302.79
20030618	200500		339	298.28	273.58
20030618	201000		290	261.04	245.22
20030618	201500		241	228.13	218.81
20030618	202000		180	199.46	195.11
20030618	202500		57	174.74	173.91
20030618	203000		26	153.49	155.18
20030618	203500		19	135.2	138.75
20030618	204000		15	119.43	124.35
20030618	204500		12	105.91	111.75
20030618	205000		9.3	94.01	100.72
20030618	205500		7.6	83.77	91.05
20030618	210000		6.1	74.88	82.56
20030618	210500		4.5	67.13	75.08
20030618	211000		3.8	60.39	68.50
20030618	211500		3.3	54.49	62.66
20030618	212000		2.8	49.3	57.48
20030618	212500		2.4	44.75	52.86
20030618	213000		2.1	40.73	48.73
20030618	213500		1.7	37.19	45.04
20030618	214000		1.5	34.03	41.72
20030618	214500		1.4	31.24	38.73
20030618	215000		1.2	28.75	36.03
20030618	215500		1.1	26.52	33.59
20030618	220000		0.98	24.52	31.37
20030618	220500		0.94	22.73	29.36
20030618	221000		0.94	21.11	27.52
20030618	221500		0.94	19.65	25.84
20030618	222000		0.94	18.32	24.30
Max Peak Flow Rate			502	430.01	359.39
Sum of Volume		1.16	5349.93	5464.69	5042.47

STREAM GAGE: Colorado Blvd

Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	1.16	inches
Rainfall Volume	70.76	acre-ft
Runoff Volume	36.86	acre-ft
Depression Loss Imperv	0.07	inches
Depression Loss Perv	0.16	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.16	inch
Rain gage	University	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	502.00	21.11	359.39
Vol (a-f)	36.86	37.64	34.73

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case	**6/18/2003**					
Station	Stream Gage at Harvard Gulch Park					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check			X			used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20030618	190500	0.06	7	57.01	0.00
20030619	191000	0.31	7	92.99	0.21
20030618	191500	0.28	7	145.50	21.79
20030619	192000	0.07	7	214.79	86.98
20030618	192500	0.11	7	297.69	165.94
20030619	193000	0.15	32	395.13	247.67
20030618	193500	0.12	65	503.75	320.97
20030619	194000	0.05	195	609.69	374.57
20030618	194500	0.02	576	691.51	411.56
20030619	195000	0.01	750	740.76	440.69
20030618	195500		696	757.06	465.53
20030619	200000		624	745.61	482.84
20030618	200500		570	713.27	489.66
20030619	201000		513	667.99	486.00
20030618	201500		460	615.53	472.66
20030618	202000		409	559.61	452.25
20030619	202500		359	504.27	426.95
20030618	203000		317	451.52	399.03
20030619	203500		279	402.94	370.19
20030618	204000		244	358.55	340.56
20030619	204500		217	317.59	311.83
20030618	205000		190	281.71	285.22
20030619	205500		166	251.32	261.16
20030618	210000		144	225.39	239.53
20030619	210500		121	203.13	219.82
20030618	211000		103	183.81	202.12
20030619	211500		89	166.75	186.2
20030618	212000		77	151.72	171.72
20030619	212500		67	138.57	158.5
20030618	213000		59	126.6	146.52
20030619	213500		53	115.55	135.83
20030618	214000		48	105.53	125.95
20030619	214500		43	96.77	116.65
20030618	215000		39	75	107.95
20030619	215500		35	65	100.08
20030618	220000		33	55	93.06
20030619	220500		30	45	86.69
20030618	221000		28	34	81.01
20030619	221500		26	25	74.24
20030618	222000		24	10	68.66
Max Peak Flow Rate			750	757.06	489.66
Sum of Volume		1.16	7736.00	12198.51	9627.66

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	1.16	inches
Rainfall Volume	197.39	acre-ft
Runoff Volume	53.29	acre-ft
Depression Loss	0.07	inches
Infiltration	0.15	inches
Loss Volume	3.00	acre-ft
Volume Balance		acre-ft
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.16	inch
Rain gage	X	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

	Observed	CUHP	SWMM5
Peak (cfs)	750.00	757.06	489.66
Vol (a-f)	53.29	84.01	66.31

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case 9/12/2002

Station Stream Gage at Colorado Blvd

Derivation of Representative Rainfall

Rain	Selection of Rain Gages					Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check	X					used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
	172500	0.16	0	83.11	54.76
20020912	173000	0.27	0	226.7	147.64
20020912	173500	0.38	268	352.4	242.31
20020912	174000	0.15	413	408.16	306.16
20020912	174500	0.06	458	422.33	336.96
20020912	175000	0.03	441	412.23	343.26
20020912	175500	0.04	413	387.16	333.28
20020912	180000	0.02	364	351.79	313.96
20020912	180500	0.02	325	311.98	290.12
20020912	181000	0.01	293	274.69	264.04
20020912	181500	0.01	249	240.74	238.24
20020912	182000	0.01	213	210.93	213.92
20020912	182500		180	185.03	191.63
20020912	183000		135	162.58	171.57
20020912	183500		111	143.14	153.71
20020912	184000		73	126.30	137.91
20020912	184500		53	111.71	123.97
20020912	185000		42	99.06	111.71
20020912	185500		34	88.13	100.92
20020912	190000		26	78.62	91.42
20020912	190500		21	70.36	83.04
20020912	191000		17	63.18	75.63
20020912	191500		14	56.89	69.09
20020912	192000		12	51.40	63.27
20020912	192500		10	46.58	58.09
20020912	193000		8.8	42.34	53.47
20020912	193500		7.3	38.60	49.33
20020912	194000		6.5	35.29	45.61
20020912	194500		5.1	32.35	42.27
20020912	195000		4.1	29.73	39.26
20020912	195500		3.6	27.39	36.54
20020912	200000		3.1	25.30	34.07
20020912	200500		2.6	23.43	31.83
20020912	201000		2.1	21.74	29.79
20020912	201500		1.7	20.22	27.93
20020912	202000		1.4	18.84	26.23
20020912					
Max Peak Flow Rate			458	422.33	343.26
Sum of Volume		1.14	4209.30	5280.44	4932.94

STREAM GAGE: Colorado Blvd

Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	1.14	inches
Rainfall Volume	69.54	acre-ft
Runoff Volume	28.99	acre-ft
Depression Loss Imperv	0.07	inches
Depression Loss Perv	0.15	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.14	inch
Rain gage	Bethesda	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	458.00	422.33	343.26
Vol (a-f)	28.99	36.37	33.97

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case	**9/12/2002**					
Station	Stream Gage at Harvard Gulch Park					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check	X					used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental Rain Depth	Obv'd Runoff HG	CUHP Runoff HG	SWMM Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20030618	190500	0.06	7	110.39	66.67
20030618	191000	0.31	7	168.87	188.47
20030618	191500	0.26	7	237.14	299.11
20030618	192000	0.07	7	322.20	360.92
20030618	192500	0.11	7	419.55	385.47
20030618	193000	0.15	32	520.26	398.66
20030618	193500	0.12	65	609.27	415.18
20030618	194000	0.05	195	672.44	436.10
20030618	194500	0.02	576	705.25	454.93
20030618	195000	0.01	750	710.55	465.26
20030618	195500		696	693.43	465.11
20030618	200000		624	660.30	455.4
20030618	200500		570	616.91	438.19
20030618	201000		513	567.45	415.49
20030618	201500		460	515.53	389.91
20030618	202000		409	463.96	362.63
20030618	202500		359	414.96	334.6
20030618	203000		317	369.88	307.36
20030618	203500		279	329.55	281.99
20030618	204000		244	291.82	258.92
20030618	204500		217	260.3	239
20030618	205000		190	233.36	218.63
20030618	205500		166	210.21	201.55
20030618	210000		144	190.2	185.95
20030618	210500		121	172.54	171.72
20030618	211000		103	156.91	158.69
20030618	211500		89	143.19	146.94
20030618	212000		77	130.93	136.25
20030618	212500		67	119.55	126.49
20030618	213000		59	109.16	117.27
20030618	213500		53	99.99	108.62
20030618	214000		48	91.67	100.75
20030618	214500		43	83.97	93.74
20030618	215000		39	75.3	87.55
20030618	215500		35	66.78	81.78
20030618	220000		33	59.05	75.14
20030618	220500		30	52.57	67.81
20030618	221000		28	47.38	60.66
20030618	221500		26	43.29	37.44
20030618	222000		24	40.04	35.35
Max Peak Flow Rate			750	710.55	465.26
Sum of Volume		1.16	7738.00	11784.99	9630.98

STREAM GAGE: Harvard Park

Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	1.14	inches
Rainfall Volume	195.99	acre-ft
Runoff Volume	53.28	acre-ft
Depression Loss		inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.14	inch
Rain gage	1.14	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	750.00	52.57	465.26
Vol (a-f)	53.28	81.18	66.33

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case	**7/8/2001**					
Station	Stream Gage at Colorado Blvd					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check	X					used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental Rain Depth	Obv'd Runoff HG	CUHP Runoff HG	SWMM Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
	163500	0.04	0.66	0	0.01
20010708	164000	0.03	309	0	0.7
20010708	164500	0.08	312	0	11.23
20010708	165000	0.33	421	0	94.15
20010708	165500	0.32	484	0.05	345.8
20010708	170000	0.46	614	3.37	611.17
20010708	170500	0.3	731	54.46	814.13
20010708	172500	0.17	707	316.07	921.41
20010708	173000	0.18	578	709.23	936.53
20010708	173500	0.13	484	996.85	901.64
20010708	174000	0.04	454	1115.5	853.58
20010708	174500	0.02	413	1096	800.7
20010708	175000	0.06	388	1032.12	732.61
20010708	175500	0.1	371	966.53	657.93
20010708	180000	0.02	335	901.43	586.54
20010708	180500	0.01	322	829.98	525.39
20010708	181000	0.01	309	740.73	471.58
20010708	181500	0.05	298	645.87	421.89
20010708	182000	0.03	266	562.24	376
20010708	182500	0.01	220	492.64	330.86
20010708	183000	0.01	182	431.07	291.25
20010708	183500	0.01	151	374.14	256.36
20010708	184000		122	318.42	226.18
20010708	184500		98	271.75	200.06
20010708	185000		78	232.73	177.43
20010708	185500		62	200.26	157.83
20010708	190000		45	173.08	140.82
20010708	190500		25	150.25	126.04
20010708	191000		16	131.02	113.18
20010708	191500		11	114.77	101.96
20010708	192000		8.3	101.01	92.15
20010708	192500		6.5	89.30	83.54
20010708	193000		5.3	79.29	75.97
20010708	193500		4.6	70.70	69.3
20010708	194000		4	63.30	63.4
20010708	194500		3.6	56.90	58.16
20010708	195000		3.2	51.33	53.48
20010708	195500		2.7	46.47	49.31
20010708	200000		2.3	42.20	45.57
20010708	200500		2.1	38.45	42.22
Max Peak Flow Rate			731	1115.5	936.53
Sum of Volume		2.41	8843.26	13499.49	12818.06

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	2.41	inches
Rainfall Volume	147.01	acre-ft
Runoff Volume	60.90	acre-ft
Depression Loss Imperv	0.07	inches
Depression Loss Perv	0.15	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	2.41	inch
Rain gage	Bethesda	
Imp Depression Loss	0.10	inch
Perv Depression Loss	0.40	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	60.90	92.97	88.28
Vol (a-f)			

The observed HG was corrected later
The peak flow was 1100 cfs

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case 7/8/2001

Station Stream Gage at Harvard Gulch Park

Derivation of Representative Rainfall

Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check	X					used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20010708	161500	0.04	2.4	0	0
20010708	163000	0.03	2.4	0	0
20010708	164500	0.08	2.4	0.22	2.16
20010708	170000	0.33	157	1.39	73.29
20010708	171500	0.32	1100	17.68	288.3
20010708		0.46		77.41	584.95
20010708		0.3		194.33	843.14
20010708		0.17		368.46	1055.87
20010708		0.18		629.89	1247.32
20010708		0.13		992.32	1407.33
20010708		0.04		1391.98	1521.3
20010708		0.02		1747.18	1580.23
20010708		0.06		2035.62	1604.93
20010708		0.1		2276.88	1594.40
20010708		0.02		2390.85	1541.65
20010708		0.01		2375.73	1440.69
20010708		0.01		2275.32	1332.07
20010708		0.05		2129.95	1221.64
20010708		0.03		1942.33	1111.41
20010708		0.01		1734.62	1003.78
20010708		0.01		1602.97	899.66
20010708		0.01		1417.94	801.01
20010708				1242.37	710.58
20010708				1094.39	629.85
20010708				941.74	558.27
20010708				815.17	495.57
20010708				706.08	441.10
20010708				612.7	393.76
20010708				532.57	352.31
20010708				464.04	314.94
20010708				405.48	282.56
20010708				355.46	255.15
20010708				311.24	231.59
20010708				273.52	211.11
20010708				242.07	193.26
20010708				215.72	177.42
20010708				193.56	163.17
20010708				174.44	150.38
20010708				157.82	139.04
20010708				143.44	129.77
Max Peak Flow Rate			1100	2390.85	1604.93
Sum of Volume		2.41	1264.20	34474.89	26983.96

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	2.41	inches
Rainfall Volume	410.10	acre-ft
Runoff Volume	6.71	acre-ft
Depression Loss Imperv	0.07	inches
Depression Loss Perv	0.15	inches
Infiltration	3.00	acre-ft
Loss Volume		acre-ft
Volume Balance		
Total precipitation depth	2.41	inch
Rain gage	Bethesda	
Imp Depression Loss	0.10	inch
Perv Depression Loss	0.40	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	1100.00	2390.85	1604.93
Vol (a-f)	8.71	237.43	185.84

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case	8/17/2000					
Station	Stream Gage at Colorado Blvd					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check				X		used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental Rain Depth	Obv'd Runoff HG	CUHP Runoff HG	SWMM Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20000817	161500	0.13	0.01	0.5	1.54
20000817	162000	0.04	116	1.71	7.57
20000817	162500	0.02	299	8.3	30.92
20000817	163000	0.02	303	37.5	91.59
20000817	163500	0.03	281	119.81	185.48
20000817	164000	0.13	309	253.43	269.14
20000817	164500	0.23	367	372.85	319.01
20000817	165000	0.19	401	429.4	337.93
20000817	165500	0.14	409	444.58	335.68
20000817	170000	0.14	401	432.45	320.8
20000817	170500	0.03	378	404.69	299.52
20000817	171000	0.01	353	369.29	275.22
20000817	171500	0.01	315	328.09	250.91
20000817	172000	0.01	261	290.12	227.9
20000817	172500	0.01	210	255.96	207.02
20000817	173000	0.01	172	226.47	188.68
20000817	173500	0.01	126	201.53	173.00
20000817	174000	0.01	91	180.79	160.89
20000817	174500	0.01	69	164.87	151.60
20000817	175000	0.01	56	153.75	143.37
20000817	175500	0.02	53	144.77	135.64
20000817	180000	0.01	50	135.73	128.13
20000817	180500	0.04	47	126.27	120.70
20000817	181000	0.04	47	116.50	113.54
20000817	181500	0.01	53	106.89	106.63
20000817	182000	0.01	58	97.68	100.14
20000817	182500	0.01	55	88.89	93.90
20000817	183000	0	45	80.66	87.89
20000817	183500	0.01	39	73.08	82.15
20000817	184000	0	34	66.23	76.71
20000817	184500	0.01	36	60.09	71.58
20000817	185000		42	54.61	66.77
20000817	185500		49	49.73	62.28
Max Peak Flow Rate			409	444.58	337.93
Sum of Volume		1.35	5523.00	5876.72	5222.29

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	1.35	inches
Rainfall Volume	82.35	acre-ft
Runoff Volume	38.04	acre-ft
Depression Loss Imperv	0.10	inches
Depression Loss Perv	0.25	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.35	inch
Rain gage	Stevens	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	409.00	444.58	337.93
Vol (a-f)	38.04	40.47	35.97

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case	8/17/2000					
Station	Stream Gage at Harvard Gulch Park					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check				X		used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20000817	161500	0.13	6.2	1.87	1.54
20000817	162000	0.04	6.2	3.46	10.27
20000817	162500	0.02	6.2	10.63	42.85
20000817	163000	0.02	104	31.95	109.08
20000817	163500	0.03	104	68.58	198.43
20000817	164000	0.13	104	122.89	289.18
20000817	164500	0.23	129	191.95	351.95
20000817	165000	0.19	128	275.25	384.09
20000817	165500	0.14	129	378.06	403.02
20000817	170000	0.14	189	496.11	421.37
20000817	170500	0.03	189	614.89	439.95
20000817	171000	0.01	189	710.27	453.51
20000817	171500	0.01	350	771.40	458.73
20000817	172000	0.01	350	797.99	455.39
20000817	172500	0.01	350	794.27	444.69
20000817	173000	0.01	264	767.29	428.45
20000817	173500	0.01	264	725.09	408.72
20000817	174000	0.01	264	674.23	388.24
20000817	174500	0.01	181	620.24	368.69
20000817	175000	0.01	181	566.73	350.04
20000817	175500	0.02	181	515.78	331.94
20000817	180000	0.01	123	468.57	314.83
20000817	180500	0.04	123	426.12	298.16
20000817	181000	0.04	123	388.27	281.63
20000817	181500	0.01	91	354.21	265.58
20000817	182000	0.01	91	323.04	250.4
20000817	182500	0.01	91	295.37	235.95
20000817	183000	0	70	270.82	222.02
20000817	183500	0.01	70	249.03	208.72
20000817	184000	0	70	229.14	196.19
20000817	184500	0.01	60	211	184.46
20000817	185000		60	194.5	173.43
Max Peak Flow Rate			350	797.99	458.73
Sum of Volume		1.35	4638.00	12549.00	9371.48

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	1.35	inches
Rainfall Volume	229.73	acre-ft
Runoff Volume	31.95	acre-ft
Depression Loss Imperv	0.10	inches
Depression Loss Perv	0.25	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.35	inch
Rain gage	Stevens	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	350.00	797.99	458.73
Vol (a-f)	31.95	86.43	64.54

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case 7/25/1998

Station Stream Gage at Colorado Blvd

Derivation of Representative Rainfall

Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check						used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
19980725	180500	0.1	0.02	11.06	2.94
19980725	181000	0.09	0.03	27.26	8.48
19980725	181500	0.14	98	64.49	23.77
19980725	182000	0.04	258	128.36	59.24
19980725	182500	0.05	306	201.56	111.53
19980725	183000	0.06	325	261.52	168.89
19980725	183500	0.14	339	297.37	218.03
19980725	184000	0.2	349	310.62	251.65
19980725	184500	0.06	389	306.77	268.43
19980725	185000	0.07	417	291.79	271.55
19980725	185500	0.05	409	270.42	264.65
19980725	190000	0.04	386	247.06	251.92
19980725	190500	0.02	353	223.91	236.67
19980725	191000	0.02	322	201.89	220.28
19980725	191500	0.01	284	181.30	203.61
19980725	192000	0.01	236	162.48	187.14
19980725	192500	0.02	203	145.58	171.56
19980725	193000	0.01	0	130.68	157.00
19980725	193500	0.01	0	117.93	143.89
19980725	194000	0	0	107.31	132.41
19980725	194500	0.01	0	98.38	122.61
19980725	195000	0	0	90.69	114.08
19980725	195500	0.01	0	84.24	106.70
19980725	200000	0.01	0	79.06	100.58
19980725	200500	0.02	0	74.95	95.65
19980725	201000	0.01	0	71.14	91.63
19980725	201500	0.01	0	67.73	88.09
19980725	202000	0.02	0	65.05	85.10
19980725	202500	0.02	0	62.96	82.85
19980725	203000	0.02	0	60.96	80.89
19980725	203500	0.01	0	59.02	79.14
19980725	204000	0.01	0	56.91	77.55
19980725	204500	0.03	0	54.57	75.69
19980725	205000	0.01	0	52.17	73.43
19980725	205500	0.01	0	49.63	70.82
19980725	210000	0.02	0		67.96
19980725	210500	0	0		64.93
19980725	211000	0.01	0		61.83
19980725	211500	0.01	0		58.71
19980725	212000	0	0		55.62
19980725	212500	0	0		35.63
19980725	213000	0	0		33.14
19980725	213500	0.01	0		30.82
19980725	214000		0		28.69
19980725	214500		0		26.73
Max Peak Flow Rate			417	310.62	271.55
Sum of Volume		1.39	4674.03	4705.66	5040.18

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	1.39	inches
Rainfall Volume	84.79	acre-ft
Runoff Volume	32.19	acre-ft
Depression Loss Imperv	0.05	inches
Depression Loss Perv	0.07	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.39	inch
Rain gage		
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	417.00	310.62	271.55
Vol (a-f)	32.19	32.41	34.71

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case	7/25/1998					
Station	Stream Gage at Harvard Gulch Park					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check						used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental Rain Depth	Obv'd Runoff HG	CUHP Runoff HG	SWMM Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
19980725	180500	0.1	18	33.46	3.75
19980725	181000	0.09	21	60.55	18.68
19980725	181500	0.14	38	95.95	43.85
19980725	182000	0.04	66	137.03	80.22
19980725	182500	0.05	104	184.06	127.33
19980725	183000	0.06	150	237.72	177.00
19980725	183500	0.14	201	301.50	220.96
19980725	184000	0.2	235	371.75	253.85
19980725	184500	0.06	311	438.15	278.99
19980725	185000	0.07	406	489.90	302.87
19980725	185500	0.05	528	520.32	327.24
19980725	190000	0.04	573	531.07	349.42
19980725	190500	0.02	573	525.69	366.70
19980725	191000	0.02	552	508.35	377.45
19980725	191500	0.01	482	482.78	381.01
19980725	192000	0.01	426	452.12	377.7
19980725	192500	0.02	382	419.05	368.65
19980725	193000	0.01	332	385.39	355.08
19980725	193500	0.01	289	351.89	338.03
19980725	194000	0	251	319.35	319.55
19980725	194500	0.01	222	290.09	301.4
19980725	195000	0	196	264.7	283.92
19980725	195500	0.01	176	242.78	267.43
19980725	200000	0.01	159	223.52	252.49
19980725	200500	0.02	145	206.72	239.17
19980725	201000	0.01	132	192.4	227.34
19980725	201500	0.01	121	180.09	216.74
19980725	202000	0.02	113	169.08	207.18
19980725	202500	0.02	106	159.22	198.9
19980725	203000	0.02	99	150.38	191.63
19980725	203500	0.01	98	142.49	185.26
19980725	204000	0.01	99	135.51	179.59
19980725	204500	0.03	96	129.17	174.3
19980725	205000	0.01	95	123	168.82
19980725	205500	0.01	94	116.81	163.01
19980725	210000	0.02	93	110.64	156.9
19980725	210500	0	93	104.64	150.62
19980725	211000	0.01	93	98.92	144.29
19980725	211500	0.01	94	93.54	138.05
19980725	212000	0	94	88.7	132
19980725	212500	0	94	83.7	93.54
19980725	213000	0	92	77.59	88.7
19980725	213500	0.01	90	70.73	83.7
19980725	214000		86	64.02	77.59
19980725	214500		79	58.07	70.73
Max Peak Flow Rate			573	531.07	381.01
Sum of Volume		1.39	8797.00	10422.59	9461.53

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	1.39	inches
Rainfall Volume	236.53	acre-ft
Runoff Volume	60.59	acre-ft
Depression Loss Perv	0.07	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.39	inch
Rain gage		
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	573.00	531.07	381.01
Vol (a-f)	60.59	71.78	65.16

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case	9/18/1993					
Station	Stream Gage at Colorado Blvd					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check						used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental Rain Depth	Obv'd Runoff HG	CUHP Runoff HG	SWMM Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
19930918	134500	0.11	7.8	19.31	18.8
19930918	135000	0.12	7.8	64.53	59.74
19930918	135500	0.03	32	144.11	130.69
19930918	140000	0.01	139	236.29	213.61
19930918	140500	0.27	345	316.57	287.72
19930918	141000	0.22	406	368.97	333.51
19930918	141500	0.06	424	384.75	350.02
19930918	142000	0.12	401	376.61	344.53
19930918	142500	0.09	370	351.53	325.67
19930918	143000	0.1	324	318.19	300.32
19930918	143500	0.02	260	283.8	272.21
19930918	144000	0.01	232	250.69	244.61
19930918	144500		201	220.54	218.79
19930918	145000		174	193.78	195.31
19930918	145500		153	170.37	174.29
19930918	150000		130	150.08	155.67
19930918	150500		114	132.51	139.28
19930918	151000		99	117.31	124.90
19930918	151500		86	104.13	112.29
19930918	152000		75	92.69	101.24
19930918	152500		66	82.73	91.55
19930918	153000		58	74.05	83.02
19930918	153500		51	66.47	75.51
19930918	154000		46	59.85	68.89
19930918	154500		41	54.06	63.03
19930918	155000		37	48.98	57.81
19930918	155500		34	44.47	53.17
19930918	160000		31	40.51	49.01
19930918	160500		28	37.00	45.30
19930918	161000		26	33.89	41.98
19930918	161500		23	31.11	38.95
19930918	162000		20	28.64	36.23
19930918	162500		18	26.43	33.77
19930918	163000		16	24.44	31.54
19930918	163500		15	22.66	29.52
19930918	164000		14	21.05	27.67
19930918	164500		13	19.60	25.98
19930918	165000		12		24.43
19930918	165500		11		23.01
19930918	170000		10		21.70
19930918	170500		9.8		
Max Peak Flow Rate			424	384.75	350.02
Sum of Volume		1.16	4552.60	4993.98	5006.45

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	1.16	inches
Rainfall Volume	70.76	acre-ft
Runoff Volume	31.35	acre-ft
Depression Loss Imperv	0.13	inches
Depression Loss Perv	0.45	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.16	inch
Rain gage		
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.10	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	424.00	384.75	350.02
Vol (a-f)	31.35	34.39	34.48

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case 7/23/1992

Station Stream Gage at Colorado Blvd

Derivation of Representative Rainfall

Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check			X			used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental Rain Depth	Obv'd Runoff HG	CUHP Runoff HG	SWMM Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
19920723	181500	0.01	0.2	111.84	66.12
19920723	182000	0.02	94	173.85	92.79
19920723	182500	0.09	266	209.03	112.56
19920723	183000	0.31	293	220.79	124.74
19920723	183500	0.16	244	218.26	130.58
19920723	184000	0.06	174	207.88	131.34
19920723	184500	0.01	88	193.17	128.47
19920723	185000	0.01	56	176.52	123.23
19920723	185500	0	40	158.71	116.62
19920723	190000	0	29	143.87	109.34
19920723	190500	0	24	128.44	101.87
19920723	191000	0.01	19	116.51	94.53
19920723	191500		14	104.96	87.48
19920723	192000		11	94.67	80.96
19920723	192500		9.6	85.48	74.69
19920723	193000		8	77.29	69.00
19920723	193500		6.9	69.97	63.78
19920723	194000		6.3	63.43	59.00
19920723	194500		5.7	57.61	54.64
19920723	195000		4.8	52.41	50.67
19920723	195500		4.1	47.77	47.05
19920723	200000		3.6	43.62	43.75
19920723	200500		3.1	39.91	40.75
19920723	201000		2.7	36.60	38.01
19920723	201500		2.6	33.63	35.50
19920723	202000		2.5	30.97	33.21
19920723	202500		2.4	28.57	31.12
19920723	203000		2.2	26.42	29.20
19920723	203500		2.1	24.48	27.44
19920723	204000		1.9		
19920723	204500		1.8		
19920723	205000		1.7		
Max Peak Flow Rate			293	220.79	131.34
Sum of Volume		0.68	1424.00	2866.83	2132.22

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	0.68	inches
Rainfall Volume	41.48	acre-ft
Runoff Volume	9.81	acre-ft
Depression Loss Imperv	0.06	inches
Depression Loss Perv	0.06	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	0.68	inch
Rain gage	Stevens	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	293.00	220.79	131.34
Vol (a-f)	9.81	19.74	14.69

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case	**7/23/1992**
Station	Stream Gage at Harvard Gulch Park

Derivation of Representative Rainfall

Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Slavens	HG Park	Mark which gages
Check			X			used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obr'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
19920723	181500	0.01	7	0.00	0.00
19920723	182000	0.02	7	178.84	134.98
19920723	182500	0.09	43	217.68	128.63
19920723	183000	0.31	96	256.28	128.61
19920723	183500	0.16	106	294.03	134.20
19920723	184000	0.06	103	327.82	141.94
19920723	184500	0.01	135	352.85	149.29
19920723	185000	0.01	210	366.91	154.89
19920723	185500	0	217	370.22	158.22
19920723	190000	0	193	364.03	159.28
19920723	190500	0	166	350.40	158.3
19920723	191000	0.01	145	331.75	155.49
19920723	191500		125	310.44	151.16
19920723	192000		109	287.6	145.76
19920723	192500		97	264.54	139.72
19920723	193000		83	242.06	133.42
19920723	193500		72	220.61	127.12
19920723	194000		60	201.23	120.76
19920723	194500		52	183.92	114.23
19920723	195000		45	168.27	107.61
19920723	195500		39	154.13	101.17
19920723	200000		35	141.51	95.15
19920723	200500		32	130.15	89.66
19920723	201000		28	119.42	84.7
19920723	201500		26	109.49	79.1
19920723	202000		23	100.43	72.33
19920723	202500		20	92.56	65.2
19920723	203000		19	85.77	58.58
19920723	203500				
19920723	204000				
19920723	204500				
19920723	205000				
19920723	205500				
19920723	210000				
19920723	210500				
19920723	211000				
19920723	211500				
19920723	212000				
19920723	212500				
19920723	213000				
Max Peak Flow Rate			217	370.22	159.28
Sum of Volume		0.68	2293.00	6222.94	3289.50

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	0.68	inches
Rainfall Volume	115.71	acre-ft
Runoff Volume	15.79	acre-ft
Depression Loss Imperv	0.05	inches
Depression Loss Perv	0.06	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	0.68	inch
Rain gage	Slavens	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	217.00	370.22	159.28
Vol (a-f)	2293.00	6222.94	3289.50

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case	**7/20/1991**					
Station	Stream Gage at Colorado Blvd					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check		X				used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
19910720	162500	0.07	0.44	0.96	4.5
19910720	163000	0.16	36	10.61	23.75
19910720	163500	0.18	151	48.53	77.06
19910720	164000	0.18	205	119.61	157.81
19910720	164500	0.2	247	185.22	237.79
19910720	165000	0.13	284	221.63	294.9
19910720	165500	0.05	306	233.22	323.84
19910720	170000	0.09	309	229.93	329.25
19910720	170500	0.04	299	218.48	318.56
19910720	171000	0.02	252	202.59	299.29
19910720	171500	0.01	194	184.74	275.15
19910720	172000	0	151	166.81	249.78
19910720	172500	0.01	99	149.98	225.06
19910720	173000	0	71	134.7	201.98
19910720	173500	0.01	56	121.04	180.94
19910720	174000	0.01	46	108.67	162.06
19910720	174500	0.01	39	98.05	145.28
19910720	175000	0	35	88.41	130.45
19910720	175500	0	30	79.83	117.39
19910720	180000	0	26	72.17	105.88
19910720	180500	0	21	65.35	95.76
19910720	181000	0	16	59.28	86.84
19910720	181500	0	12	53.86	78.97
19910720	182000	0	10	49.04	72.01
19910720	182500	0	8	44.73	65.85
19910720	183000	0.01	6.7	40.89	60.37
19910720	183500	0	5.3	37.46	55.49
19910720	184000	0	5	34.39	51.12
19910720	184500	0	5.1	31.64	47.21
19910720	185000	0	6.1	29.18	43.70
19910720	185500	0.01	7.1	26.96	40.54
19910720	190000	0.01	9.6	24.96	37.69
19910720	190500		13	23.16	35.11
19910720	191000		16	21.53	32.77
19910720	191500		17	20.06	30.64
19910720	192000		16	18.72	28.70
19910720	192500		13	17.50	26.93
19910720	193000		10	16.38	25.31
19910720	193500		8	15.37	23.82
19910720	194000		6.5	14.44	22.45
19910720	194500		5.3	13.59	21.20
Max Peak Flow Rate			309	233.22	329.25
Sum of Volume		1.20	3052.70	3332.91	4838.70

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	1.20	inches
Rainfall Volume	73.20	acre-ft
Runoff Volume	21.02	acre-ft
Depression Loss Imperv	0.10	inches
Depression Loss Perv	0.50	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.20	inch
Rain gage	Bradley	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.10	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	309.00	233.22	329.25
Vol (a-f)	21.02	22.95	33.32

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case	**7/20/1991**					
Station	Stream Gage at Harvard Gulch Park					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check		X				used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
19910720	162500	0.07	2.6	2.98	1.13
19910720	163000	0.16	56	113.36	28.69
19910720	163500	0.18	122	152.25	101.45
19910720	164000	0.18	187	194.71	188.30
19910720	164500	0.2	251	238.16	264.28
19910720	165000	0.13	324	281.46	317.41
19910720	165500	0.05	385	323.05	349.94
19910720	170000	0.09	343	358.43	373.65
19910720	170500	0.04	291	383.01	396.80
19910720	171000	0.02	291	395.53	419.48
19910720	171500	0.01	434	396.76	436.92
19910720	172000	0	471	388.34	444.42
19910720	172500	0.01	460	372.46	442.19
19910720	173000	0	401	351.37	431.54
19910720	173500	0.01	341	327.23	414.13
19910720	174000	0.01	279	302.04	392.45
19910720	174500	0.01	227	276.76	368.21
19910720	175000	0	189	252.51	341.96
19910720	175500	0	164	229.6	315.57
19910720	180000	0	141	208.97	290.53
19910720	180500	0	123	190.53	267.21
19910720	181000	0	109	174.06	245.99
19910720	181500	0	97	159.2	226.42
19910720	182000	0	86	145.9	208.54
19910720	182500	0	77	134.08	192.37
19910720	183000	0.01	67	123.06	177.68
19910720	183500	0	58	112.78	164.2
19910720	184000	0	50	103.38	151.96
19910720	184500	0	44	95.03	140.75
19910720	185000	0	39	87.99	130.72
19910720	185500	0.01	36	80.99	121.26
19910720	190000	0.01	33	73.25	112.36
19910720	190500		31	65.41	104.1
19910720	191000		29	58.22	96.74
19910720	191500		27	52.13	90.16
19910720	192000		25	47.2	84.36
19910720	192500		23	43.26	78.17
19910720	193000		21	40.11	71.04
19910720	193500		20	37.56	63.7
19910720	194000		19	35.47	56.97
Max Peak Flow Rate			471	396.76	444.42
Sum of Volume		1.20	6373.60	7408.39	9103.56

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	1.20	inches
Rainfall Volume	204.20	acre-ft
Runoff Volume	43.90	acre-ft
Depression Loss Imperv	0.10	inches
Depression Loss Perv	0.50	inches
Infiltration	3.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.20	inch
Rain gage	Bradley	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.10	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	471.00	40.11	444.42
Vol (a-f)	43.90	51.02	62.70

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case	**7/8/2001**					
Station	Stream Gage at Colorado Blvd					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check	X					used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
	163500	0.04	0.66	0	0.01
20010708	164000	0.03	309	0	0.7
20010708	164500	0.09	312	0	11.23
20010708	165000	0.33	421	0	94.15
20010708	165500	0.32	484	0.05	345.8
20010708	170000	0.46	614	3.37	611.17
20010708	170500	0.3	731	54.46	814.13
20010708	172500	0.17	707	316.07	921.41
20010708	173000	0.18	578	709.23	936.53
20010708	173500	0.13	484	996.85	901.64
20010708	174000	0.04	454	1115.5	853.58
20010708	174500	0.02	413	1096	800.7
20010708	175000	0.06	386	1032.12	732.61
20010708	175500	0.1	371	966.53	657.93
20010708	180000	0.02	335	901.43	586.54
20010708	180500	0.01	322	829.96	525.39
20010708	181000	0.01	309	740.73	471.58
20010708	181500	0.05	296	645.87	421.89
20010708	182000	0.03	266	562.24	376
20010708	182500	0.01	220	492.64	330.86
20010708	183000	0.01	182	431.07	291.25
20010708	183500	0.01	151	374.14	256.36
20010708	184000		122	318.42	226.18
20010708	184500		96	271.75	200.06
20010708	185000		78	232.73	177.43
20010708	185500		62	200.26	157.83
20010708	190000		45	173.08	140.82
20010708	190500		25	150.25	126.04
20010708	191000		16	131.02	113.18
20010708	191500		11	114.77	101.96
20010708	192000		8.3	101.01	92.15
20010708	192500		6.5	89.30	83.54
20010708	193000		5.3	79.29	75.97
20010708	193500		4.6	70.70	69.3
20010708	194000		4	63.30	63.4
20010708	194500		3.6	56.90	58.16
20010708	195000		3.2	51.33	53.48
20010708	195500		2.7	46.47	49.31
20010708	200000		2.3	42.20	45.57
20010708	200500		2.1	38.45	42.22
Max Peak Flow Rate			731	1115.5	936.53
Sum of Volume		2.41	8843.26	13499.49	12818.06

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	2.41	inches
Rainfall Volume	147.01	acre-ft
Runoff Volume	60.90	acre-ft
Depression Loss Imperv	0.07	inches
Depression Loss Perv	0.15	inches
Infiltration	4.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	2.41	inch
Rain gage	Bethesda	
Imp Depression Loss	0.10	inch
Perv Depression Loss	0.40	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	60.90	92.97	88.29
Vol (a-f)			

The observed HG was corrected later
The peak flow was 1100 cfs

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case 7/8/2001

Station Stream Gage at Harvard Gulch Park

Derivation of Representative Rainfall

Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check	X					used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20010708	161500	0.04	2.4	0	0
20010708	163000	0.03	2.4	0	0
20010708	164500	0.08	2.4	0.22	2.16
20010708	170000	0.33	157	1.39	73.29
20010708	171500	0.32	1100	17.69	288.3
20010708		0.46		77.41	584.95
20010708		0.3		194.33	843.14
20010708		0.17		368.46	1055.87
20010708		0.18		629.89	1247.32
20010708		0.13		992.32	1407.33
20010708		0.04		1391.98	1521.3
20010708		0.02		1747.18	1580.23
20010708		0.06		2035.62	1604.93
20010708		0.1		2276.88	1594.40
20010708		0.02		2390.85	1541.65
20010708		0.01		2375.73	1440.69
20010708		0.01		2275.32	1332.07
20010708		0.05		2129.95	1221.64
20010708		0.03		1942.33	1111.41
20010708		0.01		1734.62	1003.78
20010708		0.01		1602.97	899.66
20010708		0.01		1417.94	801.01
20010708				1242.37	710.58
20010708				1094.39	629.95
20010708				941.74	558.27
20010708				815.17	495.57
20010708				706.08	441.10
20010708				612.7	393.76
20010708				532.57	352.31
20010708				464.04	314.94
20010708				405.48	282.56
20010708				355.46	255.15
20010708				311.24	231.59
20010708				273.52	211.11
20010708				242.07	193.26
20010708				215.72	177.42
20010708				193.56	163.17
20010708				174.44	150.38
20010708				157.82	139.04
20010708				143.44	128.77
Max Peak Flow Rate			1100	2390.85	1604.93
Sum of Volume		2.41	1264.20	34474.89	26983.96

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	2.41	inches
Rainfall Volume	410.10	acre-ft
Runoff Volume	8.71	acre-ft
Depression Loss Imperv	0.07	inches
Depression Loss Perv	0.15	inches
Infiltration	4.00	acre-ft
Loss Volume		acre-ft
Volume Balance		
Total precipitation depth	2.41	inch
Rain gage	Bethesda	
Imp Depression Loss	0.10	inch
Perv Depression Loss	0.40	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	1100.00	2390.85	1604.93
Vol (a-f)	8.71	237.43	185.84

SUMMARY OF EVENT STUDY FOR Stream Gage at Colorado Blvd in HARVARD GULCH WATERSHED

Case	**8/17/2000**					
Station	Stream Gage at Colorado Blvd					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Slavens	HG Park	Mark which gages
Check				X		used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20000817	161500	0.13	0.01	0.5	1.54
20000817	162000	0.04	116	1.71	7.57
20000817	162500	0.02	299	8.3	30.92
20000817	163000	0.02	303	37.5	91.59
20000817	163500	0.03	281	119.81	185.48
20000817	164000	0.13	309	253.43	269.14
20000817	164500	0.23	367	372.85	319.01
20000817	165000	0.19	401	429.4	337.93
20000817	165500	0.14	409	444.58	335.68
20000817	170000	0.14	401	432.45	320.8
20000817	170500	0.03	378	404.69	299.52
20000817	171000	0.01	353	369.29	275.22
20000817	171500	0.01	315	328.09	250.91
20000817	172000	0.01	261	290.12	227.9
20000817	172500	0.01	210	255.96	207.02
20000817	173000	0.01	172	226.47	188.68
20000817	173500	0.01	126	201.53	173.00
20000817	174000	0.01	91	180.79	160.89
20000817	174500	0.01	69	164.87	151.60
20000817	175000	0.01	56	153.75	143.37
20000817	175500	0.02	53	144.77	135.64
20000817	180000	0.01	50	135.73	128.13
20000817	180500	0.04	47	126.27	120.70
20000817	181000	0.04	47	116.50	113.54
20000817	181500	0.01	53	106.89	106.63
20000817	182000	0.01	58	97.68	100.14
20000817	182500	0.01	55	88.89	93.90
20000817	183000	0	45	80.66	87.89
20000817	183500	0.01	39	73.09	82.15
20000817	184000	0	34	66.23	76.71
20000817	184500	0.01	36	60.09	71.58
20000817	185000		42	54.61	66.77
20000817	185500		49	49.73	62.28
Max Peak Flow Rate			409	444.58	337.93
Sum of Volume		1.35	5523.00	5876.72	5222.29

STREAM GAGE: Colorado Blvd

3 Balance of Observed R and R Volumes

Tributary area	732.00	acres
Rainfall Depth	1.35	inches
Rainfall Volume	82.35	acre-ft
Runoff Volume	38.04	acre-ft
Depression Loss Imperv	0.10	inches
Depression Loss Perv	0.25	inches
Infiltration	4.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.35	inch
Rain gage	Slavens	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obis' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	409.00	444.58	337.93
Vol (a-f)	38.04	40.47	35.97

SUMMARY OF EVENT STUDY FOR Stream Gage at Park in HARVARD GULCH WATERSHED

Case	8/17/2000					
Station	Stream Gage at Harvard Gulch Park					
	Derivation of Representative Rainfall					
Rain		Selection of Rain Gages				Remarks
Gage	Gage 1	Gage2	Gage3	Gage4	Gage5	
Station	Bethesda	Bradley	University	Stevens	HG Park	Mark which gages
Check				X		used for study

List of Rainfall and Runoff for Comparison

Date	Time	Incremental	Obv'd	CUHP	SWMM
		Rain Depth	Runoff HG	Runoff HG	Runoff HG
M/D/Y	H:M	inch	cfs	cfs	cfs
20000817	161500	0.13	6.2	1.87	1.54
20000817	162000	0.04	6.2	3.46	10.27
20000817	162500	0.02	6.2	10.63	42.85
20000817	163000	0.02	104	31.95	109.08
20000817	163500	0.03	104	68.58	198.43
20000817	164000	0.13	104	122.89	289.18
20000817	164500	0.23	128	191.95	351.95
20000817	165000	0.19	128	275.25	384.09
20000817	165500	0.14	128	378.06	403.02
20000817	170000	0.14	189	496.11	421.37
20000817	170500	0.03	189	614.89	439.95
20000817	171000	0.01	189	710.27	453.51
20000817	171500	0.01	350	771.40	458.73
20000817	172000	0.01	350	797.99	455.39
20000817	172500	0.01	350	794.27	444.69
20000817	173000	0.01	264	767.29	428.45
20000817	173500	0.01	264	725.09	408.72
20000817	174000	0.01	264	674.23	388.24
20000817	174500	0.01	181	620.24	368.69
20000817	175000	0.01	181	566.73	350.04
20000817	175500	0.02	181	515.78	331.94
20000817	180000	0.01	123	468.57	314.83
20000817	180500	0.04	123	426.12	298.16
20000817	181000	0.04	123	388.27	281.63
20000817	181500	0.01	91	354.21	265.58
20000817	182000	0.01	91	323.04	250.4
20000817	182500	0.01	91	295.37	235.95
20000817	183000	0	70	270.82	222.02
20000817	183500	0.01	70	249.03	208.72
20000817	184000	0	70	229.14	196.19
20000817	184500	0.01	60	211	184.46
20000817	185000		60	194.5	173.43
Max Peak Flow Rate			350	797.99	458.73
Sum of Volume		1.35	4038.00	12549.00	9371.49

STREAM GAGE: Harvard Park

3 Balance of Observed R and R Volumes

Tributary area	2042.00	acres
Rainfall Depth	1.35	inches
Rainfall Volume	229.73	acre-ft
Runoff Volume	31.95	acre-ft
Depression Loss Imperv	0.10	inches
Depression Loss Perv	0.25	inches
Infiltration	4.00	inches
Loss Volume		acre-ft
Volume Balance		acre-ft
Total precipitation depth	1.35	inch
Rain gage	Stevens	
Imp Depression Loss	0.05	inch
Perv Depression Loss	0.15	inch
Max Infiltration Rate	3.00	in/hr
Min Infiltration Rate	0.50	in/hr

Comparison Between Obs' and Predicted

	Observed	CUHP	SWMM5
Peak (cfs)	350.00	797.99	458.73
Vol (a-f)	31.95	86.43	64.54

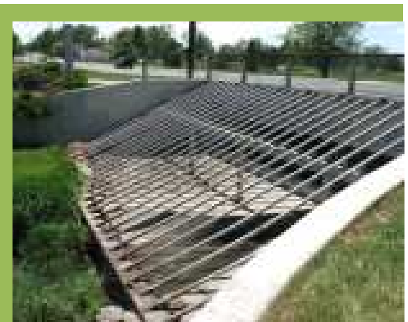
Appendix B – Data Files and Models CD

AMEC Earth & Environmental, Inc.

2000 S. Colorado Blvd., Suite 2-1000

Denver, Colorado 80222

Phone: 303.935.6505



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