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ENHANCEMENT AND EVALUATION OF A RAINFALL-RUNOFF SINGLE EVENT MODEL

By

Germania Salazar Mejia

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Civil and Environmental Engineering
in the Department of Civil and Environmental Engineering

Mississippi State, Mississippi

May 2012

ENHANCEMENT AND EVALUATION OF A RAINFALL-RUNOFF SINGLE EVENT MODEL

By

Germania Salazar Mejia

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Planning and design of stormwater facilities (including best management practices and low impact development) involve the calculation of peak flows and runoff volumes. Rainfall-runoff models are frequently utilized to estimate this information. A user-friendly rainfall-runoff tool (LIDIA) was developed using Visual Basic for Applications in Microsoft Office Excel. This research showed comprehensive guidelines on how to setup a model in LIDIA and reported the first evaluation of LIDIA using field data. LIDIA hydrologic module was tested using 10-minute rainfall, land cover, soil series, land cover management, and runoff data from two small watersheds in North Mississippi. Eleven storm events, over a period of seven months were used for the one evaluation site and 11 storm events were used for the second case study. Overall the development and results of LIDIA tool showed in this study are positive in keeping the enhancement of the model.

Key words: LIDIA, Single-Event Modeling, Stormwater Management Practices, Rainfall-Runoff, Mississippi, Curve Number Method, Santa Barbara Urban Hydrograph Method

DEDICATION

To my husband, Jairo, without whose caring support it would not have been possible

To my beloved son who is the ultimate reason for doing anything

To my family that despite the distance is with me every day in my heart

ACKNOWLEDGEMENTS

First and overall, I wish to thank God for the life and the opportunity to accomplish goals which were once unimaginable.

From the bottom of my heart, I would like to thank my husband for supporting and encouraging me every day. Also for “patiently” sharing his knowledge with me, and for his great love.

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INTRODUCTION

Faculty personnel from Mississippi State University's Forest and Wildlife Research Center and the Departments of Landscape Architecture, Civil and Environmental Engineering, and Agricultural and Biological Engineering have been working since 2004 on the development of software to quantify the impact of Best Management Practices (BMPs) and Low-Impact Development (LID) practices on water quality. Their motivation is the fact that various authorities, developers, engineers and others have expressed interest in having an easy use tool able to predict time-varying runoff and water quality as a function of rainfall and site characteristics (Wilkerson et al., 2006). The first attempt on developing software was called LATIS. This first approach connected the Hydrologic Simulation Program – FORTRAN (HSPF), and an unsteady flow model with a spreadsheet listing BMP/LID and their implementation, operation, and maintenance cost data (Wilkerson et al., 2010). Based on a survey conducted in 2008 (Moore, 2010), it was concluded that the second generation of LATIS will include a user-friendly tools that require minimal technical expertise by the end-user. The enhanced tool would enable the user to analyze a site's hydrologic output when incorporating various BMP solutions. The second generation of LATIS has been named LIDIA— Low Impact Development Implementation Assessment Tool.

LIDIA is a model developed using Visual Basic for Application (VBA) programming for Microsoft Excel, this evaluates and links rainfall-runoff generation and outflows from selected BMPs/LID facilities. Wilkerson et al., (2010) declared that the Microsoft Excel environment was selected because "*is a powerful, user-friendly tool that is widely accepted throughout the profession and supports both the familiar workbook environment and Visual Basic for Application (VBA) macro programming*." LIDIA was created from the need of a more user friendly and easy to use tool based on environmental (hydrology, flood routing, and pollutant removal mechanisms) and cost variables to evaluate the effectiveness of BMP/LID facilities (Moore, 2010). LIDIA can be used to assess effects of land use changes on rainfall-runoff processes in rural and urban drainage areas. The model can also be applied to evaluate the effect of selected BMP/LID strategies on runoff control.

LIDIA is coded in a modular structure. The first module computes rainfall-runoff processes using the U.S. Department of Agriculture (USDA) Curve Number method (Hawkins et al., 2009) and the Santa Barbara Urban Hydrograph Method – SBUH (Stubchaer, 1975). LIDIA is a lumped single-event model. Rainfall time series can be computed as designed storm events using databases and procedures in LIDIA. Observed rainfall values every 10 minutes can also be imported in LIDIA. Site specific data (area size, slope, land cover, and hydrologic soil groups) can be inputted manually or using a geographical information system shapefile format (Salazar and Wilkerson, 2010). After having runoff values from a study area, these are routed through a BMP/LID facility by using the Storage Indication Method (Ponce, 1989). Infiltration in the BMP/LID structure is taken into account using the Green & Ampt Method (Green and Ampt, 1911) The model is coded to allowed orifice and selected weirs structures (sharp crested, broad crested and v-notch) as BMP/LID outlets.

Motivation

Estimation of surface runoff is essential for the assessment of watershed yield, planning of soil and water in agricultural lands, design of hydraulic control structures (i.e., reservoirs, ponds, LID, BMP), management of industrial and public supply water resources and controlling transport and transformations of water quality variables. According to Borah and Bera (2003), "*single storm events models, are needed for analyzing severe actual or design single-event storms and evaluation watershed management practices, especially structural practices*."

Rainfall-runoff processes depend of many variables (e.g., area size, rainfall intensity, soil moisture, soil infiltration rate) making them difficult of tracking on field evaluations. Computer models can help in understanding rainfall-runoff process by processing large amount of databases (land use, soils, rainfall) lowering the costs of measured data (field operations, laboratory analysis) and producing faster and reliable results. Processes based rainfall-runoff models are also useful in evaluating scenarios (e.g., what is the effect of hydrologic, sediment, and water quality processes if a lot is converted from crop land to parking area).

Currently, there is a wide variety of rainfall-runoff computer codes available (Maidment, 1993; Borah and Bera, 2003; Zoppou, 2000, Texas A&M University, 2009). Some models can be simple, representing only a very few measured or estimated input parameters or can be very complex involving countless amount of input parameters with a very extensive requirement of information. In many cases this complexity make models available just for professionals and limit their use to some scales (e.g., end users such as irrigation districts). In addition, along with the development of hydrologic modeling it is noticed the specificity of the codes to a given application (urban, semi urban, agricultural, long term, single storm, etc.). The Development of hydrologic models has been a great advance in the understanding of the complex processes that take in the real world, but these models must to be calibrated with real data to ensure that real-world representation is successful to some extent.

Although several single-event models are developed using different programming languages, not many are programmed using Excel environment which is widely used across different users (e.g., from irrigation water users district to researchers). The lack of single-event model evaluations at the field or plot scale in Mississippi was another motivation for this study. Finally, there is a lack of scientific reports evaluating rainfall-runoff models in Mississippi agricultural areas.

Research Objective

The main objectives of this research were to enhance and evaluate LIDIA rainfall-runoff and transport algorithms. This research is relevant because coded hydraulic routing algorithms in LIDIA and reported the first evaluation with field data of LIDIA rainfall-runoff code. This report was divided in seven main chapters: introduction, LIDIA model development, LIDIA model evaluation, conclusions, recommendations, references, and appendices.

Modeling Techniques Coded in LIDIA

Rainfall-runoff processes are simulated in LIDIA using the Curve Number (CN) methodology for initial abstractions and runoff volumes. Hydrograph routing is computed using the Santa Barbara Urban Hydrograph (SBUH) method.

Curve Number Method

In LIDIA, The Curve Number (CN) method approach was adopted (SCS, 1972). This approach was developed by the USDA Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS). The CN method is one of the most popular methods to estimate the volume of direct surface runoff for a given rainfall event (Sahu et al., 2010). This method stems from Horton's achievement of the derivation of a series of empirical formulas for estimating rainfall interception based on different types of vegetal cover. His idea was the basis of the rainfall-runoff modeling process that was later enhanced by the USDA-NRCS as the CN method (Singh and Woolhiser, 2002). For the CN method, the rainfall infiltration losses depend primarily on soil characteristics and land use (surface cover); it uses a combination of soil conditions and land use to assign runoff factors known as runoff curve numbers (Hawkins et al., 2008). The method calculates the CN values for a designated sub-area based on detailed land use and hydrologic soil group (HSG) combined information. The CN methodology assumes that the total infiltration capacity of a soil can be found from the soil's tabulated CN. During a rain event this capacity is depleted as a function of cumulative rainfall and remaining capacity. SCS-CN method have being extensively describe since its apparition (Hawkins et al., 2009; SCS, 1972) and will not covered in more detail in this report.

Santa Barbara Urban Hydrograph Method

The Santa Barbara Urban Hydrograph (SBUH) method was developed by Stubchaer, (1975) for the Santa Barbara County Flood Control and Water Conservation District to determine a runoff hydrograph for an urbanized area directly without applying the SCS unit hydrograph method (Al-Houri, 2008). It is a popular method for calculating runoff, since it can be done with a spreadsheet or by hand relatively easily (Portland

Bureau of Environmental Services, 2004). The SBUH method has being widely accepted as one of the methods to calculate a site's total runoff volume and peak runoff flow under existing and proposed project conditions in design project by: Washington State Department of Ecology (2001), Portland Bureau of Environmental Services (2004), Rogue Valley Sewer Services (2006), City of Santa Barbara (2008), The City of Seattle (2009), King County (2009), Washington State Department of transportation (2010), City of Gig Harbor (2010), San Francisco Public Utilities Commission (2011), among others.

There are numerous commercial software packages that use the SBUH method as the routing method. It is implemented in the runoff calculation modules in software packages like:

- Hydrocad Stormwater modeling System where it is not limited to a given rainfall distribution (HydroCAD Software Solutions LLC., 2010),
- Detention Pond Design and Urban Hydrology Modeling (PondPack). This software is not limited to be use in urban watersheds (Bentley Systems, Incorporated, 2009).
- XPSWMM which simulates the complete hydrologic cycle in rural and urban watersheds (XP Software Inc., 2011)
- AutoCAD Civil 3D Hydraflow Hydrographs Extension (Autodesk, 2010)
- ICPR Interconnected Channel and Pond Routing Model (Streamline technologies, 2007)
- MODRET (Scientific Software Group, 2012)
- CHAN for Windows (Aquarian Software, Inc. 2007).
- StormShed (Engenious systems, Inc.)

This section presents a review of SBUH method applications. Applications that include the SBUH method in rural areas were not found in literature. Tsihrintzis and Sidan, (1998) used the SBUH to compute hydrographs for single events (duration of 0.83-10.5 h) in four small sites predominantly urban in Florida. A summary of their site description and rainfall information is shown in table 1.

Table 1 Data Summary Used in Different Studies Using the SBUH Method

Site description	**Size (acres)**	**Impervious area (acres)**	**Calibration**		**Verification**	
			Events	**Rainfall Depth Range (in)**	**Events**	**Rainfall Depth Range (in)**
Low density single family residential (LDR)	40.75	17.9	27	0.1-2.45	8	0.11-0.95
High density multifamily residential (HDR)	14.75	10.45	17	0.5-2.85	2	1.0-1.55
Highway (HW)	58.24	21.12	26	0.05-2.5	8	0.15-2.33
Commercial (COM)	20.41	20.00	28	0.17-2.16	8	0.35-1.90

Tsihrintzis and Sidan (1998, 2008)

Tsihrintzis and Sidan (1998) based their statistical analysis on the normalized error and mean normalized errors for flow peaks (-4.18%), runoff volume (5.02%), time to peak (0.40%) and time base of the hydrograph (-3.71%) in the calibration process. Same statistical parameters were used in the verification process obtaining values of 1.88% for flow peaks, 1.22% for runoff volume, 2.90% for time to peak and 1.70% for time base of the hydrograph. Time to peak was the best predicted parameter among all the evaluated and the sites with more deviation were LDR and COM sites. In addition the authors found that:

- The model predicted better the hydrograph for single peaks than multi-peak runoff events. In analyzing multi-peak hydrographs, the highest peak was nearly perfect but the secondary peak was slightly off.
- The parameter with most variation in the calibration was the time of concentration.

Tsihrintzis and Sidan (2008) used also the same data (table 1) to compare the following urban models: Illinois Urban Drainage Area Simulator ILLUDAS (Terstriep, and Stall 1974), Penn State Runoff Quality Model PSRM_QUAL[1] (Aron et. al, 1995), and SWMM (EPA, 2012). Results from this comparison showed that SBUH method had better predictions for the time to peak than the other three models. In addition, it was stated that the SBUH model can be a "*good alternative when detailed information about the watershed and drainage system is not needed.*"

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[1] PSRM-QUAL is an update of the Penn State Runoff Model (PSRM) that includes water quality algorithms.

CHAPTER II

HYDROLOGIC CALCULATOR TOOL - LIDIA

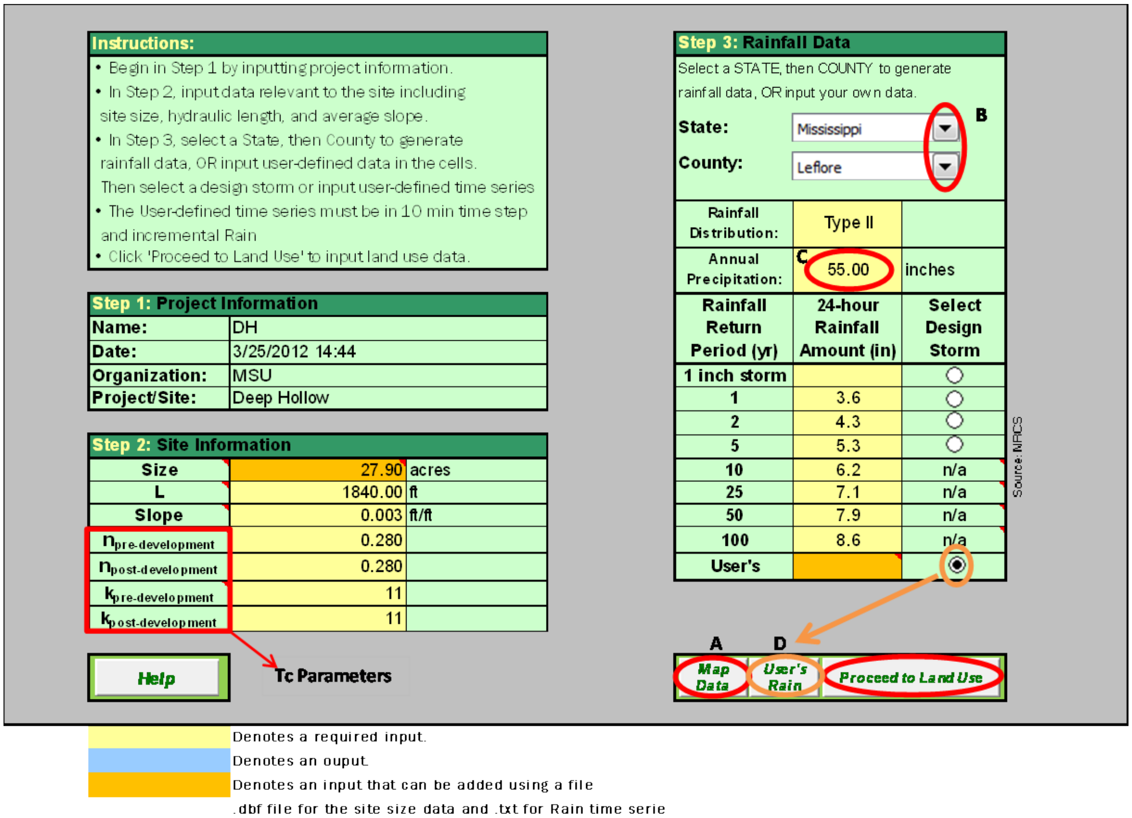
The hydrologic calculator tool - LIDIA was coded using Visual Basic for Applications in Microsoft Office Excel 2007. The program was developed in English units. LIDIA contains 10 sheets that carry the user in a fashionable way through the whole calculation process. The sheets named Site Data and BMP Design allow the user to input required data for the computations, while the remaining sheets show summaries, results, and graphs generated after running a particular project. This chapter shows detailed guidelines in how to use the LIDIA tool. In addition, instructions are also available in sheets requiring data or decisions.

Rainfall-Runoff Simulation

Site Data Sheet

By default, this is the only sheet that pops up in a new project (figure 1). The user should follow three steps in the site data sheet. Step 1 requires general project information. The step 2 is basically the input of rainfall data(inches) and input of the site information for pre and post development scenarios: area size (acres), hydraulic length (ft.), slope (ft/ft), overland roughness coefficient (City of Portland 2007, Washington State Department of Ecology 2001) and the time of concentration velocity factor (ft/s) (Washington State Department of Ecology, 2001). Size data can be input by typing in the corresponding cell or by using data from a geographical information system (GIS). GIS data can be imported by clicking the “Map Data box” (A in figure 1). The program seeks a GIS .dbf file with a site size value (figure 2). The area size from the .dbf file should be in square meters. Then, the program converts this value to acres. Appendix B contains the codes that LIDIA uses for the land use selection and appendix C shows the format of the dbf file that can be used in LIDIA.

Step 3 requests rainfall data. Precipitation data (annual values) are model-generated by the selection of state and county (B in figure 1) or manually entered by user-defined values (C in figure 1). The precipitation database is tailored for sites within Alabama, Louisiana, and Mississippi. The current version of LIDIA allows the user to choose their rainfall event and import it by using the “user’s rain” box (D in figure 1). The file containing the storm information must to have a .txt extension and contains the incremental rainfall (every 10 minutes). Then, the program will compute the accumulated rainfall.



Instructions:

- Begin in Step 1 by inputting project information.
- In Step 2, input data relevant to the site including site size, hydraulic length, and average slope.
- In Step 3, select a State, then County to generate rainfall data, OR input user-defined data in the cells. Then select a design storm or input user-defined time series
- The User-defined time series must be in 10 min time step and incremental Rain
- Click 'Proceed to Land Use' to input land use data.

Step 1: Project Information	
Name:	DH
Date:	3/25/2012 14:44
Organization:	MSU
Project/Site:	Deep Hollow

Step 2: Site Information		
Size	27.90	acres
L	1840.00	ft
Slope	0.003	ft/ft
$n_{pre\text{-}development}$	0.280	
$n_{post\text{-}development}$	0.280	
$k_{pre\text{-}development}$	11	
$k_{post\text{-}development}$	11	

Step 3: Rainfall Data

Select a STATE, then COUNTY to generate rainfall data, OR input your own data.

State: Mississippi

County: Leflore

Rainfall Distribution:	Type II	
Annual Precipitation:	55.00	inches
Rainfall Return Period (yr)	**24-hour Rainfall Amount (in)**	**Select Design Storm**
1 inch storm		○
1	3.6	○
2	4.3	○
5	5.3	○
10	6.2	n/a
25	7.1	n/a
50	7.9	n/a
100	8.6	n/a
User's		●

Source: NRCS

🟨	Denotes a required input.
🟦	Denotes an ouput.
🟧	Denotes an input that can be added using a file .dbf file for the site size data and .txt for Rain time serie

Figure 1 LIDIA Site Data sheet

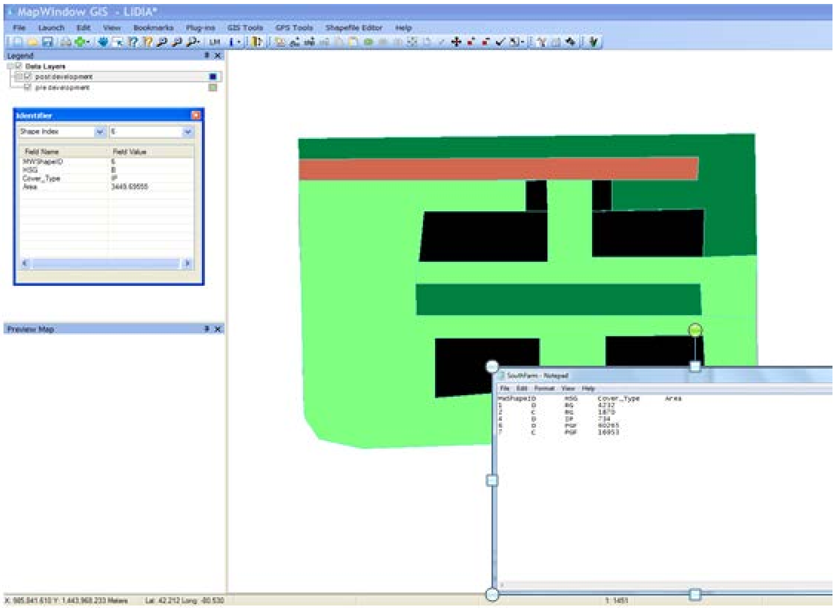


Figure 2 MapWindow project and .dbf file examples

After Steps 1, 2 and 3 are done the user should input land use and soil type data by clicking “Proceed to Land Use” button (E in figure 1). This will pop up the Land Use Form, shown in figure 3, that contains 4 tabs (Instructions, Pre-Developed, Post-Developed, and Summary). On the first tab are instructions for filling in the information related to land use by area and soil type as is shown in figure 3a.

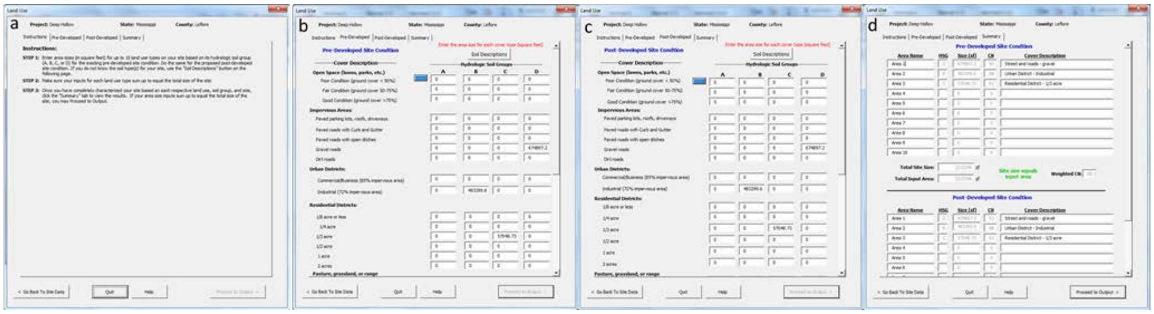
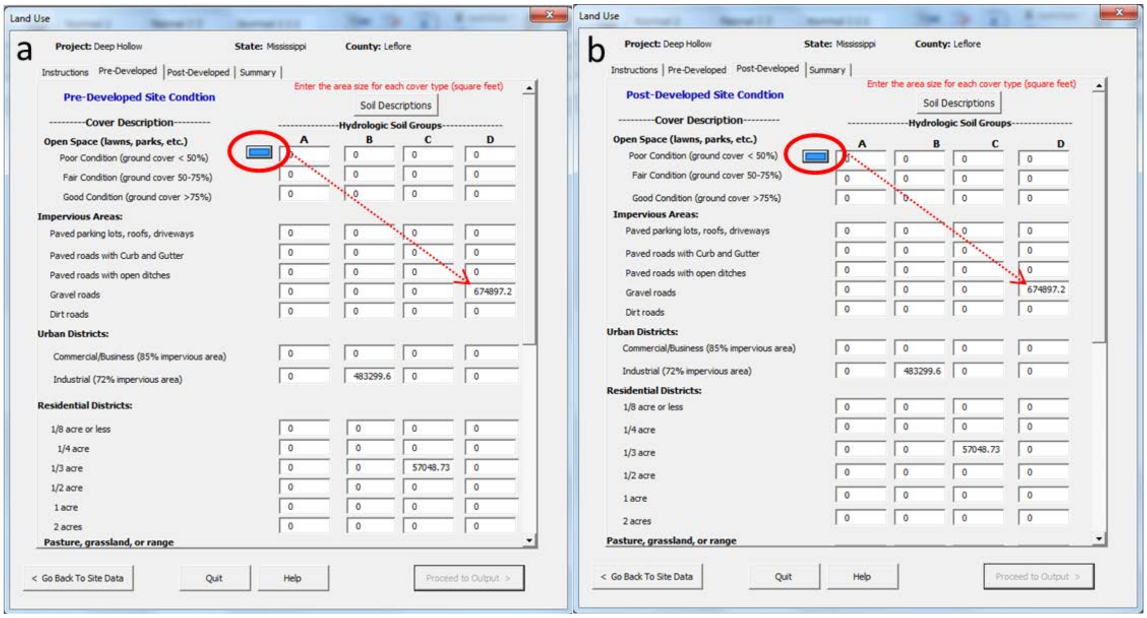


Figure 3 Land Use Form

(A)Instructions, (B) predevelopment site conditions, (C) post development site conditions and (D) summary

The second tab (Pre-Developed) allows the user to fill in the size information for the predevelopment conditions. Again the information can be filled in manually or through the blue button, which is highlighted in figure 4. Using the blue button the program calls a .dbf file and automatically extracts the required area values (the program automatically converts square meters from the .dbf file to square feet) according to land cover and hydrologic soil group characteristics (figure 2). This procedure is the same for Pre-Developed and Post-Developed tabs (figures 4 a, b). The program also allows the user to input the required information by filling up the matrix spots (hydrologic soil group and cover).



a

Project: Deep Hollow **State:** Mississippi **County:** Leflore

Pre-Developed Site Condtion

Enter the area size for each cover type (square feet)

Cover Description	A	B	C	D
Open Space (lawns, parks, etc.)				
Poor Condition (ground cover < 50%)	0	0	0	0
Fair Condition (ground cover 50-75%)	0	0	0	0
Good Condition (ground cover >75%)	0	0	0	0
Impervious Areas:				
Paved parking lots, roofs, driveways	0	0	0	0
Paved roads with Curb and Gutter	0	0	0	0
Paved roads with open ditches	0	0	0	0
Gravel roads	0	0	0	674897.2
Dirt roads	0	0	0	0
Urban Districts:				
Commercial/Business (85% impervious area)	0	0	0	0
Industrial (72% impervious area)	0	483299.6	0	0
Residential Districts:				
1/8 acre or less	0	0	0	0
1/4 acre	0	0	0	0
1/3 acre	0	0	57048.73	0
1/2 acre	0	0	0	0
1 acre	0	0	0	0
2 acres	0	0	0	0
Pasture, grassland, or range				

b

Project: Deep Hollow **State:** Mississippi **County:** Leflore

Post-Developed Site Condtion

Enter the area size for each cover type (square feet)

Cover Description	A	B	C	D
Open Space (lawns, parks, etc.)				
Poor Condition (ground cover < 50%)	0	0	0	0
Fair Condition (ground cover 50-75%)	0	0	0	0
Good Condition (ground cover >75%)	0	0	0	0
Impervious Areas:				
Paved parking lots, roofs, driveways	0	0	0	0
Paved roads with Curb and Gutter	0	0	0	0
Paved roads with open ditches	0	0	0	0
Gravel roads	0	0	0	674897.2
Dirt roads	0	0	0	0
Urban Districts:				
Commercial/Business (85% impervious area)	0	0	0	0
Industrial (72% impervious area)	0	483299.6	0	0
Residential Districts:				
1/8 acre or less	0	0	0	0
1/4 acre	0	0	0	0
1/3 acre	0	0	57048.73	0
1/2 acre	0	0	0	0
1 acre	0	0	0	0
2 acres	0	0	0	0
Pasture, grassland, or range				

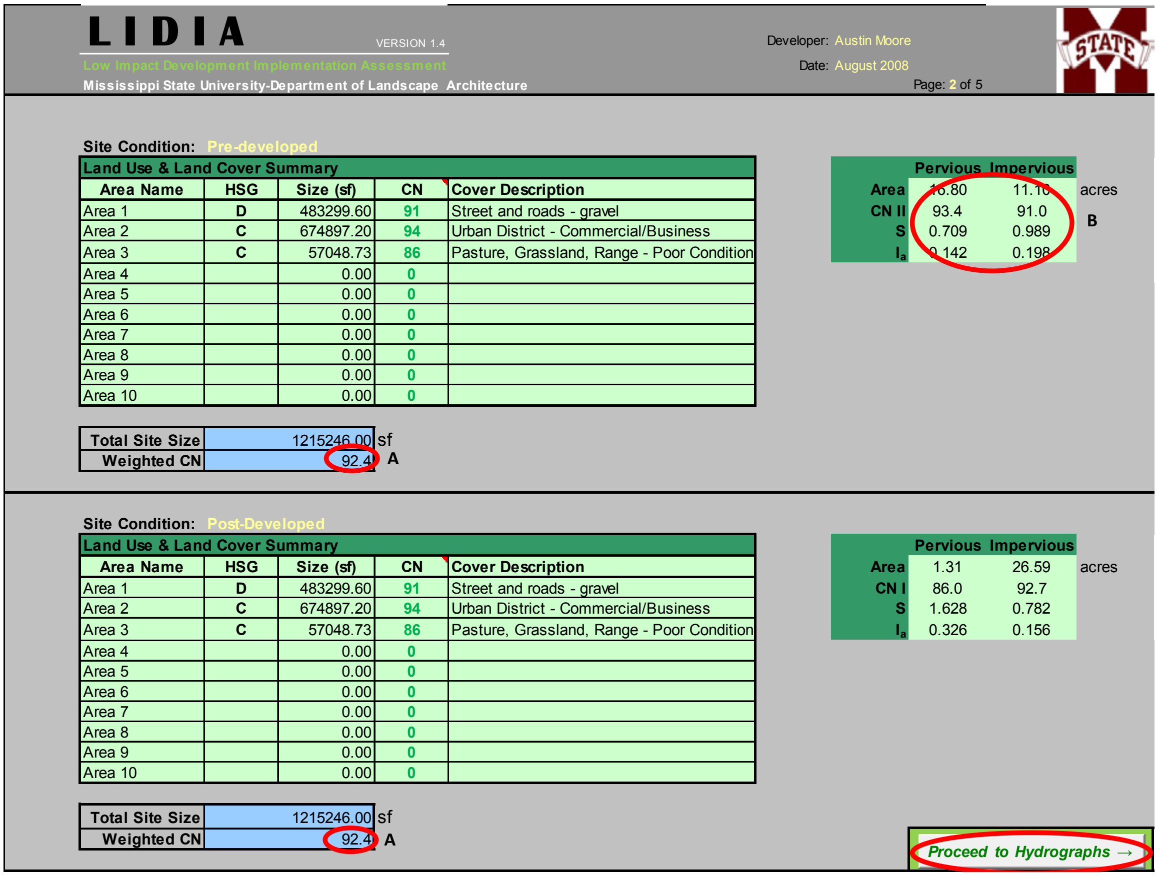
Figure 4 Land Use Form Pre and Post Conditions

(A) Pre-Development land use Information (B) Post-Development land use information

After entering pre and post-developed data, the summary tab (figure 4d) shows the distribution of the areas for the project and the CN value assigned to each one. The summary is showed for both conditions (pre and post-development). The "Proceed to Output" button lets the user see the CN calculation results and a summary of site conditions shown (figure 5).

CN Input Parameters Sheet

The information summarized on this page is the same that the summary form shows: the distribution of the total area for every hydrologic soil group (HSG), the CN for every area, the cover description, the resulting CN values, and the weighted CN values and CN parameter values ($\boldsymbol{S}$ and $\boldsymbol{I_a}$) calculation. Although a weighted CN is calculated for the entire area in each site condition (Figure 5a), this value can be considered as merely informative, because the spreadsheet uses not the weighted CN for the entire area but the weighted CN value calculate for a discretization of the area based on pervious or impervious area (Figure 5b) to solve the hydrologic system. The "Proceed to Hydrographs" button leads to model hydrograph results.



L I D I A VERSION 1.4

Low Impact Development Implementation Assessment

Mississippi State University-Department of Landscape Architecture

Developer: Austin Moore

Date: August 2008

Page: 2 of 5

Site Condition: Pre-developed

Land Use & Land Cover Summary

Area Name	HSG	Size (sf)	CN	Cover Description
Area 1	D	483299.60	91	Street and roads - gravel
Area 2	C	674897.20	94	Urban District - Commercial/Business
Area 3	C	57048.73	86	Pasture, Grassland, Range - Poor Condition
Area 4		0.00	0	
Area 5		0.00	0	
Area 6		0.00	0	
Area 7		0.00	0	
Area 8		0.00	0	
Area 9		0.00	0	
Area 10		0.00	0	

Total Site Size	1215246.00	sf
Weighted CN	92.4	A

	Pervious	Impervious	
Area	16.80	11.10	acres
CN II	93.4	91.0	B
S	0.709	0.989	
I_a	0.142	0.198	

Site Condition: Post-Developed

Land Use & Land Cover Summary

Area Name	HSG	Size (sf)	CN	Cover Description
Area 1	D	483299.60	91	Street and roads - gravel
Area 2	C	674897.20	94	Urban District - Commercial/Business
Area 3	C	57048.73	86	Pasture, Grassland, Range - Poor Condition
Area 4		0.00	0	
Area 5		0.00	0	
Area 6		0.00	0	
Area 7		0.00	0	
Area 8		0.00	0	
Area 9		0.00	0	
Area 10		0.00	0	

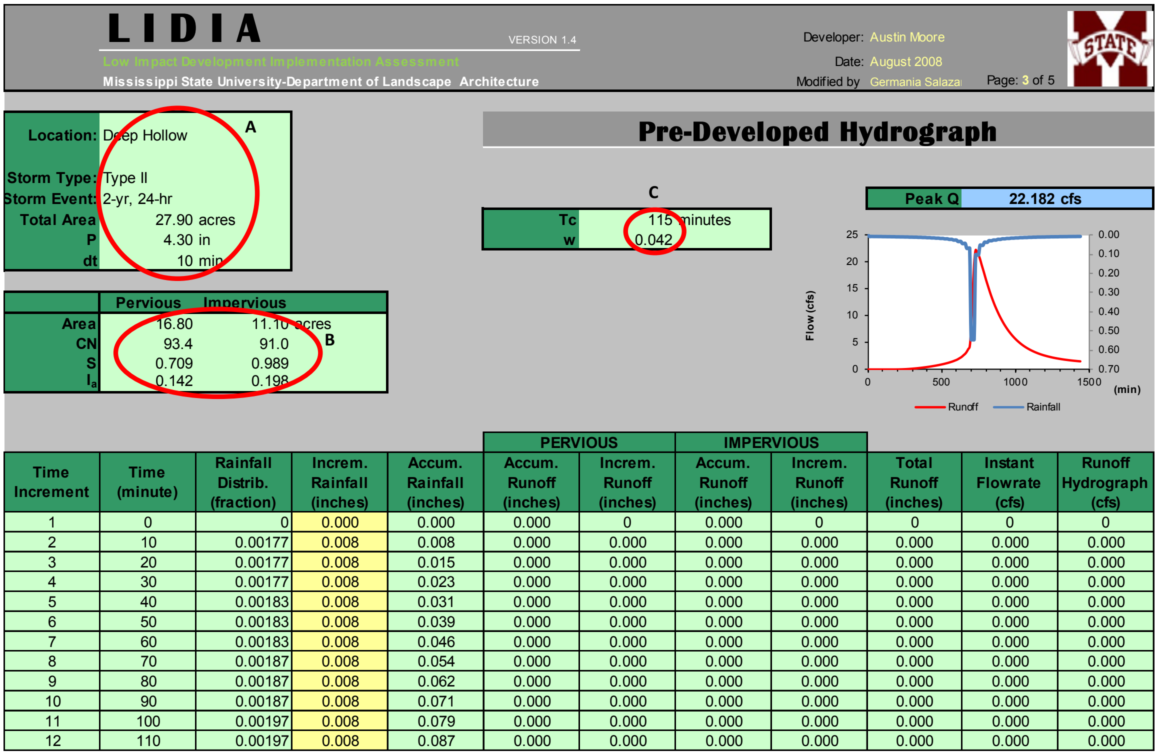
Total Site Size	1215246.00	sf
Weighted CN	92.4	A

	Pervious	Impervious	
Area	1.31	26.59	acres
CN I	86.0	92.7	
S	1.628	0.782	
I_a	0.326	0.156	

Figure 5 CN Input Parameters Sheet

Pre-Developed Hydrograph Sheet

In this sheet, tabular and graphical hydrograph results for the pre-development condition are shown (figure 6). In addition, figure 6 depicts a summary of the precipitation and site data (A), CN and related parameter values by pervious and impervious areas (B), and time of concentration needed to compute the hydrograph (C).



L I D I A VERSION 1.4

Low Impact Development Implementation Assessment

Mississippi State University-Department of Landscape Architecture

Developer: Austin Moore

Date: August 2008

Modified by Germania Salazar

Page: 3 of 5

Pre-Developed Hydrograph

A

Location:	Deep Hollow
Storm Type:	Type II
Storm Event:	2-yr, 24-hr
Total Area	27.90 acres
P	4.30 in
dt	10 min

B

	Pervious	**Impervious**
Area	16.80	11.10 acres
CN	93.4	91.0
S	0.709	0.989
I_a	0.142	0.198

C

Tc	115 minutes
w	0.042

Peak Q 22.182 cfs

Time Increment	**Time (minute)**	**Rainfall Distrib. (fraction)**	**Increm. Rainfall (inches)**	**Accum. Rainfall (inches)**	**PERVIOUS** Accum. Runoff (inches)	**PERVIOUS** Increm. Runoff (inches)	**IMPERVIOUS** Accum. Runoff (inches)	**IMPERVIOUS** Increm. Runoff (inches)	**Total Runoff (inches)**	**Instant Flowrate (cfs)**	**Runoff Hydrograph (cfs)**
1	0	0	0.000	0.000	0.000	0	0.000	0	0	0	0
2	10	0.00177	0.008	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	20	0.00177	0.008	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	30	0.00177	0.008	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	40	0.00183	0.008	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	50	0.00183	0.008	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	60	0.00183	0.008	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	70	0.00187	0.008	0.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	80	0.00187	0.008	0.062	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	90	0.00187	0.008	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	100	0.00197	0.008	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	110	0.00197	0.008	0.087	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 6 Pre-development Hydrograph Sheet

The hydrograph computed in LIDIA is developed using the Santa Barbara Urban Hydrograph (SBUH) method (Rogue Valley Sewer Services, 2006). The SBUH method computes an instantaneous and runoff hydrograph for pervious and impervious areas separately. Then, the total runoff at the drainage area outlet is computed summing the pervious and impervious hydrographs.

From the selection of the curve number (CN), the spreadsheet calculates the initial abstractions (***I_a***) as 20% of the storage index (***S***)

$$I_a = 0.2S \tag{1}$$

Where

I_a = Initial abstraction (inches)

S = Storage index given by

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

Runoff (Q) starts being computed when the accumulated rainfall (column 5 in Figure 6) exceeds the initial abstraction by:

$$Q = \frac{\left(R - I_a\right)^2}{R + 0.8S} - 10 \qquad (3)$$

Where

$Q =$ Runoff depth (in)

$R =$ Rainfall depth (in)

The result is the accumulated runoff, which is calculated separately for pervious and impervious areas. The incremental runoff is computed by subtracting two consecutive values in the accumulated runoff column. The total runoff column is the sum of the incremental runoff for each of the pervious and impervious areas, obtained using equation 4

$$Q_{Total} = \frac{A_{pervious}}{A_{total}} * Q_{pervious} + \frac{A_{impervious}}{A_{total}} * Q_{impervious} \qquad (4)$$

The instantaneous flow rate (I_i) is computed at each time step using:

$$I_i = \frac{60.5 * Q_{Total} * Area}{\Delta t} \qquad (5)$$

Where

I_i = Instantaneous flow rate (cfs)

Q_{Total} = Total runoff (inches)

$Area$ = Site size (acres)

Δt = time step (minutes)

Finally, the total hydrograph (D_Q) is calculated by routing the instantaneous flow rate from equation (5) through an imaginary reservoir based on equation (6) (Tsihrintzis and Sidan, 1997).

$$D_{Q_{i+1}} = D_{Q_i} + w\left(I_i + I_{i+1} - 2 * D_{Q_i}\right) \tag{6}$$

w is considered as the routing constant which is function of the concentration time. The w constant parameter is used to provide the hydrograph attenuation due to basin storage effects (Clay, 2009).

$$w = \frac{\Delta t}{\left(2T_c + \Delta t\right)} \tag{7}$$

$T_c =$ time of concentration (minutes)

There are several approaches to compute the time of concentration (Haan et al., 1994; Washington State Department of Ecology, 2001). Time of concentration equations are related to hydrologic and hydraulic characteristics of drainage areas (e.g., slope, channel length, roughness coefficient, curve number, etc.).

The time of concentration equation was revised due to the importance of the hydrograph generation (Wong, 2005). The current version of LIDIA is coded to compute the travel time for two distinct flow segments: sheet flow and shallow concentrated flow. Travel time for sheet flow is computed using the Manning's kinematic approximation (Haan et al., 1994):

$$T_{st} = \frac{0.007(nL)^{0.8}}{\left(P_2\right)^{0.5}(s)^{0.4}} \tag{8}$$

Where

$T_{st} =$ Travel time for sheet flow (h)

$n =$ Roughness coefficient

$L =$ Hydraulic length (ft)

The P_2 term in the Manning's kinematic travel time equation can be computed using LIDIA storm design capabilities (see B in figure 1). Sheet flow equations are applicable to flow across flat areas that do not form channels or rivulets and do not extend for more than 300 feet (Iowa State University, 2010). In the case of having more than 300 feet, the remaining length is assigned to shallow concentrated flow and calculated by equation 9 and 10 (Washington State Department of Ecology, 2001).

$$T_{ht} = \frac{L}{3600(V)} \tag{9}$$

$$V = k\sqrt{s} \tag{10}$$

Where

$T_{ht} =$ Travel time for shallow concentrate flow (h)

$V =$ Velocity (ft/s)

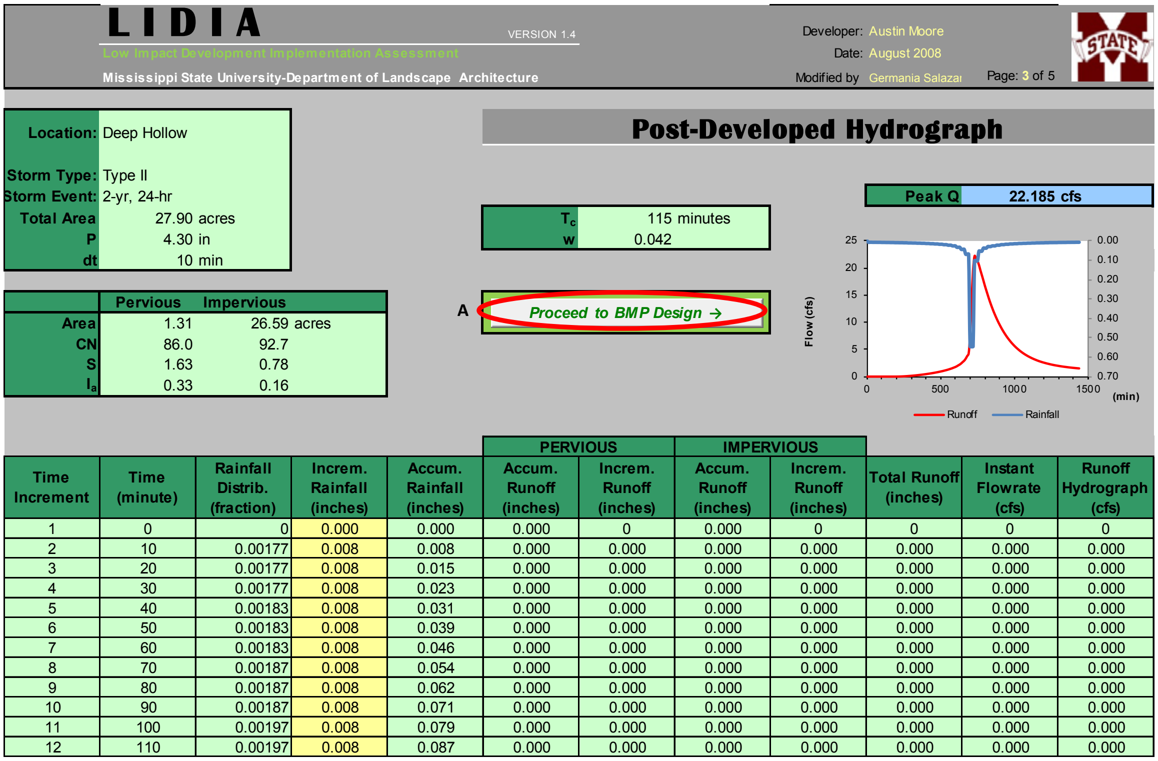
$k =$ Time of concentration velocity factor (ft/s)

$s =$ Slope of flow path (ft/ft)

The time of concentration (***T_c***) is the sum of the travel time for sheet flow (***T_{st}***) and travel time for shallow concentrate flow (***T_{ht}***). Then, T_c is used to compute the routing constant (***w***) in equation 7.

Post-Developed Hydrograph Sheet

The Post-development sheet contains information for the post-development conditions (figure 7). This sheet has the same format that the pre-developed hydrograph sheet.



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Mississippi State University-Department of Landscape Architecture

Developer: Austin Moore
Date: August 2008
Modified by Germania Salazar
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Post-Developed Hydrograph

Location:	Deep Hollow
Storm Type:	Type II
Storm Event:	2-yr, 24-hr
Total Area	27.90 acres
P	4.30 in
dt	10 min

	Pervious	Impervious
Area	1.31	26.59 acres
CN	86.0	92.7
S	1.63	0.78
I_a	0.33	0.16

T_c	115 minutes
w	0.042

A Proceed to BMP Design →

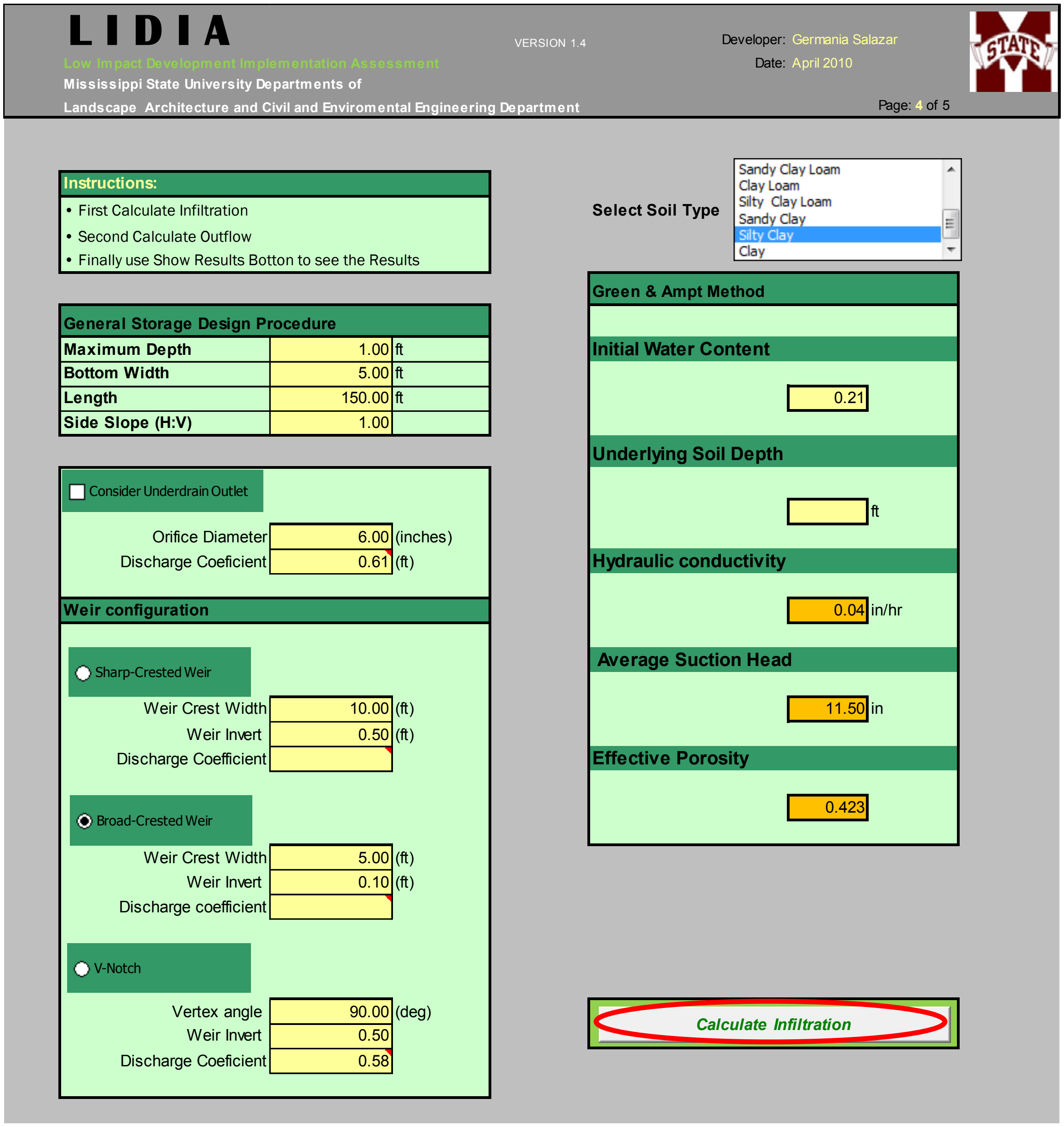
Peak Q 22.185 cfs

					PERVIOUS		IMPERVIOUS				
Time Increment	**Time (minute)**	**Rainfall Distrib. (fraction)**	**Increm. Rainfall (inches)**	**Accum. Rainfall (inches)**	**Accum. Runoff (inches)**	**Increm. Runoff (inches)**	**Accum. Runoff (inches)**	**Increm. Runoff (inches)**	**Total Runoff (inches)**	**Instant Flowrate (cfs)**	**Runoff Hydrograph (cfs)**
1	0	0	0.000	0.000	0.000	0	0.000	0	0	0	0
2	10	0.00177	0.008	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	20	0.00177	0.008	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	30	0.00177	0.008	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	40	0.00183	0.008	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	50	0.00183	0.008	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	60	0.00183	0.008	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	70	0.00187	0.008	0.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	80	0.00187	0.008	0.062	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	90	0.00187	0.008	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	100	0.00197	0.008	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	110	0.00197	0.008	0.087	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 7 Post-development Hydrograph Sheet

BMP Design

This module is accessed through the box "Proceed to BMP Design" in figure 7(A). It is intended to input all the information concerning to the best management practice (BMP) facility design. BMP hydraulic Information such as depth, width, length, side slope, and outlet structure is required to calculate the flow routing process (left side in figure 8). The right side in figure 8 shows how the soil characteristics for computing infiltration rates in the BMP can be input into LIDIA. The Green and Ampt infiltration method was selected to compute infiltration losses through the BMP.



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Landscape Architecture and Civil and Enviromental Engineering Department

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Developer: Germania Salazar
Date: April 2010

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Instructions:

- First Calculate Infiltration
- Second Calculate Outflow
- Finally use Show Results Botton to see the Results

General Storage Design Procedure		
Maximum Depth	1.00	ft
Bottom Width	5.00	ft
Length	150.00	ft
Side Slope (H:V)	1.00	

☐ Consider Underdrain Outlet

Orifice Diameter	6.00	(inches)
Discharge Coeficient	0.61	(ft)

Weir configuration

○ Sharp-Crested Weir

Weir Crest Width	10.00	(ft)
Weir Invert	0.50	(ft)
Discharge Coefficient		

● Broad-Crested Weir

Weir Crest Width	5.00	(ft)
Weir Invert	0.10	(ft)
Discharge coefficient		

○ V-Notch

Vertex angle	90.00	(deg)
Weir Invert	0.50	
Discharge Coeficient	0.58	

Select Soil Type

Sandy Clay Loam
Clay Loam
Silty Clay Loam
Sandy Clay
Silty Clay
Clay

Green & Ampt Method

Initial Water Content	0.21	
Underlying Soil Depth		ft
Hydraulic conductivity	0.04	in/hr
Average Suction Head	11.50	in
Effective Porosity	0.423	

Figure 8 BMP Design Sheet

Water Infiltration Model

In LIDIA, the Green & Ampt method (Chin, 2006) was coded to compute soil infiltration rates. The Green & Ampt infiltration method is one of the most realistic models of infiltration available (Chin, 2006). Parameters such as hydraulic conductivity, average suction head, and effective porosity are input in the sheet just by selecting the soil type through the pull down selection menu located in the upper right part in figure 8. Table 2 shows typical values of Green-Ampt parameters. These are the values that can be inputted by selecting the BMP soil type from the predetermined database. Rawls et al., (1982), and Rawls et al., (1983) determined these parameters from soil properties. Users can also type their own values for the required characteristics and must input the initial water content.

Table 2 Typical Values of Green-Ampt Parameters

Soil texture	**Avg. Capillary Suction Head (in)**	**Saturated Hydraulic conductivity (in/hr)**	**Effective porosity**
Sand	1.95	9.28	0.417
Loamy Sand	2.41	2.35	0.401
Sandy Loam	4.33	0.86	0.412
Loam	3.5	0.52	0.434
Silt Loam	6.57	0.27	0.486
Sandy Clay Loam	8.6	0.12	0.33
Clay Loam	8.22	0.08	0.309
Silty Clay Loam	10.75	0.08	0.432
Sandy Clay	9.41	0.05	0.321
Silty Clay	11.5	0.04	0.423
Clay	12.45	0.02	0.385

(Rawls et. al, 1983)

The basic equations of the Green & Ampt model are:

$$f = f_p = K_s + \frac{Ks(n-\theta_i)\Phi_f}{F} \quad t > t_p \tag{11}$$

If the rainfall intensity (*i)* is initially less than the infiltration capacity, then the actual infiltration (*f*) becomes equal to the rainfall intensity, at this time $t = t_p$

Where

F = Cumulative infiltration (in)

f = Actual infiltration (in/h)

f_p = Potential infiltration rate (in/h)

K_s = Hydraulic conductivity (in/h)

$n =$ Effective porosity

θ_i = Initial water content

Φ_f = Suction head (in)

t_p = Time to ponding (h)

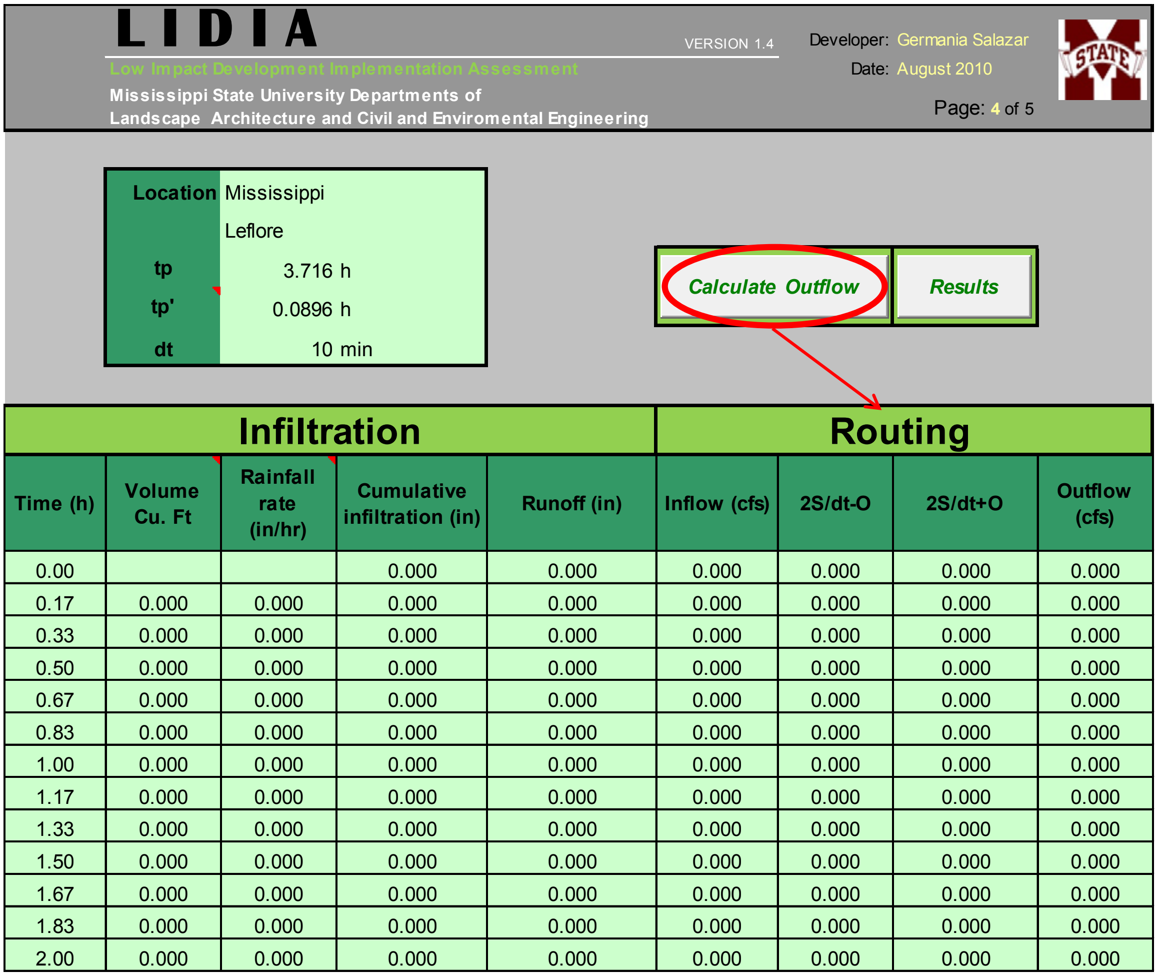
For $t > t_p$, the rainfall intensity exceeds the potential infiltration rate, and the infiltration continues at the potential rate given by (11). At this time the cumulative infiltration can be calculated by:

$$K_s\left(t - t_p + t_p'\right) = F - \left(n - \theta_i\right)\Phi_f \ln\left[1 + \frac{F}{\left(n - \theta_i\right)\Phi_f}\right] \tag{12}$$

Where t_p' is the equivalent time to infiltrate F under the condition of surface ponding from $t = 0$. Further information about how the Green-Ampt model is solved can be found in Chin (2006).

The evaluation of spatial and temporal variation of flows is required to estimate the effect of a BMP on peak attenuation. The routing process uses mathematical expressions to calculate flow from a reservoir or a storage facility once inflow, initial conditions, facility hydraulic characteristics, and operational rules are known. To start the flow routing process in the BMP/LID facility, the user must to provide the stage-storage relationship or the geometry of the new facility and the design of its respective outlet structures.

Clicking on the “Calculate Infiltration” button (bottom right of figure 8) executes the Green and Amp model and takes the user to the next sheet where the infiltration results are shown and the routing model is initiated. By clicking the “Calculate Outflow” box (figure 9) the program runs the routing model and computes the outflow hydrograph from the BMP.



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Location	Mississippi
	Leflore
tp	3.716 h
tp'	0.0896 h
dt	10 min

Infiltration					**Routing**			
Time (h)	**Volume Cu. Ft**	**Rainfall rate (in/hr)**	**Cumulative infiltration (in)**	**Runoff (in)**	**Inflow (cfs)**	**2S/dt-O**	**2S/dt+O**	**Outflow (cfs)**
0.00			0.000	0.000	0.000	0.000	0.000	0.000
0.17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.33	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.67	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.33	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.67	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1.83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 9 Infiltration Results and Routing Execution Sheet

Flow Routing Method

In LIDIA, the Storage Indication method (Ponce, 1989) is coded to compute flow routing trough a BMP/LID facility. The Storage Indication method is recommended for reservoir routing calculations for detention facilities final design (Metropolitan

Government of Nashville and Davidson County, 2009). The use of this method requires reliable descriptions of the following three items (Ponce, 1989):

- An inflow runoff hydrograph for the subject flood
- Determination of the relationships between stage and storage
- The performance characteristics of the outlets facilities associated with the operation of the facility. These are known as discharge-stage relationships.

The runoff hydrograph is obtained from the post-developed sheet. Stage-storage and discharge-stage relationships are generated by the model using the information provided by the user.

The stage-storage relationship is developed by successive calculations of storage vs. associated stages in the storage facility. Basically storage is the volume of water held by the facility as a function of the water surface elevation or depth. The volume of storage is calculated by using simple geometric formulas expressed as a function of depth. Currently, this tool allows only trapezoidal-shaped channels. The formula used to determine the facility volume is shown below

$$V = LWD + (L+W) * ZD^2 + \frac{4}{3}Z^2D^2 \tag{13}$$

Where:

$V =$ Volume of trapezoidal channel (ft^3)

$L =$ Length of channel at base (ft)

$W =$ Width of channel at base (ft)

$D =$ Depth of channel (ft)

$Z =$ Side slope factor, ratio of horizontal to vertical

The stage-outflow relationship is based on the association of the reservoir stage (head) and the resulting outflow from the storage facility. The outflow from a facility is determined by devices that control it; a typical storage facility has two of those devices (outlets or spillways): a principal outlet and a secondary (or emergency) outlet.

Several hydraulic outlet structures such as, orifices and weirs are used in detention facilities (NCDENR, 2007). Three kinds of weirs are typically used: sharp-crested, broad-crested and v-notch. The basic equations for sharp-crested and broad-crested weirs are:

$$Q = C_w L H^{3/2} \tag{14}$$

Where

$Q =$ Discharge (cfs)

$C_w =$ Discharge coefficient

$L =$ Length of weir, measured along the crest (ft)

$H =$ Driving head (ft)

The general equation for flow through orifices is (NCDENR, 2007):

$$Q = CA(2gH)^{1/2} \tag{15}$$

Where

$C =$ Discharge coefficient

$A =$ Cross-sectional area of orifice or pipe (ft^2)

$g =$ Acceleration due to gravity (32.2 ft/s^2)

$H =$ Effective head on the orifice

With stage-storage and stage-outflow relations established, storage and outflow can be related at each stage. The relationship is described in the form of:

$$O \text{ Versus } \left(\frac{2S}{\Delta t}\right) + O \tag{16}$$

The storage-outflow ratings are computed automatically based on a representative reach cross-section of the channel (BMP). LIDIA solves the flow routing through the BMP after having all the required relations. These relations are show in figure 10. The procedure to calculate outflows is shown in table 3. Flow routing is computed by clicking on "Calculate Outflow" button (i.e. shown in figure 9).

Table 3 Storage indication calculations

Inflow	$(\frac{2S}{\Delta t}) - O$	$(\frac{2S}{\Delta t}) + O$	**Outflow**
		1 →	2
	3 ←	←	←
	$\frac{2S}{\Delta t} + O - 2(O)$		From the Storage-Outflow Relationship
		4 →	5
		$I_1 + I_2 + \frac{2S}{\Delta t} - O$	

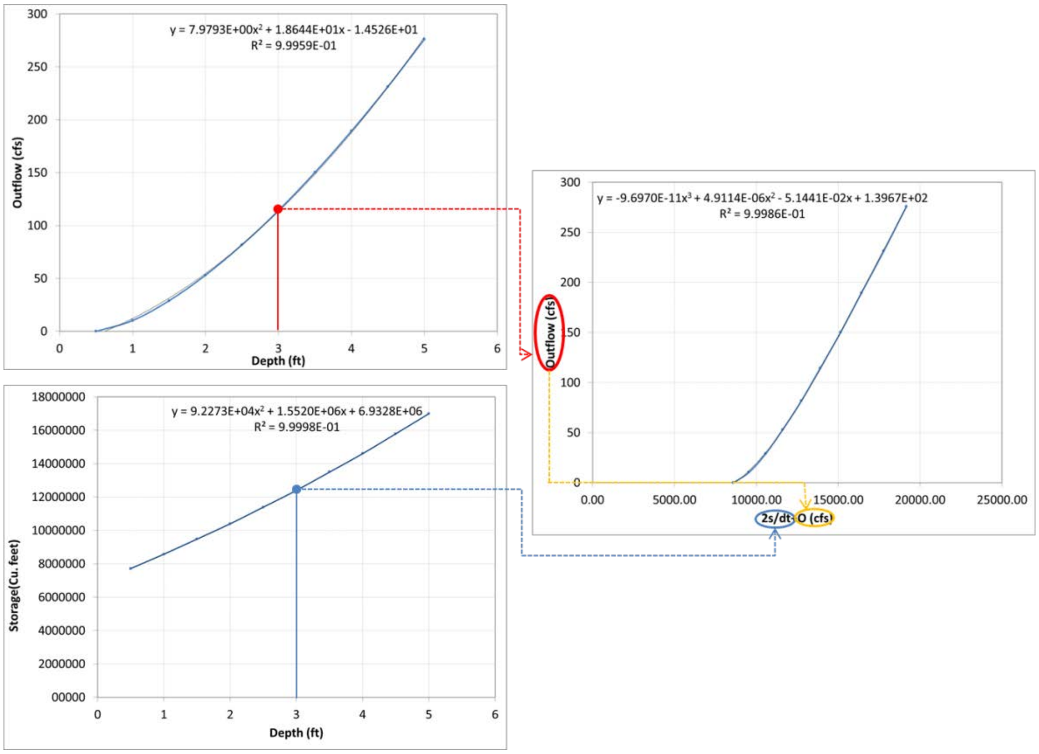
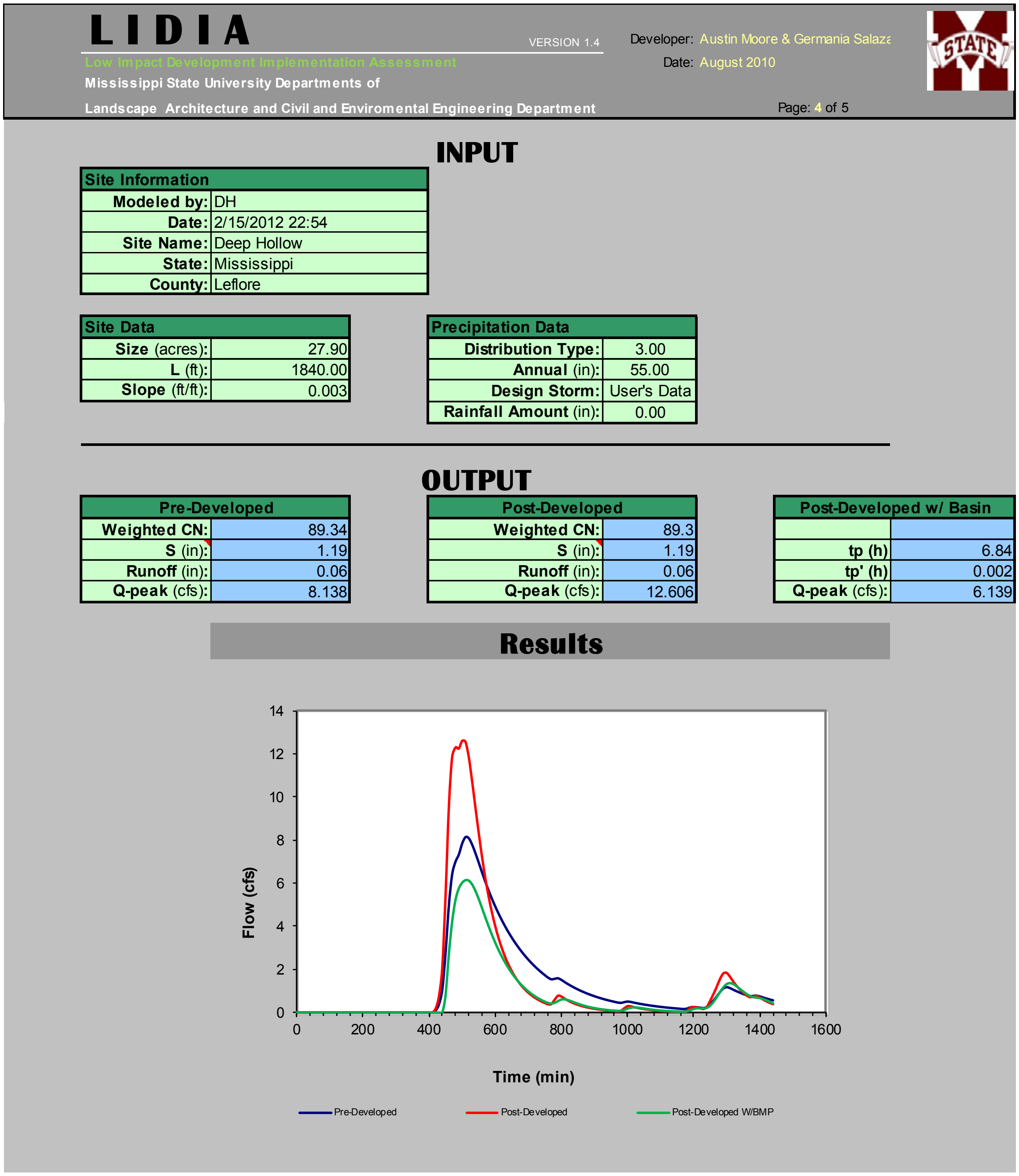


Figure 10	Storage-outflow function development

(A) stage-storage, (B) stage-discharge and (C) storage indication function.

Results Sheets

This sheet summarizes all the model results (figure 11). Relevant results such as peak flow from pre, post, and post-developed with BMP are shown in this sheet.



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Developer: Austin Moore & Germania Salaza

Date: August 2010

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INPUT

Site Information	
Modeled by:	DH
Date:	2/15/2012 22:54
Site Name:	Deep Hollow
State:	Mississippi
County:	Leflore

Site Data	
Size (acres):	27.90
L (ft):	1840.00
Slope (ft/ft):	0.003

Precipitation Data	
Distribution Type:	3.00
Annual (in):	55.00
Design Storm:	User's Data
Rainfall Amount (in):	0.00

OUTPUT

Pre-Developed	
Weighted CN:	89.34
S (in):	1.19
Runoff (in):	0.06
Q-peak (cfs):	8.138

Post-Developed	
Weighted CN:	89.3
S (in):	1.19
Runoff (in):	0.06
Q-peak (cfs):	12.606

Post-Developed w/ Basin	
tp (h)	6.84
tp' (h)	0.002
Q-peak (cfs):	6.139

Results

Figure 11 Final Model Results Sheet

CHAPTER III

LIDIA MODEL EVALUATION

This chapter shows the methods and results of two LIDIA applications in different sites in Mississippi. LIDIA hydrologic module was tested using the runoff time series from two small drainage areas (20.79 and 27.9 acres). The first catchment is a cattle area draining to a vegetated swale channel located on the Mississippi State University's South Farm, Oktibbeha County, MS. The second study area is located in an agricultural field (Deep Hollow Lake) located in Greenwood, Leflore County, MS. Fourteen storm events, over a period of 7 months (7/20/2011-02/13/2012), were analyzed on the South Farm study area and 11 storm events (1/23/1997-1/29/1999) on Deep Hollow case study.

The first part of this chapter will present the field data collection methods and the model setup of South Farm catchment. Then, a review of the model setup of Deep Hollow drainage area will be discussed. Next section will show the methods used to evaluate LIDIA model performance in both case studies. Finally, LIDIA model results will be analyzed and discussed.

South Farm

South Farm is located in the headwaters of the Noxubee River, has an area of 20.77 acres, and has two primary hydrologic soil groups (HSG): C representing a 22.40% of the total area and D a 77.60% (figure 12). The area is a cattle farm with 92% of the area covered by pasture (Table 4). The climate of Oktibbeha County is characterized by long, hot summers, and short mild winters. The Mississippi State University station

(COOP ID: 228374) is the closest National Climate Data Center -NCDC- station to South Farm (NOAA-NCDC, 2012). Climatologic data from the mentioned station was analyzed; precipitation and average temperature records were available for a period between 1949 and 2009. In addition, potential evapotranspiration time series were computed using the Hamon temperature method (Hamon, 1963) in the Better Assessment Science Integrating Point & Non-point Sources (BASINS) program (USEPA, 2012). The NCDC State University station is located 3.7 mi from South Farm. The average monthly temperatures varied from 43 to 81°F with a maximum record in July and a minimum in January.

Monthly precipitation values were generally well distributed along the year (figure 13). The mean monthly precipitation was 4.4in, with maximum records from December-January, and March-April (>5 in). Monthly potential evapotranspiration values were higher than rainfall values from June to August. This suggests that the vegetative cover could be stressed by lack of water availability.

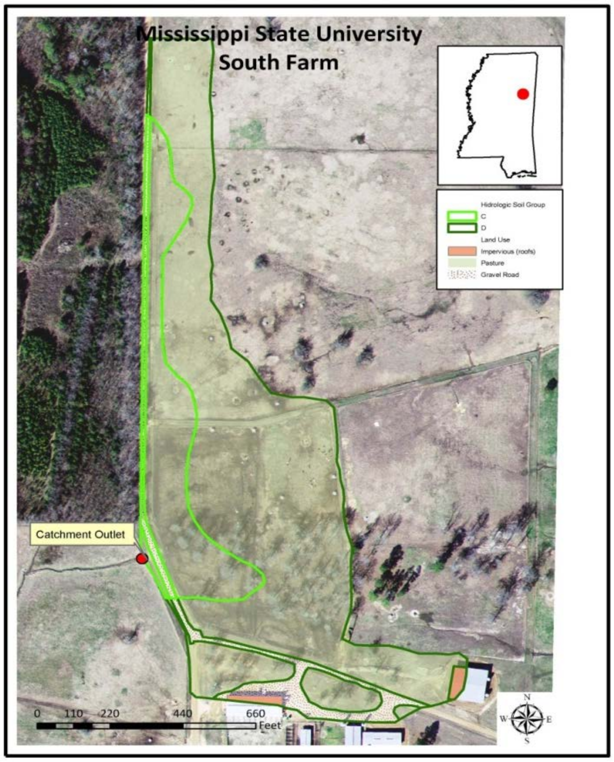

Figure 12 South Farm Catchment Map

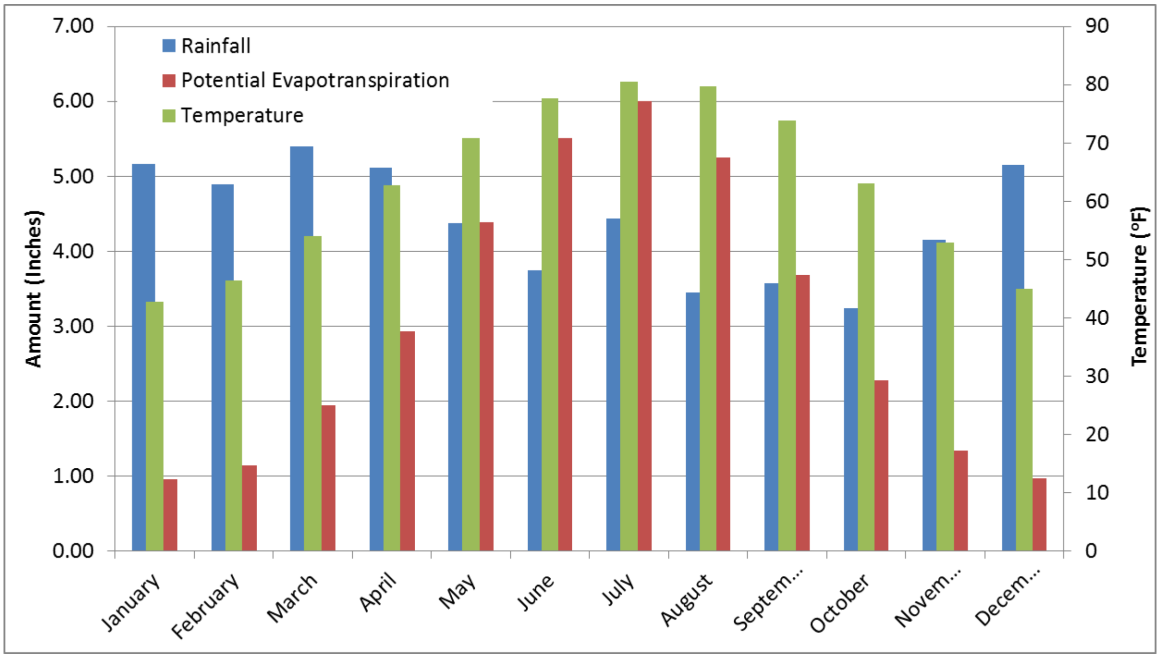

Figure 13 Climate Variables for Areas Surrounding South Farm (1949-2009)

A land cover map was generated by ground truthing and digital orthophotos in ArcMap (Figure 12). Soil information data for the study area was extracted from the U.S. Department of Agriculture SSURGO database and is listed in Table 4 (USDA, 2010). Digital orthophotos, elevation models, and field inspection were used to delineate the catchment boundaries. Verification of flow paths was performed by ground truthing in a major storm event (Bassi et al. 2010).

Table 4 South Farm Soil Data Information Used in LIDIA Application

HSG	**Cover Type**	**Area (acres)**	**Roughness (n)**	**Velocity factor (k)**	**Soils description**
D	Gravel Road	1.05	0.020	27	Kipling silty clay loam, 2 to 5% slopes, eroded (62%) Oktibbeha fine sandy loam, thick solum variant, 5 to 8 % slopes, eroded (13%) Oktibbeha silty clay loam, 2 to 5% slopes, eroded (2%).
	Impervious area (roofs)	0.18	0.018	27	
	Pasture fair conditions^2	14.89	0.15	11	
C	Gravel Road	0.46	0.020	27	Catalpa silty clay loam (18%)
	Pasture fair conditions	4.19	0.15	11	Marietta fine sandy loam (5%)

Model Setup

Land cover and soil data shown in Table 4 was used in LIDIA to compute the lumped Curve Numbers for pervious and impervious areas. The hydraulic length (1,690 feet) was considered as the most remote point of the study area and measured using GIS tools in ArcMap. The average topographic slope (5.88%) was measured on the field using geographical position systems and a total station. The roughness coefficient (0.14) and the velocity (12) factors required for T_c calculation were calculated as a weighted coefficient using values showed in Table 4. The 2-year, 24-hour rainfall depth (4.2 in)

Ground cover 50-75

for South Farm was computed using the NRCS Type II rainfall distribution database in LIDIA.

LIDIA calculates by default the Curve Number (CN) II which assumes a medium antecedent moisture condition (AMC II). In this study, CN I (dry soil) and CN III (wet soil) conditions were computed as error bands as suggested by Hawkins et al. 2008. CN I and CN III conditions for the study area were calculated by Chow equations (Chow et al. 1988).

$$CN(I) = \frac{4.2CN(II)}{[(10 - 0.058CN(II))]} \tag{17}$$

$$CN(III) = \frac{23CN(II)}{[(10 + 0.13CN(II))]} \tag{18}$$

Results obtained using the CN II were chosen to perform the model evaluation using several statistical criteria. According to Hawkins et al, 2008, the CN II condition is a proper basis for design situations. As stated earlier, the other two CN conditions were estimated as error bands.

Besides the uncertainty in selecting the CN condition for a given application, the Initial Abstraction Ratio (λ) parameter could also contribute substantially to uncertainty in model results. Different studies have proposed a new approach to the Initial abstraction ratio (λ) considered in the NRCS method (Woodward et al., 2003; Hawkins et al., 2008). Even though Woodward found that λ is not constant from storm to storm, or catchment to catchment, he suggested that the assumption of λ=0.20 is unusually high. A proposed value that seems more appropriated for general application is 0.05. This value was considered for the LIDIA case in South Farm. A change in the value of λ requires a change in the original values of CN. Re-computed CN values were done using equation 19:

$$CN_{0.05} = \frac{100}{\left\{1.879\left[\frac{100}{CN_{0.2}} - 1\right]^{1.15} + 1\right\}} \tag{19}$$

Field Monitoring

Rainfall Data

South Farm is equipped with a Series 525 Rainfall Sensor tipping bucket rain gage. This instrument uses a CR1000 data logger that records the rainfall at a given delta time (Campbell Scientific, Inc. 2000). In South Farm the rain gage is set up to record rainfall every 10 minutes. Site precipitation values were compared for consistency against rainfall data from the Geoscience Department climatological station located in Hillbun Hall at Mississippi State University. The Hillbun Hall rain gauge is located 2.6 mi North from South Farm. In this research, the total rainfall depth reported is the total of the precipitation times the interval used (10 minutes).

Flow Rating Curve

A flow rating curve (water depth vs. discharge) was developed at the entrance of the vegetated swale (VS) (Figure 14).

Figure 14 South Farm Site

Drainage area (left) and vegetated swale (right)[3]

The entrance of the VS represents the outlet of the catchment. A SonTek FlowTracker Handheld ADV (2D Acoustic Doppler Velocimeter), was used to measure flow velocities at the entrance of the channel (Burks, 2009). A brief description of the instrumentation used in South farm can be seen in appendix D. A total station was used to survey the entrance cross-sectional area. Field flow velocities and water depths were recorded at different intervals by David Bassi (MSU-CEE senior student), Gabriel Roman (University of Puerto Rico intern student at MSU-CEE), David Rivas (Universidad Nacional de Colombia intern student at MSU-CEE), and Jairo Diaz (MSU-CEE faculty) during two storm events (June 21, 2011 and September 19, 2011). The flow rating curve (Figure 15) was computed using field data and Excel by Gabriel Roman, David Rivas, and Germania Salazar (Roman and Rivas, 2011). The 95% confidence interval for the rating curve was developed and equations for the boundaries were also generated:

$$Q_{upper} = 2.5057x^{1.6298} \tag{20}$$

$$Q_{Lower} = 1.6209x^{2.470} \tag{21}$$

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[3] Source Dr. Jairo Diaz

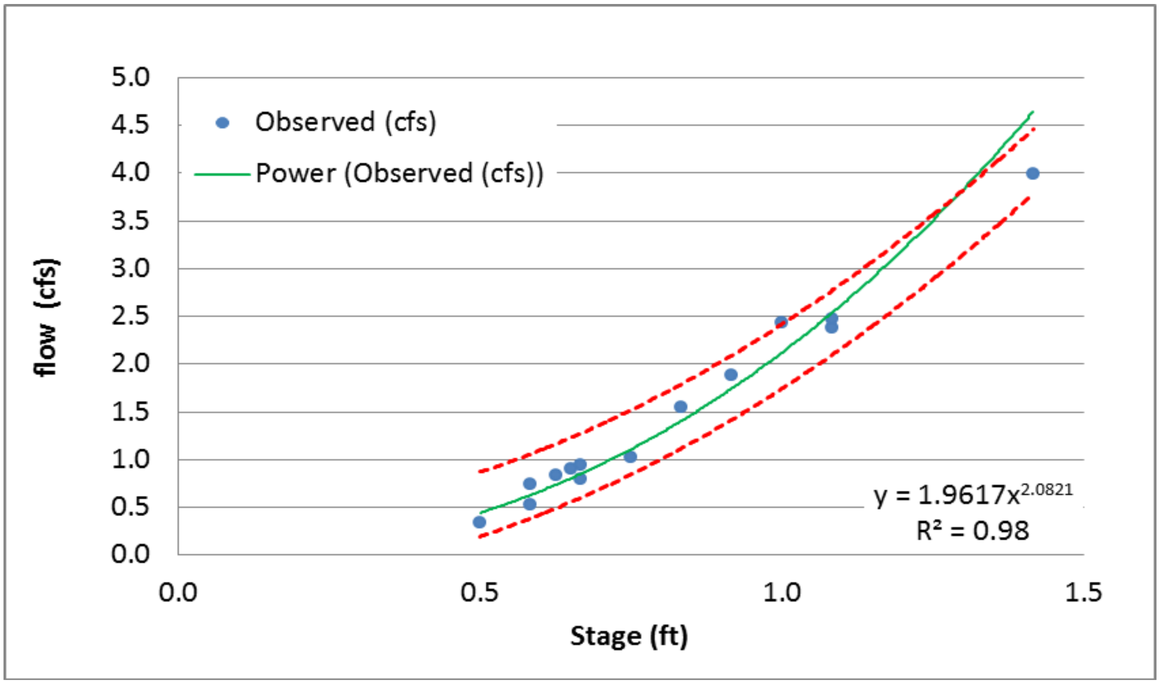
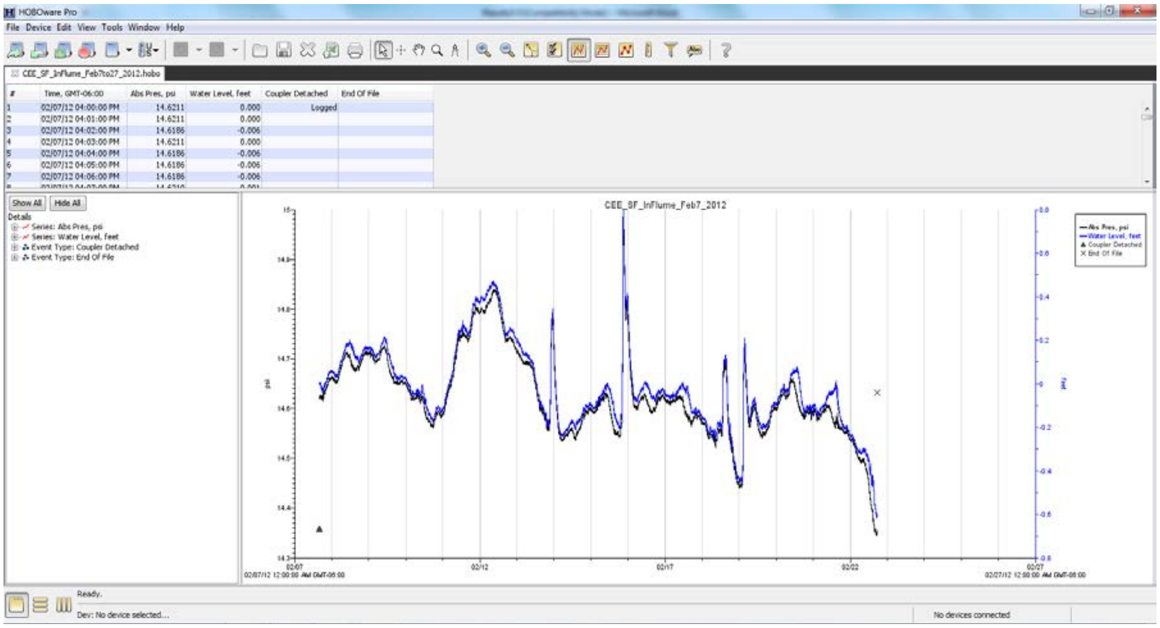


Figure 15 Rating Curve at VS Entrance

Source Roman, Rivas, Salazar

Water Level Measures

One Onset HOBO water level logger was located at the VS entrance and recorded data at 1-minute intervals. Field data (pressure) storage by the logger was converted to water depth (Figure 16) using HOBOware Pro software (Onset, 2010).



#	Time, GMT-06:00	Abs Pres, psi	Water Level, feet	Coupler Detached	End Of File
1	02/07/12 04:00:00 PM	14.6211	0.000	Logged	
2	02/07/12 04:01:00 PM	14.6211	0.000		
3	02/07/12 04:02:00 PM	14.6186	-0.006		
4	02/07/12 04:03:00 PM	14.6211	0.000		
5	02/07/12 04:04:00 PM	14.6186	-0.006		
6	02/07/12 04:05:00 PM	14.6186	-0.006		
7	02/07/12 04:06:00 PM	14.6186	-0.006		

Figure 16 HOBO Software Main Window Screenshot

Deep Hollow

Detailed information about the area size, slope, land cover, and soil types were extracted from Yuan et al. (2001). A summary of physical characteristics of the study area are shown in Table 5. Deep Hollow catchment (Figure 17) has an area of 27.90 acres and three HSG: D accounting for 55.5% of the total area, C a 41.2%, and B a 3.3 %.

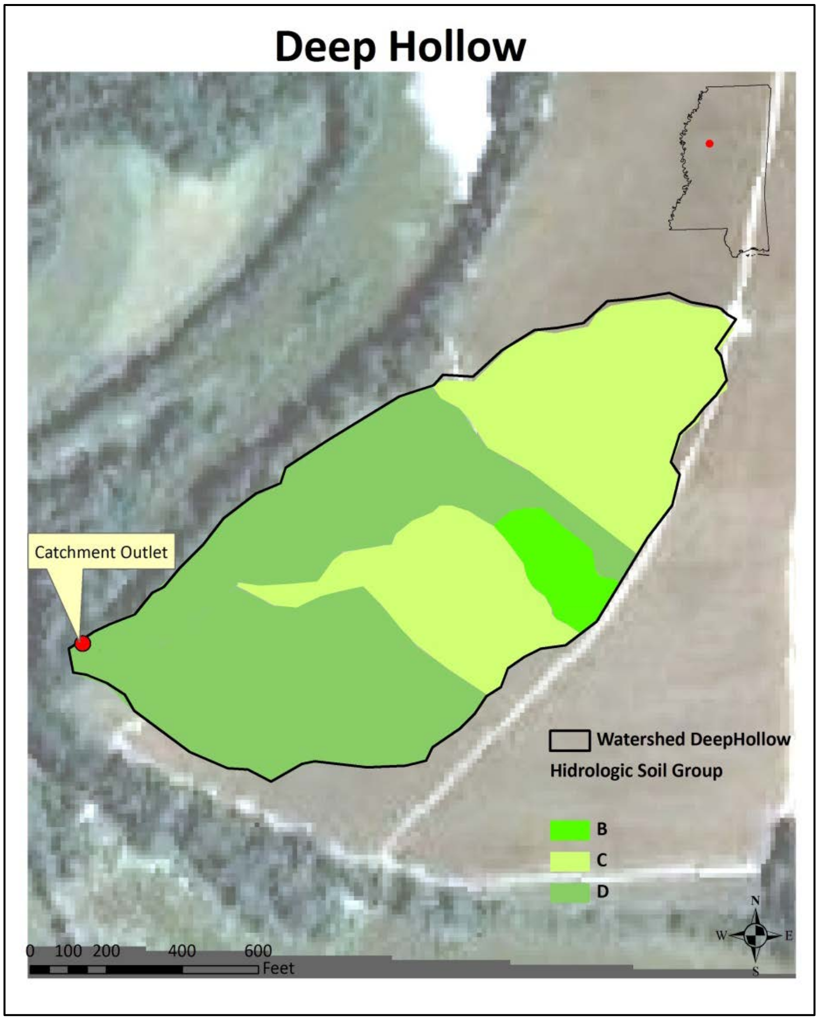


Figure 17 Deep Hollow Catchment Map

Map adapted from Yuan et al. 2001

Analyses of weather data for the study area were used from the NOAA-NCDC Greenwood station that is located 8 mi from Deep Hollow. Weather records and methods for the climate analyses (Figure 18) are the same as those described in section 3.1. The average monthly temperatures, calculated for a 60 year period (1949-2009), varied from 44 to 81°F with a maximum record in July and minimum in January. The mean monthly precipitation is 4.4in, with the maximum from December-January and March-April (>5in) and the minimum in August. Monthly potential evapotranspiration values were higher than rainfall values from June to September (NOAA, 2012). This suggests that crops could be stressed by lack of water availability, and irrigation could be required.

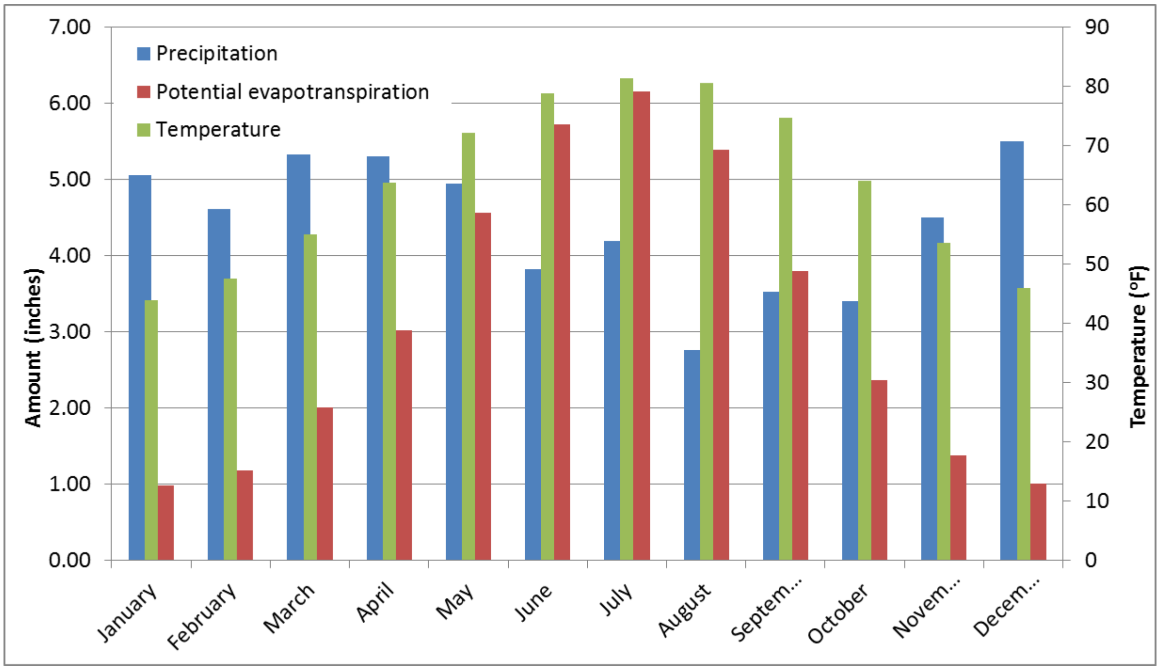


Figure 18 Climate Variables for Areas Surrounding Deep Hollow (1949-2009)

Model Set up[4]

The land cover of Deep Hollow is listed as poorly covered and the drainage area use is uniform consisting of row crops: soybean and cotton, through June to October, winter wheat between December and March and for April, May, October, and November it is uncovered. Soil data information for the study area was extracted from the U.S. Department of Agriculture SSURGO database (USDA, 2010). The soil information description and distribution is depicted in Table 5. The way it was distributed and managed according with every event conditions is shown in the results section.

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[4] All data from Deep hollow was provided by Rebich and Bigner (2001)

Table 5 Hydrologic Soil Group (HSG) and Land Cover for Deep Hollow Catchment

HSG	Area (acres)	Soils type
B	1.31	Dundee loam, 0 to 1% slopes (38%)
C	11.09	Tensas silty clay loam, 1 to 3% slopes (54%)
D	15.5	Dubbs loam, 1 to 3% slopes (5%)
		Alligator clay, 0 to 1% slopes (3%)

The average catchment slope was measured as 0.002957 ft/ft using a 33-ft digital elevation model developed by U.S Geological Survey. The hydraulic length (1,840ft), the distance from the outlet to the most remote point, was measured using the GIS developed for the study area and ArcMap. The 2-year, 24-hour rainfall depth (4.3 in) for Deep Hollow catchment was computed using the NRCS Type II rainfall distribution database in LIDIA.

LIDIA parameters adjusted throughout this study were related to time of concentration (***Tc***) which consists of: Manning's coefficient for overland flow (***n***), and the time of concentration velocity factor (***k***). These parameters were estimated from the literature values to match field conditions (Washington State Department of Ecology, Water Quality Program, 2001). In this study, ***n*** and ***k*** values changed seasonally as a function of the vegetative conditions (higher values between December-January and lower values in April). LIDIA Deep Hollow's application used Curve Number (CN) II conditions and error bands were calculated using CN I and CN III conditions.

Rainfall and runoff time series were measured by USGS at the catchment outlet (USGS station 0728711620), (USGS, 2011). Published rainfall data series (15-minute intervals) were disaggregated to 10-minute intervals required by LIDIA using the time series editor 2.0 tool in WMS 8.3 (Aquaveo LLC., 2012).

Model Evaluation

Simulated runoff values were evaluated against measured runoff time series at each site. Eleven storm events were evaluated in the South Farm model application from July 2011 to February 2012. In the Deep Hollow catchment model evaluation, eleven rainfall-runoff events were used from January 1997 to December 1999. This study used graphical and statistical analyses to evaluate the model performance in each site application. Further details about the graphical and statistical analyses are described below.

Graphical Evaluation

According to Moriasi et al. (2007) the objectives of single-event modeling are the determination of peak flow rate and timing, flow volume, and recession curve shape. Graphical techniques provide an overview of model performance and the assessment of some of these objectives. In this study, the following graphs were developed and analyzed: simulated and observed runoff versus time and scatter plots of observed peaks and volumes against corresponding simulated values.

Statistical Evaluation

Different statistical criteria were used to evaluate the simulated versus the observed runoff data (ASCE, 1993; Moriasi et al. 2007). They are as follows: the deviation of runoff volumes ($\boldsymbol{D_V}$), the percent error in peak (***PEP***), the sum of square of residuals (***RSS***), the total sum of square of residuals (***TRSS***), the total sum of absolute residuals (***TSAR***), the Nash-Sutcliffe coefficient (***NSE***), and the coefficient of determination ($\boldsymbol{R^2}$). Table 6 shows more details about the objective functions used in this research. The criteria $PEP \leq 25\%$, $NSE > 0.4$, and $R^2 > 0.6$ suggested by Bhardwaj et al (2008) for evaluation of single storm event simulations was adopted in this study

Table 6 Statistical Criteria Used to Evaluate the Quality of the Model Results

Description	**Symbol**	**Equation**	**Best fit**
Deviation of runoff volume	DV	$D_v = \frac{V_m - V_s}{V_m} * 100$	0
Percentage error in peak	PEP	$PEP = \frac{Q_m - Q_s}{Q_m} * 100$	0
Square Error	RSS	$RSS = \sum_{i=1}^{n} \left[Q_m(t_i) - Q_s(t_i)\right]^2$	
Total Square Error	TRSS	$TRSS = \sum_{j=1}^{m} \sum_{i=1}^{n} \left[Q_m(t_i) - Q_s(t_i)\right]_j^2$	
Total Absolute Error	TSAR	$TSAR = \sum_{j=1}^{m} \sum_{i=1}^{n} \left[Q_m(t_i) - Q_s(t_i)\right]_j$	
Nash-Sutcliffe coefficient	NSE	$NSE = 1 - \frac{\sum_{i=1}^{n} \left[Q_m - Q_s\right]^2}{\sum_{i=1}^{n} \left[Q_m - \overline{Q}_m\right]^2}$	1
Square of the Pearson Coefficient of correlation	R^2	$R^2 = \frac{\left[\sum_{i=1}^{n} \left(Q_m - \overline{Q_m}\right)\left(Q_S - \overline{Q_s}\right)\right]^2}{\sum_{i=1}^{n} \left[Q_m - \overline{Q}_m\right]^2 \sum_{i=1}^{n} \left[Q_s - \overline{Q}_s\right]^2}$	1

Subscript ***s*** and ***m*** represent the simulated and measured parameter respectively

Results

South Farm

A total of 15 rainfall events from July 2011 to February 2012 were identified as target for this study, these events had rainfall and their corresponding water levels measures. Rain gauge time series showed total rainfall depths from 2 to 12 in. When analyzing the observed rainfall and runoff values, it was found that total rainfall depth values below 2.2 inches did not produce runoff. This reduced the amount of storm events to input in LIDIA to 11. Total rainfall depths analyzed ranged from 2.5 to 18 inches, and storms duration ranged from 70 to 540 min. (Table 7). Missing rainfall data from four storm events (marked with + in Table 7) at the site were replaced with data recorded at the climate station in Hillbun Hall.

It was noticed that the percentage of measured rainfall that was converted to observed runoff went from 3% for a 4.8 inches precipitation to 50% for an 11.4 inches rainfall event.

Table 7 Rainfall Events Used in LIDIA Simulations

Event	**Date**	**Total Rainfall Depth (in)**	**Storm Duration (min)**	**Evaluation time**
1	07/20/2011	12.0	230	4:40pm-8:30pm
2	07/21/2011	5.1	220	8:20 am-12:00pm
3	07/24/2011	5.9	100	2:50 pm-5:20pm
4	07/25/2011	4.8	540	9:30 am-1:10pm
5	08/04/2011	6.4	150	7:20 pm-10:50 pm
6	09/19/2011[+]	18	250	3:40 pm-8:20pm
7	09/27/2011	2.9	80	11:10 am-12:50pm
8	11/16/2011[+]	2.5	70	4:50 am-4:50pm
9	11/22/2011[+]	5.2	220	1:10 pm-3:40 pm
10	11/26-27/2011[+]	11.40	360	10:30 pm-3:30 am
11	2/13/2011	5.75	330	6:00 pm-11:00 pm

Evaluation time is the time of available flow measures

Rainfall data collected in Hillbun Hall station

[+] Data from Geoscience Department Meteorological Station located in Hillbun Hall.

The South Farm analysis included the exercise of modifying the initial abstraction ratio (λ) from 0.2 to 0.05. It was found that λ=0.05 increased both peak and volume values in a range of 1 to 98%, making simulated values closer to observed ones. The differences, in peak and volumes, obtained from the comparison are more significant in cases of smaller storms or using dry antecedent moisture content –AMC I–. Table 8 shows Curve Number (CN) values obtained using initial abstraction ratio values of 0.2 and 0.05.

Table 8 Curve Number Conversion Values in South Farm

HSG	**$CN_{0.2}$**	**$CN_{0.05}$**	**Description**
D	98	97.9	Impervious Area - Paved parking, roof,
C	89	85.5	Street and roads - gravel
D	91	88.4	Street and roads - gravel
C	79	70.9	Pasture, Grassland, Range - Fair Condition
D	84	78.2	Pasture, Grassland, Range - Fair Condition

As explained before, LIDIA discretizes the total area into impervious and pervious areas calculating hydrograph for each one. Then, the SBUH method average the total runoff. Values of the CN and related parameters obtained for South Farm are shown in table 9. It is clear that the storage index (*S*) decrease by increasing AMC which in turn affects the selection of the CN.

Table 9 CN Values and Related Parameters Assigned by LIDIA

Description	**Area (Acres)**	**CN I**	***S***	**I_a**	**CN II**	***S***	**I_a**	**CN III**	***S***	**I_a**
Pervious	20.59	58.8	7.0	0.35	77.3	2.94	0.15	88.7	1.28	0.06
Impervious	0.18	95.4	0.49	0.024	98.00	0.20	0.01	99.1	0.09	0.004

Through several runs were observed that the time of concentration (***T_c***) parameter highly affected model results. The parameters affecting ***T_c*** were modified, trying to match the observed runoff with the simulated one. Initial values were calculated as a weighted average of the values showed in Table 4 which were based on the 2001 Stormwater Management Manual for Western Washington (Washington State Department of Ecology, 2001). The initial values were set to 0.15 for ***n*** and 15 for ***k***. The best results were achieved using 0.10 and 12 as the values for ***n*** and ***k***, respectively.

In general, an average soil moisture condition (AMC II) was the one better describing the system. Exceptions on this trend were the events on 07/25/2011, 09/19/2011, 11/16/2011, and 11/26-27/2011 that were better represented using either AMC I or AMC III. Results found in this study are shown in Table 10.

Table 10 Results Using the Best AMC Condition

	Simulated Volume (Cu ft.)	Observed Volume (Cu ft.)	Simulated Peak (cfs)	Observed Peak (cfs)	Better AMC fit	Observation
7/20/2011	22840.40	18587.84	2.67	2.56	CN II	
7/21/2011	9537.88	11858.74	1.43	2.37	CN III	Rain the day before
7/24/2011	5173.70	7786.99	1.03	2.61	CN II	
7/25/2011	7400.95	5614.19	0.93	0.93	CN III	Rain July 20-21-24
8/4/2011	6331.68	3816.43	1.13	0.92	CN II	
9/19/2011	18817.66	16573.08	4.00	2.26	CN I	Last rainfall event 13 days before
9/27/2011	639.98	659.62	0.38	0.22	CN II	
11/16/2011	3538.070	6005.40	1.34	0.60	CN III	Rain 1 day before
11/22/2011	3602.560	3392.80	1.19	0.81	CN II	
11/26-27/2011	35063.702	43400.84	5.92	5.44	CN III	Slight rain was reported before the event
2/13/2012	4986.98	2604.58	0.92	1.34	CN II	

Water levels were recorded every minute at the entrance of the vegetated swale. Continuous 1-minute runoff time series were computed using a flow rating curve and water levels at the outlet of the catchment. The measured hydrograph was averaged into 10-min time steps for consistent comparison with LIDIA results. Figures 19 and 20 show simulated and observed runoff hydrographs for each of the storm events analyzed in this study. Simulated peak discharges ranged from 0.4 cfs to 5.9 cfs, with percentage simulation error ranging from -251.59% to 74.12% (Table 11). LIDIA over-predicted peak discharge for 5 events and under-predicted for 6. The largest over-predicted discrepancies were computed in events 8/4/2011, 9/19/2011, and 2/13/2012. Differences in under-predicted discharge values were computed in events 7/25/2011, 11/26-27/2011, 7/21/2011 and 11/16/2011 (Table 11 and Figures 19-20). In respect to time to peak discrepancies, it was found that simulated errors were between 10 and 120 minutes. Model results in Figures 19 and 20 indicated that the peak discharge was predicted too late by the model for July and August events and too early for September and November events.

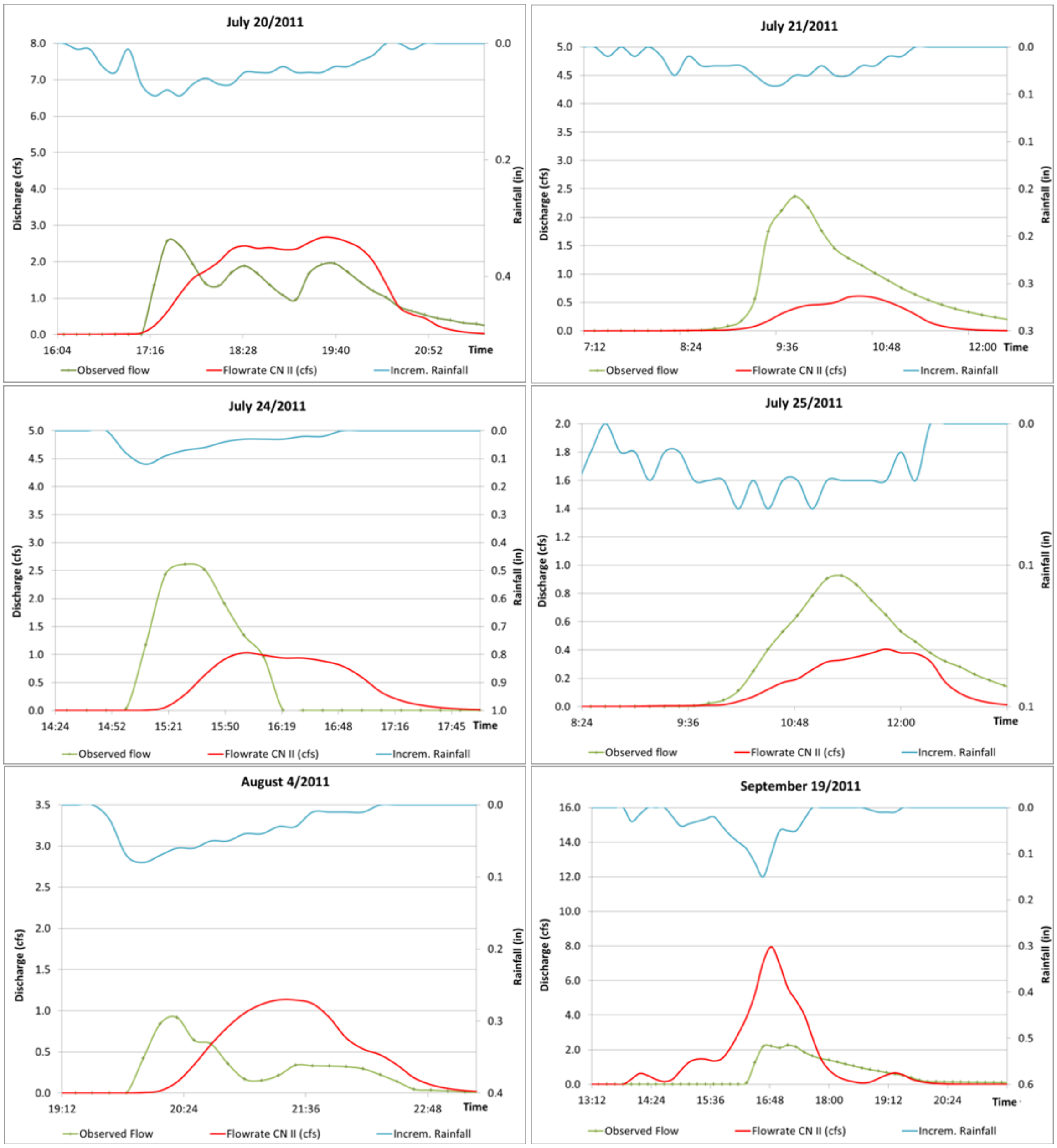

Figure 19 Observed and Predicted Runoff Rate (cfs) for Each Event

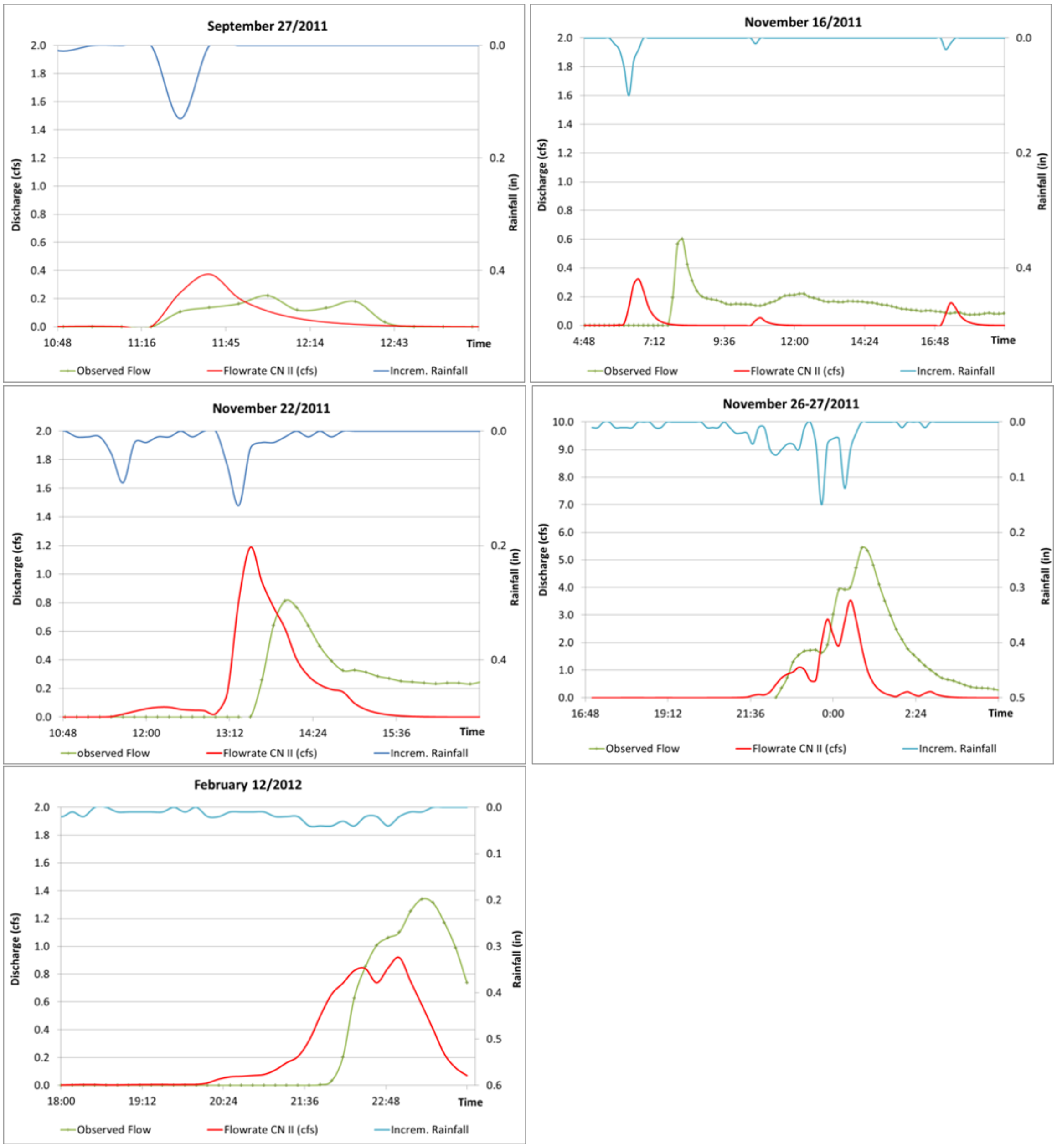

Figure 19 (continued)

RSS values (squared cfs) ranged from 0.13 to 155.00 with a mean value of 22.82. The sum of residuals (cfs) ranged from -34.53 to 14.14 with an average value of -1.12 (table 11). LIDIA over-predicted total discharge volume in 5 events out of 11 events. The percentage error went from -127.81% to 85.65% (Table 11). The largest discrepancy in volume (under-predicted by a 127.81%) was observed in the rainfall event on 9/19/2011. Although the precipitation was measured by the rain gage in site, the one used as input in LIDIA was taken from Hillbun's meteorological station. Comparison between both records allowed us to notice that rainfall data from Hillbun's station was consistently higher than the data recorded on the site.

Table 11 Statistical Analysis Results of Observed and Simulated Values for AMC II

	***D_v* (%)**	***PEP* (%)**	***RSS* cfs^2**	**Sum of residuals (cfs)**
7/20/2011	-22.88	-4.18	17.42	-7.08
7/21/2011	70.78	74.12	17.23	14.14
7/24/2011	33.56	60.60	16.02	4.31
7/25/2011	55.99	56.24	2.04	5.31
8/4/2011	-65.91	-23.04	5.14	-4.20
9/19/2011	-127.85	-251.59	155.00	-34.53
9/27/2011	2.98	-70.45	0.13	0.03
11/16/2011	85.65	46.09	2.55	8.62
11/22/2011	-6.18	-45.95	3.33	-0.22
11/26-27/2011	58.29	34.89	28.33	0.53
2/13/2012	-91.47	31.34	3.87	0.74

+ and – indicate higher and lower compare with observed values respectively

By visual inspection of the simulated and observed storm-runoff hydrographs and the statistical analysis results it is shown that the errors in the predictions of peak runoff and volume were high for the South Farm model evaluation. Only two, 7/20/2011 and 8/4/2011, out of the 11 events reached the PEP less than the 25% criteria established in this study.

The Nash and Sutcliffe coefficient (NSE) and the Pearson coefficient of correlation (R^2) were computed for all the events analyzed using the average condition (AMC II). The NSE and R^2 values for volume were 0.17 and 0.33, respectively. The NSE and R^2 values for peaks were -0.95 and 0.21, respectively. The "goodness-of-fit" values found for volume and peak did not reach the criteria established for this study (NSE > 0.4 and $R^2 > 0.6$).

Taking into consideration that other AMC can represent better a particular event, an analysis was performed with the best AMC (5 out of 11 events were changed) for each rainfall-runoff events. Using this approach, the NSE and R^2 values for runoff volumes increased to 0.93 and 0.94, respectively. The peak values were also improved with NSE value of 0.21 and R^2 of 0.28. Although of the improvement of the statistical criteria, the simulation of peaks did not reach the study target. Figures 21 and 22 show results using the two approaches. In general, LIDIA performance was better at predicting runoff volume than simulating peak runoff. A summary of model results using AMC I and III are shown in Appendices E and F.

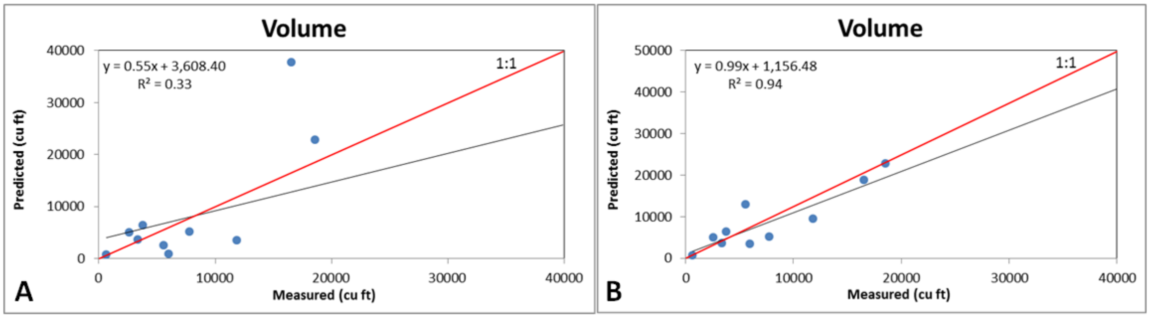

Figure 20 Scatterplot of Observed Versus Simulated Volume for the Entire Data Set (A) CN II and (B) Better fit using a different CN

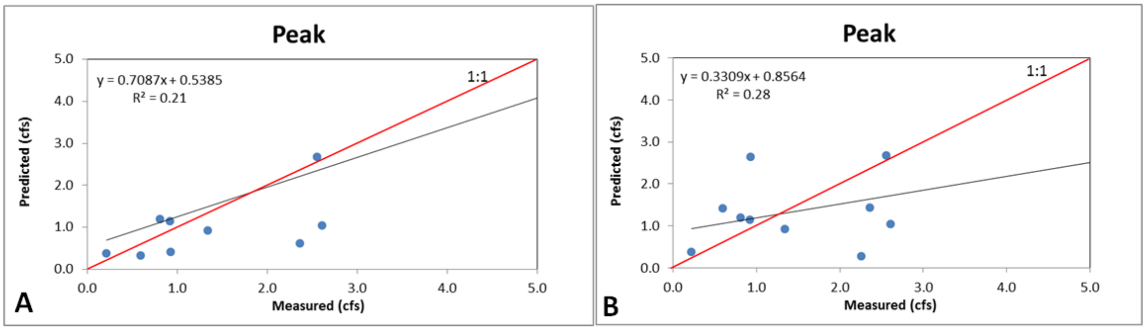

Figure 21 Scatterplot of Observed Versus Simulated Peak for the Entire Data Set (A) CN II and (B) Better fit using a different CN

Deep Hollow

A total of 11 rainfall events from January 1997 to January 1999 (Table 12) were selected for this study, these events had rainfall and their corresponding flow measure on field. Total rainfall depths analyzed ranged from 15 to 94.5 inches. Storm duration ranged from 90 min to 490 min.

Table 12 Rainfall Data Information

Event	Date	Total Rainfall Depth (in)	Storm Duration (min)	Evaluation time
1	01/23/1997	31.2	280	8:50 pm-10:30pm
2	04/05/1997	21.9	150	8:10 am-12:30pm
3	04/27/1997	16.8	210	8:10 am-10:50am
4	06/10/1997	15.0	90	7:20 pm-9:20 pm
5	12/21/1997	15.9	390	7:10 am-11:40am
6	04/28/1998	22.9	210	12:20am-5:20am
7	06/05/1998	15.8	80	12:50pm-2:40pm
8	07/13/1998	20.4	390	3:10am-8:10am
9	12/07/1998	21.4	170	7:20am-11:30am
10	01/22/1999	27.4	480	10:10am-9:50pm
11	01/29/1999	94.5	490	11:30am-2:10pm

Table 13 shows the Curve Number values considered to input in LIDIA Deep Hollow evaluation. In this case study the initial abstraction ratio (λ) was kept in the default value of 0.2. Model results using λ of 0.05 were not better than those using 0.2. The table 13 describes three scenarios that were developed according with field practices. Row crops (soybean/cotton) were established on the field through June to September, winter wheat was established from December to March, and for April, May, October and November the soil was not cultivated and covered by crop residues.

Table 13 CN Parameter Selection for Deep Hollow

HSG	$CN_{0.2}$	Description
D	91	Row crops-poor condition
C	88	
B	81	
D	93	Fallow + crop residue cover
C	90	
B	85	
D	76	Small grain straight row+ crop residue
C	84	
B	88	

The whole area in Deep Hollow was pervious. Significant changes in the storage index and the initial abstraction values were due to the changes in land cover management (i.e. in December the soil could be able to retain more water than in April). Values of the CN and related parameters for the Deep Hollow case study are shown in table 14.

Table 14 CN Values and Related Parameters Assigned by LIDIA

Land Use	CN I	S	Ia	CN II	S	Ia	CN III	S	Ia
Row crops	77.9	2.84	0.57	89.3	1.19	0.24	95.0	0.52	0.10
Fallow + crop residue cover	81.8	2.23	0.45	91.4	0.94	0.19	96.0	0.41	0.08
Small grain	71.8	3.93	0.79	85.8	1.65	0.33	93.3	0.72	0.14

As stated before the time of concentration T_c is a very important factor for the LIDIA program. The parameter values (k and n) affecting T_c were calibrated to improve model results. In the calibration processes, it was found that lower k and n values suggested in literature could improve model results, but it was decided to keep the values in the proposed ranges (Haan et al. 1994, Washington State Department of Ecology 2001).

Table 15 Time of Concentration Parameter Range Used for Deep Hollow

	Initial			Best		
	n	***K***	T_c (min)	***n***	***K***	T_c (min)
1/23/1997	0.15	10	91	0.28	9	124
4/5/1997 **4/27/1997**	0.10	11	75	0.28	6	151
6/10/1997	0.20	10	102	0.28	12	111
12/21/1997				0.28	9	124
4/28/1998	0.10	11	75	0.28	6	151
6/5/1998	0.20	10	102	0.28	12	111
7/13/1998	0.25	10	113			
12/7/1998 **1/22/1999** **1/29/1999**	0.15	10	91	0.28	9	124

Overall the AMC II described very well the runoff conditions of eighth out of eleven events tested in Deep Hollow system, exception were events on 4/5/1997, 6/10/1997, and 4/28/1998. Table 16 shows the best results reached in this application.

Table 16 Results Using the Best Condition

	Simulated Volume (Cu ft)	**Observed Volume (Cu ft)**	**Simulated Peak (cfs)**	**Observed Peak (cfs)**	**Better AMC fit**	**Observation**
1/23/1997	24498.18	23031.00	11.76	-	CN II	
4/5/1997	140701.75	48588.00	9.55	4.90	CN I	Very small rain (0.15in) 1 day before, after 10 days without rain
4/27/1997	30682.99	35820.00	5.77	4.80	CN II	
6/10/1997	27059.17	41953.00	5.39	7.70	CN III	Rain 1 day before (1.7 in)
12/21/1997	25114.54	50046.00	3.30	4.60	CN II	
4/28/1998	89855.94	106662.00	11.33	14.00	CN III	Rain (0.55in) 1 hour prior to the analyzed event.
6/5/1998	43284.31	39192.00	8.68	7.70	CN II	
7/13/1998	78245.23	79272.00	5.70	6.00	CN II	
12/7/1998	68564.41	70832.40	7.19	7.00	CN II	
1/22/1999	140766.33	145338.00	5.28	6.00	CN II	
1/29/1999	171504.37	155727.00	30.96	-	CN II	

The measured hydrograph was discretized into 10-min time steps for consistent comparison. Scatter plots were used to evaluate observed versus simulated flows and acquire an insight of the overall performance of the model evaluating timing, magnitude of peak flows and hydrograph shape. Figures 23 and 24 show simulated and observed runoff hydrographs for each of the storm events used in this area.

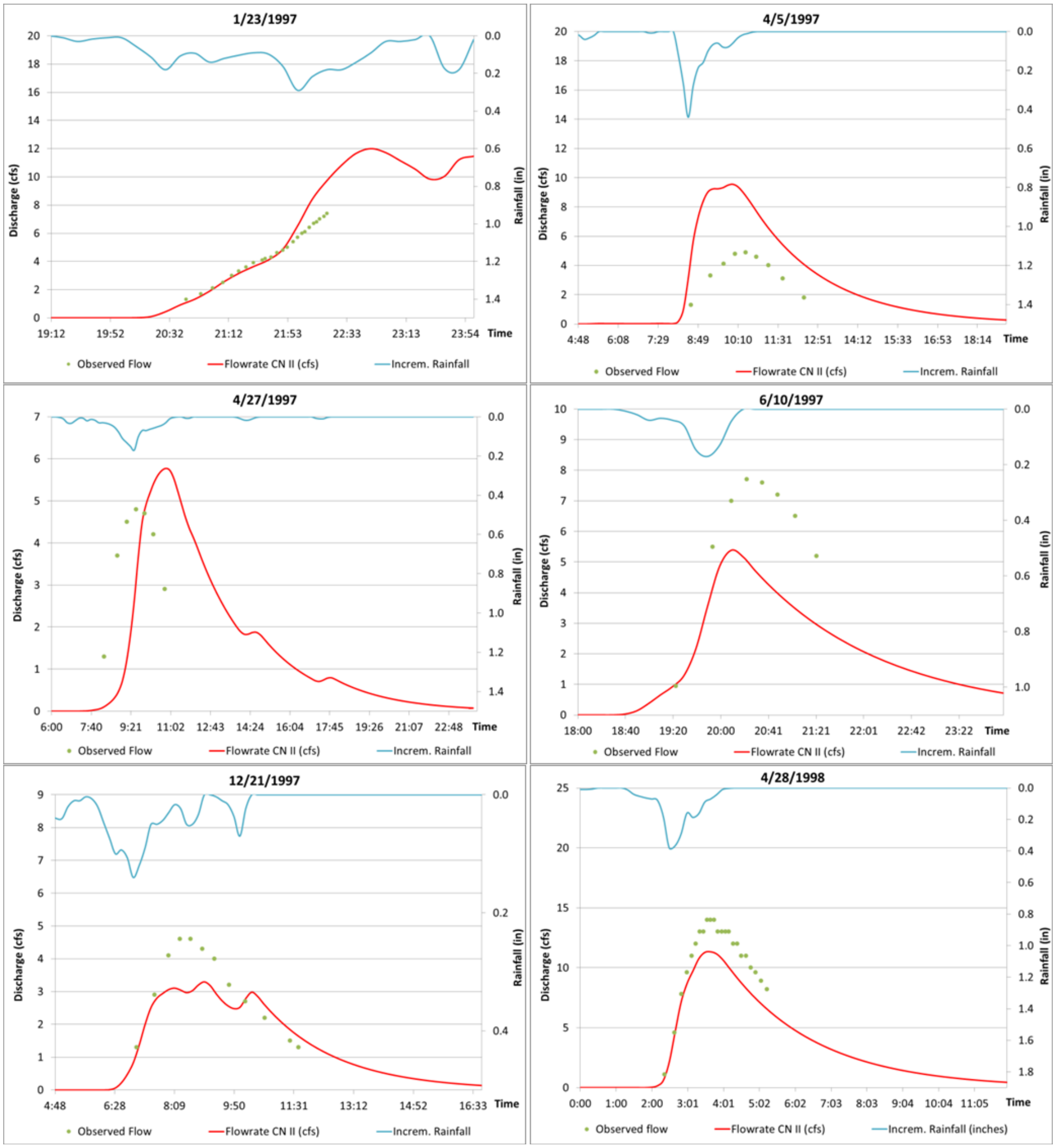

Figure 22 Observed and Predicted Runoff Rate (cfs) For Each Event

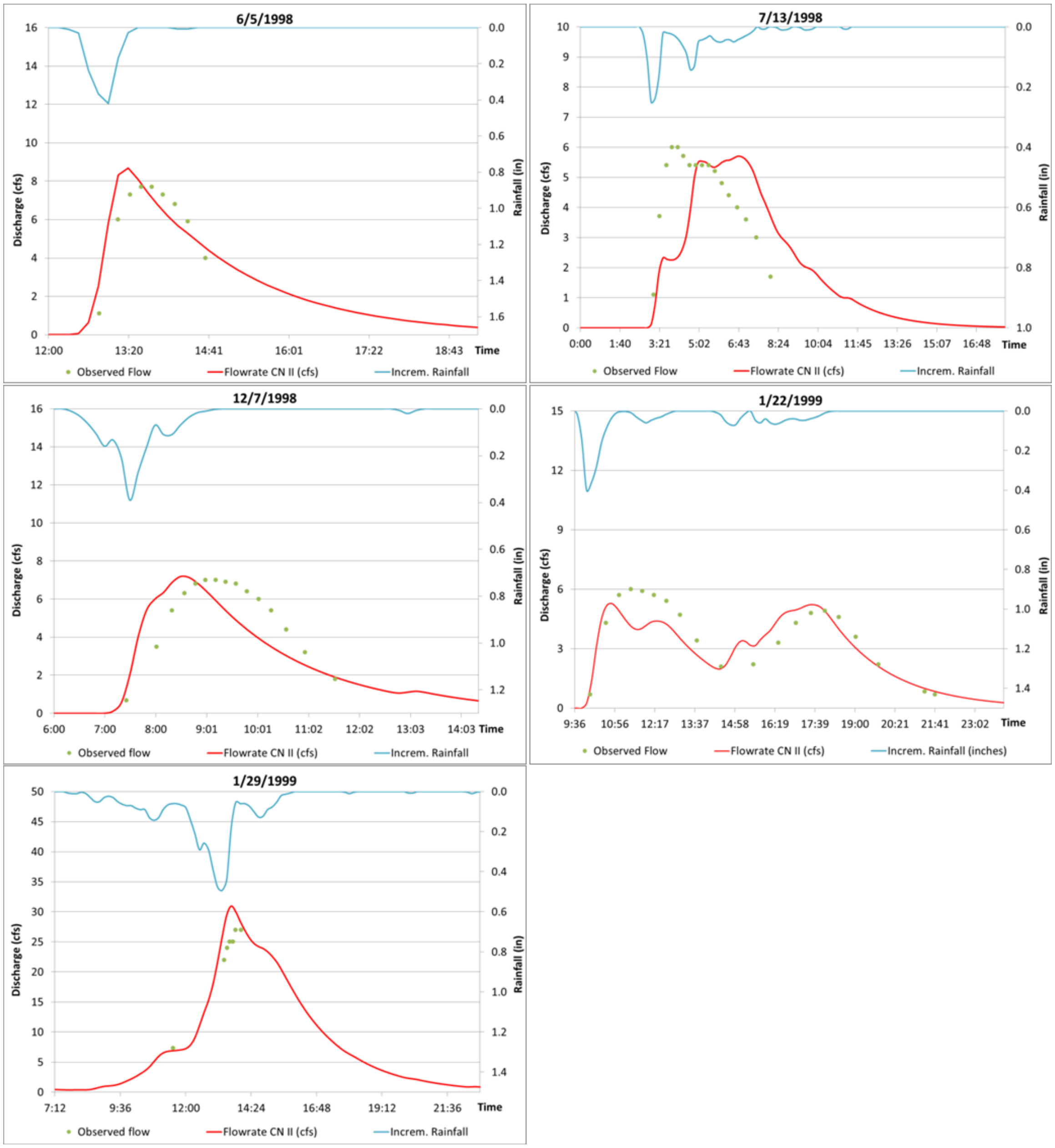

Figure 22 (continued)

Simulated peak discharges ranged from 3.34 cfs to 30.96 cfs, with percentage simulation error ranging from -94.98% to 30% (Table 17). The evaluation of the model performance in peaks was evaluated using the percentage error in peak. From the results shown in Figures 23-24 and Table 17, we can see that the largest discrepancies in peaks were computed in April events (over-predicted by 95% and 20%) and 6/10/1997 (under-predicted by 30%). It was mentioned before that the events on 4/5/1997 and 4/28/1998 had better fit using AMC I and AMC III respectively. When using AMC I on 4/5/1997 the peak results improved PEP from 95% to -13.55%. Similarly, the model peak results on 6/10/1997 improved PEP from 30% (AMC II) to 9% (AMCIII). Over-prediction on peaks agreed with over-prediction on flows in almost all the events, exceptions are found on 4/27/97 and 12/7/97 where peaks are over-predicted while the volume is under-predicted. Calculating NSE and R^2 values, on the peaks, for all analyzed events the values were 0.43 and 0.46, respectively. Taking into account the previous observation of the most inconsistent values and using the best AMC, the NSE and R^2 values for peaks improved to 0.91 and 0.92 respectively (Figure 25).

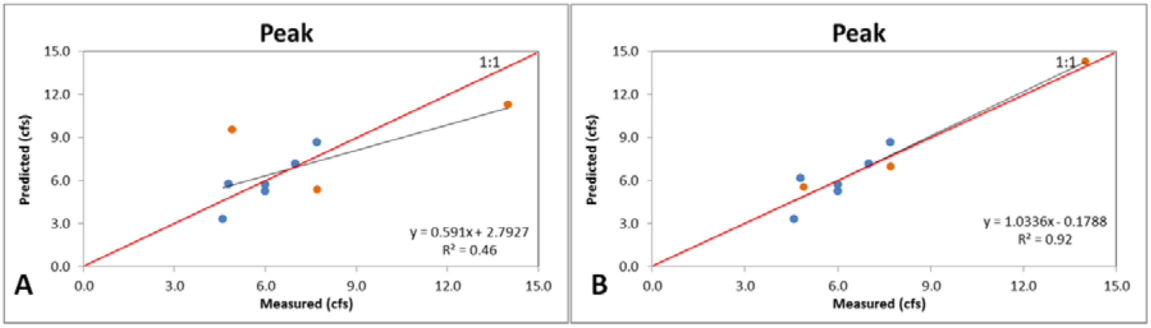

Figure 23 Scatterplot of Observed Versus Simulated Peak for the Entire Data Set CN II (B) Best AMC condition

Table below shows the summary of the statistical criteria used to evaluate the LIDIA model application in Deep Hollow. The evaluation was performed on the results representing the average soil moisture content (AMC II); results for other conditions can be seen in appendix H. Seven out of eleven runoff volumes were under-predicted by LIDIA. The over or under prediction of volume was not consistent throughout each month or season. The biggest discrepancies in volume were observed in the events on 4/5/1997 (over-predicted by 190%) and 12/21/1997 (under-predicted by 50%). Analyzing the worst event we can see that the better fit for 4/5/1997 was CN I (Dv =-20% NSE= 0.37 and R^2=0.75). Five out of nine observed peaks (two observed events missed the peaks) reached the PEP less than 25% criteria established in this study. Six out of 11 events reached NSE and R^2 values greater than the criteria established for the study (NSE > 0.4 and R^2 > 0.6).

Table 17 Statistical Analysis Results of Observed and Simulated Values for AMC II

	Dv (%)	***PEP (%)***	***RSS cfs^2***	**Sum of residuals (cfs)**	***NSE***	***R^2***	**Peak time difference (min)**
1/23/1997	-6.37	-	9.60	-4.20	0.86	0.97	-
4/5/1997	-189.58	-94.98	381.70	-88.30	-14.67	0.43	-26
4/27/1997	14.34	-20.21	66.65	7.80	-4.35	0.17	65
6/10/1997	35.50	30.03	65.03	25.98	-0.13	0.84	-13
12/21/1997	49.82	28.35	19.75	12.73	0.44	0.75	13
4/28/1998	15.76	19.06	43.05	23.22	0.71	0.98	6
6/5/1998	-10.44	-12.76	18.85	-5.24	0.59	0.65	-13
7/13/1998	1.30	4.98	114.73	3.91	-1.46	0.00	152
12/7/1998	3.20	-2.66	60.44	5.29	0.33	0.42	-30
1/22/1999	3.15	11.94	51.73	8.53	0.69	0.69	-39
1/29/1999	-10.13	-	190.56	5.65	0.70	0.93	-

Positive peak time difference means that the simulated hydrograph is delayed

Figure 26 depicts the performance of the model predicting runoff volumes for the entire evaluation period using CN II (figure 26A) and best fit (figure 26B). Figure 26A shows in orange dot the event with the largest discrepancy (4/5/1997). The NSE and R^2 values for all the events analyzed using CN II were 0.5 and 0.66, respectively. After using the best AMC, the NSE and R^2 values improved to 0.92 and 0.94 respectively. In general, the NSE and R^2 values found in this model application reached the criteria established for this study (NSE > 0.4 and $R^2 > 0.6$).

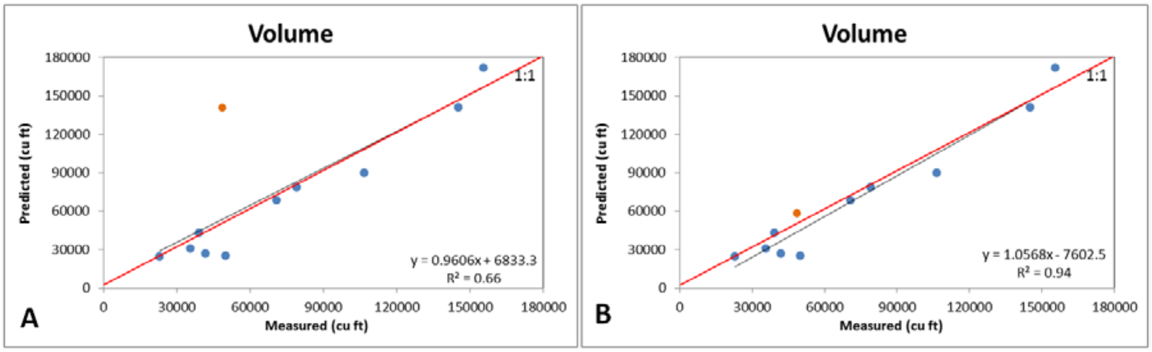

Figure 24 Scatterplot of Observed Versus Simulated Volume for the Entire Data Set (A) CN II (B) Best AMC condition

The residual sum of square (RSS) criterion is commonly used to assess the hydrograph shape (ASCE, 1993). This criterion is very dependent on the synchronization of the ordinates of the simulated hydrograph with the corresponding ordinates of the observed one. In this study, the simulated hydrograph usually was not completely synchronized with the observed one.

An analysis of the factors affecting the RSS criterion was performed. The biggest RSS corresponded to 4 events, 2 of them were due to volume and the others were due to a shifted in the simulated hydrograph. In these cases the simulated hydrograph for each event was moved forward and backward until reach the closest time to peak between the simulated and observed hydrograph. This method improved model results (lower RSS and higher NSE) especially on 4/27/1997 and 7/13/1998 events. The original total RSS (squared cfs units) value for all events was 1022.1. The RSS could be decreased to 611.6

by synchronizing the 4/27/1997 and 7/13/1998 events. However, the biggest impact on RSS was deleting the storm event happened on 4/5/1997 (RSS of 640). The sum of residuals statistic behaves in the same manner that RSS, so the previous analysis applied also to this criterion. In Table 17, the total sum of residuals was -4.6 cfs. In conclusion, the poorest model performance was noticed in events observed on 4/5/1997 and 6/10/1997, these basically due to over or under-estimation of volume. The following events did not show good simulations results: 4/27/1997, 7/13/1998 and 12/7/1998. The lack of good performance on these events was due to the offset in time of the simulated hydrograph.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Model testing is a major component of model development. Currently, environmental model development evolves faster that their required evaluation or verification. The objectives of this work were to enhance and evaluate the Mississippi State University LIDIA model algorithms. LIDIA was enhanced by coding hydraulic routing algorithms using storage-outflow relationships. This research showed comprehensive guidelines on how to setup a model in LIDIA. Rainfall-runoff and flow routing equations used in LIDIA were described in this report. This study presented LIDIA software applications developed for rainfall-runoff processes, especially focus on calculating and analyzing storm runoff volume, peak rate of discharge, and time to peak. Storm runoff volume, peak runoff, and time to peak are key parameters in the design of storage facilities (e.g., ponds, vegetative swales) and important factors in single-event hydrologic modeling evaluation. Results presented in this research convened at two major conclusions: LIDIA model development and LIDIA model evaluation.

LIDIA Model Development Conclusion

The LIDIA model is a lumped single-event model that requires few input parameters. Other advantageous features that make the model easy to understand are: LIDIA application is straightforward, it displays clearly the answers to the key questions (what is the shape and volume of the runoff hydrograph and how much is the peak flow), and it is able to use readily available or collected information. Data can be input manually by selecting databases already coded or by using input files (i.e. GIS input file or rainfall time series).

LIDIA is capable of estimating runoff hydrographs based on pre- and post-developed site conditions using the widely-accepted U.S. Department of Agriculture (USDA) runoff curve number (CN) method and route the resulting hydrograph using the Santa Barbara Urban Hydrograph (SBUH) method. In addition, the current version of LIDIA can route flows through storage facilities (e.g., ponds and vegetative swales). The USDA-CN method fixes the biggest difficulties with the SBUH method that is the estimation of the infiltration losses from pervious areas (Stubchaer, 1975). The SBUH method was selected in LIDIA code because computes separate hydrographs for each area (pervious and impervious), through this process errors associated with averaging these areas, to have a final hydrograph, are avoided. In addition, the resulting runoff hydrograph shape is better approximated to the reality.

After a review of applications of the SBUH method it was found that the method may give acceptable estimates of total runoff volumes, but tends to overestimate peak flow rates from pervious areas (Washington State Department of Ecology, 2001). The reason to SBUH overestimates the peak flow rate for pervious areas is that the actual time of concentration is typically greater than the one obtained with the approximation made. The inclusion of different equations that include more physical variables (n and K) make the spreadsheet more suitable for other conditions and not just the urban (impervious) initial conception.

LIDIA Model Evaluation Conclusion

This research evaluated the LIDIA rainfall-runoff code in two agricultural areas in North Mississippi: Deep Hollow (Leflore County) and South Farm (Oktibbeha County) drainage areas. The results obtained in both study areas are dissimilar, that is why a strong conclusion about the performance of the model could not be done.

Based on LIDIA algorithm assumptions, the model applications in Deep Hollow and South Farm drainage areas were adequate due to small catchment sizes that did not represent great influence of channel transmission losses and the homogeneity of the site's land cover and soils that were well represented by lumped CN numbers.

The most appropriate value of initial abstraction (λ) for Deep Hollow was kept in the default value (0.20). However, for South Farm application a λ of 0.05 was the best approach. The difficulty of selecting λ values arose from the fact that the CN theory was generated with λ=0.20 as the underlying assumption. Modification of the initial abstraction ratio has to comprise modification of the CN value. According to this approach, this study changed the CN values used in South Farm application to the values corresponding to λ =0.05. In this study, the use of λ=0.05 rather than the default λ=0.20 had more impact in cases that involved either lower rainfall depths or lower CNs. According with SCS (1972) the initial abstraction consists of interception and infiltration during early stages of the storm, and surface depression storage. Then, initial abstraction is proportional to water retention. Review of climatologic data and descriptions of soils of both sites evaluated in this research showed great similarity. The largest areas of soil series (tensas silty clay loam in Deep Hollow, and Kipling silty clay loam in South Farm) in both case studies were somewhat poorly drained. The most divergent characteristics were the land cover and management. Deep Hollow was under periodic tillage with presence of crops in 8 out of 12 moths every year. This land cover management improved soil ability to retain moisture. In the other hand, South Farm land cover was on cattle use that can generate compaction of the soil, hence reduction in its capacity to infiltrate water. Base on the previous statement, it can explain why the better abstraction ratio for South Farm was lower than the one for Deep Hollow.

Calibration was focused on the time of concentration (Tc) parameter in Deep Hollow. Results showed that was not possible to match all the peaks and the time to peak just adjusting the Tc parameter. The error in volume in all simulations in Deep Hollow was much smaller compared to the error in peaks; this was not the general case for South Farm evaluation. The Tc parameter was a sensitive parameter in this study. The Tc value affected the value of the routing constant w (Equation 7) which in turn affected the shape and peak of the resulting hydrographs. Therefore, selection of Tc requires correct determination.

Several studies have shown that the largest relative errors on runoff depth and peak flow are found for small events. South Farm case did not show clear relations between event volume or peak flow and error magnitude. Also, no clear relationship about the discrepancies was determined between the runoff and rainfall amount or between the total rainfall depth and peak flows. Largest errors in volume and peak estimation were more related to magnitude of the runoff (the lower the runoff value the larger the model error) in Deep Hollow case study. It was not found an apparent correlation between these factors in South Farm evaluation.

According to Tsihrintzis and Sidan (1997) and Chahinian et al. (2005) both the CN and SBUH methods have been originally developed for predicting response to large storm events and it is common found a poor performance at low-runoff and low-rainfall intensity events. The largest rainfall data used in South Farm was almost the same amount of the lowest precipitation value at Deep hollow. This analysis could explain (at some extend) the disparity in the performance of LIDIA application on both sites.

While the LIDIA model proved very good predictions for Deep Hollow events, the model application in South Farm was just fair. After model calibration, the largest discrepancies in volume magnitudes found in South Farm and Deep Hollow evaluations were 91% and 17%, respectively. Largest peak errors in South Farm and Deep Hollow evaluations were 123% and 54%, respectively. In Deep Hollow case study, rainfall and runoff data were collected by the U.S Geological Survey. In South Farm evaluation, rainfall and runoff time series were collected and processed by Mississippi State University individuals. These differences in data collection methods could explain some of the uncertainties in South Farm model evaluation.

In analyzing individual events in Deep Hollow case study, the Nash and Sutcliffe (NSE) and the coefficient of determination (R^2) values obtained were above the threshold criteria (NSE > 0.4 and R^2 >0.6) for 6 out of 11 storm events. Two events out of the five rejected by the threshold criteria could reach better results by changing the default value of CN II. In analyzing individual events in South Farm evaluation, just one event was above the threshold criteria.

This study incorporated seasonal land cover changes in Deep Hollow evaluation as well as variation of curve numbers. It is believed that this approach enhanced LIDIA model results and that user judgment on selecting NRCS curve number is important to have a better refined model, hence better results.

Overall the development and results of LIDIA tool showed in this study are positive in keeping the enhancement of the model. Even thought of the assumptions of

LIDIA, the model could represent the physical process with some accuracy degree in both case studies. After considering the AMC I and AMC III conditions as error bands, it was found that LIDIA applications in Deep Hollow and South Farm could reach acceptable results.

CHAPTER V

RECOMMENDATIONS

Recommendations to improve the rainfall-runoff model code:

- Insert a Look up table in the site data sheet to help select parameters related to the time of concentration (***n*** and ***K*** parameters).
- The SBUH method calculates runoff from pervious and impervious areas. LIDIA will produce errors if there is no area representing each condition. One solution can be to force the LIDIA code to accept a zero value for any of these areas. Other option could be change the threshold in the "Land Cover" sheet that determine above which CN the area is considered impervious.
- Add more land uses to the land use form, there is none for agricultural land

Recommendations to improve model performance:

- Further research with different λ values to include a larger range that have been proposed in several studies (0-0.3).
- Perform validation of Deep Hollow and South Farm models using different rainfall time series.
- Perform analyses varying model parameters such as land cover conditions, hydraulic length, etc.
- More research is needed to reduce the uncertainties of LIDIA parameters. Code an optimization tool in LIDIA tool could reduce the model uncertainties.

- In keeping South Farm data collection efforts, develop more rigorous quality assessment and quality control strategies. The flow rating curve should keep updated. Also it is important to verify constantly the flow velocity meter on the field to assure the accuracy of the field data. Experience with monitoring equipment in South Farm has suggested improvement and additions. For example, check the equipment in lab conditions to become familiar with its use and understand the way it operates. In addition, check the data obtained in a short period of time following its recording it will help to understand easily the obtained values and provide the ability to correct any anomaly in the sampling.
- Perform more LIDIA evaluations under different scenarios (larger size areas, different land covers, different soil type)
- The definition of antecedent moisture conditions is not quantitative. A technique to define antecedent soil moisture content is required.
- Further research is required to develop threshold criteria for evaluation model performance. More specific criteria indicating the resolution time for applications should be reported. For example, this study used a coefficient of determination greater than 0.6 as threshold criterion recommended by Bhardwaj et al (2008). It was not clear from the source if this criterion is applicable for individual storm events or the average of multiple events.

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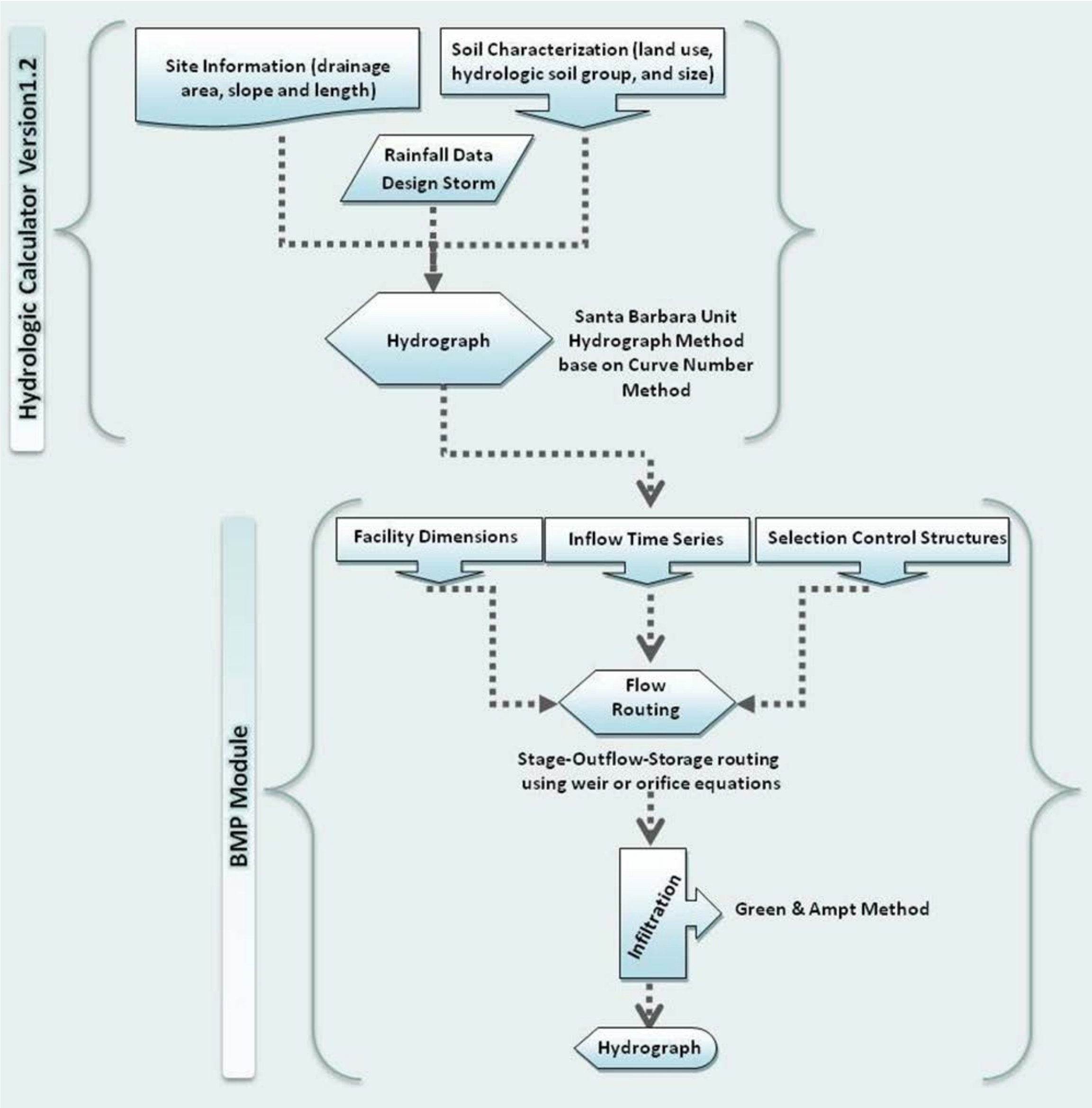
APPENDIX A

FLOW CHART DETAILING LIDIA DEVELOPMENT


Hydrologic Calculator Version1.2
Site Information (drainage area, slope and length)
Soil Characterization (land use, hydrologic soil group, and size)
Rainfall Data Design Storm
Hydrograph
Santa Barbara Unit Hydrograph Method base on Curve Number Method
BMP Module
Facility Dimensions
Inflow Time Series
Selection Control Structures
Flow Routing
Stage-Outflow-Storage routing using weir or orifice equations
Infiltration
Green & Ampt Method
Hydrograph

APPENDIX B

LOOK UP TABLE FOR LIDIA

Cover Type	**Abbreviation**
Fully developed urban areas (vegetation established)	
Open space (lawns, parks, golf courses, cemeteries, etc) [5]	
1. Open Space Poor	**OSP**
2. Open Space Fair	**OSF**
3. Open Space Good	**OSG**
Impervious Areas	
4. Impervious Parking/roofs/driveways	**IP**
Street and Roads:	
5. Impervious Road w/Gutter	**IRG** Paved, curbs and storm sewers (excluding right-of-way)
6. Impervious Road w/Ditch	**IRD** Paved, open ditches (including right-of-way)
Gravel	**RG**
Dirt	**RD**
Urban Districts	
7. Urban District Commercial	**UDC**
8. Urban District Industrial	**UDI**
Residential districts by average lot size	
9. Residential District <1/8 or less	**RD1** (town houses)
10. Residential District <1/4	**RD2**
11. Residential District <1/3	**RD3**
12. Residential District <1/2	**RD4**
13. Residential District <1	**RD5**
14. Residential District <2	**RD6**
Developing urban Areas	
Newly graded areas (pervious area only)	
Agricultural Lands	
Continuous forage for grazing	
15. Pasture Grassland Poor	**PGP** <50% ground cover or heavily grazed no mulch
16. Pasture Grassland Fair	**PGF** 50-75% ground cover and not heavily grazed no mulch
17. Pasture Grassland Good	**PGG** >75% ground cover and lightly grazed

---

[5] CN's are equivalent to these of pasture

Continuous grass, protected from grazing and generally mowed for hay

18. Meadow	**M**

Brush –brush-weed-grass mixture with brush the major element

19. Brush Poor	**BP**
20. Brush Fair	**BF**
21. Brush Good	**BG**

Woods—grass combination (orchard or tree farm)

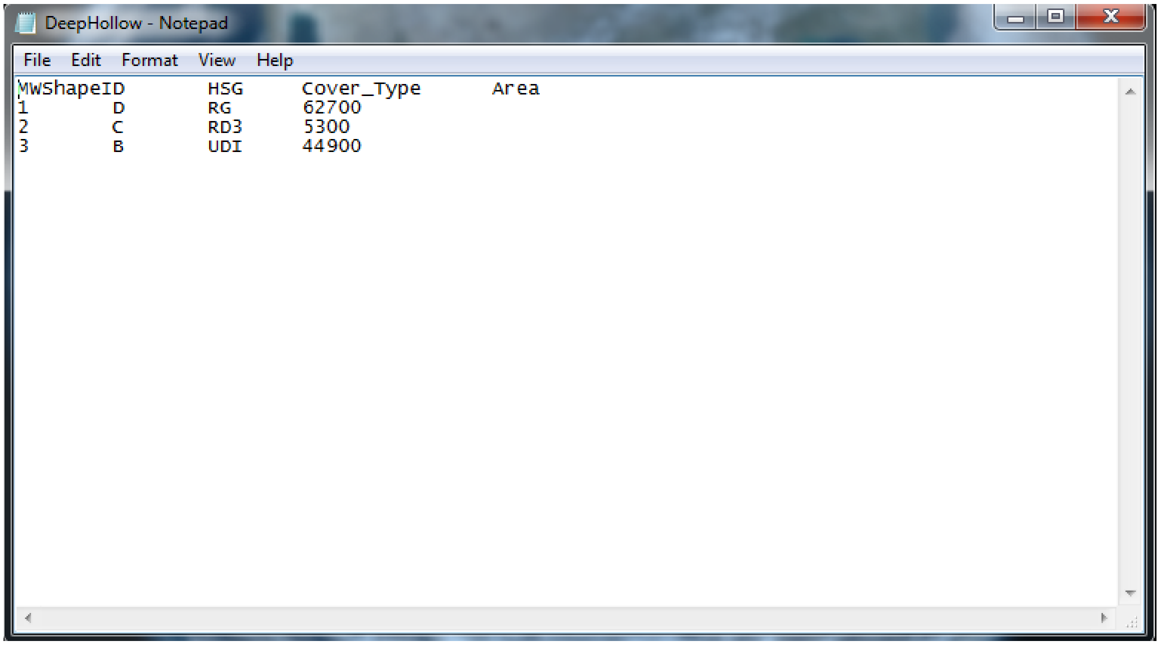
22. Wood-grass combination Poor	**WGP**
23. Wood-grass combination Fair	**WGF**
24. Wood-grass combination Good	**WGG**

Woods

25. Woods Poor	**WP**	Forest litter, small trees, brush destroyed by grazing or regular burning
26. Woods Fair	**WF**	grazed but not burned, some forest litter covers the soil
27. Woods Good	**WG**	protected from grazing, litter and brush adequately cover the soil

APPENDIX C

LIDIA .DBF FILE FORMAT



```
MWShapeID       HSG     Cover_Type      Area
1       D       RG      62700
2       C       RD3     5300
3       B       UDI     44900
```

APPENDIX D

SOUTH FARM INSTRUMENTATION

Flow Velocity meter

Acoustic Doppler Velocimeter (ADV): An instrument that measures stream velocity by sensing the phase change caused by the Doppler shift in acoustic frequency that occurs when a transmitted acoustic signal reflects off particles in the flow.

Rain Gage

Series 525 Rainfall Sensors, this sensor consists of a gold anodized aluminum collector funnel with a knife-edge that diverts the water to a tipping bucket mechanism.

Specifications

Resolution: 0.01” or 0.1 mm
Accuracy:
English
Metric
1.0% at 1”/hr or less
1.0% at 10 mm/hr or less
Average Switch Closure Time: 135 ms
Maximum Bounce Settling Time: 0.75 ms
Maximum Switch Rating: 30 VDC @ 2 A, 115 VAC @ 1 A
Temperature Limits: +32°F to +125°F
Humidity Limits: 0 to 100%
Height: 10.125”
Weight: 2.5 pounds

Water level meters


[6]

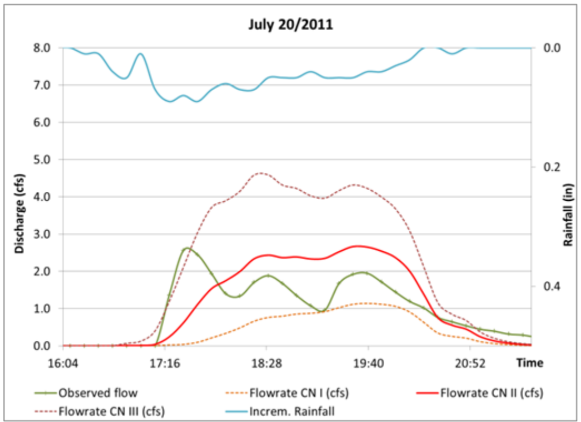
Specifications
Range: 0-30’; 0-30 psia
Resolution: ± 0.007’
Accuracy: ± 0.015’

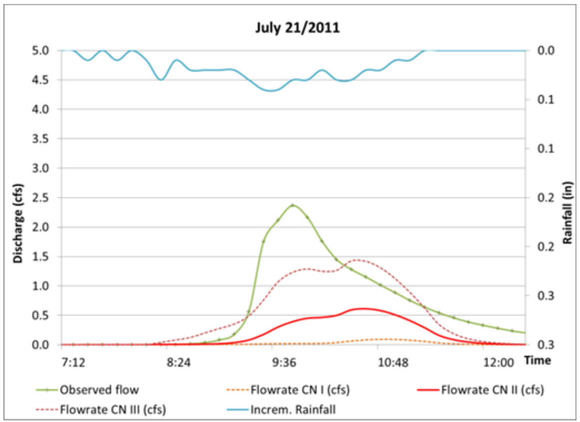
---

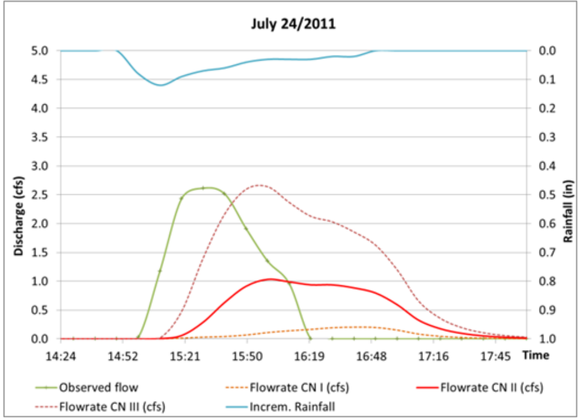
[6] Water level set up in the field

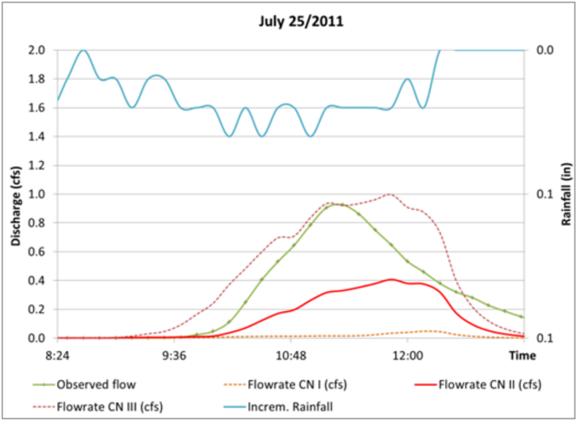
APPENDIX E

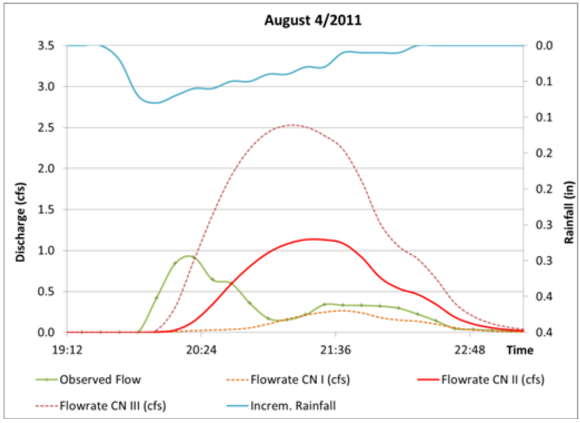
OBSERVED AND PREDICTED RUNOFF RATE (CFS) FOR ALL AMC CONDITIONS (SOUTH FARM)

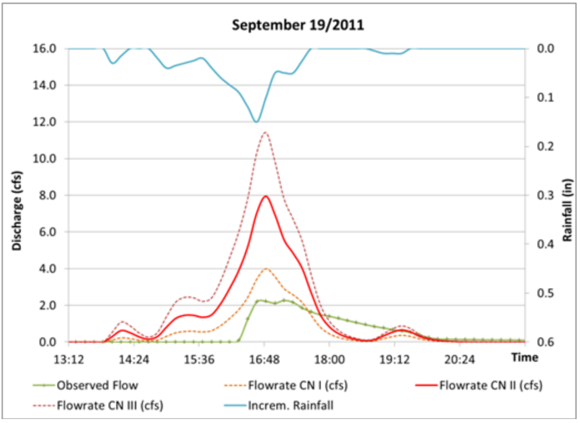

July 20/2011

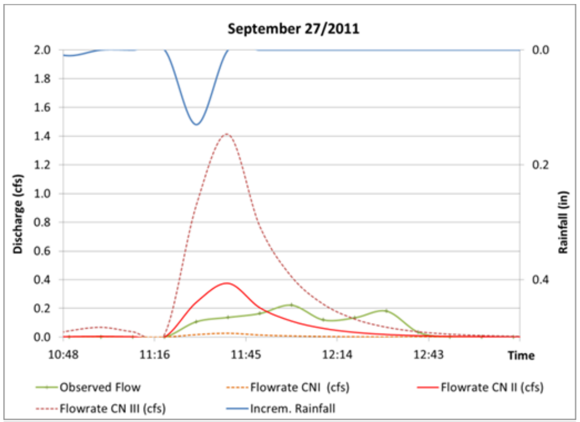

July 21/2011

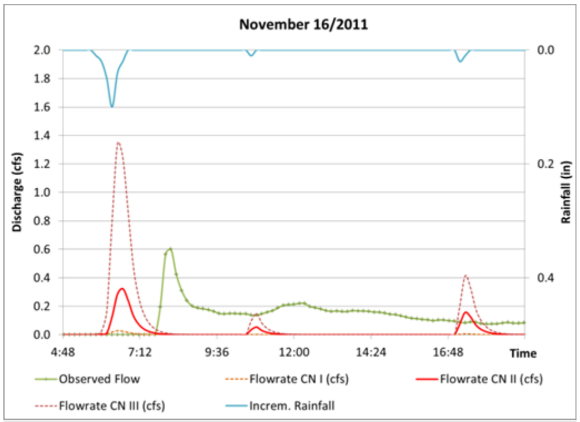

July 24/2011

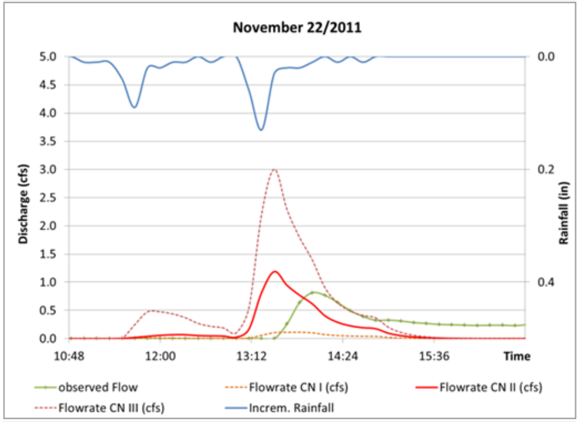

July 25/2011

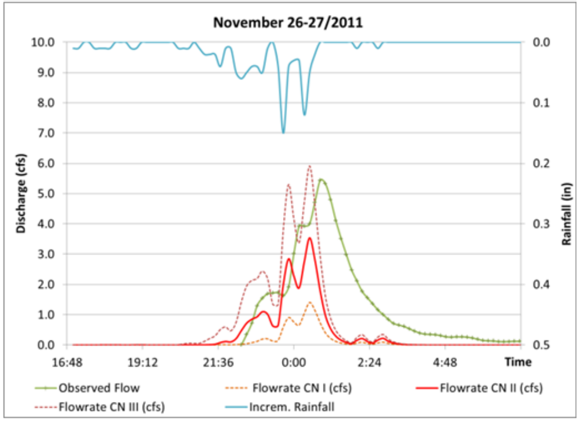

August 4/2011

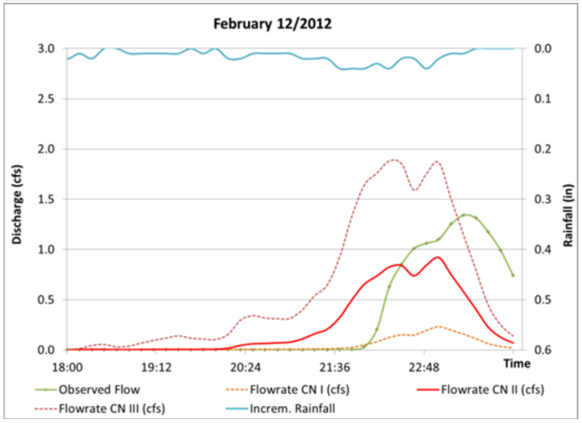

September 19/2011


September 27/2011
Discharge (cfs)
Rainfall (in)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
10:48
11:16
11:45
12:14
12:43
Time
Observed Flow
Flowrate CNI (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall


November 16/2011
Discharge (cfs)
Rainfall (in)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
4:48
7:12
9:36
12:00
14:24
16:48
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall


November 22/2011
Discharge (cfs)
Rainfall (in)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
10:48
12:00
13:12
14:24
15:36
Time
observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall


November 26-27/2011
Discharge (cfs)
Rainfall (in)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
0.1
0.2
0.3
0.4
0.5
16:48
19:12
21:36
0:00
2:24
4:48
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall


February 12/2012
Discharge (cfs)
Rainfall (in)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
18:00
19:12
20:24
21:36
22:48
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall

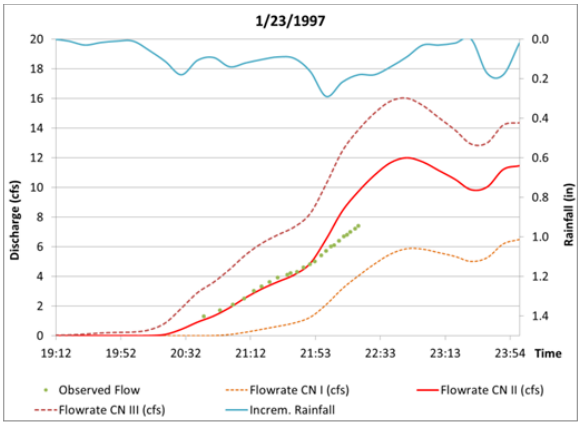
APPENDIX F

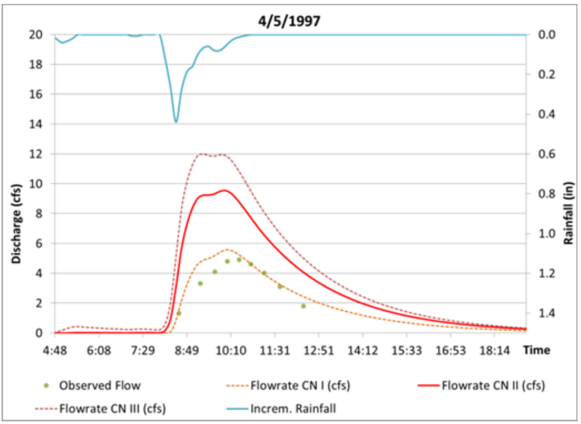
STATISTICAL ANALYSIS RESULTS OF OBSERVED AND SIMULATED VALUES FOR AMC I AND III (SOUTH FARM)

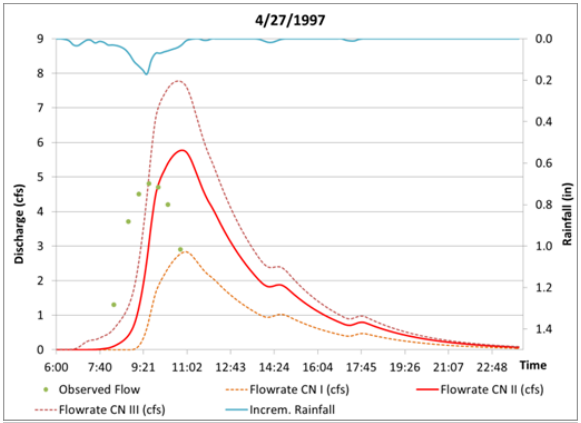
	***Dv* %**		***PEP* %**		***RSS***		**Sum of residuals**	
	CN I	**CN III**	**CN I**	**CN III**	**CN I**	**CN III**	**CN I**	**CN III**
7/20/2011	57	-128	55	-79.30	24.48	99.07	17.91	-39.82
7/21/2011	96	20	96	39.75	28.40	5.06	19.20	4.01
7/24/2011	89	-66	92	-0.99	25.17	16.94	11.49	-8.72
7/25/2011	96	-32	92	-7.10	5.50	0.92	9.05	-2.91
8/4/2011	68	-298	71	-174.35	2.47	32.82	4.32	-18.96
9/19/2011	-14	-230	-77	-405.04	21.51	404.38	-3.38	-62.34
9/27/2011	93	-272	88	-541.82	0.15	2.72	1.02	-2.97
11/16/2011	99	41	95	-123.13	2.32	7.27	9.93	4.16
11/22/2011	86	-156	86	-268.92	2.44	20.21	4.97	-8.67
11/26-27/2011	87	19	74	-8.88	22.79	107.98	20.50	-25.12
2/13/2012	57	-128	83	-40.30	8.19	14.01	8.32	-12.80

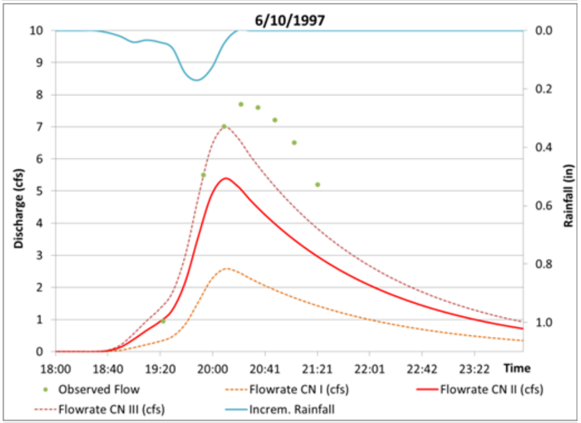
APPENDIX G

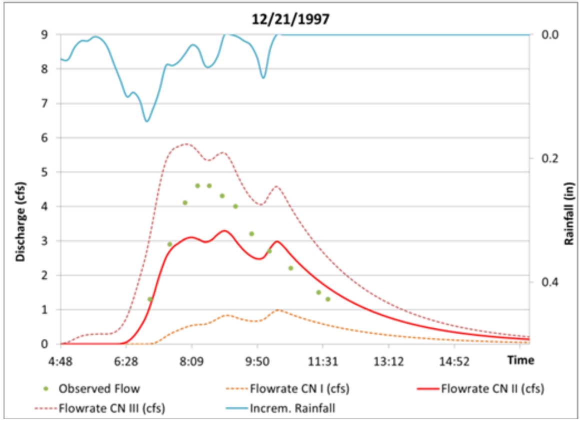
OBSERVED AND PREDICTED RUNOFF RATE (CFS) FOR ALL AMC CONDITIONS (DEEP HOLLOW)

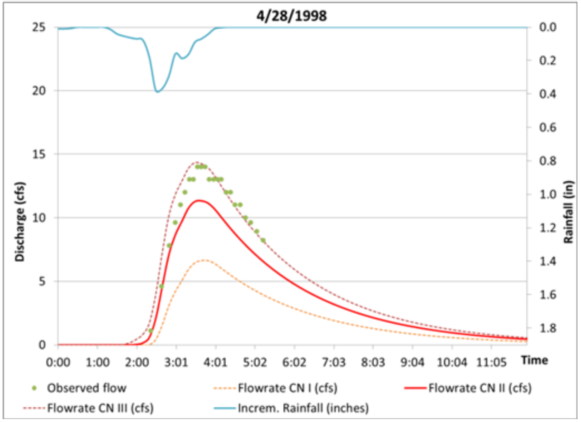

1/23/1997
Discharge (cfs)
Rainfall (in)
20
18
16
14
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
19:12
19:52
20:32
21:12
21:53
22:33
23:13
23:54
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall

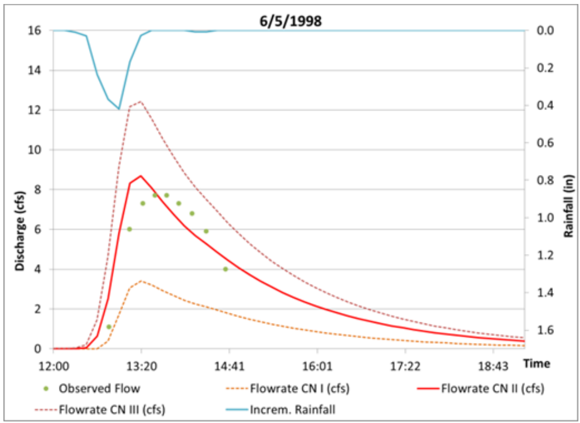

4/5/1997
Discharge (cfs)
Rainfall (in)
20
18
16
14
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
4:48
6:08
7:29
8:49
10:10
11:31
12:51
14:12
15:33
16:53
18:14
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall

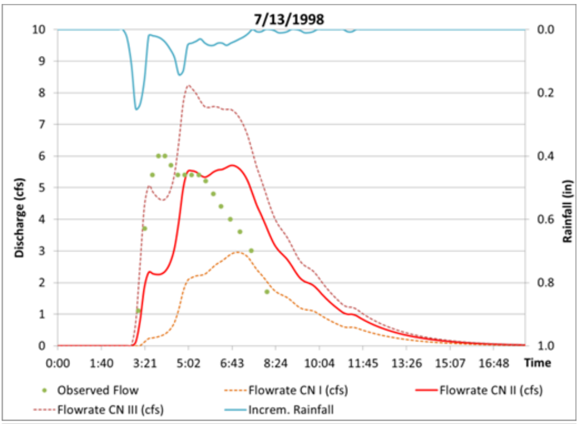

4/27/1997
Discharge (cfs)
Rainfall (in)
9
8
7
6
5
4
3
2
1
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
6:00
7:40
9:21
11:02
12:43
14:24
16:04
17:45
19:26
21:07
22:48
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall

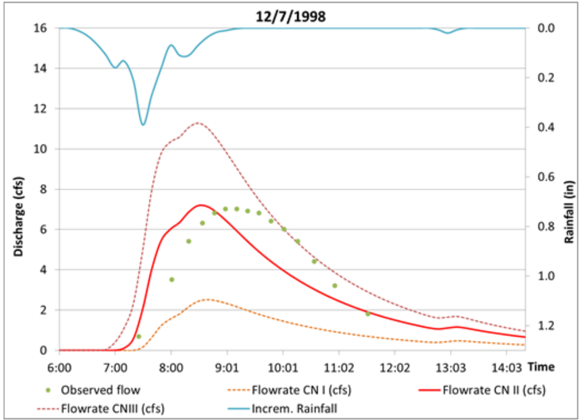

6/10/1997
Discharge (cfs)
Rainfall (in)
10
9
8
7
6
5
4
3
2
1
0
0.0
0.2
0.4
0.6
0.8
1.0
18:00
18:40
19:20
20:00
20:41
21:21
22:01
22:42
23:22
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall

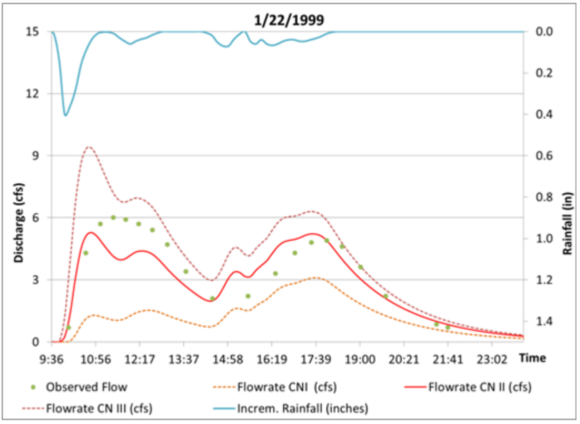

12/21/1997
Discharge (cfs)
Rainfall (in)
9
8
7
6
5
4
3
2
1
0
0.0
0.2
0.4
4:48
6:28
8:09
9:50
11:31
13:12
14:52
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall

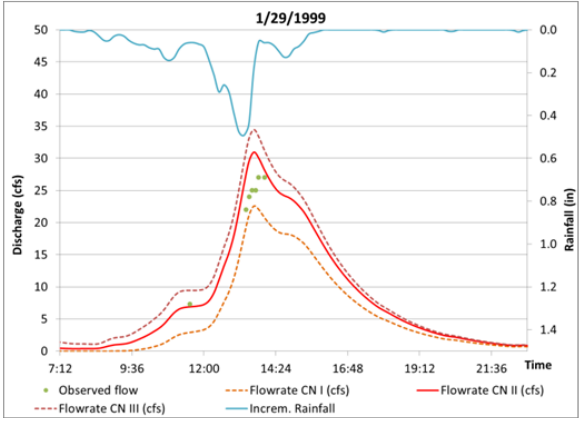

4/28/1998
Discharge (cfs)
Rainfall (in)
25
20
15
10
5
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0:00
1:00
2:00
3:01
4:01
5:02
6:02
7:03
8:03
9:04
10:04
11:05
Time
Observed flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall (inches)


6/5/1998
Discharge (cfs)
Rainfall (in)
16
14
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
12:00
13:20
14:41
16:01
17:22
18:43
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall


7/13/1998
Discharge (cfs)
Rainfall (in)
10
9
8
7
6
5
4
3
2
1
0
0.0
0.2
0.4
0.6
0.8
1.0
0:00
1:40
3:21
5:02
6:43
8:24
10:04
11:45
13:26
15:07
16:48
Time
Observed Flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall


12/7/1998
Discharge (cfs)
Rainfall (in)
16
14
12
10
8
6
4
2
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
6:00
7:00
8:00
9:01
10:01
11:02
12:02
13:03
14:03
Time
Observed flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CNIII (cfs)
Increm. Rainfall


1/22/1999
Discharge (cfs)
Rainfall (in)
15
12
9
6
3
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
9:36
10:56
12:17
13:37
14:58
16:19
17:39
19:00
20:21
21:41
23:02
Time
Observed Flow
Flowrate CNI (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall (inches)


1/29/1999
Discharge (cfs)
Rainfall (in)
50
45
40
35
30
25
20
15
10
5
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time
Observed flow
Flowrate CN I (cfs)
Flowrate CN II (cfs)
Flowrate CN III (cfs)
Increm. Rainfall

APPENDIX H

STATISTICAL ANALYSIS RESULTS OF OBSERVED AND SIMULATED VALUES FOR AMC I AND III (DEEP HOLLOW)

	Dv %		*PEP %*		*RSS*		**Sum of residuals**	
	CN I	**CN III**	**CN I**	**CN III**	**CN I**	**CN III**	**CN I**	**CN III**
1/23/1997	72.58	-86.53	-	-	90.35	154.33	29.23	-36.70
4/5/1997	-20.40	-273.88	-13.55	-144.80	15.25	869.05	-14.10	-133.75
4/27/1997	66.75	-30.64	40.83	-61.88	126.58	114.36	40.35	-19.20
6/10/1997	70.09	15.46	66.57	9.29	225.66	20.93	50.73	11.68
12/21/1997	78.75	-51.31	78.68	-26.40	189.15	76.68	66.89	-38.91
4/28/1998	53.11	-10.07	52.64	-2.36	454.07	37.72	86.40	-18.58
6/5/1998	58.69	-61.25	55.83	-61.45	159.04	157.61	40.93	-38.95
7/13/1998	58.72	-45.81	50.79	-36.97	310.39	190.45	78.94	-57.54
12/7/1998	68.10	-55.30	64.03	-61.13	310.46	307.97	81.05	-62.42
1/22/1999	56.34	-38.09	48.27	-56.01	398.99	218.09	137.11	-90.80
1/29/1999	28.63	-29.36	-	-	689.48	349.43	93.27	-38.41