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16. Abstract

The present study has been conducted to evaluate eight flood prediction models for an ungauged small watershed. These models are either frequently used by or were developed by Louisiana Department of Transportation and Development (LADOTD). The eight models were applied to calculate flood frequency for the watershed on Ward Creek at Government Street in Baton Rouge. By comparing the results of the models with the flood peaks derived using the systematic flood records observed at the Ward Creek gauge station and by following the U.S. Water Resources Council (WRC) procedure, it was found that four of the eight models have better accuracy than the others. These four models are the U.S. Geological Survey (USGS) seven-parameter model, the USGS three-parameter model, the Lowe model and the Neely model. The U.S. Soil Conservation Service (SCS) model is widely used for flood prediction for small urban watersheds, but the accuracy of the model for the Ward Creek watershed is relatively low. This study shows that the accuracy of the SCS model can be significantly improved with the parameters calibrated using short-term field data. A procedure of parameter calibration using one- to two-year field data was developed in this study. The procedure may be used for more accurate flood prediction for watersheds with short-term stream gauging data or watersheds with long-term stream gauging data that have undergone significant hydrological changes.

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ESTIMATION OF FREQUENCY BASED FLOOD PEAKS FOR AN UNGAUGED WATERSHED USING FIELD CALIBRATION

FINAL REPORT

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ABSTRACT

The present study has been conducted to evaluate eight flood prediction models for an ungauged small watershed. These models are either frequently used by or were developed by Louisiana Department of Transportation and Development (LADOTD). The eight models were applied to calculate flood frequency for the watershed on Ward Creek at Government Street in Baton Rouge. By comparing the results of the models with the flood peaks derived using the systematic flood records observed at the Ward Creek gauge station using the U.S. Water Resources Council (WRC) procedure, it was found that four of the eight models have better accuracy than the others. These four models are the U.S. Geological Survey (USGS) seven-parameter model, the USGS three-parameter model, the Lowe model and the Neely model. The U.S. Soil Conservation Service (SCS) model is widely used for flood prediction for small urban watersheds, but the accuracy of the model for the Ward Creek watershed is relatively low. This study shows that the accuracy of the SCS model can be significantly improved with the parameters calibrated using short-term field data. A procedure of parameter calibration using one- to two-year field data was developed in this study. The procedure may be used for more accurate flood prediction for watersheds with short-term stream gauging data or watersheds with long-term stream gauging data that have undergone significant hydrological changes.

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IMPLEMENTATION STATEMENT

The results of this study may assist LADOTD design engineers in selecting a flood prediction model for highway drainage design. The procedure of flood prediction developed in this study for ungauged watersheds with parameters calibrated using short-term field data demonstrated more accuracy and reliability than other methods that did not calibrate parameters. The improvement of the accuracy of flood frequency prediction is especially significant for models developed without using local field data, such as the SCS model.

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CHAPTER 1
INTRODUCTION

Accurate estimations of flood peak, frequency, and volume are needed for safe and economical design of highway drainage and flood control structures. For watersheds with systematic stream gauging records of sufficient length, flood frequency analysis can be conducted by following the U.S. Water Resources Council (WRC) procedure *[1]*. The WRC procedure uses log-Pearson Type III distribution as a base method for flood frequency studies.

Accurate flood frequency analysis is more difficult for ungauged watersheds or watersheds with significant changes in land use or in drainage systems. Hydraulics design engineers often need to resort to information transfer techniques or regionalization procedures to estimate flood peaks and hydrographs. The information transfer techniques may consist of: (1) regional regression equations correlating peak discharge to climatic and watershed parameters *[2], [3], [4], [5]*, (2) rainfall-runoff models calibrated by watershed characteristics *[6]*, (3) regionalization models using data from nearby watersheds that exhibit similar climatic and hydrogeologic conditions *[7], [8]*, and (4) the transfer of a flood frequency curve from nearby gauging stations. Each flood prediction model has its own assumptions and calibration conditions upon which the model was developed. Hence, estimated discharges from a watershed by different models may vary substantially. In many cases, designs may be over- or underestimated by 50 percent or more.

The accuracy of model prediction is heavily dependent on the accuracy of model parameter estimation. For an ungauged watershed, model parameter estimation is a rather difficult but necessary task in flood frequency analysis. Although tables and nomographs for parameter estimation are often provided by each model, determination of model parameters from these tables or nomographs is subject to large errors. Therefore, model calibration using short-term field data may be a better approach. If an accurate estimation of flood frequency is technically necessary and economically justified for a proposed project, one-year or longer rainfall-runoff data may be observed to calibrate model parameters. This is especially true for the south central region of the United States where less variation of annual rainfall is experienced.

This report presents: (1) calculation of flood frequency for the Ward Creek watershed using eight flood prediction models, (2) establishment of the rating curve (stage-discharge relation) for the Ward Creek watershed, (3) evaluation of these flood prediction models, and (4) a procedure to apply a flood prediction model with parameters calibrated by using short-term field data. The eight selected models are (1) the Neely model *[2]*, (2) the Lowe model *[3]*, (3) the USGS seven-parameter model *[4]*, (4) the USGS three-parameter model *[4]*, (5) the Lee model *[5]*, (6) the U.S. Soil Conservation Service (SCS) model *[6]*, (7) the Louisiana Regional GEV-PWM model *[7]*, and (8) the Louisiana GEV-OPT model *[8]*.

A rural watershed on Beaver Bayou above Hooper Road in Baton Rouge was also selected at the beginning of the study. During the study, it was discovered that Beaver Bayou overbanks almost every year, so a proper rating curve cannot be established. The results for the Beaver Bayou watershed are not included in this report.

CHAPTER 2
OBJECTIVES

The objectives of this study are:

(1) To compute flood magnitudes at the return periods of 2, 5, 10, 25, 50, and 100 years for an ungauged watershed using eight watershed models. The eight models are:

(a) the Neely model *[2]*
(b) the Lowe model *[3]*
(c) the USGS seven-parameter model *[4]*
(d) the USGS three-parameter model *[4]*
(e) the Lee model *[5]*
(f) the SCS model *[6]*
(g) the Regional GEV-PWM model *[7]* and
(h) the Regional GEV-OPT model *[8]* ;

(2) To evaluate the eight models by comparing the model results with those derived from the WRC procedures *[1]* using long-term stream gauging data. The advantages and disadvantages of each model will be discussed; and

(3) To develop a field-calibration procedure for flood prediction when more accurate estimation of flood peaks are economically justified. This requires the designer(s) to set up a network of rain gauges and a flowmeter to collect rainfall-runoff data for one year or more. The model parameters are calibrated using short-term rainfall-runoff data to improve the accuracy of the model.

CHAPTER 3
SCOPE

The scope of this project encompasses selection of eight frequently used flood prediction models, selection of a small watershed, installation of three rain gauges and a flowmeter on the watershed, computation of flood magnitudes and frequencies for the watershed using the eight models, evaluation of the eight models by comparing the model results with the flood peaks derived using the WRC procedure, and development of a procedure to improve flood prediction accuracy by calibrating model parameters using short-term field data.

CHAPTER 4
DATA COLLECTION

Watershed Selection

The Ward Creek watershed is an urban watershed located in downtown Baton Rouge (Figure 4.1). The outlet is on the main channel of Ward Creek at Government Street. The drainage area is 4.63 square miles (12.0 km^2). In 1968 the main channel of Ward Creek was upgraded from a natural ditch to a concrete lined channel. As shown in Figure 4.2, the cross-section of the lined main channel at the flowmeter installation site 200 ft (61 meters) upstream from Government Street is trapezoidal with a bottom width of 24.1 ft (7.3 m), top width of 62.0 ft (18.9 m), and depth of 11.4 ft (3.5 m). The USGS has maintained a gauge station on Ward Creek at Government Street since 1954, with a station number of 7379000.

Rainfall Data Collection

Three rain gauges (ISCO 674L Model) were installed on the watershed. A picture of the rain gauge is shown in Appendix 1(a). The locations of the rain gauges are shown in Figure 4.1, and they are listed below:

Rain Gauge A:	265 S. Foster Drive (State Police Headquarters)
Rain Gauge B:	2654 Mission Drive (Magnolia Construction Company)
Rain Gauge C:	4045 Scenic Highway (Exxon Baton Rouge Refinery)

From February 1994 to July 1995, hourly rainfall data were recorded by the rain gauges. From July 1995 to December 1996, the rainfall recording interval was 10 minutes.

Stage and Discharge Data Collection

Stage and discharge data for the Ward Creek gauge station were obtained from the USGS Baton Rouge District Office. From 1954 to 1967, the USGS recorded continuous stage and discharge data for the Ward Creek watershed. In 1968, there was a one-year data gap during the channel lining construction. Since 1969, only continuous stage data have been recorded by USGS.

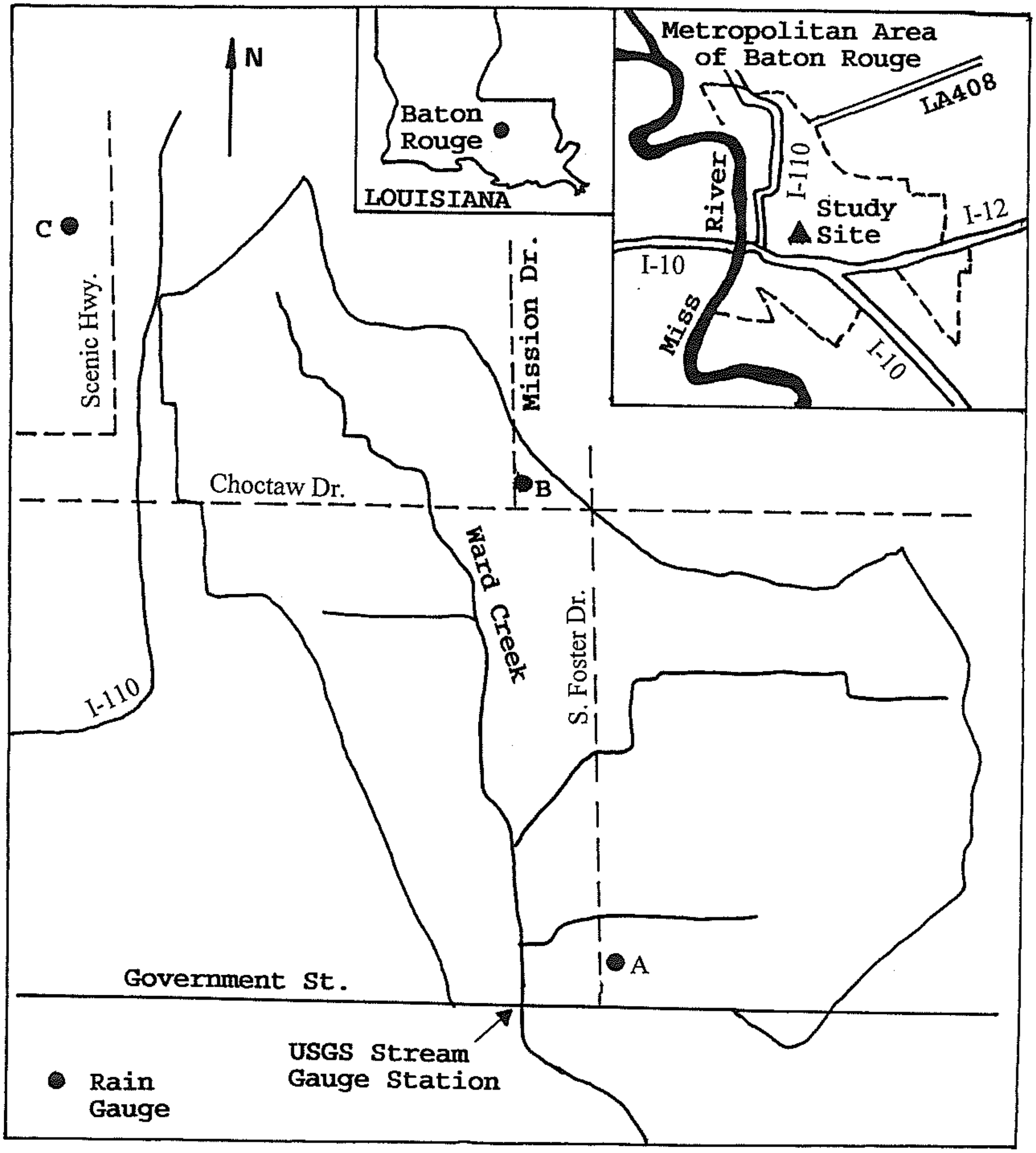

Figure 4.1
The Ward Creek watershed above Government Street in Baton Rouge

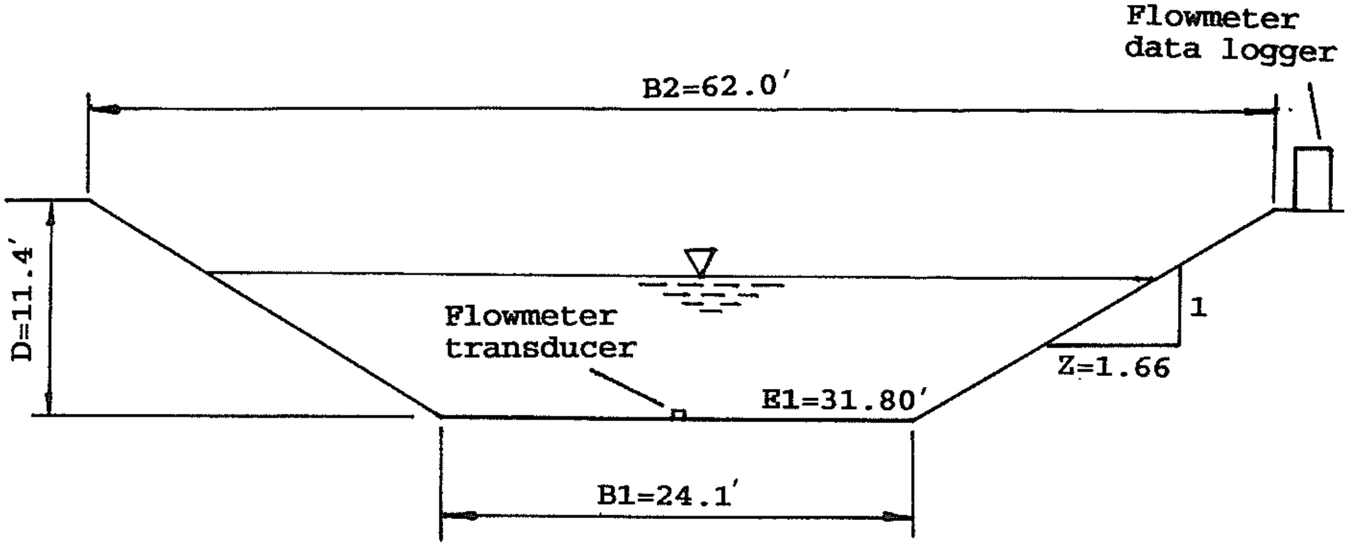

Figure 4.2
Cross-section of Ward Creek at Government Street

In order to convert the USGS stage data from 1969 through 1995 to discharge data, a flowmeter with data logger (American Sigma 950AV Model) was purchased to establish the rating curve. A picture of the flowmeter is shown in Appendix 1(b). The flowmeter is capable of measuring both water level and flow velocity. As described in the manufacturer's manual, the Doppler ultrasonic transducer measures the average flow velocity near the transducer. The error of velocity measurements is ±2 percent and the error of water level measurements is ±0.012 ft. The rating curve was established based on the water level and flow velocity data collected from May to August 1996.

Other Data

The geometric parameters of the watersheds (drainage area, channel length, and main channel slope) were obtained from topographic maps published by USGS in cooperation with LADOTD. The land use data for the two watersheds were obtained from East Baton Rouge Parish Department of Public Works.

CHAPTER 5

SELECTED FLOOD PREDICTION MODELS

Eight flood estimation models frequently used by LADOTD or developed with the involvement of LADOTD are selected to estimate flood peaks for the Ward Creek watershed. These models were developed for ungauged small watersheds. Each model is briefly described in this chapter. The reader should refer to the original reports or papers for more details.

1. The Neely Model

Neely *[2]* developed a model to estimate the magnitudes of floods for streams in Louisiana with recurrence intervals of 2 to 100 years. Data from 170 gauging stations in Louisiana, with drainage areas between 0.01 and 3,000 square miles (0.026 and 7,800 square kilometers), were used in the analysis. Flood magnitudes for different return periods at each gauging station were computed by fitting a log-Pearson Type III distribution. The model for unregulated or rural watersheds was developed by multiple regression technique.

$$Q_2=3.40A^{0.72}(P-35)^{0.95}S^{0.38} \tag{5-1a}$$

$$Q_5=4.77A^{0.76}(P-35)^{0.88}S^{0.54} \tag{5-1b}$$

$$Q_{10}=5.04A^{0.79}(P-35)^{0.88}S^{0.63} \tag{5-1c}$$

$$Q_{25}=5.31A^{0.81}(P-35)^{0.89}S^{0.71} \tag{5-1d}$$

$$Q_{50}=5.40A^{0.82}(P-35)^{0.90}S^{0.75} \tag{5-1e}$$

$$Q_{100}=5.32A^{0.83}(P-35)^{0.92}S^{0.80} \tag{5-1f}$$

where Q_x = peak discharge (cfs) for a corresponding rural watershed for a recurrence interval of x years

A = drainage area (square miles)

P = mean annual precipitation (inches)

S = main channel slope (ft/mile).

The main channel slope is measured between two points along the main channel from the outlet to the upper divide, one point at 10 percent of the channel length and the other at 85 percent of the channel length. When the main channel slope is less than 0.5 ft/mile, 0.5 is used. When the main channel is greater than 30 ft/mile, 30 is adopted. For urban watersheds, Neely *[2]* modified Sauer's *[9]* urban model and recommended the following flood estimation equations:

$$Q_{2u}=R_L Q_2 \tag{5-2a}$$

$$Q_{5u}=1.66(R_L-1)Q_2+0.167(7-R_L)Q_5 \tag{5-2b}$$

$$Q_{10u}=1.97(R_L-1)Q_2+0.167(7-R_L)Q_{10} \tag{5-2c}$$

$$Q_{25u}=2.38(R_L-1)Q_2+0.167(7-R_L)Q_{25} \tag{5-2d}$$

$$Q_{50u}=2.68(R_L-1)Q_2+0.167(7-R_L)Q_{50} \tag{5-2e}$$

$$Q_{100u}=2.98(R_L-1)Q_2+0.167(7-R_L)Q_{100} \tag{5-2f}$$

where Q_{xu} = peak discharge (cfs) for an urban watershed at the return period of x years; Q_x = peak discharge (cfs) for a corresponding rural watershed at the return period of x years calculated using a rural runoff model such as Equation (5-1a) through Equation (5-1f); R_L = urban adjustment ratio, which was defined as the ratio of mean annual urban peak discharge, $Q_{2.33u}$, to the mean annual natural peak discharge, $Q_{2.33}$ *[10]*. The percentage of impervious area in the basin and the percentage of the basin served by storm sewers (including improved channels) are needed to estimated R_L. The urban adjustment ratio can be determined from Figure 15 in Neely's report *[2]*.

2. The Lowe Model

Regression equations for estimating magnitude and frequency of peak discharge for small streams in Louisiana were developed by Lowe *[3]*. Three independent parameters were used for non-linear multiple parameter regression. The three parameters are the main channel slope, drainage area, and mean annual precipitation. The following regression equations were obtained by Lowe

[3] for watersheds that drain less than 10 square miles (25.9 km²), have main channel slopes between 5 and 100 ft/mile, and are not affected by regulation.

$$Q_2=5.50A^{0.56A^{-0.08}}S^{1.10S^{-0.20}}(P-35)^{0.69} \tag{5-3a}$$

$$Q_5=8.32A^{0.61A^{-0.08}}S^{1.25S^{-0.20}}(P-35)^{0.63} \tag{5-3b}$$

$$Q_{10}=10.2A^{0.63A^{-0.06}}S^{1.28S^{-0.20}}(P-35)^{0.62} \tag{5-3c}$$

$$Q_{25}=12.9A^{0.64A^{-0.04}}S^{1.30S^{-0.20}}(P-35)^{0.63} \tag{5-3d}$$

$$Q_{50}=12.9A^{0.65A^{-0.06}}S^{1.33S^{-0.20}}(P-35)^{0.66} \tag{5-3e}$$

$$Q_{100}=12.6A^{0.67A^{-0.06}}S^{1.36S^{-0.20}}(P-35)^{0.68} \tag{5-3f}$$

where A, S and P were defined as in Neely *[2]*. To determine the flood peaks for an urban watershed, the flood peaks for a corresponding rural watershed are calculated using the Lowe model. Then the flood peaks for the urban watershed are calculated using the Neely model defined by Equation (5-2a) through Equation (5-2f).

3. The USGS Seven-Parameter Model

Sauer *et al. [4]* analyzed 269 gauged urban watersheds in 56 cities and 31 states in the U.S. and developed a seven-parameter regression model and a three-parameter regression model for estimating flood peaks at the return periods of 2, 5, 10, 25, 50, and 100 years. One watershed in Baton Rouge was included in the study by Sauer *et al. [4]*. The seven-parameter model developed by Sauer *et al. [4]* was defined by the following equations:

$$\mathrm{Q_{2u} = 2.35A^{0.41}S^{0.17}(I_2+3)^{2.04}(ST+8)^{-0.65}(13\text{-}BDF)^{-0.32}IA^{0.15}Q_2{}^{0.47}} \tag{5-4a}$$

$$\mathrm{Q_{5u} = 2.70A^{0.35}S^{0.16}(I_2+3)^{1.86}(ST+8)^{-0.59}(13\text{-}BDF)^{-0.31}IA^{0.11}Q_5{}^{0.54}} \tag{5-4b}$$

$$\mathrm{Q_{10u} = 2.99A^{0.32}S^{0.15}(I_2+3)^{1.75}(ST+8)^{-0.57}(13\text{-}BDF)^{-0.30}IA^{0.09}Q_{10}{}^{0.58}} \tag{5-4c}$$

$$\mathrm{Q_{25u} = 2.78A^{0.31}S^{0.15}(I_2+3)^{1.76}(ST+8)^{-0.55}(13\text{-}BDF)^{-0.29}IA^{0.07}Q_{25}{}^{0.60}} \tag{5-4d}$$

$$\mathrm{Q_{50u} = 2.67A^{0.29}S^{0.15}(I_2+3)^{1.74}(ST+8)^{-0.53}(13\text{-}BDF)^{-0.28}IA^{0.06}Q_{50}{}^{0.62}} \tag{5-4e}$$

$$\mathrm{Q_{100u} = 2.50A^{0.29}S^{0.15}(I_2+3)^{1.76}(ST+8)^{-0.52}(13\text{-}BDF)^{-0.28}IA^{0.06}Q_{100}{}^{0.63}} \tag{5-4f}$$

where Q_{xu} = peak discharge (cfs) for an urban watershed at the return period of x years

A = drainage area (square miles)

S = main channel slope (ft/mile)

I_2 = rainfall intensity (inches) for the duration of 2 hours and return period of 2 years

ST = basin storage, the percentage of the watershed occupied by lakes, reservoirs, swamps, and wetlands

BDF = basin development factor, an index of the prevalence of the drainage aspects of (a) storm sewers, (b) channel improvements, (c)impervious channel linings, and (d) curb-and-gutter streets

IA = impervious area, percentage of the drainage basin occupied by impervious surface, such as houses, buildings, streets, and parking lots

Q_x = peak discharge (cfs) for a corresponding rural drainage basin for the recurrence interval of x years.

The corresponding rural discharges are computed using other rural flood prediction models.

4. The USGS Three-Parameter Model

By dropping the less significant variables in the USGS seven-parameter model, Sauer *et al.* *[4]* developed a three-parameter model to estimate urban peak discharge.

$$Q_{2u}=13.2A^{0.21}(13-BDF)^{-0.43}Q_2^{0.73} \tag{5-5a}$$

$$Q_{5u}=10.6A^{0.17}(13-BDF)^{-0.39}Q_5^{0.78} \tag{5-5b}$$

$$Q_{10u}=9.51A^{0.16}(13-BDF)^{-0.36}Q_{100}^{0.79} \tag{5-5c}$$

$$Q_{25u}=8.68A^{0.15}(13-BDF)^{-0.34}Q_{25}^{0.80} \tag{5-5d}$$

$$Q_{50u}=8.04A^{0.15}(13-BDF)^{-0.32}Q_{50}^{0.81} \tag{5-5e}$$

$$Q_{100u}=7.70A^{0.15}(13-BDF)^{-0.32}Q_{100}^{0.82} \tag{5-5f}$$

where Q_{xu}, A, BDF, and Q_x are defined the same as in the seven-parameter model.

5. The Lee Model

Lee *[5]* analyzed 217 stream-gauging sites in Louisiana and bordering states of Mississippi and Arkansas. Regression equations were developed using these watersheds that are basically natural and unregulated with drainage areas less than 3,000 square miles (7770 km^2).

$$Q_2=5.45A^{0.62}(P-35)^{1.00}S^{0.33} \tag{5-6a}$$

$$Q_5=5.50A^{0.68}(P-35)^{1.01}S^{0.51} \tag{5-6b}$$

$$Q_{10}=5.24A^{0.71}(P-35)^{1.03}S^{0.61} \tag{5-6c}$$

$$Q_{25}=4.85A^{0.74}(P-35)^{1.06}S^{0.71} \tag{5-6d}$$

$$Q_{50}=4.25A^{0.77}(P-35)^{1.10}S^{0.78} \tag{5-6e}$$

$$Q_{100}=3.85A^{0.79}(P-35)^{1.13}S^{0.84} \tag{5-6f}$$

where Q_x, A, P and S are defined the same as in Neely *[2]* and Lowe *[3]*. With the results from Equations (5-6a) through (5-6f), the flood peaks for an urban watershed can be determined by using the Neely model defined by Equations (5-2a) through (5-2f).

6. The SCS Model

The Soil Conservation Service Model *[4]*, which was published in the SCS Technical Release 55 (TR-55), presents simplified procedures to calculate storm runoff volume, peak discharge, and hydrographs,. The SCS model was developed for urban small watersheds. The TR-55 report says that the model applies to watersheds with time of concentration from 0.1 to 10 hours. Therefore, the SCS model should be applicable to the Ward Creek watershed because its time of concentration is about 3 hours (see Appendix 2).

The model starts with the assumption that a gross rain amount P (in inches) is uniformly distributed in the watershed. To account for the initial losses before runoff occurs and subsequent losses due to infiltration, depression, evapotranspiration, *etc.*, the amount of rainfall is converted to mass direct runoff R (in inches) or the excess rainfall by the following equation,

$$R=\frac{[P-0.2(\frac{1000}{CN}-10)]^2}{P+0.8(\frac{1000}{CN}-10)} \tag{5-7}$$

where CN is the runoff curve number, which depends on soil group, cover type, and antecedent moisture condition. CN can be determined by using Table 2.2, Figures 2.3 and 2.4 given in the SCS manual *[6]*, and by using the local hydrological soil group maps obtainable from local SCS offices. Peak discharge can be estimated either by the graphical peak discharge method or by the tabular hydrograph method. If hydrograph is not of interest, peak discharge can be estimated by the graphical peak discharge method using the following equation:

$$Q_p=q_u A R F_p \tag{5-8}$$

where Q_p = peak discharge (cfs)

q_u = unit peak discharge per square mile of drainage area per inch of runoff (cfs/mile^2.in), which can be estimated by using Exhibit 4-I, 4-IA, 4-II or 4-III provided by the SCS manual *[6]*

A = drainage area (square miles)

R = direct runoff computed from Equation (5-7)

F_p = pond and swamp adjustment factor, which can be determined from Table 4.2 in the SCS manual] *[6]*.

7. The Louisiana Regional GEV-PWM Model

Naghavi *et al. [7]* divided Louisiana into four hydrologically homogeneous regions based on the analyses of soil, topographic, and climatic maps. The four regions are: southeast, southwest, northeast, and northwest. For each of the four regions, a regression equation was developed to estimate the mean annual maximum flood in terms of the drainage area.

For the southeast region,

$$Q_m = 10^{2.695 A^{0.072}} \tag{5-9a}$$

For the southwest region,

$$Q_m = 10^{2.561 A^{0.076}} \tag{5-9b}$$

For the northeast region,

$$Q_m = 10^{2.406 A^{0.063}} \tag{5-9c}$$

For the northwest region,

$$Q_m = 10^{2.836 A^{0.052}} \tag{5-9d}$$

where Q_m = mean annual maximum discharge (cfs)
A = drainage area (square miles).

The method is called GEV-PWM model because the regression coefficients were determined by the generalized extreme value (GEV) distribution with the probability weighted moments (PWM). With these four regression equations, the indexed regional optimization procedure developed in this study can be easily extended to predict flood frequency at ungauged sites. This can be done by using the following three steps:

Step 1: Estimate the drainage area, A, for the ungauged watershed and identify the region in which the watershed is located using Figure 3 in Naghavi *et al. [7]*;

Step 2: Calculate the mean annual maximum discharge, Q_m, by using one of the equations from Equation (5-9a) to Equation (5-9d);

Step 3: Calculate the design discharge for a selected frequency by multiplying the regional flood quantile (dimensionless) at the same frequency by the mean annual maximum discharge calculated at Step 2. The dimensionless regional quantiles for the return periods of 2, 5, 10, 25, 50, and 100 years of flood for the four hydrologically homogeneous regions are given in Table 5.1.

This method did not consider urbanization. Both rural and urban watersheds were used for regression analysis of the GEV-PWM model.

8. The Louisiana Regional GEV-OPT Model

Naghavi and Yu *[8]* modified the Louisiana Regional GEV-PWM Model *[7]*. In the modified model, the dimensionless regional flood quantiles were estimated by using the GEV distribution and optimization method (GEV-OPT). Ninety gauged stream sites in Louisiana were selected for the study. To determine the peak discharge for return periods of 2, 5, 10, 25, 50, and 100 years for the four homogeneous regions in Louisiana, the three steps described previously in the Louisiana Regional GEV-PWM model are followed. Equation (5-9a) through Equation (5-9d) are used to calculate the mean annual maximum discharge. The dimensionless regional flood quantiles are listed in Table 5.2.

Table 5.1
Dimensionless regional flood quantiles for the GEV-PWM model

Return period (years)	Hydrologically homogeneous region			
	Southeast	Southwest	Northeast	Northwest
2	0.811	0.758	0.978	0.712
5	1.410	1.380	1.300	1.350
10	1.920	1.910	1.470	1.965
25	2.638	2.773	1.659	2.971
50	3.237	3.584	1.778	3.957
100	3.916	4.570	1.882	5.198

Source: Naghavi *et al. [7]*.

Table 5.2
Dimensionless regional flood quantiles for the GEV-OPT procedure

Return period (years)	Hydrologically homogeneous region			
	Southeast	Southwest	Northeast	Northwest
2	0.812	0.763	0.999	0.708
5	1.315	1.320	1.325	1.260
10	1.932	1.980	1.544	2.018
25	2.607	2.862	1.732	3.026
50	3.162	3.674	1.845	3.989
100	3.766	4.642	1.938	5.175

Source: Naghavi and Yu *[8]*.

CHAPTER 6
RESULTS OF MODEL APPLICATION

In this chapter, flood peaks are estimated using the eight ungauged watershed models for the Ward Creek watershed. The model parameters are estimated based on information of watershed characteristics, land use, and regional climatology. No parameter is calibrated using stream gauging data.

1. The Neely Model

The Neely model consists of four model parameters: (1) drainage area, A, in square miles, (2) average annual precipitation, P, in inches, (3) main channel slope, S, in ft/mile, and (4) urban adjustment ratio, R_L. These parameters have been described in detail in Chapter 5. For the Ward Creek watershed, $A=4.63$ square miles, $P=56$ inches/year, and $S=3.564$ ft/mile *[3]*. The value of R_L is estimated based on the assumption that 95 percent of the drainage area is served by storm sewer systems and the average residential lot size is 1/3 acre. The percentage of impervious area is calculated using the method described in the TR-55 report *[6]*,

$$\begin{aligned} A_i &= 0.30(\text{Resi. area}) + 0.85\ (\text{Commerc. area}) + 0.72\ (\text{Industr. area}) \\ &= 0.30\ (1692) + 0.85\ (919) + 0.72\ (64) \\ &= 1335 \text{ acres } (45\% \text{ of the total}) \end{aligned} \tag{6-1}$$

Using Figure 15 in Neely *[2]*, the urban adjustment ratio (R_L) for the Ward Creek watershed is determined to be 3.6. The flood peaks for a corresponding rural watershed calculated from Equations (5-1a) through (5-1f) are 299.6, 442.5, 548.9, 680.6, 762.3, and 863.6 cfs, respectively. The 2-, 5-, 10-, 25-, 50-, and 100-year flood peaks for the Ward Creek watershed determined from Equations (5-2a) through (5-2f) are 1079, 1544, 1846, 2240, 2520, and 2812 cfs, respectively.

2. The Lowe Model

The Lowe model *[3]* has the same parameters as the Neely model, but they have different regression coefficients. The flood peaks for a corresponding rural watershed calculated using the Lowe model defined by Equations (5-3a) through

(5-3f) are 284.0, 444.0, 575.5, 794.4, 884.1, and 972.9 cfs, respectively. With the urban adjustment ratio $R_L = 3.6$, the flood peaks at the six frequencies for the Ward Creek watershed calculated using Equations (5-2a) through (5-2f) are 1022, 1478, 1781, 2208, 2481, and 2753 cfs, respectively.

3. The USGS Seven-Parameter Model

The seven parameters in this model are: (1) drainage area, A, in square miles, (2) basin development factor, BDF, (3) flood peak, Q_x, for a corresponding rural watershed in cfs, (4) main channel slope, S, in ft/mile, (5) the two-hour, two-year rainfall, I_2, in inches, (6) basin storage as determined by the percentage of drainage area occupied by water, ST, and (7) the percentage of drainage area occupied by impervious area, A_i.

For the Ward Creek watershed, the drainage area is 4.63 square miles (12.0 km^2), and the basin development factor is 12. The flood peaks for a corresponding rural watershed estimated by the Lowe model are $Q_2 = 284.0$, $Q_5 = 444.0$, $Q_{10} = 575.5$, $Q_{25} = 794.4$, $Q_{50} = 884.1$, and $Q_{100} = 972.9$ cfs. The main channel slope is 3.564 ft/mile. The two-hour, two-year rainfall estimated using the I-D-F relations *[11]* is 2.682 inches. The watershed has no permanent water body such as lakes or reservoirs. Therefore, the basin storage, ST, is 0. The impervious area is 45 percent of the watershed drainage area as shown in Equation (6-1). The flood peaks at the return periods of 2, 5, 10, 25, 50, and 100 years for the Ward Creek watershed calculated using the seven-parameter USGS model are 1233, 1716, 2122, 2631, 2901, and 3264 cfs, respectively.

4. The USGS Three-Parameter Model

The parameters in the USGS three-parameter model are defined the same as in the seven-parameter model. The 2-, 5-, 10-, 25-, 50-, and 100-year flood peaks for the Ward Creek watershed calculated using Equations (5-5a) through (5-5f) are 1125, 1597, 1841, 2282, 2465, and 2732 cfs, respectively.

5. The Lee Model

The Lee model and the Neely model have the same parameters but different regression coefficients. The flood peaks for a corresponding rural watershed calculated using the Lee model defined by Equations (5-6a) through (5-6f) are 450.2, 645.5, 777.1, 936.9, 1061.3, and 1172.2 cfs. The flood peaks at the return periods of 2, 5, 10, 25, 50, and 100 years for the Ward Creek watershed determined using the Neely model defined by Equations (5-2a) through (5-2f) are 1621, 2310, 2747, 3318, 3740, and 4154 cfs, respectively.

6. The SCS Model

To use the SCS model for estimating flood peaks from the Ward Creek watershed, the following eight parameters are needed: (1) Drainage area, A, is 4.63 square miles; (2) Rainfall peaks in Baton Rouge for 24-hour duration and at the return periods of 2, 5, 10, 25, 50, and 100 years are determined to be 4.66, 6.54, 7.61, 9.52, 11.27 and 13.05 inches, respectively, using the LADOTD 24-hour rainfall frequency maps *[12]* ; (3) Percentage of pond and swamp areas, A_w, is zero; (4) Pond and swamp adjustment factor, Fp, is 1.0 for $A_w=0$; (5) The composite curve number, CN. As shown in Figure 6.1, the Ward Creek watershed has three types of soil, Type C, Type D and combination of Types C and D (designated as C/D in Figure 6.1) based on the SCS soil classification *[6]*. The composite CN for the Ward Creek watershed shown in Table 6.1 is 86; (6) Rainfall time distribution type. From Figure B-2 in the TR-55 manual it was found that the rainfall distribution type in Louisiana is III; (7) Initial abstraction, Ia, is found to be 0.325 for CN=86 by using Table 4.1 in the TR-55 manual; and (8) Time of concentration is estimated as $T_c=3.0$ hours (see Appendix 2). The flood peaks using the SCS method are listed in Table 6.2. In Table 6.2, P is the 24-hour rainfall for different return periods, R is mass direct runoff calculated from equation (5-7), and Q_p is the peak discharge at different return periods determined from Equation (5-8) with $q_u=154$ cfs/mile^2/inch.

7. The Louisiana Regional GEV-PWM Model

Since Ward Creek is located in the southeast region of Louisiana, the mean annual maximum discharge can be estimated by using Equation (5-9a). With A = 4.63 square miles, the mean annual maximum discharge calculated using Equation (5-9a) is 1022 cfs. By multiplying the mean annual maximum discharge and dimensionless flood quantiles listed in Table 5.1, the flood peaks for the

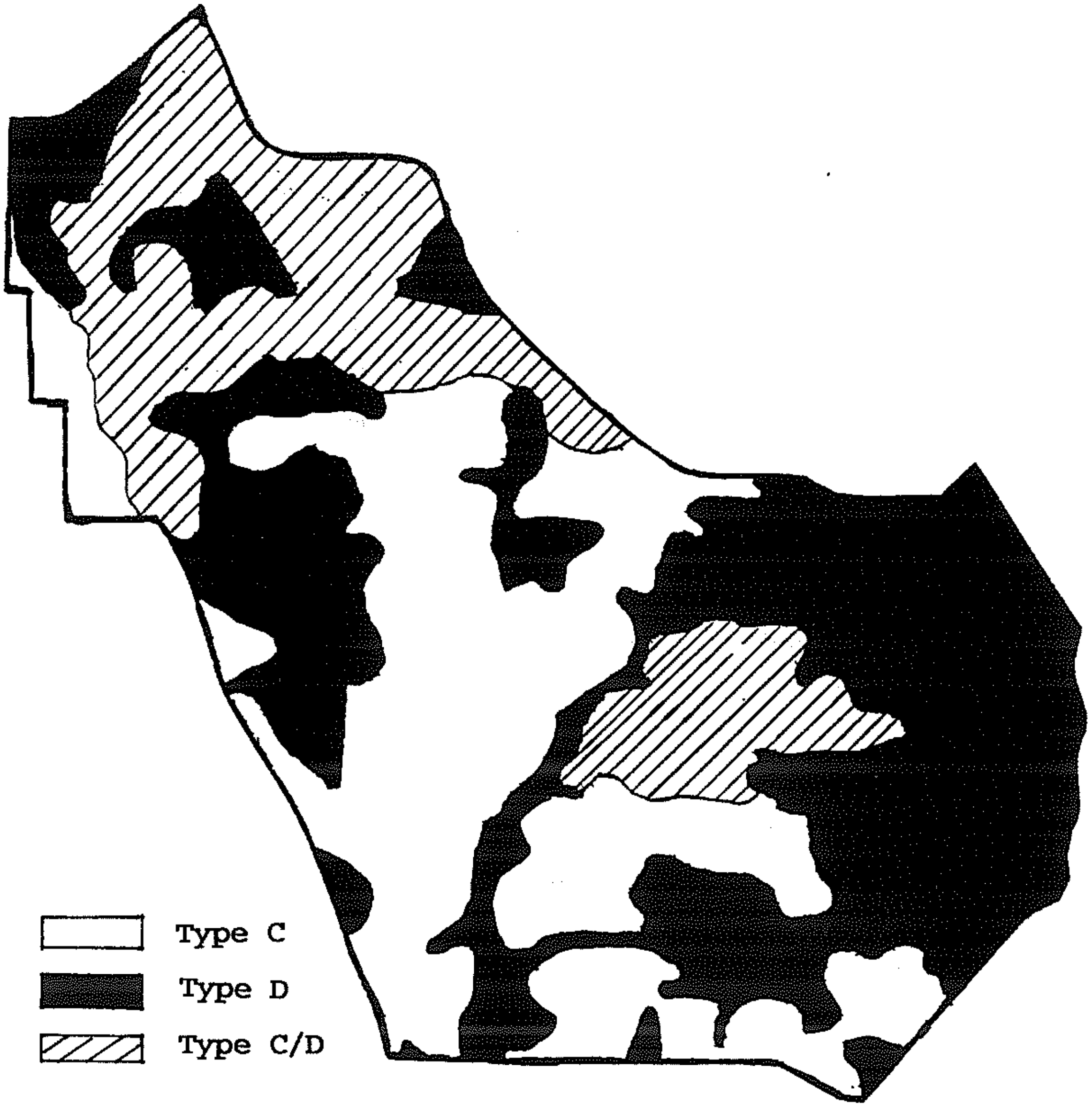

Figure 6.1
Soil classification for the Ward Creek watershed

Ward Creek watershed at the return periods of 2, 5, 10, 25, 50, and 100 years are 829, 1441, 1962, 2696, 3308, and 4002 cfs respectively.

Table 6.1
Computation of the runoff curve number for the Ward Creek watershed

Land use	Soil type	CN	Area (acres)	CN × Area
Residential *	C	82	854	69255
	C/D	84	318.3	26578
	D	87	519.8	44703
Commercial	C	94	464.1	43625
	C/D	94	172.8	16243
	D	95	282.1	26800
Industrial	C	91	32.3	2939
	C/D	92	12.0	1104
	D	93	19.6	1823
Undeveloped	C	74	145.4	10760
	C/D	77	54.1	4166
	D	80	88.4	7072
Σ			2963	255067
CN = 255067/2963 = 86				

Note:* Assuming the average residential lot size is 1/3 acre.

Table 6.2
Flood calculation for the Ward Creek watershed using the SCS model

	Return period (years)					
	2	5	10	25	50	100
P (in)	4.66	6.54	7.61	9.52	11.27	13.05
R (in)	3.151	4.924	5.954	7.811	9.527	11.28
Q_p(cfs)	2247	3511	4245	5570	6793	8044

8. The Louisiana Regional GEV-OPT Model

The mean annual maximum flood for the Louisiana Regional GEV-OPT model is 1022 cfs, the same as that for the Louisiana Regional GEV-PMW model. By using the dimensionless flood quantiles listed in Table 5.2, the flood peaks at the return periods of 2, 5, 10, 25, 50, and 100 years calculated using the Louisiana Regional GEV-OPT model are 830, 1344, 1975, 2664, 3232, and 3849 cfs, respectively.

CHAPTER 7
MODEL EVALUATION USING OBSERVED DATA

The flood peaks for the Ward Creek watershed are determined using the eight models in Chapter 6. The Ward Creek watershed is treated as if it were an ungauged watershed in the previous chapter. In this chapter, the flood magnitudes will be determined using the long-term stream gauging records of the watershed by following the WRC procedure *[1]*. The results determined from the eight models will be compared with those derived using the WRC procedure.

1. Water Resources Council Procedure

The flood magnitude and frequency are determined by following the Water Resources Council procedure *[1]*.

Step 1: Data Preparation

The annual peak discharges in Ward Creek at Government Street from 1954 through 1967 were recorded by USGS. The USGS did not establish the stage-discharge relation at this gauge station for the period from 1969 through 1995. As part of this study, a flowmeter (American Sigma 950 Area Velocity Flowmeter) was installed in Ward Creek to collect both flow velocity and water level.The observed discharge in Ward Creek is calculated using the following equations,

$$A=(B1+ZD)D \tag{7-1}$$

$$Q=VA \tag{7-2}$$

where A = flow area (ft^2)
B1 = bottom width (ft)
Z = side slope
D = water depth (ft)
Q = water discharge (cfs)
V = flow velocity (ft/sec)

The observed water depth and discharge data at the Ward Creek gage station are listed in Appendix 3. The rating curve for the station is represented by the following regression equations,

$$Q = 8.96D^2 + 72.70D - 13.06 \qquad (7-3)$$

$$Q = 8.96(H - H_0)^2 + 72.70(H - H_0) - 1 \qquad (7-4)$$

where D = water depth (ft)
H = stage elevation (ft, NGVD) observed by USGS at the Ward Creek gauge station
H_0 = channel bottom elevation (ft, NGVD), which is 31.80 ft.

The stage-discharge relation shown in Figure 7.1 is determined by 591 data points collected from May to August 1996, which are listed in Appendix 3. The annual peak discharges from 1969 through 1995 were obtained by converting the annual peak stages to discharges using the rating curve defined by Equation (7-4). The annual maximum discharges from 1954 to 1967 were observed by the USGS. To fill the data gap in 1968 due to channel lining construction, a regression relationship between stages of Ward Creek at Government Street and at Siegen Lane, about 7 miles (11.3 km) downstream, is obtained using the USGS stage data at the two gauge stations from 1954 through 1967 (Figure 7.2). The peak stage at Siegen Lane in 1968 was 14.69 ft. The peak stage at Government Street in 1968 was determined to be 11.66 ft using the relation shown in Figure 7.2. The peak discharge in Ward Creek at Government Street in 1968 is calculated as 1850 cfs using the rating curve for Ward Creek at Government from 1961 through 1966 (see Figure 7.1).

Step 2: Data List

Annual peak dicharge data of 42 years (1954-95) are listed in Table 7.1 and their logarithms, squares and cubes of logarithms are calculated.

Step 3: Statistical Analysis

Using the data in Table 7.1 and equations in the WRC report *[1]*, the mean, standard deviation and skew coefficient of these data are computed.

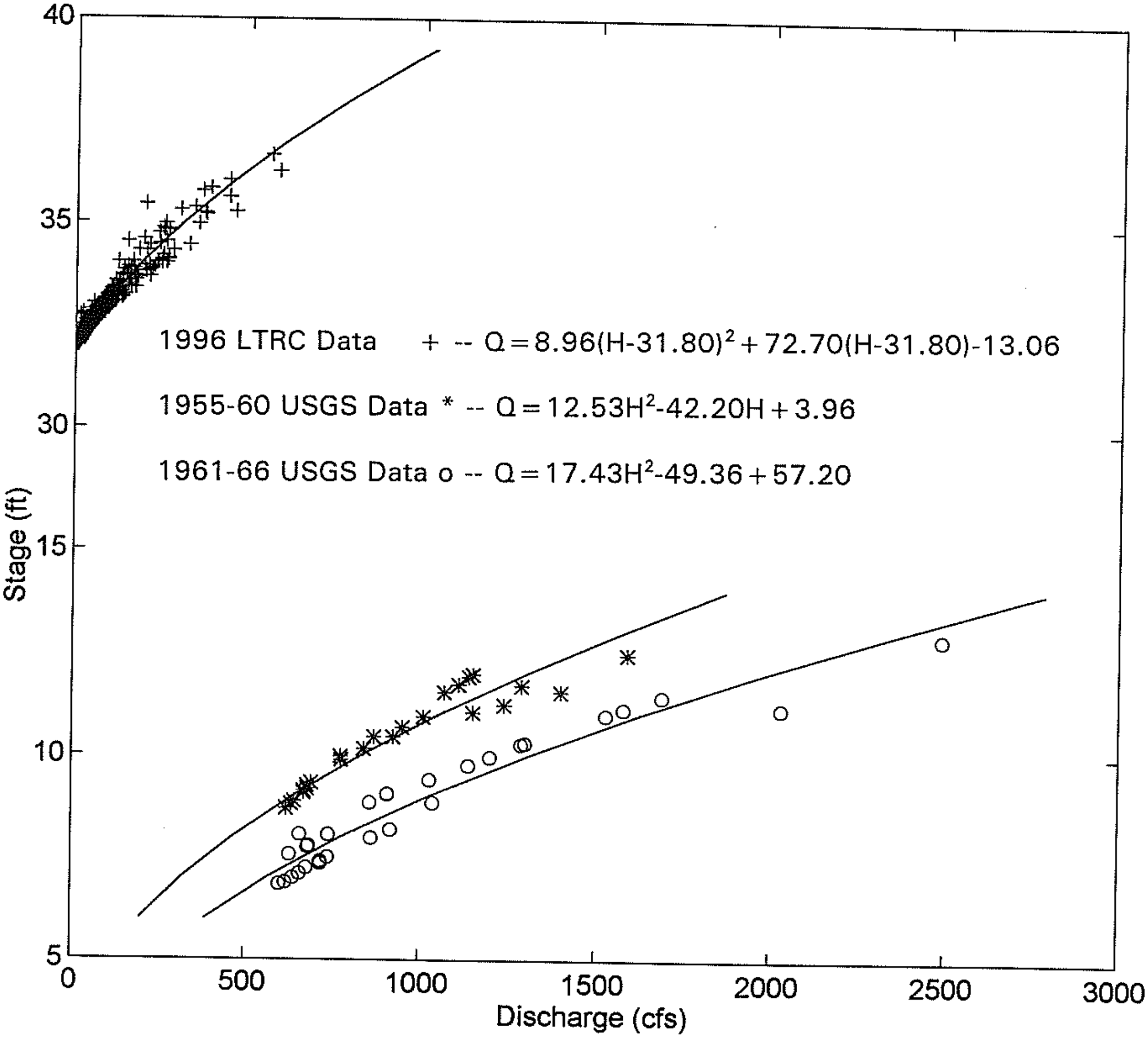

Figure 7.1
Rating curves for the Ward Creek watershed

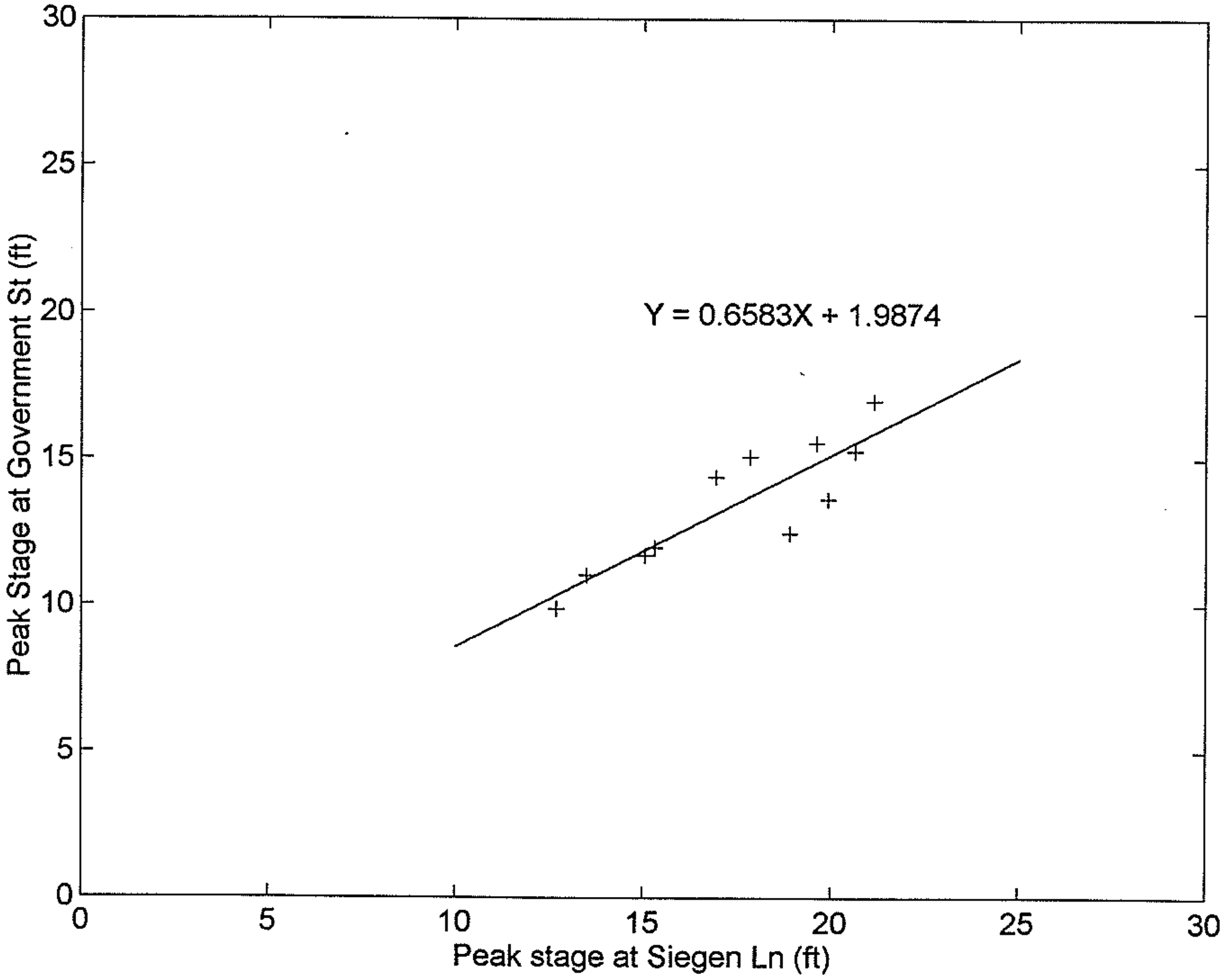

Figure 7.2
Relation between peak stages in Ward Creek at Government Street and Siegen Lane

Table 7.1
Computation of summations

Year	Peak discharge (cfs)	X=LOG(Q)	X^2	X^3
1954	895	2.95182	8.71326	25.72000
1955	1150	3.06070	9.36787	28.67222
1956	777	2.89042	8.35453	24.14812
1957	1590	3.20140	10.24894	32.81094
1958	1290	3.11059	9.67577	30.09735
1959	1400	3.14613	9.89812	31.14076
1960	1150	3.06070	9.36787	28.67222
1961	1040	3.01703	9.10249	27.46252
1962	2030	3.30750	10.93953	36.18245
1963	720	2.85733	8.16435	23.32826
1964	1290	3.11059	9.67577	30.09735
1965	1690	3.22789	10.41925	33.63217
1966	1530	3.18469	10.14226	32.29997
1967	2490	3.39620	11.53417	39.17234
1968	1850	3.26717	10.67441	34.87513
1969	2350	3.37107	11.36410	38.30915
1970	1360	3.13354	9.81907	30.76840
1971	1590	3.20140	10.24894	32.81094
1972	1890	3.27646	10.73520	35.17348
1973	2070	3.31597	10.99566	36.46128
1974	1620	3.20952	10.30099	33.06117
1975	1610	3.20683	10.28373	32.97814
1976	1450	3.16137	9.99425	31.59549
1977	1330	3.12385	9.75845	30.48395
1978	1371	3.13704	9.84100	30.87160
1979	1200	3.07918	9.48136	29.19482
1980	1560	3.19313	10.19604	32.55724
1981	750	2.87506	8.26598	23.76519
1982	570	2.75588	7.59485	20.93045
1983	1660	3.22011	10.36910	33.38961
1984	1200	3.07918	9.48136	29.19482
1985	1140	3.05691	9.34467	28.56576
1986	690	2.83885	8.05906	22.87847
1987	1690	3.22789	10.41925	33.63217
1988	1660	3.22011	10.36910	33.38961
1989	2110	3.32428	11.05085	36.73616
1990	1990	3.29885	10.88243	35.89954
1991	2180	3.33846	11.14529	37.20807
1992	2180	3.33846	11.14529	37.20807
1993	1370	3.13672	9.83902	30.86224
1994	1790	3.25285	10.58105	34.41861
1995	2420	3.38382	11.45021	38.74538
$\sum$	--	132.54690	419.29490	1329.40200

$$X_m = \frac{\Sigma X}{N} = \frac{132.54690}{42} = 3.15588$$

$$S^2 = \frac{\Sigma X^2 - (\Sigma X)^2/N}{N-1}$$

$$= \frac{419.29490 - (132.54690)^2/42}{42-1}$$

$$= 0.024219$$

$$S = 0.15562$$

$$G = \frac{N^2(\Sigma X^3) - 3N(\Sigma X)(\Sigma X^2) + 2(\Sigma X)^3}{N(N-1)(N-2)S^3}$$

$$= \frac{42^2(1329.40200^3)-3\times 42(132.54690)(419.29490)+2(132.54690)^3}{42(42-1)(42-2)\times 0.15562^3}$$

$$= - 0.74223$$

where X = logarithm of annual peak discharge
N = number of observations of the data set
X_m = mean of log-transformed annual maximum series
S = standard deviation of logarithms
G = skew coefficient of the log-transformed flood series.

Step 4: Computation of the Frequency Curve Coordinates

The frequency curve coordinates are calculated using the follwing equation,

$$LOG\ Q = X_m + KS \tag{7-5}$$

where K is the frequency factor, which is a function of the skew coefficient and the selected frequency. The K values at the six frequencies for Ward Creek watershed for S=0.15562 obtained from Appendix 3 of the WRC report *[1]* are listed in Table 7.2. The flood peaks are computed using Equation (7-5). An example computation for an exceedance of 0.5 (two-year occurrence) is shown below, and others are list in Table 7.2.

$$\begin{aligned}\text{Log } Q &= X_m + KS \\ &= 3.15588 + 0.12263 \times 0.15562 \\ &= 3.17496\end{aligned}$$

$$Q = 1496 \text{ cfs}$$

The peak discharge at a selected frequency can be determined by following four steps: (1) find the logarithm of annual peak discharge; (2) calculate X_m, S and G; (3) find the value of K from Appendix 3 of the WRC report *[1]* for the frequency and skew coefficient; and (4) calculate discharge using Eq. (7-5).

2. Evaluation of the Model Results

The flood peaks for the Ward Creek watershed calculated in Chapter 6 from the eight models are summarized in Table 7.3 and plotted in Figure 7.3 along with the observed data from the WRC procedure. The eight models are evaluated by comparing the flood peaks calculated using the models with the flood peaks derived from historical flood records using the WRC procedure. The relative root mean square error (RRMSE) is used to evaluate the flood prediction models.

$$RRMSE=\sqrt{\frac{1}{n}\sum\left[\frac{Q_x-Q_{WRC,x}}{Q_{WRC,x}}\right]^2} \qquad (7-6)$$

where RRMSE = relative root mean square error

Q_x = flood peak at the return period of x years calculated using one of the eight models

$Q_{WRC,x}$ = flood peak at the return period of x years calculated using the WRC procedure

n = number of frequencies to be compared (n=6 here).

Table 7.2
Computation of frequency curve coordinates

Return Period (years)	Freq. (1/yr.)	K	Log(Q)	Q (cfs)
2	0.5	0.12263	3.17496	1496
5	0.2	0.85662	3.28919	1946
10	0.1	1.17598	3.33889	2182
25	0.04	1.40871	3.37510	2372
50	0.02	1.63909	3.41096	2576
100	0.01	1.77518	3.43213	2705

Table 7.3
Results of model application to the Ward Creek watershed

Model	Return period (years)						RRMSE
	2	5	10	25	50	100	
Neely	1079	1544	1846	2240	2520	2812	0.16
Lowe	1022	1478	1781	2208	2481	2753	0.18
USGS-7	1233	1716	2122	2631	2901	3264	0.14
USGS-3	1125	1597	1841	2282	2465	2732	0.14
Lee	1621	2310	2747	3318	3740	4154	0.35
SCS	2247	3511	4245	5570	6793	8044	1.30
GEV-PWM	829	1441	1962	2696	3308	4002	0.32
GEV-OPT	830	1344	1975	2664	3232	3849	0.30
WRC	1496	1946	2182	2426	2576	2705	--

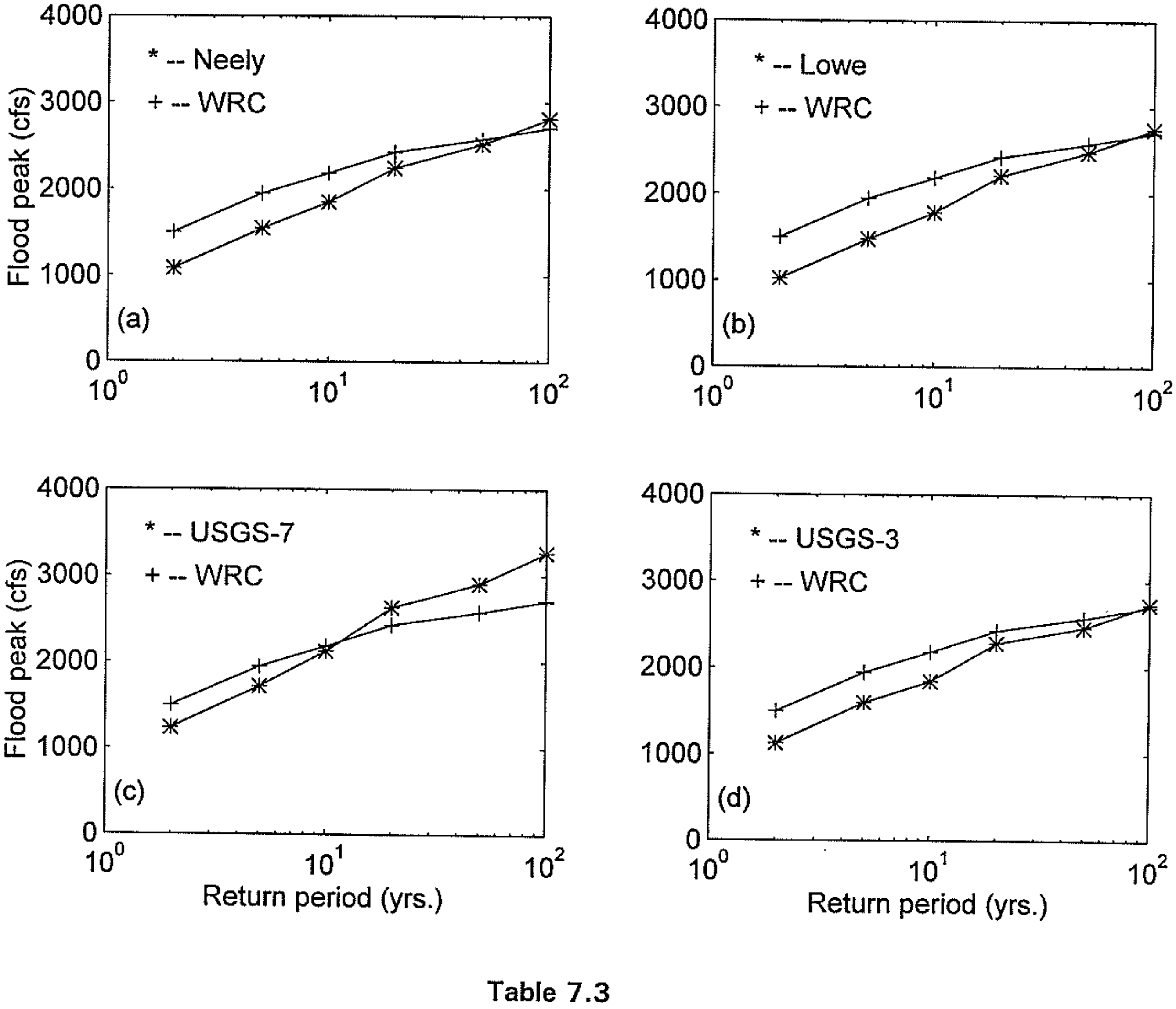

Table 7.3
Comparison of model results with those using the WRC procedure

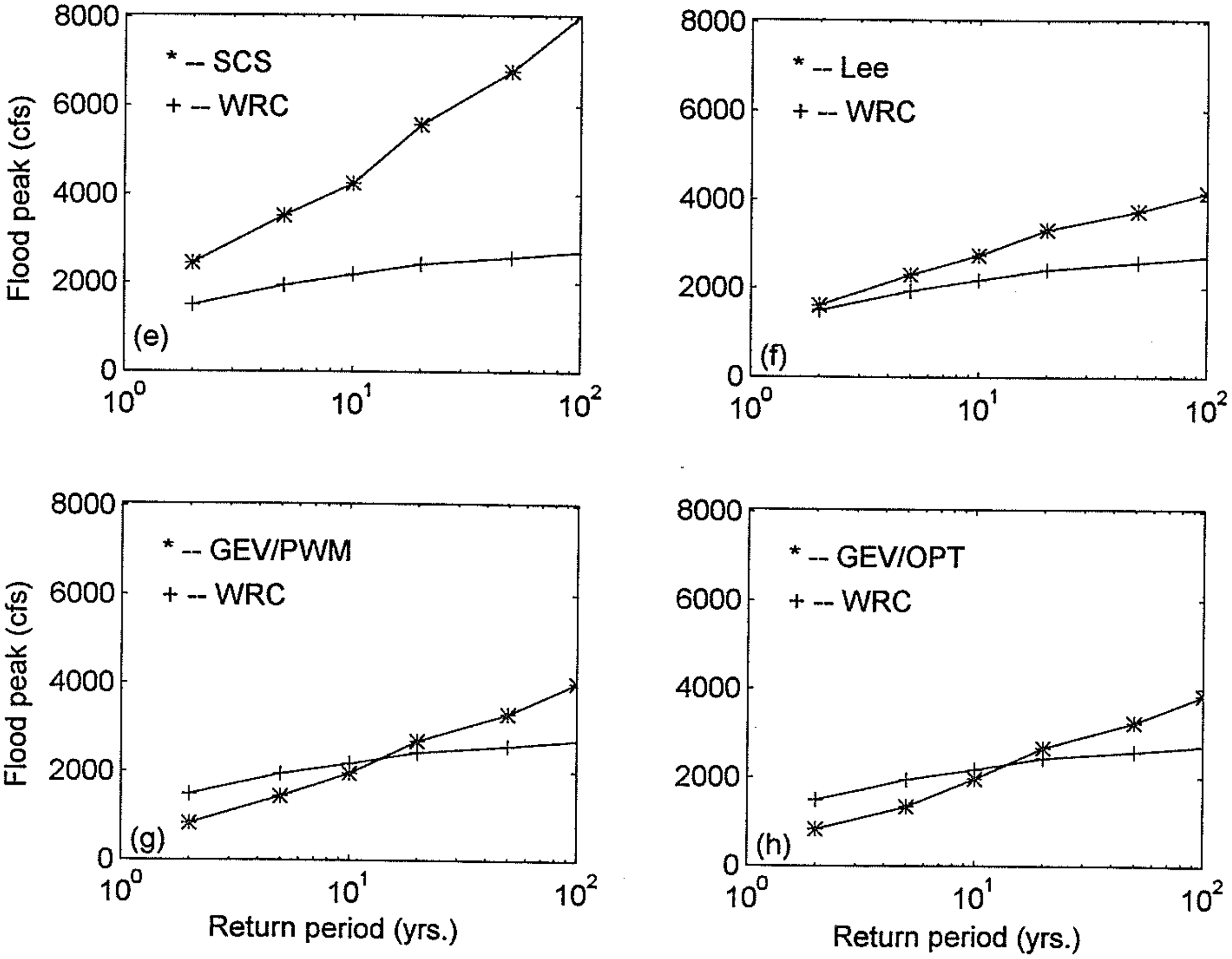

Table 7.3 (Continued)
Comparison of model results with those using the WRC procedure

The values of RRMSE for the eight models are listed in Table 7.3. The USGS 7-parameter model, USGS 3-parameter model, the Lowe model and the Neely model have the least relative root mean square error. Therefore, these four models are better than the other models in predicting flood frequency for the Ward Creek watershed. The four models have better accuracy because: (1) the field data for developing the Lowe model and the Neely model were all from Louisiana, and one watershed was used for development of the two USGS models; (2) the drainage area of the Ward Creek watershed is within the ranges which the four models apply; and (3) the parameters for the four models, such as drainage area, main channel slope, mean annual precipitation, impervious area, basin storage, basin development factor, urban adjustment ratio, *etc.*, do not depend significantly on personal judgement.

The Louisiana regional GEV-PWM and GEV-OPT models were developed based on field data for rural watersheds. The accuracy of flood prediction for highly developed urban watersheds like the Ward Creek watershed is relatively low. The GEV-PWM and GEV-OPT models are simple to apply because only drainage area and watershed location are needed. However, they can be used for quick but rough estimation of flood peaks. For more accurate estimation of flood magnitudes, more information of the watershed is needed to use other models such as the two USGS models, the Lowe model, and the Neely model.

The SCS model has the least accuracy for the Ward Creek watershed. The accuracy of the SCS model is low at all six frequencies. This is due to the limitations of the model itself and errors in estimating the model parameters. When the runoff curve number is estimated, personal judgement is involved. When estimating the unit peak discharge, the ratio of I_a/P was out of the range in the nomograph *[6]* at all six frequencies. The TR-55 manual *[6]* suggests that the boundary values be used. Therefore, the unit peak discharge (q_u) was determined to be 154 for all six frequencies. Obviously, a large error was introduced.

CHAPTER 8

DETERMINATION OF FLOOD PEAKS USING SHORT-TERM FIELD DATA CALIBRATION

The SCS model is re-applied here with parameters calibrated using short-term field data. Two parameters, runoff curve number (CN) in Equation (5-7) and unit peak discharge (q_u) in Equation (5-8), in the SCS model are calibrated using field data. However, parameter calibration is not applicable to the rest of the eight models because they were developed using data of multiple watersheds.

1. Runoff Curve Number Calibration

A data set of 24-hour rainfall and net runoff was obtained from the rain gauge and flowmeter records. In Table 8.1, 24-hour rainfall is the arithmetic average of 24-hour rainfall recorded by the three rain gauges. To calculate the net runoff for a rainfall event, the stage data corresponding to the rainfall event are converted to discharge data using the rating curve derived in Chapter 7. The net runoff is calculated by integration. Baseflow is neglected because the depth of baseflow in Ward Creek at Government Street is usually one to two inches. The 24-hour rainfall and net runoff data listed in Table 8.1 will be used for runoff curve number calibration. The standard deviation of the calculated net runoff using Equation (5-7) from the observed net runoff is represented by the following equation

$$s = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (R_{ci} - R_{oi})^2} \qquad (8-1)$$

where s = standard deviation

n = number of storm events

R_{ci} = calculated net runoff (in.) during the i'th storm event

R_{oi} = observed net runoff (in.) during the i'th storm event.

R_{ci} is calculated using Equation (5-7). By substituting Equation (5-7) into equation (8-1), we obtain

$$s=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{[P_i-0.2\ S)]^2}{P_i+0.8\ S}-R_{oi}\right)^2} \tag{8-2}$$

where $S = 1000/CN - 10$.

Table 8.1
Rainfall and runoff field data for the Ward Creek watershed

Date	Rainfall (inches)				Net runoff (inches)	Peak runoff (cfs)
	Foster	Mission	Scenic	Average		
03/09/94	0.94	1.91	3.11	1.99	0.47	324
06/12/94	2.79	--	--	2.79	0.79	985
07/08/94	3.16	3.19	--	3.18	0.66	1095
07/27/94	1.90	2.39	2.18	2.16	0.81	1383
08/23/94	--	1.42	1.79	1.61	0.40	870
03/07/95	1.77	1.82	1.82	1.8	0.53	768
03/13/95	3.57	3.43	3.54	3.51	1.35	898
03/28/95	3.50	3.89	4.20	3.86	1.52	1024
04/10/95	6.10	6.60	6.43	6.38	4.12	2449
05/18/95	2.90	3.10	4.17	3.39	1.33	1353
09/21/95	1.38	1.84	2.09	1.77	0.43	524
11/02/95	4.80	4.37	--	4.59	0.85	827
01/01/96	0.74	1.00	1.19	0.98	0.24	342
01/26/96	2.77	3.55	3.77	3.36	1.37	1525
02/28/96	1.76	2.02	1.79	1.86	0.16	333
04/12/96	2.22	1.85	2.66	2.24	0.78	1007
06/24/96	1.35	1.73	1.26	1.45	0.54	1019

CN is determined by minimizing the standard deviation in Equation (8-2). This is done by: (1) plugging the field-observed values of P_i and R_{oi} in Equation (8-2); (2) finding the derivative of s with respect to CN; (3) setting ds/d(CN) = 0; and (4) solving the equation to determine CN. An alternative method to determine CN is by: (1) calculating the values of standard deviation using Equation (8-2) for CN's from 40 to 100 with an interval of 5; (2) plotting standard deviation (s) vs. runoff curve number (CN); and (3) finding the value of CN at which the standard deviation is minimum. Figure 8.1 shows the relation between standard deviation and runoff curve number. The value of standard deviation becomes minimum when CN = 76. Therefore, the runoff curve number for the Ward Creek watershed calibrated using the field data is 76, compared with the estimated runoff curve number of 86 in Chapter 6. The relation between rainfall and net runoff represented by Equation (5-7) with CN = 76 fits the field data set better than with CN=86 (Figure 8.2).

2. Unit Peak Discharge

The unit peak discharge in Equation (5-8) is calibrated using the rainfall-runoff data listed in Table 8.1. The unit peak discharge is defined as

$$q_u = \frac{Q_p}{ARF_p} \qquad (8-3)$$

where q_u, A, R, F_p and Q_p are defined in Chapter 5. Using the field data listed in Table 8.1, a regression relation between q_u and (ARF_p) is developed as follows

$$q_u = \frac{632}{(A\ R\ F_p)^{0.25}} - 192 \qquad (8-4)$$

The curve fitting is shown in Figure 8.3. The unit peak discharge decreases with $A\,R\,F_p$.

3. Model Application Using Calibrated Parameters

Table 8.2 lists the flood peaks calculated from the SCS model using the calibrated runoff curve number and unit peak discharge, in which P is the 24-hour rainfall at a certain return period derived from the LADOTD 24--hour rainfall frequency maps *[12]*; R is the net 24-hour runoff at that return period calculated

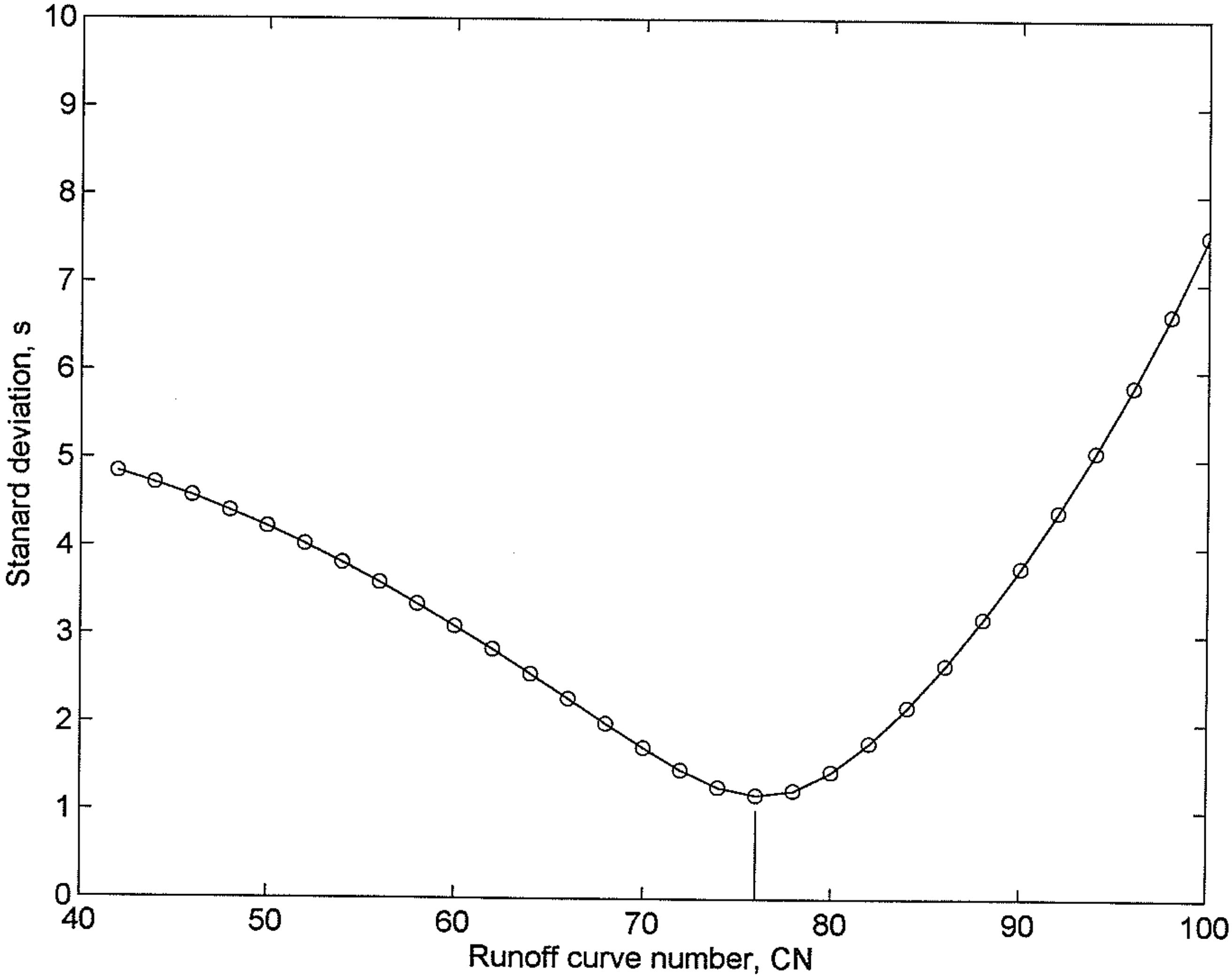

Figure 8.1
Calibration of runoff curve number for the Ward Creek watershed

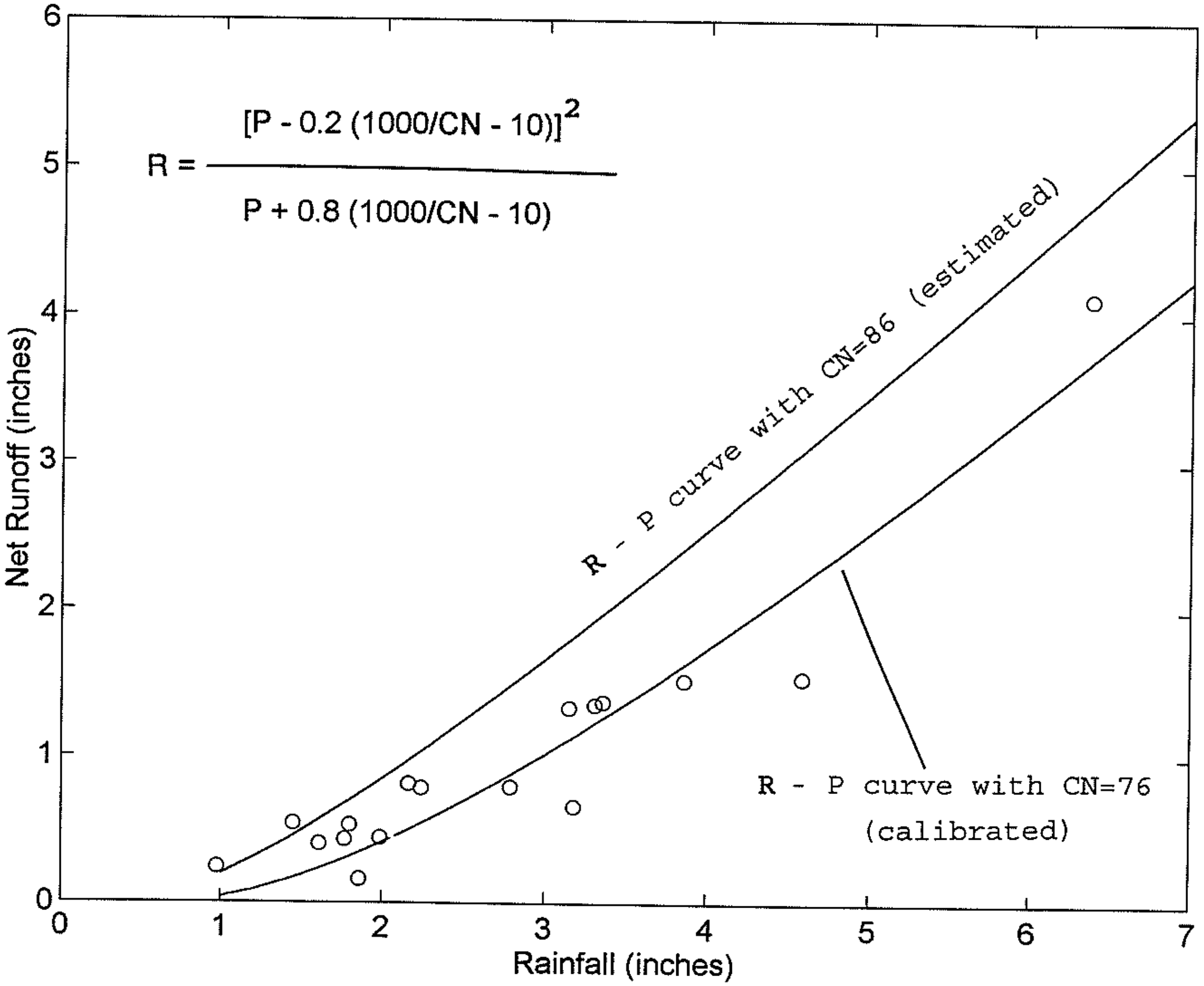

Figure 8.2
Comparison of the estimated runoff curve number with the calibrated runoff curve number

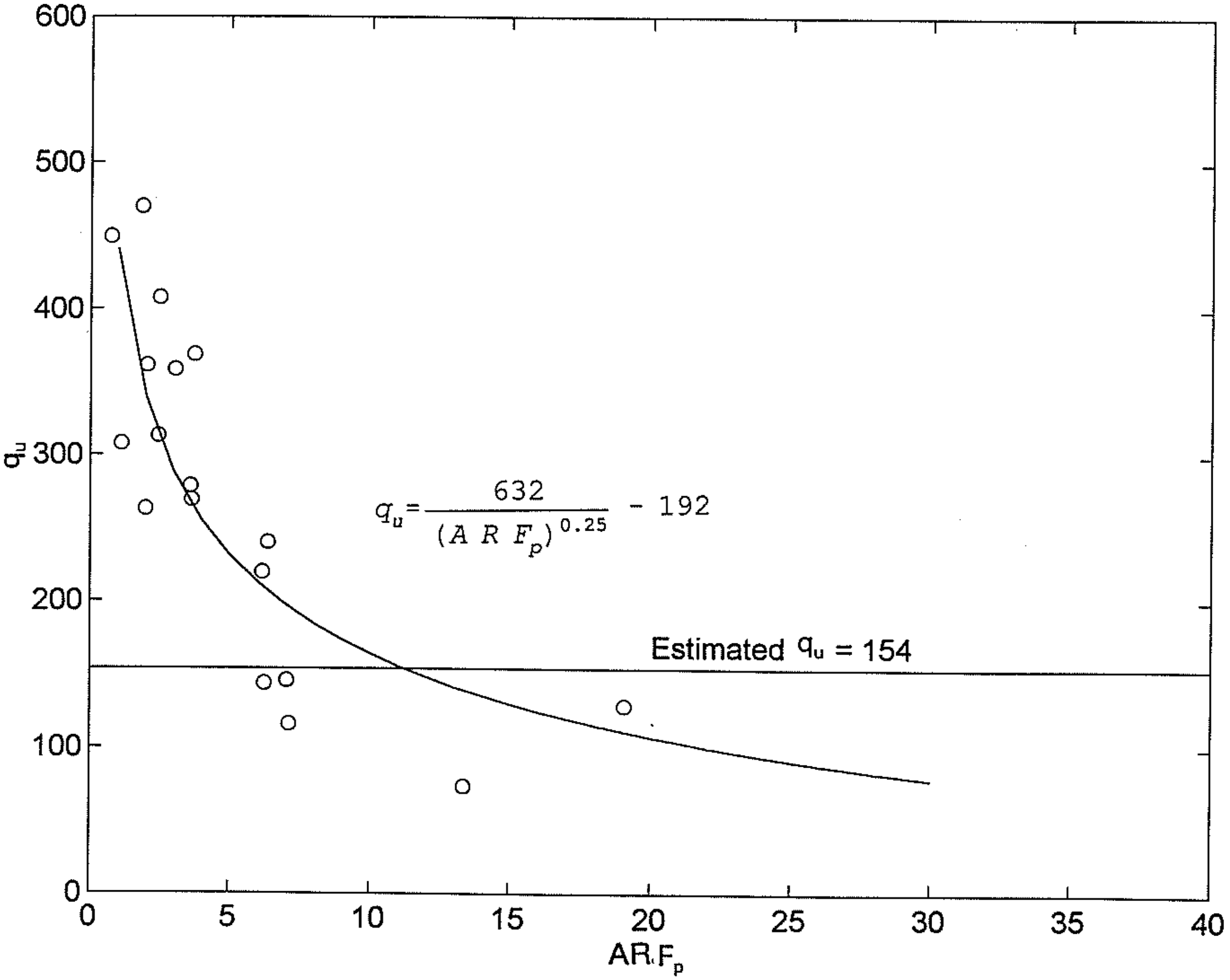

Figure 8.3
Calibration of unit peak discharge for the Ward Creek watershed

using Equation (5-7) with the curve number equal to 76; and q_u is the unit peak discharge calculated using Equation (8-4). The peak runoff rates, Q_p, at the return periods of 2, 5, 10, 25, 50, and 100 years calculated using Equation (5-8) are 1667, 2060, 2203, 2345, 2377, and 2333 cfs, respectively.

Table 8.2

Flood calculation using the SCS model with parameter calibration

	Return period (years)					
	2	5	10	25	50	100
P (in)	4.66	6.54	7.61	9.52	11.27	13.05
R (in)	2.258	3.851	4.804	6.558	8.203	9.901
q_u	190	135	110	86.1	72.4	59.7
Q_p(cfs)	1667	2060	2203	2345	2377	2333

Compared with the flood peaks derived using the WRC procedure, the relative errors of the flood peaks determined using the SCS model with parameter calibration are 11.4, 5.9, 1.0, -3.3, -7.7, and -13.8 percent, respectively. The relative errors of the flood peaks calculated using the SCS model without parameter calibration (in Table 7.3) are 50.2, 80.4, 94.5, 129.6, 163.7, and 197.4 percent, respectively. The RRMSE defined in Equation (7-6) for the SCS method with parameter calibration is 0.070, compared with 1.30 for the SCS model without parameter calibration. Overall, flood prediction by the SCS model using short-term field data calibration can be significantly improved as compared with the parameter estimation procedure suggested by the TR-55 manual *[6]*. The problem is that the calculated 50-year flood is higher than 100-year flood. This is because of the error in parameter calibration at 50- and 100-year return periods. Since the most severe rainfall storm used for parameter calibration in this study is equivalent to five-year return period (see Table 8.1), the calculated flood peaks at 2-, 5-, 10-, and 25-year are more reliable. In case the 50-year or 100-year flood is needed for a design application, the 50-year and 100-year floods may be corrected by extrapolation. In Figure 8.4, the regression relation between flood peak and return period is determined using

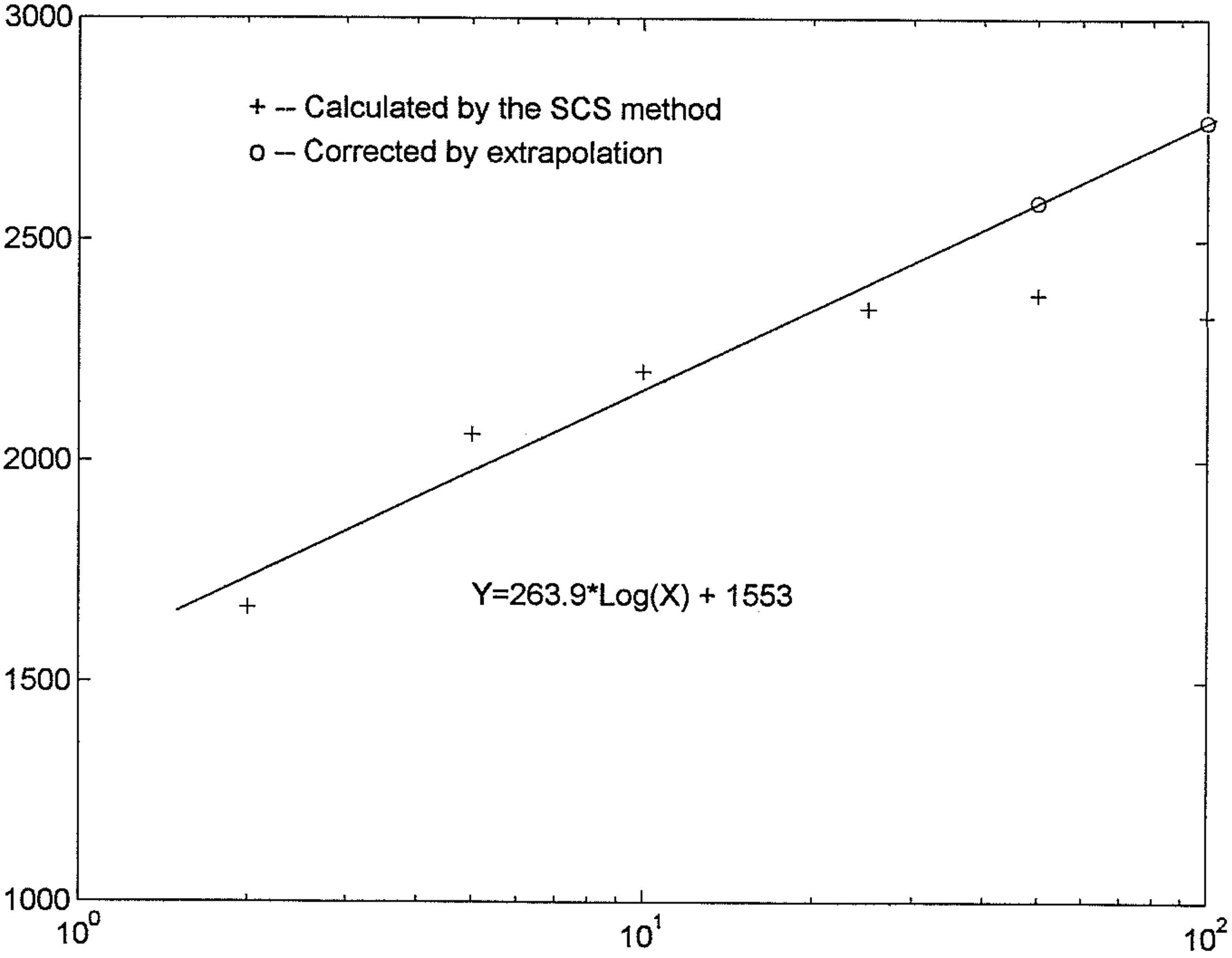

Figure 8.4
Correction of 50- and 100-year flood peaks by extrapolation

four points at 2-, 5-, 10-, and 25-year return periods. The corrected flood peaks at 50- and 100-year return periods determined using extrapolation are 2585 and 2768 cfs, respectively, which are closer to the results determined using the WRC procedure (see Table 7.3).

CHAPTER 9
CONCLUSION

In this study, eight flood prediction models for ungauged watersheds are applied to the Ward Creek watershed, and the results are compared with those derived using long-term stream gauging records by following the U.S. Water Resources Council procedure. It is found that the USGS 7-parameter model, the USGS 3-parameter model, the Lowe model, and the Neely model have better accuracy than the others. The Lee model was developed using watershed data from Louisiana, Mississippi and Arkansas, however, the model overestimates flood magnitudes for the Ward Creek watershed. The Louisiana Regional GEV-PWM and the Louisiana regional GEV-OPT models are simple to apply because only drainage area and watershed location are needed. They may be used for quick and rough estimation of flood peaks. The SCS model is most widely used for flood prediction. However, the accuracy of flood prediction for the Ward Creek watershed using the SCS model is low. The RRMSE defined in Equation (7-6) is as high as 1.30 and the relative errors of the peak discharge prediction at all six frequencies are 50.2, 80.4, 94.5, 129.6, 163.7, and 197.4 percent, respectively. Errors in parameter estimation are substantial because the model was not calibrated using local data.

This study demonstrates that the accuracy of peak discharge prediction using the SCS model can be significantly improved if parameters are calibrated using short-term field data. With the runoff curve number and unit peak discharge calibrated using two-year rainfall-runoff data for the Ward Creek watershed, the RRMSE defined in Equation (7-6) is reduced to 0.07 and the relative errors of the peak discharge prediction at all six frequencies are 11.4, 5.9, 1.0, -3.3, -7.7, and -13.8 percent, respectively.

CHAPTER 10
RECOMMENDATION

To estimate flood peaks from a watershed, it is of vital importance to choose an appropriate model of flood prediction. The selection of a flood prediction model depends on the watershed data availability and required accuracy.

1. For quick and approximate estimation of flood peaks with known drainage area and watershed location in Louisiana, the Louisiana Regional GEV-PWM or the GEV-OPT model may be used.

2. If the watershed geometry, land coverage and local climatic data are known, one of the four models (the two USGS models, the Lowe model and the Neely model) may be used. One may also use all the four models and take the average of the model results.

3. If accurate flood prediction is technically necessary and economically justified, a temporary network of rain gauges and flowmeter may be set up to obtain rainfall-runoff data for one to two years. The SCS model is be applied with the parameters calibrated using the short-term field data. This study has shown that the accuracy of the SCS model can be significantly improved with the runoff curve number and unit peak discharge calibrated using short-term rainfall-runoff data. The procedure is (1) calibrate runoff curve number using 24-hour rainfall and net runoff data; (2) develop a unit peak discharge curve using peak discharge and net runoff data; (3) find 24-hour rainfall at the return periods of 2, 5, 10, 25, 50, and 100 years using 24-hour rainfall frequency maps or I-D-F curves; (4) calculate net runoff at each frequency using Equation (5-7) in this report with calibrated runoff curve number; (5) determine unit peak discharge at each frequency using the calibrated unit peak discharge curve; and (6) compute peak discharge at each frequency using Equation (5-8) in this report.

4. If a watershed has long-term stream gauging data but has undergone significant hydrological changes, the flood peaks may be determined using the SCS

model with parameter calibrated using the most recent stream gauging data and local rainfall data.

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APPENDIX 1

PICTURES OF RAIN GAUGE AND FLOWMETER

(a) ISCO 674L rain gauge

(b) American Sigma 950 flowmeter

APPENDIX 2

TIME OF CONCENTRATION CALCULATION FOR THE WARD CREEK WATERSHED

Time of concentration can be estimated by the TR-55 method *[6]*. Figure A.2 shows the ranges of three types of surface flows (sheet flow, shallow concentrated flow, and open channel flow) and locations of eight cross-sections along the main channel of Ward Creek.

For sheet flows, the following equation *[13]* is used,

$$T_c = \frac{0.42\,(nL)^{0.8}}{P_2^{0.5} S^{0.4}} \qquad \text{(A-1)}$$

where the Manning's roughness coefficient (n) was chosen as 0.05 considering that the drainage area is composed of paved surface and short-grass surface, the overland flow length (L) is 300 feet, the average slope (S) is 0.001, and the 2-year 24-hour rainfall (P_2) is 4.66 inches determined using Louisiana 24-hour rainfall frequency maps *[12]*. The travel time of the sheet flow is 26.8 minutes as calculated using Equation (A-1).

For shallow concentrated flows, two equations were developed based on the Chezy-Manning equation with different assumptions of the Manning roughness coefficient (n) and hydraulic radius (r_h). With the assumptions of the Manning roughness coefficient $n=0.05$ and hydraulic radius $r_h=0.4$ ft for unpaved surfaces, and $n=0.025$ and $r_h=0.2$ ft for paved surfaces, the following equations are used to estimate the time of concentration,

$$T_c = \frac{L/60}{16.1345\sqrt{s}} \quad \textit{unpaved} \qquad \text{(A-2)}$$

$$T_c = \frac{L/60}{20.3282\sqrt{s}} \quad \textit{paved} \qquad \text{(A-3)}$$

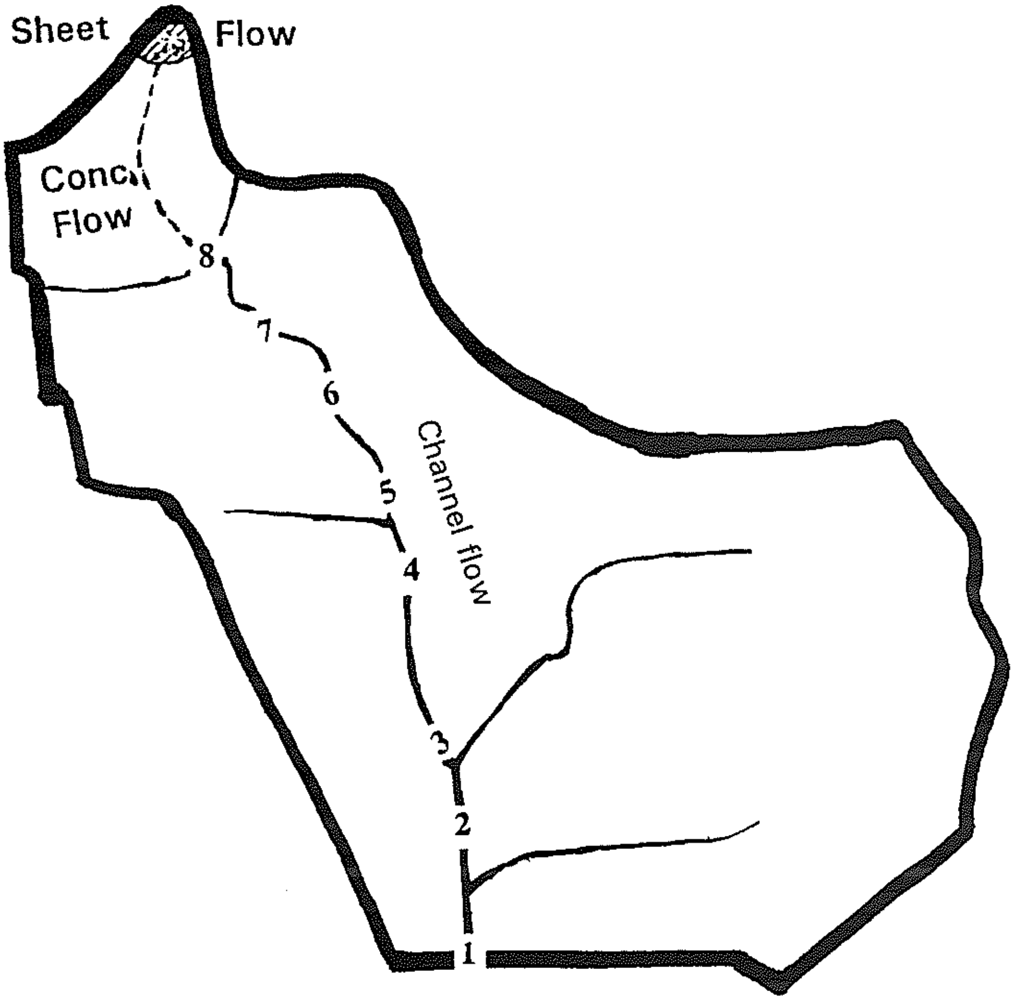

Figure A.2
Flow path for calculating time of concentration for the Ward Creek watershed

As shown in Figure A.2, the length of the shallow concentrated flow for the Ward Creek watershed is 4000 ft and the average land slope is 0.00127. By taking the average values of the time of concentration computed from Equations (A-2) and (A-3), the travel time for the shallow concentrated flow is 104.0 minutes.

To estimate travel time for channel flow, the main channel is divided into eight sections. Figure A.2 shows the locations of the eight cross-sections and Table A.1 lists the geometric parameters of each cross-section. The discharge at cross-section 8 is estimated by using the Rational Formula. The drainage area above cross-section 8 is about 256 acres. The runoff coefficient is estimated as 0.35 based on single-family residential area. The two-year rainfall itensity during time of concentration of 26.8 + 104.0 = 131 minutes computed using the I-D-F curve in the LADOTD Hydraulcs Manual *[11]* is I = 1.355 in/hr. The discharge at cross-section 8 computed using the Ration Formula is 121.3 cfs. The mean annual maximum discharge at cross-section 1 is estimated using Equation (5-9a) at 1022 cfs. Water discharges at other cross-sections were calculated using the total channel length (including tributaries) above the cross-section as the weight by the following equation:

$$Q_i = Q_8 + \frac{\sum_{j=i}^{8} L_j}{\sum_{j=1}^{8} L_j} (Q_1 - Q_8) \tag{A-4}$$

where L_j is the total channel length including tributaries between two successive cross-sections, j and j + 1.

Flow velocity between two cross-sections is calculated using the Chezy-Manning equation by using average channel geometries and flow discharges. As a result, the travel time through the main channel is 50.9 minutes. The result of the calculation is listed in Table A.1. The time of concentration of the entire watershed is 26.8 + 104.2 + 50.9 = 181.9 minutes or approximately 3.0 hours.

Table A.1
Estimation of travel time through the main channel of Ward Creek

Cross-section no.	1	2	3	4	5	6	7	8
Station no.	7 + 12.5	32+ 1.0	41+ 95.2	73+ 50	87+ 17.5	110+ 50	124+ 78	151 +79
Discharge (cfs)	1022	821	507	419	302	237	197	121
b (ft)	24	18	18	14	12	8	8	8
Z (ft/ft)	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5
E1 (ft)	31.02	33	33.95	36.63	37.67	41.08	42.22	50
E2 (ft)	44	46	49	48.5	49	52	53	54.5
Distance (ft)	--	2488	995	3155	1388	2333	1428	2701
Tributary length (ft)	4724	10236	0	2835	0	0	0	0
Slope (%)	--	0.08	0.095	0.085	0.076	0.146	0.08	0.288
Avg. b	--	21	18	16	13	10	8	8
Avg. n	--	0.016	0.016	0.016	0.016	0.016	0.016	0.025
Avg. Q	--	921.2	663.8	463	360.4	269.2	216.7	159
Flow depth (ft)	--	5.11	4.37	3.91	3.87	3.11	3.57	3.93
Flow area (sq ft)	--	146.5	107.3	85.46	72.8	45.68	47.59	54.6
Velocity (ft/sec)	--	6.29	6.19	5.42	4.95	5.89	4.55	2.91
Travel time (minutes)	--	6.59	2.68	9.7	4.6	6.6	5.23	15.47

Note: Watershed information is from East Baton Rouge Parish Department of Public Works.

APPENDIX 3

STAGE AND DISCHARGE DATA FOR WARD CREEK AT GOVERNMENT ST (1996)

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
5	23	6:30	0.167	0.270	4.068	1.10
5	23	6:45	0.224	1.209	5.477	6.62
5	23	7:00	0.273	1.122	6.698	7.51
5	23	7:15	0.280	0.997	6.873	6.85
5	23	7:30	0.273	0.926	6.698	6.20
5	23	7:45	0.271	0.764	6.648	5.08
5	23	8:00	0.270	0.517	6.623	3.42
5	23	8:15	0.269	0.444	6.598	2.93
5	23	8:30	0.267	0.364	6.548	2.38
5	23	8:45	0.258	0.327	6.323	2.07
5	23	9:00	0.249	0.130	6.099	0.79
5	23	9:15	0.230	0.009	5.626	0.05
5	23	9:30	0.206	0.068	5.031	0.34
5	23	9:45	0.176	0.069	4.290	0.30
5	23	15:00	0.173	0.219	4.216	0.92
5	23	15:15	0.173	0.389	4.216	1.64
5	23	15:30	0.183	0.232	4.462	1.04
5	23	15:45	0.189	0.142	4.610	0.65
5	23	16:00	0.191	0.155	4.660	0.72
5	23	16:15	0.198	0.054	4.833	0.26
5	23	16:30	0.202	0.023	4.932	0.11
5	23	16:45	0.204	0.040	4.981	0.20
5	23	17:00	0.200	0.108	4.882	0.53
5	23	17:15	0.206	0.064	5.031	0.32
5	23	17:30	0.207	0.064	5.056	0.32
5	23	17:45	0.207	0.144	5.056	0.73
5	23	18:00	0.209	0.117	5.105	0.60
5	23	18:15	0.200	0.331	4.882	1.62
5	23	18:30	0.186	0.545	4.536	2.47
5	23	18:45	0.188	0.493	4.586	2.26
5	23	19:00	0.195	0.300	4.759	1.43
5	23	19:15	0.191	0.352	4.660	1.64
5	23	19:30	0.191	0.316	4.660	1.47
5	23	19:45	0.183	0.532	4.462	2.37
5	23	20:00	0.182	0.336	4.438	1.49
5	23	20:15	0.170	0.501	4.142	2.07
5	29	12:15	0.735	1.533	18.596	28.51
5	29	12:30	0.985	1.891	25.329	47.90
5	29	12:45	1.331	2.301	34.991	80.51
5	29	13:00	1.769	2.412	47.792	115.27
5	29	13:15	2.025	2.498	55.569	138.81
5	29	13:30	2.108	2.593	58.137	150.75
5	29	13:45	2.067	2.779	56.866	158.03
5	29	14:00	2.000	2.842	54.800	155.74
5	29	14:15	1.906	2.646	51.927	137.40
5	29	14:30	1.769	2.676	47.792	127.89
5	29	14:45	1.609	2.716	43.042	116.90
5	29	15:00	1.441	2.556	38.146	97.50
5	29	15:15	1.300	2.485	34.109	84.76
5	29	15:30	1.171	2.408	30.474	73.38
5	29	15:45	1.058	1.593	27.335	43.54
5	29	16:00	0.958	2.364	24.592	58.14
5	29	16:15	0.868	2.324	22.152	51.48
5	29	16:30	0.796	2.273	20.219	45.96
5	29	16:45	0.733	2.229	18.543	41.33
5	29	17:00	0.679	2.229	17.116	38.15
5	29	17:15	0.628	2.191	15.777	34.57
5	29	17:30	0.587	2.128	14.707	31.30
5	29	17:45	0.552	1.990	13.798	27.46
5	29	18:00	0.520	1.987	12.970	25.77
5	29	18:15	0.485	1.827	12.069	22.05
5	29	18:30	0.452	1.770	11.223	19.87
5	29	18:45	0.430	1.289	10.661	13.74
5	29	19:00	0.402	1.448	9.948	14.41
5	29	19:15	0.383	0.979	9.466	9.27
5	29	19:30	0.367	0.312	9.061	2.83
5	29	19:45	0.349	0.212	8.606	1.82
5	29	20:00	0.324	0.308	7.976	2.46
5	29	20:15	0.308	0.103	7.574	0.78

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
5	29	20:30	0.281	0.700	6.898	4.83
5	29	20:45	0.273	0.078	6.698	0.52
5	29	21:00	0.253	0.207	6.198	1.28
5	29	21:15	0.234	0.241	5.726	1.38
5	29	22:00	0.194	0.157	4.734	0.74
5	29	22:15	0.172	0.207	4.191	0.87
6	7	16:00	0.238	1.353	5.825	7.88
6	7	16:15	0.674	1.373	16.984	23.32
6	7	16:30	1.930	2.747	52.658	144.65
6	7	16:45	3.061	2.810	89.263	250.83
6	7	17:00	3.009	3.063	87.486	267.97
6	7	17:15	2.635	2.833	74.977	212.41
6	7	17:30	2.236	2.646	62.142	164.43
6	7	17:45	1.871	2.631	50.865	133.83
6	7	18:00	1.569	2.577	41.868	107.89
6	7	18:15	1.317	2.374	34.593	82.12
6	7	18:30	1.112	2.321	28.830	66.91
6	7	18:45	0.948	2.208	24.320	53.70
6	7	19:00	0.814	2.072	20.701	42.89
6	7	19:15	0.707	2.067	17.854	36.90
6	7	19:30	0.617	1.949	15.489	30.19
6	7	19:45	0.543	1.910	13.565	25.91
6	7	20:00	0.481	1.833	11.967	21.93
6	7	20:15	0.429	1.786	10.636	19.00
6	7	20:30	0.383	1.713	9.466	16.22
6	7	20:45	0.347	1.682	8.556	14.39
6	7	21:00	0.311	1.614	7.649	12.35
6	7	21:15	0.281	1.332	6.898	9.19
6	7	21:30	0.259	1.069	6.348	6.79
6	7	21:45	0.250	0.385	6.124	2.36
6	7	22:00	0.210	1.571	5.130	8.06
6	7	22:15	0.205	0.851	5.006	4.26
6	7	22:30	0.183	1.474	4.462	6.58
6	7	22:45	0.283	1.695	6.948	11.78
6	7	23:00	0.808	2.143	20.540	44.02
6	7	23:15	1.237	2.452	32.327	79.27
6	7	23:30	1.436	2.519	38.002	95.73
6	7	23:45	1.530	2.649	40.728	107.89
6	8	0:00	1.516	2.600	40.320	104.83
6	8	0:15	1.436	2.534	38.002	96.30
6	8	0:30	1.319	2.468	34.650	85.52
6	8	0:45	1.190	2.508	31.006	77.76
6	8	1:00	1.061	2.334	27.418	63.99
6	8	1:15	0.945	2.238	24.238	54.24
6	8	1:30	0.840	2.241	21.399	47.95
6	8	1:45	0.747	2.103	18.914	39.78
6	8	2:00	0.665	2.072	16.747	34.70
6	8	2:15	0.597	2.028	14.967	30.35
6	8	2:30	0.537	1.947	13.410	26.11
6	8	2:45	0.484	1.825	12.044	21.98
6	8	3:00	0.436	1.812	10.814	19.60
6	8	3:15	0.395	1.711	9.771	16.72
6	8	3:30	0.359	1.661	8.859	14.71
6	8	3:45	0.328	1.498	8.077	12.10
6	8	4:00	0.306	0.825	7.524	6.21
6	8	4:15	0.289	0.407	7.098	2.89
6	8	4:30	0.264	0.257	6.473	1.66
6	8	4:45	0.247	0.196	6.049	1.19
6	8	5:00	0.226	0.247	5.527	1.37
6	8	5:15	0.208	0.146	5.080	0.74
6	8	5:30	0.195	0.075	4.759	0.36
6	14	10:45	0.172	1.242	4.191	5.21
6	14	11:00	0.513	1.459	12.790	18.66
6	14	11:15	0.898	1.758	22.962	40.37
6	14	11:30	0.813	1.732	20.674	35.81
6	14	11:45	0.798	1.843	20.273	37.36
6	14	12:00	1.227	1.588	32.045	50.89
6	14	12:15	2.236	1.979	62.142	122.98
6	14	12:30	3.177	2.759	93.257	257.30
7	3	16:00	0.187	0.953	4.561	4.35
7	3	16:15	0.969	0.794	24.892	19.76
7	3	16:30	2.797	2.457	80.338	197.39
7	3	16:45	3.972-	2.991	121.835	364.41
7	3	17:00	4.040	3.108	124.377	386.56
7	3	17:15	3.567	3.202	107.014	342.66
7	3	17:30	3.007	2.914	87.418	254.74

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
7	3	17:45	2.513	2.888	70.996	205.04
7	3	18:00	2.100	2.731	57.889	158.09
7	3	18:15	1.768	2.592	47.762	123.80
7	3	18:30	1.499	2.495	39.826	99.37
7	3	18:45	1.288	2.331	33.769	78.72
7	3	19:00	1.119	2.216	29.024	64.32
7	3	19:15	0.987	2.116	25.384	53.71
7	3	19:30	0.878	2.009	22.422	45.05
7	3	19:45	0.792	1.998	20.113	40.19
7	3	20:00	0.719	1.888	18.172	34.31
7	3	20:15	0.659	1.869	16.590	31.01
7	3	20:30	0.606	1.818	15.202	27.64
7	3	20:45	0.562	1.815	14.057	25.51
7	3	21:00	0.522	1.762	13.022	22.94
7	3	21:15	0.488	1.724	12.146	20.94
7	3	21:30	0.454	1.584	11.274	17.86
7	3	21:45	0.430	1.432	10.661	15.27
7	3	22:00	0.410	0.802	10.152	8.14
7	3	22:15	0.397	0.314	9.821	3.08
7	3	22:30	0.374	0.195	9.238	1.80
7	3	22:45	0.357	0.202	8.808	1.78
7	3	23:00	0.342	0.013	8.430	0.11
7	3	23:15	0.316	0.625	7.775	4.86
7	3	23:30	0.307	0.357	7.549	2.69
7	3	23:45	0.297	0.171	7.298	1.25
7	7	16:15	0.214	1.350	5.229	7.06
7	7	16:30	0.469	1.907	11.659	22.23
7	7	16:45	1.309	2.485	34.365	85.40
7	7	17:00	1.611	2.511	43.101	108.23
7	7	17:15	1.560	2.430	41.605	101.10
7	7	17:30	1.414	2.380	37.368	88.94
7	7	17:45	1.251	2.247	32.722	73.53
7	7	18:00	1.097	2.045	28.413	58.11
7	7	18:15	0.967	1.984	24.838	49.28
7	7	18:30	0.857	1.906	21.856	41.66
7	7	18:45	0.766	1.877	19.419	36.45
7	7	19:00	0.691	1.796	17.432	31.31
7	7	19:15	0.626	1.727	15.725	27.16
7	7	19:30	0.572	1.725	14.317	24.70
7	7	19:45	0.528	1.689	13.177	22.26
7	7	20:00	0.488	1.648	12.146	20.02
7	7	20:15	0.452	1.615	11.223	18.13
7	7	20:30	0.422	1.617	10.457	16.91
7	7	20:45	0.398	1.239	9.847	12.20
7	7	21:00	0.373	1.212	9.213	11.17
7	7	21:15	0.352	0.997	8.682	8.66
7	7	21:30	0.342	0.489	8.430	4.12
7	7	21:45	0.321	0.606	7.901	4.79
7	7	22:00	0.312	0.080	7.675	0.61
7	7	22:15	0.298	0.117	7.323	0.86
7	7	22:30	0.285	0.272	6.998	1.90
7	7	22:45	0.265	0.455	6.498	2.96
7	7	23:00	0.255	0.510	6.248	3.19
7	7	23:15	0.255	0.155	6.248	0.97
7	7	23:30	0.248	0.052	6.074	0.32
7	7	23:45	0.240	0.161	5.875	0.95
7	13	12:00	0.255	0.661	6.248	4.13
7	13	12:15	0.526	0.456	13.125	5.99
7	13	12:30	0.484	1.288	12.044	15.51
7	13	12:45	0.485	1.469	12.069	17.73
7	13	13:00	0.433	1.481	10.738	15.90
7	13	13:15	0.408	1.514	10.101	15.29
7	13	13:30	0.513	1.766	12.790	22.59
7	13	13:45	0.612	1.712	15.359	26.29
7	13	14:00	0.615	1.748	15.437	26.98
7	13	14:15	0.582	1.736	14.577	25.31
7	13	14:30	0.539	1.738	13.461	23.40
7	13	14:45	0.493	1.781	12.275	21.86
7	13	15:00	0.451	1.665	11.198	18.64
7	13	15:15	0.420	1.460	10.406	15.19
7	13	15:30	0.398	0.681	9.847	6.71
7	13	15:45	0.373	0.438	9.213	4.04
7	13	16:00	0.356	0.119	8.783	1.05
7	13	19:30	0.221	0.154	5.403	0.83
7	13	19:45	0.209	0.331	5.105	1.69
7	13	20:00	0.203	0.307	4.957	1.52

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
7	13	20:15	0.202	0.232	4.932	1.14
7	13	20:30	0.199	0.065	4.858	0.32
7	13	20:45	0.190	0.333	4.635	1.54
7	13	21:00	0.187	0.312	4.561	1.42
7	13	21:15	0.190	0.052	4.635	0.24
7	13	21:30	0.183	0.058	4.462	0.26
7	13	21:45	0.175	0.018	4.265	0.08
7	14	11:45	0.229	0.703	5.601	3.94
7	14	12:00	0.483	1.461	12.018	17.56
7	14	12:15	0.525	1.409	13.100	18.46
7	14	12:30	0.518	1.323	12.919	17.09
7	14	12:45	0.497	1.334	12.378	16.51
7	14	13:00	0.465	1.167	11.556	13.49
7	14	13:15	0.439	0.969	10.891	10.55
7	14	13:30	0.413	0.969	10.228	9.91
7	14	13:45	0.400	0.574	9.898	5.68
7	14	14:00	0.386	0.412	9.542	3.93
7	14	14:15	0.369	0.321	9.112	2.92
7	14	14:30	0.363	0.046	8.960	0.41
7	14	14:45	0.347	0.073	8.556	0.62
7	14	15:00	0.329	0.117	8.102	0.95
7	14	15:15	0.319	0.069	7.850	0.54
7	14	15:30	0.305	0.076	7.499	0.57
7	14	15:45	0.297	0.076	7.298	0.55
7	14	16:00	0.284	0.084	6.973	0.59
7	14	16:15	0.276	0.073	6.773	0.49
7	14	16:30	0.268	0.047	6.573	0.31
7	14	16:45	0.263	0.036	6.448	0.23
7	14	17:00	0.256	0.019	6.273	0.12
7	17	17:00	0.203	0.760	4.957	3.77
7	17	17:15	0.256	0.868	6.273	5.45
7	17	17:30	0.262	0.844	6.423	5.42
7	17	17:45	0.264	0.932	6.473	6.03
7	17	18:00	0.465	1.537	11.556	17.76
7	17	18:15	0.675	1.894	17.010	32.22
7	17	18:30	0.706	1.959	17.828	34.92
7	17	18:45	0.673	1.888	16.958	32.02
7	17	19:00	0.620	1.768	15.568	27.52
7	17	19:15	0.567	1.683	14.187	23.88
7	17	19:30	0.519	1.573	12.945	20.36
7	17	19:45	0.478	1.553	11.890	18.46
7	17	20:00	0.442	1.497	10.968	16.42
7	17	20:15	0.410	1.468	10.152	14.90
7	17	20:30	0.381	1.371	9.415	12.91
7	17	20:45	0.354	1.338	8.732	11.68
7	17	21:00	0.331	1.163	8.152	9.48
7	17	21:15	0.311	1.035	7.649	7.92
7	17	21:30	0.294	0.839	7.223	6.06
7	17	21:45	0.274	0.886	6.723	5.96
7	17	22:00	0.259	0.723	6.348	4.59
7	17	22:15	0.255	0.571	6.248	3.57
7	17	22:30	0.243	0.399	5.949	2.37
7	17	22:45	0.236	0.286	5.775	1.65
7	17	23:00	0.231	0.159	5.651	0.90
7	18	17:45	0.193	0.837	4.709	3.94
7	18	18:00	0.385	1.320	9.517	12.56
7	18	18:15	0.488	1.685	12.146	20.47
7	18	18:30	0.816	2.337	20.755	48.50
7	18	18:45	0.967	2.422	24.838	60.16
7	18	19:00	0.991	2.331	25.494	59.43
7	18	19:15	0.943	2.252	24.184	54.46
7	18	19:30	0.855	2.090	21.802	45.57
7	18	19:45	0.759	1.964	19.233	37.77
7	18	20:00	0.668	1.847	16.826	31.08
7	18	20:15	0.584	1.768	14.629	25.86
7	18	20:30	0.518	1.666	12.919	21.52
7	18	20:45	0.462	1.577	11.479	18.10
7	18	21:00	0.414	1.469	10.254	15.06
7	18	21:15	0.376	1.400	9.289	13.00
7	18	21:30	0.342	1.315	8.430	11.08
7	18	21:45	0.312	1.199	7.675	9.20
7	18	22:00	0.292	1.126	7.173	8.08
7	18	22:15	0.267	0.972	6.548	6.36
7	18	22:30	0.254	0.787	6.223	4.90
7	18	22:45	0.238	0.697	5.825	4.06
7	18	23:00	0.237	0.253	5.800	1.47

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
7	18	23:15	0.231	0.088	5.651	0.50
7	18	23:30	0.219	0.098	5.353	0.52
7	18	23:45	0.205	0.112	5.006	0.56
7	31	16:00	0.906	0.540	23.179	12.52
7	31	16:15	2.517	2.561	71.126	182.15
7	31	16:30	3.403	3.702	101.168	374.52
7	31	16:45	3.644	1.842	109.790	202.23
7	31	17:00	3.468	4.435	103.474	458.91
7	31	17:15	2.937	2.818	85.042	239.65
7	31	17:30	2.521	3.937	71.256	280.53
7	31	17:45	2.123	3.879	58.604	227.32
7	31	18:00	1.773	3.283	47.912	157.30
7	31	18:15	1.493	3.367	39.652	133.51
7	31	18:30	1.263	2.932	33.061	96.93
7	31	18:45	1.089	2.856	28.192	80.52
7	31	19:00	0.927	2.323	23.749	55.17
7	31	19:15	0.817	2.435	20.781	50.60
7	31	19:30	0.727	2.379	18.384	43.73
7	31	19:45	0.648	2.794	16.301	45.54
7	31	20:00	0.578	2.471	14.473	35.76
7	31	20:15	0.526	2.392	13.125	31.40
7	31	20:30	0.468	2.302	11.633	26.78
7	31	20:45	0.431	2.285	10.687	24.42
7	31	21:00	0.391	2.070	9.669	20.01
7	31	21:15	0.354	1.769	8.732	15.45
7	31	21:30	0.324	1.975	7.976	15.75
7	31	21:45	0.299	1.870	7.348	13.74
7	31	22:00	0.278	2.019	6.823	13.77
7	31	22:15	0.251	1.816	6.149	11.17
7	31	22:30	0.234	1.920	5.726	10.99
7	31	22:45	0.217	1.708	5.304	9.06
7	31	23:00	0.202	1.599	4.932	7.89
8	1	10:30	0.167	1.834	4.068	7.46
8	1	10:45	0.399	2.325	9.872	22.95
8	1	11:00	0.529	2.262	13.203	29.86
8	1	11:15	0.674	2.243	16.984	38.10
8	1	11:30	0.569	1.746	14.239	24.86
8	1	11:45	0.533	1.861	13.306	24.76
8	1	12:00	0.582	2.392	14.577	34.87
8	1	12:15	0.691	2.137	17.432	37.25
8	1	12:30	0.796	2.977	20.219	60.19
8	1	12:45	2.675	3.181	76.292	242.69
8	1	13:00	4.254	3.318	132.477	439.56
8	1	13:15	4.861	3.589	156.278	560.88
8	1	13:30	4.471	4.146	140.845	583.94
8	1	13:45	3.825	3.785	116.393	440.55
8	1	14:00	3.179	3.776	93.326	352.40
8	1	14:15	2.648	4.332	75.404	326.65
8	1	14:30	2.223	4.023	61.733	248.35
8	1	14:45	1.873	3.416	50.925	173.96
8	1	15:00	1.600	4.018	42.778	171.88
8	1	15:15	1.362	3.368	35.876	120.83
8	1	15:30	1.180	3.348	30.726	102.87
8	1	15:45	1.041	3.157	26.866	84.82
8	1	16:00	0.910	3.127	23.287	72.82
8	1	16:15	0.816	3.080	20.755	63.92
8	1	16:30	0.727	2.775	18.384	51.01
8	1	16:45	0.646	2.630	16.248	42.73
8	1	17:00	0.582	2.358	14.577	34.37
8	1	17:15	0.533	2.569	13.306	34.18
8	1	17:30	0.489	2.440	12.172	29.70
8	1	17:45	0.446	2.386	11.070	26.41
8	1	18:00	0.410	2.130	10.152	21.62
8	1	18:15	0.368	2.165	9.086	19.67
8	2	13:45	1.270	3.474	33.259	115.54
8	2	14:00	1.994	3.708	54.616	202.52
8	2	14:15	2.225	3.848	61.796	237.79
8	2	14:30	2.305	3.862	64.324	248.42
8	2	14:45	2.327	4.088	65.023	265.81
8	2	15:00	2.290	4.172	63.848	266.38
8	2	15:15	2.273	3.934	63.310	249.06
8	2	15:30	2.217	4.256	61.544	261.93
8	2	15:45	2.062	3.897	56.711	221.00
8	2	16:00	1.870	4.224	50.834	214.72
8	2	16:15	1.637	3.631	43.867	159.28
8	2	16:30	1.428	3.720	37.771	140.51

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
8	2	16:45	1.246	3.421	32.581	111.46
8	2	17:00	1.073	3.454	27.749	95.85
8	2	17:15	1.169	3.234	30.418	98.37
8	2	17:30	1.281	3.192	33.570	107.16
8	2	17:45	1.372	3.767	36.163	136.22
8	2	18:00	1.446	3.690	38.291	141.29
8	2	18:15	1.438	3.762	38.060	143.18
8	2	18:30	1.353	3.715	35.619	132.32
8	2	18:45	1.225	3.274	31.989	104.73
8	2	19:00	1.104	3.308	28.608	94.63
8	2	19:15	0.976	3.153	25.083	79.09
8	2	19:30	0.856	2.935	21.829	64.07
8	2	19:45	0.757	2.851	19.180	54.68
8	2	20:00	0.684	2.677	17.247	46.17
8	2	20:15	0.609	2.631	15.280	40.20
8	2	20:30	0.552	2.574	13.798	35.52
8	2	20:45	0.507	2.360	12.635	29.82
8	2	21:00	0.461	2.444	11.454	27.99
8	2	21:15	0.433	2.433	10.738	26.13
8	2	21:30	0.394	2.330	9.745	22.71
8	2	21:45	0.376	2.013	9.289	18.70
8	2	22:00	0.345	2.194	8.505	18.66
8	2	22:15	0.316	2.118	7.775	16.47
8	2	22:30	0.302	2.100	7.424	15.59
8	2	22:45	0.293	2.093	7.198	15.07
8	2	23:00	0.286	1.935	7.023	13.59
8	2	23:15	0.276	1.909	6.773	12.93
8	2	23:30	0.268	1.986	6.573	13.05
8	2	23:45	0.256	2.132	6.273	13.37
8	3	0:00	0.264	2.035	6.473	13.17
8	3	0:15	0.263	1.957	6.448	12.62
8	3	0:30	0.273	2.007	6.698	13.44
8	3	0:45	0.282	1.993	6.923	13.80
8	3	1:00	0.270	2.124	6.623	14.07
8	3	1:15	0.259	2.015	6.348	12.79
8	3	1:30	0.233	1.859	5.701	10.60
8	3	1:45	0.220	1.574	5.378	8.46
8	6	11:30	0.167	1.235	4.068	5.02
8	6	11:45	0.784	1.385	19.899	27.56
8	6	12:00	1.121	2.478	29.080	72.06
8	6	12:15	1.166	2.666	30.334	80.87
8	6	12:30	1.266	3.131	33.146	103.78
8	6	12:45	1.218	2.728	31.792	86.73
8	6	13:00	1.151	2.927	29.915	87.56
8	6	13:15	1.203	2.984	31.371	93.61
8	6	13:30	1.218	3.056	31.792	97.16
8	6	13:45	1.143	3.066	29.692	91.04
8	6	14:00	1.028	2.841	26.508	75.31
8	6	14:15	0.896	2.792	22.908	63.96
8	6	14:30	0.770	2.485	19.526	48.52
8	6	14:45	0.673	2.558	16.958	43.38
8	6	15:00	0.599	2.237	15.020	33.60
8	6	15:15	0.518	2.136	12.919	27.59
8	6	15:30	0.462	2.161	11.479	24.81
8	6	15:45	0.415	2.116	10.279	21.75
8	6	16:00	0.367	2.052	9.061	18.59
8	6	16:15	0.333	1.987	8.203	16.30
8	6	16:30	0.306	2.025	7.524	15.24
8	6	16:45	0.276	1.912	6.773	12.95
8	6	17:00	0.255	1.768	6.248	11.05
8	6	17:15	0.234	1.879	5.726	10.76
8	6	17:30	0.214	1.831	5.229	9.57
8	6	17:45	0.199	1.743	4.858	8.47
8	7	14:30	0.415	1.807	10.279	18.57
8	7	14:45	0.445	1.963	11.044	21.68
8	7	15:00	0.349	1.763	8.606	15.17
8	7	15:15	0.275	1.821	6.748	12.29
8	7	15:30	0.335	2.121	8.253	17.50
8	7	15:45	0.407	2.217	10.076	22.34
8	7	16:00	0.519	2.216	12.945	28.69
8	7	16:15	0.567	2.320	14.187	32.91
8	7	16:30	0.556	2.213	13.902	30.76
8	7	16:45	0.518	2.119	12.919	27.38
8	7	17:00	0.470	2.084	11.684	24.35
8	7	17:15	0.428	2.086	10.610	22.13
8	7	17:30	0.377	2.081	9.314	19.38

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
8	7	17:45	0.342	1.929	8.430	16.26
8	7	18:00	0.308	1.881	7.574	14.25
8	7	18:15	0.281	1.940	6.898	13.38
8	7	18:30	0.250	1.710	6.124	10.47
8	7	18:45	0.228	1.818	5.577	10.14
8	7	19:00	0.209	1.821	5.105	9.30
8	7	19:15	0.208	0.000	5.080	0.00
8	7	19:30	0.199	0.000	4.858	0.00
8	9	14:30	0.223	1.794	5.452	9.78
8	9	14:45	0.752	2.517	19.047	47.94
8	9	15:00	0.940	2.591	24.102	62.45
8	9	15:15	0.922	2.298	23.613	54.26
8	9	15:30	0.832	2.213	21.184	46.88
8	9	15:45	0.734	2.206	18.569	40.96
8	9	16:00	0.639	2.091	16.065	33.59
8	9	16:15	0.553	1.977	13.824	27.33
8	9	16:30	0.500	2.174	12.455	27.08
8	9	16:45	0.446	1.986	11.070	21.98
8	9	17:00	0.411	1.876	10.177	19.09
8	9	17:15	0.368	1.803	9.086	16.38
8	9	17:30	0.341	1.873	8.404	15.74
8	9	17:45	0.314	1.913	7.725	14.78
8	9	18:00	0.288	1.745	7.073	12.34
8	9	18:15	0.264	1.736	6.473	11.24
8	9	18:30	0.241	1.393	5.900	8.22
8	9	18:45	0.227	1.714	5.552	9.52
8	9	19:00	0.207	1.307	5.056	6.61
8	9	19:15	0.195	1.437	4.759	6.84
8	9	19:30	0.167	1.377	4.068	5.60
8	9	19:45	0.190	0.000	4.635	0.00
8	10	14:15	0.419	1.721	10.381	17.87
8	10	14:30	1.145	2.515	29.748	74.82
8	10	14:45	1.507	2.620	40.058	104.95
8	10	15:00	1.497	2.898	39.768	115.25
8	10	15:15	1.373	2.732	36.191	98.87
8	10	15:30	1.223	2.701	31.933	86.25
8	10	15:45	1.056	2.525	27.280	68.88
8	10	16:00	0.924	2.436	23.667	57.65
8	10	16:15	0.808	2.461	20.540	50.55
8	10	16:30	0.691	2.479	17.432	43.21
8	10	16:45	2.733	1.919	78.210	150.08
8	10	17:00	3.509	2.879	104.936	302.11
8	10	17:15	3.439	3.621	102.443	370.95
8	10	17:30	3.029	3.035	88.169	267.59
8	10	17:45	2.738	3.343	78.375	262.01
8	10	18:00	2.401	3.728	67.386	251.21
8	10	18:15	2.068	2.951	56.897	167.90
8	10	18:30	1.795	3.536	48.572	171.75
8	10	18:45	1.583	3.038	42.278	128.44
8	10	19:00	1.394	3.313	36.793	121.90
8	10	19:15	1.231	2.967	32.158	95.41
8	10	19:30	1.089	2.855	28.192	80.49
8	10	19:45	0.960	2.661	24.647	65.58
8	10	20:00	0.861	2.954	21.963	64.88
8	10	20:15	0.766	2.829	19.419	54.94
8	10	20:30	0.674	2.635	16.984	44.75
8	10	20:45	0.596	2.426	14.941	36.25
8	10	21:00	0.541	2.486	13.513	33.59
8	10	21:15	0.492	2.331	12.249	28.55
8	10	21:30	0.450	2.289	11.172	25.57
8	10	21:45	0.414	2.102	10.254	21.55
8	10	22:00	0.378	2.189	9.339	20.44
8	10	22:15	0.352	2.027	8.682	17.60
8	10	22:30	0.329	2.000	8.102	16.20
8	10	22:45	0.310	2.011	7.624	15.33
8	10	23:00	0.275	1.859	6.748	12.54
8	10	23:15	0.254	1.655	6.223	10.30
8	10	23:30	0.242	1.818	5.925	10.77
8	11	9:45	0.597	1.800	14.967	26.94
8	11	10:00	0.959	2.558	24.619	62.98
8	11	10:15	1.571	2.864	41.927	120.08
8	11	10:30	1.899	3.266	51.714	168.90
8	11	10:45	2.137	3.570	59.040	210.77
8	11	11:00	2.220	3.827	61.639	235.89
8	11	11:15	2.139	3.367	59.102	199.00
8	11	11:30	2.024	3.841	55.538	213.32

Month	Date	Time (CDT)	Depth (ft)	Velocity (ft/sec)	Area (ft2)	Discharge (cfs)
8	11	11:45	1.856	3.547	50.411	178.81
8	11	12:00	1.685	3.343	45.288	151.40
8	11	12:15	1.527	3.112	40.641	126.47
8	11	12:30	1.354	3.121	35.648	111.26
8	11	12:45	1.220	3.190	31.848	101.60
8	11	13:00	1.082	3.032	27.998	84.89
8	11	13:15	0.955	2.959	24.510	72.53
8	11	13:30	0.858	2.770	21.883	60.62
8	11	13:45	0.770	2.808	19.526	54.83
8	11	14:00	0.697	2.626	17.590	46.19
8	11	14:15	0.629	2.424	15.803	38.31
8	11	14:30	0.580	2.570	14.525	37.33
8	11	14:45	0.530	2.391	13.229	31.63
8	11	15:00	0.488	2.393	12.146	29.07
8	11	15:15	0.453	2.230	11.249	25.09
8	11	15:30	0.416	2.251	10.305	23.20
8	11	15:45	0.391	2.092	9.669	20.23
8	11	16:00	0.358	2.089	8.833	18.45
8	11	16:15	0.343	2.005	8.455	16.95
8	11	16:30	0.319	1.950	7.850	15.31
8	11	16:45	0.294	1.841	7.223	13.30
8	11	17:00	0.282	1.988	6.923	13.76
8	11	17:15	0.256	1.832	6.273	11.49
8	11	17:30	0.247	1.802	6.049	10.90
8	11	17:45	0.231	1.686	5.651	9.53
8	11	18:00	0.218	1.783	5.328	9.50
8	12	6:45	0.265	1.769	6.498	11.49
8	12	7:00	0.482	2.292	11.992	27.49
8	12	7:15	0.531	2.428	13.255	32.18
8	12	7:30	0.607	2.518	15.228	38.34
8	12	7:45	0.678	2.581	17.089	44.11
8	12	8:00	0.736	2.684	18.622	49.98
8	12	8:15	0.765	2.790	19.393	54.11
8	12	8:30	0.755	2.411	19.127	46.11
8	12	8:45	0.739	2.566	18.702	47.99
8	12	9:00	0.712	2.295	17.986	41.28
8	12	9:15	0.657	2.380	16.537	39.36
8	12	9:30	0.603	2.535	15.124	38.34
8	12	9:45	0.554	2.372	13.850	32.85
8	12	10:00	0.506	2.319	12.609	29.24
8	12	10:15	0.463	2.219	11.505	25.53
8	12	10:30	0.426	2.265	10.559	23.92
8	12	10:45	0.385	2.042	9.517	19.43
8	12	11:00	0.352	1.996	8.682	17.33
8	12	11:15	0.327	1.885	8.052	15.18
8	12	11:30	0.304	1.924	7.474	14.38
8	12	11:45	0.284	1.814	6.973	12.65
8	12	12:00	0.261	1.797	6.398	11.50
8	12	12:15	0.257	1.876	6.298	11.82
8	12	12:30	0.251	1.774	6.149	10.91
8	12	12:45	0.242	1.817	5.925	10.76
8	12	13:00	0.226	1.663	5.527	9.19
8	12	13:15	0.216	1.581	5.279	8.35
8	12	13:30	0.214	1.819	5.229	9.51
8	12	13:45	0.201	1.548	4.907	7.60
8	12	14:00	0.197	1.615	4.808	7.77
8	12	18:45	0.188	1.621	4.586	7.43
8	12	19:00	0.337	1.881	8.303	15.62
8	12	19:15	0.359	1.815	8.859	16.08
8	12	19:30	0.336	1.878	8.278	15.55
8	12	19:45	0.322	1.817	7.926	14.40
8	12	20:00	0.289	1.814	7.098	12.88
8	12	20:15	0.258	1.630	6.323	10.31
8	12	20:30	0.239	1.587	5.850	9.28
8	12	20:45	0.221	1.657	5.403	8.95
8	12	21:00	0.203	1.687	4.957	8.36

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