# Evaluation and Modification of Five Techniques for Estimating Stormwater Runoff for Watersheds in West-Central Florida

*By* J.T. Trommer, J.E. Loper, *and* K.M. Hammett

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U.S. Geological Survey

Water-Resources Investigations Report 96–4158

Prepared in cooperation with the
SARASOTA COUNTY, FLORIDA

Tallahassee, Florida
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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## CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.40 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| inch per hour (in/hr) | 25.40 | millimeter per hour |
| feet per mile (ft/mi) | 0.1894 | meter per kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| acre | 0.4047 | hectare |
| acre-foot (acre-ft) | 1.233 | cubic meter |
| cubic feet ($ft^3$) | 0.02832 | cubic meter |
| cubic feet per second ($ft^3/s$) | 0.02832 | cubic meter per second |

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = 5/9 \times (°F - 32)$$
$$°F = (1.8\ °C) + 32$$

*Sea level:* In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

## ABBREVIATIONS

CN = curve number
DUHs = dimensionless unit hydrographs
HEC-1 = Hydrologic Engineering Center-1 (U.S. Army Corps of Engineers)
LT = lag time
NEH-4 = National Engineering Handbook, Section 4-Hydrology (Soil Conservation Service)
NRCS = Natural Resources Conservation Service
SCS = Soil Conservation Service (U.S. Dept. of Agriculture)
SWMM = Surface Water Management Model (U.S. Environmental Protection Agency)
TR-20 = Technical Release No. 20 Procedure Model (Natural Resources Conservation Service)
USGS = U.S. Geological Survey

# Evaluation and Modification of Five Techniques for Estimating Stormwater Runoff for Watersheds in West-Central Florida

*By* J.T. Trommer, J.E. Loper, *and* K.M. Hammett


## Abstract

Several traditional techniques have been used for estimating stormwater runoff from ungaged watersheds. Applying these techniques to watersheds in west-central Florida requires that some of the empirical relations be extrapolated beyond tested ranges. As a result, there is uncertainty as to the accuracy of these estimates.

Sixty-six storms occurring in 15 west-central Florida watersheds were initially modeled using the Rational Method, the U.S. Geological Survey Regional Regression Equations, the Natural Resources Conservation Service TR-20 model, the U.S. Army Corps of Engineers HEC-1 model, and the U.S. Environmental Protection Agency Storm Water Management Model. The techniques were applied according to the guidelines specified in the user manuals or standard engineering textbooks as though no field data were available and the selection of input parameters was not influenced by observed data.

Computed estimates were compared with observed runoff to evaluate the accuracy of the techniques. One watershed was eliminated from further evaluation when it was determined that the area contributing runoff to the stream varies with the amount and intensity of rainfall. Therefore, further evaluation and modification of the input parameters were made for only 62 storms in 14 watersheds.

Runoff ranged from 1.4 to 99.3 percent of rainfall. The average runoff for all watersheds included in this study was about 36 percent of rainfall. The average runoff for the urban, natural, and mixed land use watersheds was about 41, 27, and 29 percent of rainfall, respectively.

Initial estimates of peak discharge using the Rational Method produced average watershed errors that ranged from an underestimation of 50.4 percent to an overestimation of 767 percent. The coefficient of runoff ranged from 0.20 to 0.60. Calibration of the technique produced average errors that ranged from an underestimation of 3.3 percent to an over estimation of 1.5 percent. The average calibrated coefficient of runoff for each watershed ranged from 0.02 to 0.72. The average values of the coefficient of runoff necessary to calibrate the urban, natural, and mixed land use watersheds were 0.39, 0.16, and 0.08, respectively.

The U.S. Geological Survey regional regression equations for determining peak discharge produced errors that ranged from an underestimation of 87.3 percent to an overestimation of 1,140 percent. The regression equations for determining runoff volume produced errors that ranged from an underestimation of 95.6 percent to an overestimation of 324 percent.

Regression equations developed from data used for this study produced errors that ranged between an underestimation of 82.8 percent and an

overestimation of 328 percent for peak discharge and from an underestimation of 71.2 percent to an overestimation of 241 percent for runoff volume. Use of the equations developed for west-central Florida streams produced average errors for each type of watershed that were lower than errors associated with use of the U.S. Geological Survey regional equations.

Initial estimates of peak discharges and runoff volumes using the Natural Resources Conservation Service TR-20 model, produced average errors of 44.6 and 42.7 percent, respectively, for all the watersheds. Curve numbers and times of concentration were adjusted to match estimated and observed peak discharges and runoff volumes. The average change in the curve number for all the watersheds was a decrease of 2.8 percent. The average change in the time of concentration was an increase of 59.2 percent. The shape of the input dimensionless unit hydrograph also had to be adjusted to match the shape and peak time of the estimated and observed flood hydrographs. Peak rate factors for the modified input dimensionless unit hydrographs ranged from 162 to 454. The mean errors for peak discharges and runoff volumes were reduced to 18.9 and 19.5 percent, respectively, using the average calibrated input parameters for each watershed.

Initial estimates of peak discharges and runoff volumes using the U.S. Army Corp of Engineers Hydrologic Engineering Center-1 model, produced average errors of 105 and 26.8 percent respectively, for all the watersheds. Curve numbers and lag times were adjusted to match estimated and observed peak discharges and runoff volumes. The average change in the curve number for all the watersheds was a decrease of 2.5 percent. The average change in the lag time was an increase of 169 percent. The mean errors for peak discharges and runoff volumes were reduced to 5.8 and 1.4 percent, respectively, using the average calibrated input parameters for each watershed. The observed and estimated peak discharges and runoff volumes could be matched by adjusting curve numbers and lag time using the U.S. Army Corp of Engineers Hydrologic Engineering Center-1 model; however, the shape of the estimated flood hydrograph and timing of the peak could not be matched. The input dimensionless unit hydrograph must also be changed to increase the accuracy of the Hydrologic Engineering Center-1 model for watersheds in west-central Florida. The source code has to be modified and recompiled to enter different dimensionless unit hydrographs into the HEC-1 program.

During application ofthe U.S. Environmental Protection Agency Storm Water Management Model, two separate infiltration methods were evaluated. Initial estimates of peak discharges and runoff volumes produced mean errors of 46.5 and 6.8 percent, respectively, for all watersheds using the Green-Ampt infiltration method, and 48.8 and 9.5 percent, respectively, using the Horton infiltration method. The mean errors were reduced to 18 and 0.3 percent for the Green-Ampt method and 20.9 and 7.2 percent for the Horton method using the average calibrated input parameters for each watershed.

Estimates of peak discharges and runoff volumes were initially made for watersheds in west-central Florida using recommended procedures, then compared to observed peak discharges and runoff volumes. Subsequently, the procedures were modified to increase accuracy for this area. The same methods used during the study could be used in other parts of the world to evaluate the accuracy of standard methods for estimating stormwater runoff.

## INTRODUCTION

Low topographic relief, flat water-surface gradients, and intense or prolonged rainfall events associated with tropical storms can produce recurring problems with stormwater flooding in the coastal lowlands of west-central Florida. These naturally occurring problems are being further compounded by rapid increases in population and the accompanying development. Local, State, and Federal agencies have recognized the potential impacts of population growth and development and have imposed regulations on stormwater discharges. To comply with regulation and permit requirements, design engineers have used several techniques for estimating the peak discharge and volume of stormwater runoff from ungaged watersheds. However, applying these techniques to watersheds in west-central Florida requires that empirical relations be extrapolated beyond tested limits, resulting in uncertainty as to the accuracy of the estimates. Underestimating the volume of stormwater runoff can have detrimental environmental and possibly severe economic consequences, whereas overestimation can result in severe and unnecessary economic burdens on the community. The U.S. Geological Survey (USGS) began a cooperative investigation in April 1991 with the Sarasota County Environmental Stormwater Utility to better understand the uncertainty of five of these techniques when applied to low-gradient watersheds common in west-central Florida.

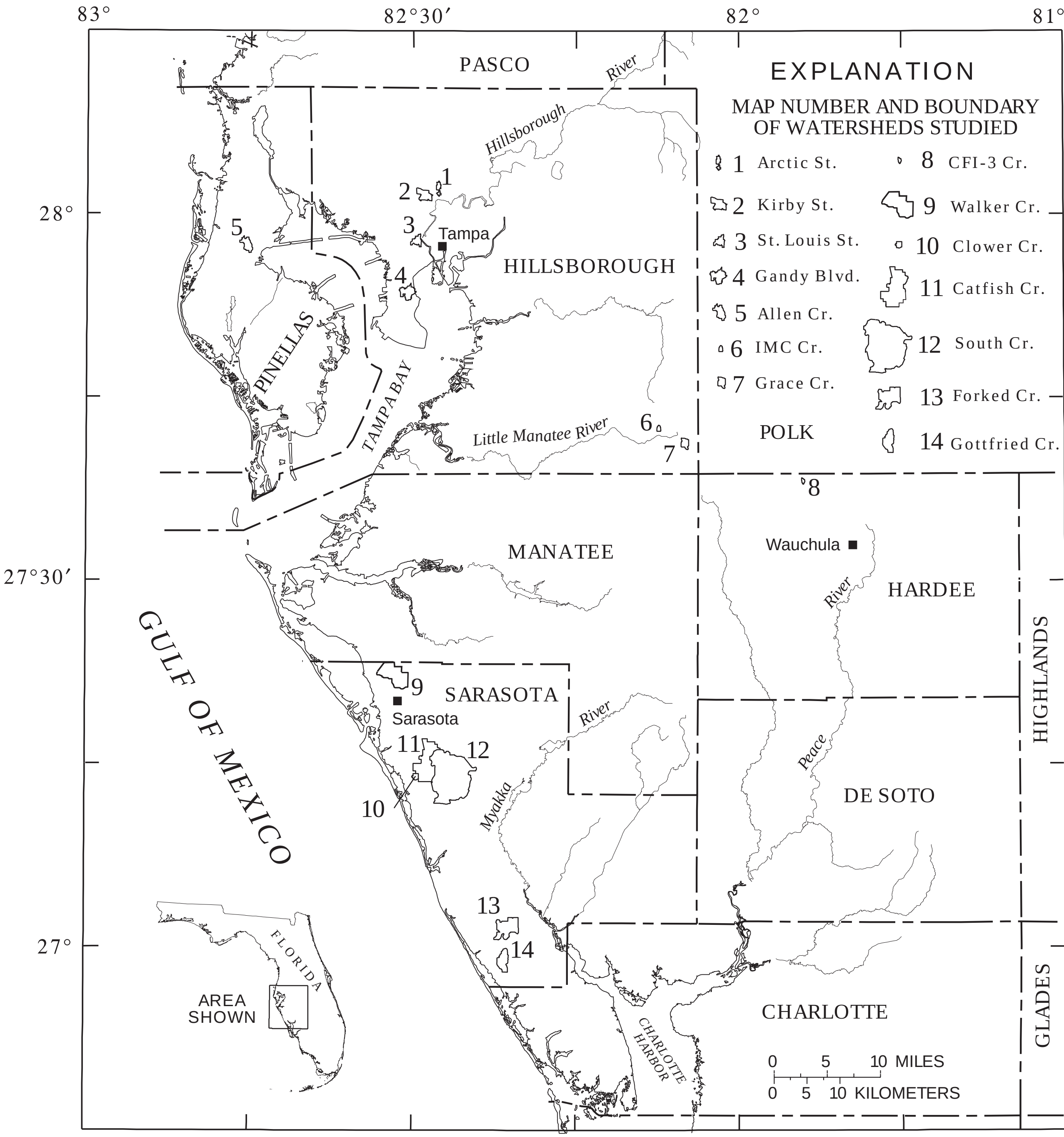
Sixty-six storms occurring in 15 watersheds were initially modeled. The watersheds ranged in size from 0.14 to 15.20 $mi^2$, with slopes that range from 1.4 to 47 ft/mi. A previous report (Trommer and others, 1996) describes the study area, data collection and application methodology and presents comparisons between estimated and observed peak discharges and runoff volumes. The following techniques were used to make the estimates: (1) the Rational Method; (2) the USGS Regional Regression Equations; (3) the Natural Resources Conservation Service Technical Release No. 20 procedure (TR-20 Model); (4) the U.S. Army Corps of Engineers Hydrologic Engineering Center-1 (HEC-1) Model; and (5) the U.S. Environmental Protection Agency Surface Water Management Model (SWMM). Six urban watersheds, 6 natural watersheds, and 3 watersheds with mixed land use were included in the study. Watersheds were considered to be urban if less than 25 percent of the total area contained pastures (including golf courses), forests, wetlands, and other open areas. Natural watersheds contained little or no development. Mixed watersheds contained some development but also contained pastures, forests, wetlands, and other open areas that totaled more than 25 percent of the watershed. The watersheds included in the study are: the urban watersheds of the Arctic Street storm drain, the Kirby Street drainage ditch, the St. Louis Street drainage ditch, the Gandy Boulevard drainage ditch, Allen Creek and Clower Creek; the natural watersheds of IMC creek, Grace Creek, CFI-3 Creek, South Creek, and Forked Creek; the mixed land use watersheds of Walker Creek, Catfish Creek and Gottfried Creek (fig. 1). Data were collected and initial model runs were also made for the natural watershed of Rock Creek (also known as Ainger Creek). The design techniques were applied according to the guidelines specified in the user manuals or standard engineering textbooks as though no measured field data were available and the selection of input parameters was not influenced by observed data.

The initial estimates and observed data were compared to evaluate the accuracy of the techniques. The Rock Creek watershed was eliminated from further evaluation when it was determined that the area contributing water to the stream varies with the amount and intensity of rainfall. Relief in the watershed is less than 3 ft/mi and the divide along parts of the southern watershed boundary is less than 0.5 ft high. About 1.7 $mi^2$ of the watershed contributed runoff to the stream during the June 1992 storm. Rainfall intensities during this storm were as much as 5 in/hr, with an overall accumulation of 16.40 in. Runoff from storms of lower intensity and shorter duration did not move as sheet flow across the watershed divide. As much as 5 $mi^2$ could have contributed water to the stream from these storms. Sixty-two storms in 14 watersheds were further evaluated and modeled for this report. The characteristics for these watersheds are summarized in table 1.

## Purpose and Scope

The specific objectives of this report are to: (1) evaluate the reliability of five techniques used in west-central Florida to accurately estimate stormwater runoff, and (2) suggest modifications to these techniques that will increase accuracy when applied to watersheds in west-central Florida. Fourteen watersheds in Sarasota, Hardee, Hillsborough, and Pinellas Counties were included in this study (fig. 1). The watersheds included urban, natural and mixed land use watersheds. A previous report described basin characteristics, the methods used to collect rainfall and runoff data, and the techniques used to estimate stormwater runoff from these watersheds (Trommer and other, 1996). That report also presented preliminary comparisons of the estimated and observed runoff for specific storms in those watersheds.

Modifications to the original input parameters used in the five design techniques were made to determine if the accuracy of the techniques could be increased. Each storm in each watershed was calibrated so that estimates were as close as possible to observed peak discharges and runoff volumes. The calibrated input parameters were averaged for each watershed and the average input parameters were used to determine the peak discharge and runoff volume estimates for each watershed. The procedure was repeated for each technique, with the exception of the USGS regression equations. Multiple regression analyses were applied to the observed data to see if equations for local discharge and runoff could be derived. The resulting estimates were compared to the observed data and to the initial estimates. Error values presented in this report assume that all error is in estimating technique and not in measurement of discharges and runoff volumes.




Base from Southwest Florida Water Management District digital data, 1:500,000, 1992
Universal Transverse Mercator projection, Zone 17

**Figure 1.** Location of the study area and the watersheds.

**Table 1.** Watershed characteristics

[mi$^2$, square miles; ft, feet; ft/mi, feet per mile. Commercial includes commercial, industrial, and roads; U, urban; N, natural; M, mixed; --, undetermined]

| Map no. | Identification no. | Watershed name | Watershed classification | Drainage area (mi$^2$) | Slope (ft/mi) | Main channel length (approximate) (ft) | Effective impervious area (mi$^2$) | Land use, in percent of total area | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Wetland | Residential | Commercial | Agriculture | Pasture | Forest | Open space |
| 1 | 02306002 | Arctic Street storm drain | U | 0.34 | 12.3 | 6,600 | 40.0 | 0 | 50.0 | 50.0 | 0 | 0 | 0 | 0 |
| 2 | 02306006 | Kirby Street drainage ditch | U | 1.15 | 8.1 | 12,700 | 5.5 | 3.1 | 72.3 | 11.1 | 0 | 0 | 0 | 13.5 |
| 3 | 02306021 | St. Louis Street drainage ditch | U | 0.51 | 10.2 | 5,900 | 9.0 | 0 | 68.0 | 16.0 | 0 | 0 | 0 | 16.0 |
| 4 | 02306071 | Gandy Boulevard drainage ditch | U | 1.29 | 4.6 | 8,600 | 20.0 | 0.9 | 42.3 | 33.4 | 0 | 0 | 0 | 23.4 |
| 5 | 02307731 | Allen Creek | U | 1.79 | 23.4 | 7,400 | 20.0 | 0.9 | 63.0 | 20.0 | 0 | 0 | 0 | 16.1 |
| 6 | 274215082072000 | IMC Creek | N | 0.17 | 47.0 | -- | 0 | 0 | 0 | 0 | 0 | 67.0 | 33.0 | 0 |
| 7 | 274141082051300 | Grace Creek | N | 0.66 | 26.0 | 7,200 | 0 | 0 | 0 | 0 | 33.0 | 33.0 | 34.0 | 0 |
| 8 | 273806081535000 | CFI-3 Creek | N | 0.14 | 36.0 | 2,200 | 0 | 0 | 0 | 0 | 0 | 67.0 | 33.0 | 0 |
| 9 | 02299861 | Walker Creek | M | 4.78 | 6.3 | 15,500 | 40.0 | 1.0 | 52.0 | 16.0 | 0 | 0 | 16.0 | 15.0 |
| 10 | 02299742 | Clower Creek | U | 0.35 | 3.7 | 3,300 | 85.0 | 0.1 | 14.9 | 85.0 | 0 | 0 | 0 | 0 |
| 11 | 02299741 | Catfish Creek | M | 4.77 | 3.5 | 23,500 | 10.0 | 0.5 | 25.0 | 10.0 | 0 | 10.0 | 29.5 | 25.0 |
| 12 | 02299737 | South Creek | N | 15.20 | 2.9 | 23,000 | 0 | 31.0 | 10.0 | 0 | 0 | 35.0 | 24.0 | 0 |
| 13 | 02299684 | Forked Creek | N | 2.70 | 2.8 | 12,400 | 0 | 15.0 | 0 | 0 | 30.0 | 55.0 | 0 | 0 |
| 14 | 02299681 | Gottfried Creek | M | 2.00 | 1.4 | 11,000 | 10.0 | 15.0 | 50.0 | 10.0 | 0 | 0 | 0 | 25.0 |

## Acknowledgments

This investigation was coordinated with J. P. Marchand, Deputy Director of the Sarasota County Environmental Stormwater Utility. The authors gratefully acknowledge the cooperation and assistance of Mr. Marchand and his staff, without which this study would not have been conducted. Thanks are also extended to the land owners who allowed access to the streams and construction of the rainfall/runoff stations used in this study, particularly the Palmer and Taylor Ranches. Special thanks are extended to Stephen M. Suau, consulting engineer, Kimley-Horn and Associates, Inc. for providing extensive information and maps for the Catfish Creek and South Creek watersheds.


# COMPARISON OF OBSERVED RAINFALL AND RUNOFF

The observed rainfall and runoff volumes and the runoff in percentage of rainfall from each watershed for each storm are shown in table 2. Observed storm runoff ranged from a low of 1.4 percent of the rainfall in the IMC Creek watershed, a small, natural watershed, to a high of 99.3 percent of the rainfall in the Clower Creek watershed, an urban watershed with about 85 percent impervious area. Runoff is typically higher for the urban watersheds than for the natural watersheds.

The average runoff in each watershed ranged from 16.3 to 66.4 percent of rainfall (table 2), with a mean of about 36 percent. Average runoff for the all urban watersheds ranged from 20.4 to 66.4 percent, with a mean of about 41percent. Average runoff for all natural watersheds ranged from 16.3 to 49.4 percent, with a mean of about 27 percent. Average runoff for all watersheds with mixed land use ranged from 20.6 percent to 34.8 percent, with a mean of about 29 percent.

# EVALUATION AND MODIFICATION OF STORMWATER RUNOFF ESTIMATING TECHNIQUES

Five different techniques were used to estimate peak discharges and runoff volume for 62 storms events in 14 west-central Florida watersheds. Input parameters were determined using procedures recommended in documentation for each of the techniques. Input parameters were then modified with the intent of improving the accuracy of the techniques when applied to streams in west-central Florida. Estimates of peak discharge and runoff were then compared to the observed values to evaluate the accuracy of the techniques as originally applied and the effects that modifications to the procedures had on the accuracy of the estimates.

## The Rational Method

The rational method is widely used because it is simple and easy to apply. The method determines peak discharge by using rainfall intensity, watershed area, and a coefficient of runoff. The method cannot be used to determine runoff volume. The rational method is typically recommended for application in sewered or natural watersheds with drainage areas less than 5 $mi^2$, where infiltration, surface detention, and time of concentration are not large influences. The method was applied to all watersheds included in this study because the method is often used by design engineers to estimate stormwater runoff from watersheds not meeting recommended application criteria. The following equation is used to calculate peak discharge:

$$Q = CIA \tag{1}$$

where

Q = the peak discharge, in acre-inches per hour or cubic feet per second;

C = coefficient of runoff;

I = average rainfall intensity, in inches per hour; and

A = area of the watershed, in acres.

The coefficient of runoff (C) is a ratio of the peak runoff to the average rainfall intensity (Williams, 1950, p. 309) and can roughly be related to the watershed characteristics. The values of C used in the initial estimates were based on the tables presented by Williams (1950, p. 314-315) and Viessman (1989, p. 311). Average rainfall intensity was calculated from the measured rainfall and storm duration data recorded for each storm. Watershed drainage area was estimated from available maps.

The rational method, using the above input parameters, produced errors for each storm that ranged from an underestimation of 90.7 percent to an overestimation of 1,960 percent (app. A). Average errors for each watershed ranged from an underestimation of 50.4 percent to an overestimation of 767 percent (table 3). The average errors are positive in all but the St. Louis Street and the CFI-3 watersheds. The mean average errors for the urban, natural, mixed, and for all the watersheds

**Table 2.** The observed rainfall and runoff volumes, the percentage of rainfall that runs off for each storm in each watershed, and the average watershed runoff percentage

[U, urban; N, natural; M, mixed]

| Watershed name | Watershed classification | Observed rainfall (inches) | Observed runoff (inches) | Runoff (as percentage of rainfall) | Average watershed runoff (percent) | Date of storm |
|---|---|---|---|---|---|---|
| Arctic Street storm drain | U | 2.50 | 0.76 | 30.4 | 36.2 | 08/03/76 |
| | | 2.09 | .97 | 46.4 | | 08/04/76 |
| | | 1.87 | .58 | 31.0 | | 09/26/77 |
| | | 3.49 | 1.30 | 37.2 | | 05/20/78 |
| Kirby Street drainage ditch | U | 2.36 | .30 | 12.7 | 23.2 | 07/19/75 |
| | | 3.78 | .77 | 20.4 | | 08/30/75 |
| | | 2.08 | .76 | 36.5 | | 08/15/78 |
| St. Louis St. drainage ditch | U | 3.60 | .92 | 25.5 | 20.4 | 05/15/76 |
| | | 2.27 | .40 | 17.6 | | 06/18/76 |
| | | 2.48 | .45 | 18.1 | | 06/29/77 |
| Gandy Blvd. drainage ditch | U | 1.69 | .50 | 29.6 | 51.4 | 06/18/75 |
| | | 2.06 | 1.19 | 57.8 | | 07/11/75 |
| | | 1.14 | .71 | 62.3 | | 08/07/75 |
| | | 3.79 | 2.46 | 64.9 | | 05/15/76 |
| | | 2.06 | .87 | 42.2 | | 05/17/76 |
| Allen Creek | U | 0.86 | .69 | 80.2 | 50.2 | 07/28/76 |
| | | 1.61 | .60 | 37.3 | | 07/01/77 |
| | | 2.25 | 1.64 | 72.9 | | 07/01/77 |
| | | .88 | .51 | 57.9 | | 07/03/77 |
| | | 1.11 | .18 | 16.2 | | 12/02/77 |
| | | 1.98 | .71 | 36.9 | | 02/18/78 |
| Clower Creek | U | 2.15 | 1.45 | 67.4 | 66.4 | 02/05/92 |
| | | 17.20 | 17.08 | 99.3 | | June 92 |
| | | 1.64 | 1.07 | 65.2 | | 09/02/92 |
| | | 3.10 | 2.31 | 74.5 | | 09/13/92 |
| | | 1.75 | .67 | 38.3 | | 01/14/93 |
| | | 2.48 | 1.37 | 55.2 | | 03/13/93 |
| | | 4.48 | 2.90 | 64.7 | | 04/01/93 |
| IMC Creek | N | 1.17 | .66 | 56.4 | 21.1 | 11/23/88 |
| | | 3.00 | .17 | 5.7 | | 07/12/89 |
| | | 2.57 | .36 | 1.4 | | 02/23/90 |
| | | 2.25 | .47 | 20.9 | | 07/21/90 |
| Grace Creek | N | 2.99 | 1.00 | 33.4 | 24.4 | 08/07/88 |
| | | 1.98 | .72 | 36.4 | | 08/23/88 |
| | | 2.10 | .23 | 10.9 | | 07/12/90 |
| | | 3.19 | .54 | 16.9 | | 07/14/90 |
| CFI-3 Creek | N | 1.91 | .44 | 23.0 | 16.3 | 07/05/89 |
| | | 3.02 | .29 | 9.6 | | 02/23/90 |
| South Creek | N | 17.20 | 4.30 | 25.0 | 23.9 | June 92 |
| | | 1.17 | .13 | 11.1 | | 09/06/92 |
| | | 1.83 | .39 | 21.3 | | 09/13/92 |
| | | 2.93 | .69 | 23.6 | | 03/13/93 |
| | | 3.30 | 1.27 | 38.5 | | 04/01/93 |
| Forked Creek | N | 13.36 | 8.54 | 63.9 | 49.4 | June 92 |
| | | 5.29 | 1.85 | 34.9 | | 08/09/92 |

**Table 2.** The observed rainfall and runoff volumes, the percentage of rainfall that runs off for each storm in each watershed, and the average watershed runoff percentage (Continued)

[U, urban; N, natural; M, mixed]

| Watershed name | Watershed classification | Observed rainfall (inches) | Observed runoff (inches) | Runoff (as percentage of rainfall) | Average watershed runoff (percent) | Date of storm |
|---|---|---|---|---|---|---|
| Walker Creek | M | 15.51 | 6.89 | 44.4 | 34.8 | June 92 |
| | | 2.56 | 0.91 | 35.5 | | 07/23/92 |
| | | 1.78 | .96 | 53.9 | | 08/07/92 |
| | | 2.39 | . 77 | 32.2 | | 09/04/92 |
| | | 1.95 | .41 | 21.0 | | 09/05/92 |
| | | 2.17 | .56 | 25.8 | | 09/25/92 |
| | | 1.46 | .74 | 50.7 | | 09/26/92 |
| | | 2.14 | .76 | 35.5 | | 01/15/93 |
| | | 3.05 | .94 | 30.8 | | 04/01/93 |
| | | 2.52 | .46 | 18.2 | | 07/01/93 |
| Catfish Creek | M | 1.82 | .21 | 11.5 | 20.6 | 01/14/93 |
| | | 1.27 | .25 | 19.7 | | 01/15/93 |
| | | 2.50 | .49 | 19.6 | | 03/13/93 |
| | | 4.48 | 1.41 | 31.5 | | 04/01/93 |
| Gottfried Creek | M | 16.78 | 6.70 | 39.9 | 30.9 | June 92 |
| | | 1.25 | .32 | 25.6 | | 08/11/92 |
| | | 2.09 | .57 | 27.3 | | Oct 92 |

were 69.6, 425, 287, and 227 percent, respectively. The errors indicate that the rational method tends to overestimate peak discharges for each type of watershed in west-central Florida.

The coefficient of runoff is the most subjective parameter estimated in the rational method and is the most probable source of error when applied to west-central Florida watersheds. The initial values of C ranged from 0.20 to 0.60. Mean average values of C for the urban, natural, mixed and for all the watersheds were 0.47, 0.26, 0.33, and 0.36, respectively. Specific values of C can be calculated for each storm by substituting the observed peak discharge and rainfall intensity into equation 1. C was calculated in this manner for each storm and averaged for each watershed. The average calculated C for each watershed ranged from 0.02 to 0.73 and the mean average values for the urban, natural, mixed and for all the watersheds were 0.46, 0.18, 0.10, and 0.28, respectively. The average calculated C for each watershed (table 3) was then used to recalculate peak discharges for each storm (app. A). The average peak discharge errors were positive for all the watersheds and ranged from 1.1 to 480 percent. The mean average errors for the urban, natural, mixed, and for all the watersheds were reduced to 19.6, 107, 16, and 42.7 percent, respectively.

Smaller average values of C were still necessary to calibrate the method for each watershed. The average value of C was reduced until the average error was as close to zero as possible. The average calibrated value of C ranged from 0.02 to 0.72.

Values of C ranging from 0.05 to 0.72, and averaging 0.39 were necessary to calibrate the six urban watersheds. The smallest value of C was for the Kirby Street watershed, which is drained by an open ditch. All the other urban watersheds are drained either through underground storm sewers or a combination of open ditches and underground storm sewers.

Values of C ranging from 0.02 to 0.58, and averaging 0.16 were necessary to calibrate the five natural watersheds. All these watersheds drain through open ditches. Values of C were smallest for the watersheds with the least defined stream channels or flattest slopes.

Values of C ranging from 0.06 to 0.11, and averaging 0.08 were necessary to calibrate the watersheds with mixed land use, all of which are drained through open ditches. The Walker Creek watershed has the steepest slope and the best defined stream channels of the three mixed land use watersheds; consequently, the calibrated value of C is the largest. The calibrated value of C for the Catfish Creek watershed is the smallest of the mixed land use watersheds. The Catfish Creek

**Table 3.** The average initial, calculated, and calibrated coefficient of runoff for each watershed, for each watershed type, and for all watersheds, and the resulting errors between estimated and observed peak discharges for simulations made using the Rational Method

[U, urban; N, natural; M, mixed; -, negative values represent underestimations; <, less than; C, coefficient of runoff]

| Watershed | Watershed classification | Initial | | Calculated | | Calibrated | |
|---|---|---|---|---|---|---|---|
| | | Average | | Average | | Average | |
| | | C | Percent error | C | Percent error | C | Percent error |
| Arctic Street storm drain | U | 0 .40 | 4.6 | 0 .43 | 12.0 | 0.38 | <0.1 |
| Kirby Street drainage ditch | U | .30 | 525 | .05 | 6.0 | .05 | .2 |
| St. Louis Street drainage ditch | U | .50 | -31.0 | .73 | 1.1 | .72 | .1 |
| Gandy Blvd. drainage ditch | U | .50 | 29.7 | .58 | 56.9 | .37 | .6 |
| Allen Creek | U | .50 | 13.3 | .53 | 20.6 | .44 | - .3 |
| Clower Creek | U | .60 | 31.1 | .44 | 10.3 | .40 | < .1 |
| All Urban Watersheds | | 0.47 | 69.6 | 0.46 | 19.6 | 0.39 | 2.7 |
| IMC Creek | N | 0.30 | 511 | 0.13 | 162 | 0.05 | 1.5 |
| Grace Creek | N | .20 | 163 | .10 | 32.7 | .08 | 0.4 |
| CFI-3 Creek | N | .30 | -50.4 | .64 | 44.4 | .58 | -3.3 |
| South Creek | N | .20 | 767 | .02 | 8.4 | .02 | - .1 |
| Forked Creek | N | .30 | 397 | .03 | 480 | .06 | -1.2 |
| All Natural Watersheds | | 0.26 | 425 | 0.18 | 107 | 0.16 | -0.3 |
| Walker Creek | M | 0.40 | 219 | 0.13 | 12.0 | 0.11 | .2 |
| Catfish Creek | M | .30 | 360 | .08 | 30.1 | .06 | .1 |
| Gottfried Creek | M | .30 | 319 | .08 | 10.7 | .07 | .7 |
| All Mixed Watersheds | | 0.33 | 287 | 0.10 | 16.0 | 0.08 | <-0.1 |
| All Watersheds | | .36 | 227 | 0.28 | 42.7 | 0.24 | 1.1 |

watershed has well defined and maintained stream channels and the watershed slope is similar to other watersheds in the area; however, there are numerous control structures and management practices in place in the watershed which attenuates streamflow.

The average calibrated C for each watershed (table 3) was used to recalculate peak discharges for each storm (app. A). The average peak discharge errors for each watershed ranged from an underestimation of 3.3 percent to an overestimation of 1.5 percent. The mean average errors for the urban, natural, mixed, and for all the watersheds were reduced to 2.7, -0.3, less than -0.1, and 1.1 percent, respectively.

## The U.S. Geological Survey Regional Regression Equation Method

The U.S. Geological Survey regional regression equations for Florida were developed to estimate peak discharges for storms of a given recurrence interval on natural-flow streams. Multiple linear regression analyses were used to relate peak discharges to various watershed characteristics for 182 watersheds within Florida. The State was divided into three hydrologic regions and a separate equation was developed for each region. All of the watersheds included in this study are within Region A. It is recommended that these equations be used for estimating peak discharges only from watersheds without significant urban development (Bridges, 1982, p. 43); nevertheless, they were applied to all the watersheds included in this study because they are often used by design engineers to estimate stormwater runoff from watersheds not strictly meeting the recommended criteria

The USGS regression equations for peak discharge do not use rainfall from specific storms to calculate peak discharge. The method is based on the frequency distribution of peak flows. Due to a lack of long-term peak flow data for the types of watersheds located in the study area, the recurrence interval for peak flows was assumed to be equal to the rainfall recurrence interval. Fifteen observed peak discharges were then associated with specific recurrence-interval flood estimates.

The USGS regression equations for estimating flood peaks produced errors that ranged from an underestimation of 87.3 percent to an overestimation of 1,140 percent (Trommer and others, 1996, p. 49). The average error for the peak-discharge estimates was an underestimation of about 25 percent in the four urban watersheds and about 14 percent in the mixed watersheds (table 4). Peak discharges were overestimated by about 344 percent for the natural watersheds. The USGS regional regression equation for peak discharge is more accurate for the urban and mixed watersheds and least accurate for the natural watersheds included in this study. Most of the basin characteristics for the watersheds included in this study fall within the ranges of those used by Bridges (1982) to develop the regression equations for peak discharge; however, the basin characteristics for this study are near the extremes of these ranges, increasing the probability of error. The assumption that rainfall frequency is equal to flow frequency also contributes to the probability of error.

Another equation developed by Stricker and Sauer (1982, p. 19) can be used to estimate runoff volumes. This equation was developed separately from the Florida regional equations and was derived by relating runoff volume to flood peaks and watershed characteristics for 55 urban watersheds in Pennsylvania, Missouri, Oklahoma, Oregon, and Texas. The equation probably should not be applied to natural or mixed watersheds; however, it was applied to all watersheds included in this study because it is often used as a quick estimate of runoff volume from different watershed types.

The equation developed by Stricker and Sauer (1982) produced errors in runoff volume that ranged from an underestimation of 95.6 percent to an overestimation of 324 percent for the same 15 storms

**Table 4.** Summary of average watershed estimation errors for peak discharge and runoff volumes for each watershed, for each watershed type, and for all watersheds made using the U.S. Geological Survey regression equations and the regression equations developed for west-central Florida

[U, urban; N, natural; M, mixed; -, negative values represent underestimations;--, undetermined; all values are in percent]

| | | Peak discharge | | Runoff volume | |
|---|---|---|---|---|---|
| Watershed name | Watershed classification | USGS average error | West-central Florida average error | USGS average error | West-cenral Florida average error |
| Arctic Street storm drain | U | -87.3 | -23.5 | -87.7 | 16.4 |
| Kirby Street drainage ditch | U | 24.7 | 227 | 34.9 | 116 |
| St. Louis Street Drainage dictch | U | -- | -80.2 | -- | 109 |
| Gandy Boulevard drainage ditch | U | -74.4 | -21.6 | -52.0 | -15.2 |
| Allen Creek | U | -- | 6.4 | -- | 16.0 |
| Clower Creek | U | -44.7 | 40.2 | -93.9 | -31.8 |
| Urban Watersheds | | -25.3 | 19.9 | -31.8 | 19.2 |
| IMC Creek | N | 1140 | 58.4 | 324 | 47.6 |
| Grace Creek | N | -- | -19.5 | -- | -2.9 |
| CFI-3 Creek | N | 283 | -14.6 | 290 | 40.1 |
| South Creek | N | -2.3 | 21.3 | -90.2 | 37.6 |
| Forked Creek | N | -42.9 | 6.7 | -93.9 | 47.8 |
| Natural Watersheds | | 344 | 14.5 | 107 | 20.7 |
| Walker Creek | M | -42.2 | -19.2 | -75.1 | 2.8 |
| Catfish Creek | M | -- | 94.1 | -- | 50.5 |
| Gottfied Creek | M | 72.3 | -35.3 | -90.9 | -0.9 |
| Mixed Watersheds | | -13.5 | 4.6 | -79.1 | 13.4 |
| All Watersheds | | 76.4 | 14.2 | -12.5 | 18.0 |

**Table 5.** Constants and exponents used in equations 2 and 3 for calculating peak discharge and runoff volume

[$B_1$, regression exponent for rainfall; $B_2$, regression expontent for watershed drainage area; U, urban; N, natural; M, mixed]

| Wateshed classifi-cation | Peak discharge | | | | | Runoff volume | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Constant C | Exponents $B_1$ | Exponents $B_2$ | Multiple correlation coefficient R | Standard error of estimation (percent) | Constant C | Exponent $B_1$ | Multiple correlation coefficient R | Standard error of estimation (percent) |
| U | 155.730 | 0.403 | 0.729 | 0.59 | 69.0 | 0.366 | 1.133 | 0.77 | 57.6 |
| N | 18.363 | .495 | .618 | .92 | 65.7 | .155 | 1.207 | .74 | 88.4 |
| M | 2.404 | .748 | 2.525 | .90 | 51.3 | .238 | 1.188 | .92 | 39.9 |

(Trommer and others, 1996, p. 49). The average errors for runoff volume in the urban and mixed watersheds were underestimations of about 32 and 79 percent, respectively. The average error for runoff volume in the natural watersheds was an overestimation of about 107 percent (table 4). The characteristics of many watersheds in west-central Florida are outside the range of those used by Stricker and Sauer (1982) to develop the runoff volume equation; therefore, use of this equation may not produce reliable estimates for watersheds similar to those in west-central Florida.

Multiple linear regression analyses were also used during this study to develop equations that were more specific to west-central Florida. Relations were developed between the observed peak discharge (dependent variable) and the watershed characteristics (independent variables). The independent variables included watershed type, watershed area, impervious area (in percent), wetland area (in percent), watershed slope, observed rainfall, and storm duration. The analyses were repeated using the observed runoff volume as the dependent variable. Regression constants and coefficients were developed for each of the watershed types.

The most significant variable determined for peak discharge was the rainfall; the second most significant was the watershed area. The equation for peak discharge has the following form:

$$Q = CR^{B_1}DA^{B_2} \qquad (2)$$

where

Q = the peak discharge, in cubic feet per second;
C = the regression constant;
R = observed rainfall, in inches;
DA = the watershed area, in square miles; and
$B_1$ and $B_2$ are exponents of the regression.

The only significant variable determined for runoff volume was rainfall. The equation for runoff volume has the following form:

$$V = CR^{B_1} \qquad (3)$$

where

V = the runoff volume, in inches;
C = the regression constant;
R = observed rainfall, in inches; and
$B_1$ is an exponent of the regression.

The peak discharge and runoff volume regression constants and exponents for each watershed type are shown in table 5. Estimates of peak discharge and runoff volume were made for all 62 storms included in this study using the above equations.

Equation 2, for peak discharge, produced errors that ranged from an underestimation of 82.8 percent to an overestimation of 328 percent (app. B). The average peak discharge errors for storms in the urban, natural, and mixed watersheds, and for all the watersheds were overestimations of about 20, 14, 5, and 14 percent, respectively (table 4). Equation 2 appears to be more accurate for the natural and mixed watersheds than for the urban watersheds. Equation 3 for runoff volume produced errors that ranged from an underestimation of 71.2 percent to an overestimation of 241 percent (app. B). The average runoff volume errors for all storms in the urban, natural, and mixed watersheds, and for all the watersheds were overestimations of about 19, 21, 13, and 18 percent respectively (table 4); equation 3 appears to be more accurate for the natural watersheds.

Both equations 2 and 3 developed for west-central Florida have a tendency to overestimate; however, the errors are reduced compared to the errors produced using the U.S. Geological Survey regional equations (table 4). Because of the simplicity of these equations, the method could be used for preliminary estimates or as a quick check or guideline to the appropriateness of other, more complicated methods.

## The Natural Resources Conservation Service TR-20 Model

One of the most commonly used methods for estimating peak discharges and runoff volumes was developed by the Natural Resources Conservation Service (NRCS). This method is relatively simple and can be applied to a wide range of watershed conditions. Although computations for the method can be done manually, they are usually accomplished using a digital computer as described in TR-20 (Technical Release No. 20, SCS, 1983). TR-20 is a single event model that computes direct runoff, develops flood hydrographs, and routes the flow through stream channels and reservoirs. The TR-20 model combines hydrographs at subbasin boundaries (if the watershed has been subdivided) and computes peak discharge, time of occurrence, and runoff volume.

The model calculates runoff from rainfall by using the NRCS runoff equation and a watershed storage parameter that is calculated as a function of the curve number (CN). The CN is based on watershed characteristics, including soils, land use, amount of impervious area, and surface storage. The development of these procedures is outlined in NEH-4 (National Engineering Handbook, Section 4-Hydrology, Soil Conservation Service, 1985) and tables for determining CNs are in Technical Release No. 55 (Soil Conservation Service, 1986). Peak discharge is determined by converting runoff from the watershed or watershed subbasin to a runoff hydrograph using a dimensionless unit hydrograph and the peak rate equation. Chapter 16 of the NEH-4 (Soil Conservation Service, 1985) describes the hydrograph development method used by the NRCS. The time of concentration ($T_c$) of the watershed is used in this procedure and is related to the watershed lag time which was calculated using the NRCS lag equation. The $T_c$ and lag equation are defined in chapter 15 of NEH-4.

The initial calculations were made using the standard procedures recommended by the NRCS for estimating the input parameters as if there were no observed data available. Rainfall from actual storms was used for the simulations. Watersheds with complex hydrology were divided into subbasins to more accurately define the CN. The standard dimensionless unit hydrograph, with a peak rate factor of 484, was not used to estimate peak discharges and runoff volumes because the NRCS recommends that a dimensionless unit hydrograph with a peak rate factor of 284, developed for the Delmarva Peninsular, in Maryland, be used in Florida (SCS, 1986, Florida Bulletin NO. 210-7-2). Watersheds in the Delmarva Peninsular have characteristics somewhat similar to watersheds in Florida. The shape of the NRCS 484 and 284 dimensionless unit hydrographs are shown in figure 2.

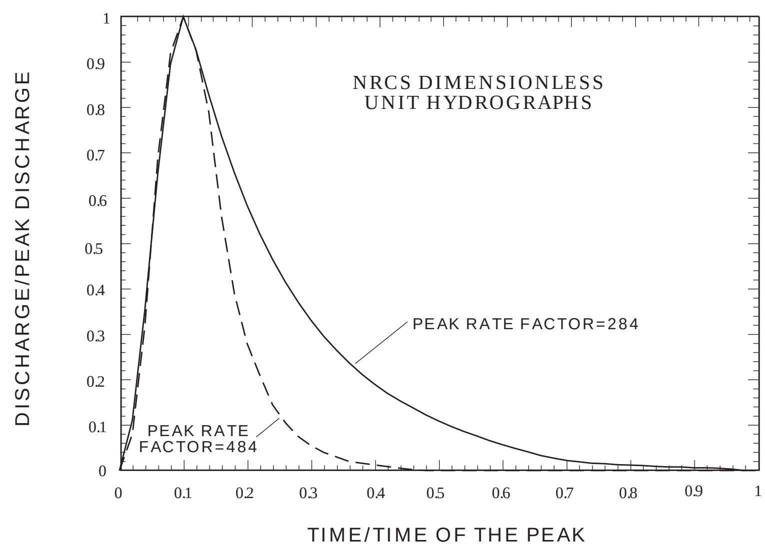



**Figure 2.** The National Resources Conservation Service 484 and 284 dimensionless unit hydrographs.

The CN, $T_c$, and the shape of the dimensionless unit hydrograph were modified to try to increase the accuracy of estimates. CNs and $T_c$s were adjusted until the estimated peak discharge and runoff volumes were equal to the observed. The dimensionless unit hydrograph was similarly adjusted until the shape of the estimated hydrograph was as close as possible to the observed flood hydrogaph. Only storms that had simple, single peak hydrographs were used for calibration. Calibrated CNs, $T_c$s, and dimensionless unit hydrographs were developed for each storm in each watershed; then they were averaged for each watershed.

**Table 6.** The average initial and modified CNs and $T_c$s, the differences for each watershed, each watershed type, and for all watersheds, and the average modified peak rate factor for each watershed for the Natural Resources Conservation Service TR-20 model

[CN, curve number; $T_c$, time of concentration; PRF, peak rate factor; U, urban; N, natural; M, mixed; +, increase; -, decrease]

| Watershed name | Classification | Initial CN | Modified CN | Percent difference | Initial $T_c$ | Modified $T_c$ | Percent difference | [1]Modified PRF |
|---|---|---|---|---|---|---|---|---|
| Arctic Street storm drain | U | 83 | 75 | -9.6 | 0.99 | 0.80 | -19.2 | 261 |
| Kirby Street drainage ditch | U | 70 | 67 | -4.3 | 4.92 | 2.27 | -54.0 | 210 |
| St. Louis Street drainage ditch | U | 85 | 70 | -17.6 | 2.29 | 0.15 | -93.5 | 284 |
| Gandy Boulevard drainage ditch | U | 87 | 88 | -1.1 | 1.06 | 1.06 | 0.0 | 318 |
| Allen Creek | U | 85 | 89 | +4.7 | 0.51 | 2.06 | +304 | 454 |
| Clower Creek | U | 95 | 92 | -3.1 | 2.68 | 1.75 | -34.7 | 192 |
| Urban Watersheds | | | | -5.2 | | | +17.1 | |
| IMC Creek | N | 70 | 72 | +2.9 | 1.56 | 3.13 | +101 | 299 |
| Grace Creek | N | 72 | 76 | +5.5 | 2.66 | 3.54 | +33.1 | 241 |
| CFI-3 Creek | N | 73 | 58 | -20.5 | 1.26 | 1.25 | -1.0 | 246 |
| South Creek | N | 75 | 78 | +4.0 | 6.63 | 15.0 | +126 | 162 |
| Forked Creek | N | 72 | 70 | -2.7 | 3.25 | 9.29 | +186 | 173 |
| Natural Watersheds | | | | -2.2 | | | +89.0 | |
| Walker Creek | M | 81 | 83 | +2.5 | 5.37 | 2.95 | -45.1 | 174 |
| Catfish Creek | M | 79 | 70 | -11.4 | 9.21 | 4.90 | -46.8 | 230 |
| Gottfried Creek | M | 74 | 82 | +10.8 | 5.81 | 27.5 | +373 | 383 |
| Mixed Watersheds | | | | +0.6 | | | +93.7 | |
| All Watersheds | | | | -2.8 | | | +59.2 | |

[1] PRF of 284 was used for all initial estimates as recommended by SCS, Florida Bulletin NO. 210-7-2 (1986).

Table 6 shows the average initial and calibrated CNs and $T_c$s, and the average peak rate factor for the modified dimensionless unit hydrographs for each watershed. The difference between the average initial and calibrated CNs ranged from an increase of 10.8 percent to a decrease of 20.5 percent. The average difference in CN for all the urban watersheds was a decrease of 5.2 percent, for all the natural watersheds was a decrease of 2.2 percent, and for all the mixed watersheds was an increase of 0.6 percent.

The difference between the average initial and calibrated $T_c$s ranged from an increase of 373 percent to a decrease of 93.5 percent. The average difference in $T_c$s for the storms in all the urban watersheds was an increase of 17.1 percent. However, most of the urban watersheds required a decrease in $T_c$s to match observed peak discharges. The Allen Creek watershed required an increase in the $T_c$ of 304 percent. When Allen Creek is not included in the average for the urban watersheds, the difference was a decrease of 40.3 percent. The average difference in $T_c$s for all the natural watersheds was an increase of 89.0 percent, and the average difference for all the mixed watersheds was an increase of 93.7 percent. However, two of the three watersheds included in the mixed watershed average (Walker Creek and Catfish Creek) required decreases of 45.1 and 46.8 percent to matched observed peak discharge rates. The third watershed, Gottfried Creek, required an increase of 373 percent and may be anomalous for these types of watersheds. When Gottfried Creek is not included in the average, the difference was a decrease of about 46 percent. The Walker and Catfish Creek watersheds have characteristics which are similar to characteristics for urban watersheds. The Gottfried Creek watershed is more similar to natural watersheds than the Walker and Catfish Creek watersheds.

CNs were decreased an average of 2.8 percent and $T_c$s were increased an average of 59.2 percent to match observed peak discharges and runoff volumes of all the watersheds. The NRCS procedures for calculating CNs are probably applicable to the study area, if detailed knowledge of the watershed is available and adjustments are made to account for wetlands and other depressional storage present in most watersheds in west-central Florida. The NRCS procedures for calculating $T_c$s may not be as applicable in the study area.

Peak rate factors for the modified dimensionless unit hydrographs ranged from 162 to 454. Figure 3 shows the shapes of various dimensionless unit hydrographs with peak rate factors ranging from 150 to 450 that were developed from flood hydrographs for watersheds in west-central Florida. Appendix C shows these dimensionless unit hydrographs in tabular form.

The average calibrated input parameters for each watershed were then used to recalculate the estimated peak discharge and runoff volume for each storm.

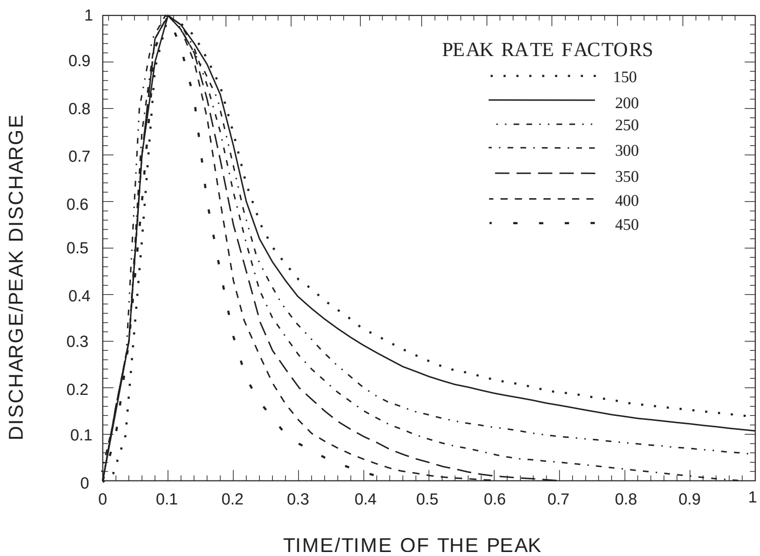



**Figure 3.** The shape of various dimensionless unit hydrographs with peak rate factors ranging from 150 to 450, developed for west-central Florida.

Appendix D lists the observed peak discharges and runoff volumes for each storm, with the initial estimates and estimates made using the calibrated input parameters.

The NRCS procedures for determining input parameters produced mean errors of 44.6 percent for peak discharge and 42.7 percent for runoff volume for all the storms. The mean errors for all watersheds were reduced to 18.9 and 19.5 percent, respectively, using the average calibrated input parameters for each watershed. For the urban watersheds, the mean errors were reduced from 12.3 and 31.1 percent to 3.3 percent and 6.2 percent for peak discharge and runoff volume. Mean errors were reduced from 95.9 and 55.6 percent to 41.7 and 39.9 percent for the natural watersheds and from 46.6 and 49.1 percent to 22.1 and 21.1 percent for the mixed watersheds, for peak discharges, and runoff volumes, respectively. All mean errors were positive.

## The U.S. Army Corps of Engineers HEC-1 Model

The HEC-1 model was developed by the U.S. Army Corps of Engineers as a single event model to simulate the surface runoff response of a watershed to precipitation by representing the watershed as an interconnected system of hydrologic and hydraulic components. The model components are based on simple mathematical relations that are intended to represent average conditions for the meteorologic, hydrologic, and hydraulic processes. These processes are precipitation, interception/infiltration (precipitation loss), transformation of rainfall to runoff, and flood hydrograph routing (Hydrologic Engineering Center, 1990). The HEC-1 model gives the user choices of methods to calculate each of the individual processes. The user's manual (Hydrologic Engineering Center, 1990) outlines the options available and the parameters required for each method.

Measured rainfall from actual storms was used for the HEC-1 simulations. Precipitation loss and rainfall excess was calculated using the NRCS curve number method because the other methods available within the model require input parameters or coefficients that are difficult to estimate for ungaged watersheds or are more appropriate for cultivated agricultural watersheds. The average antecedent moisture condition was used. Rainfall excess was transformed to a runoff hydrograph by the unit hydrograph method. The watershed lag time (LT) is used in this procedure and was calculated using the NRCS lag equation. The standard NRCS unit hydrograph (484 peak rate factor) contained within the HEC-1 model was used for the simulations because the source code would have to be modified and the program recompiled in order to enter the Delmarva unit hydrograph (284 peak rate factor).

Watershed subbasin flood hydrographs were routed through stream reaches or reservoirs and combined where necessary. Reservoir routing was accomplished using the storage routing method (Hydrologic Engineering Center, 1990). Hydrograph flood routing was accomplished using the Muskingum-Cunge channel routing method.

To increase the accuracy of the estimates, the CNs and LTs were adjusted until the estimated peak discharge and runoff volumes were equal to the observed. Only storms that had simple, single peak hydrographs were used for the calibration. Calibrated CNs and LTs were developed for each storm in each watershed, then averaged for the watershed.

The average initial and calibrated CNs and LTs for each watershed are listed in table 7. The difference between the average initial and calibrated CNs ranged from an increase of 22.2 percent to a decrease of 27.4 percent. The average difference for all the urban water-

**Table 7.** The average initial and modified CNs and LTs, and the difference for each watershed, each watershed type, and for all the watersheds for the U.S. Army Corps of Engineers HEC-1 model
[CN, curve number; LT, Lag time; U, urban; N, natural; M, mixed; +, increase; -, decrease]

| Watershed name | Classification | Initial CN | Modified CN | Percent difference | Initial LT | Modified LT | Percent difference |
|---|---|---|---|---|---|---|---|
| Arctic Street storm drain | U | 83 | 81 | -2.4 | 0.59 | 0.90 | +52.5 |
| Kirby Street drainage ditch | U | 70 | 69 | -1.4 | 2.95 | 3.80 | +28.8 |
| St. Louis Street drainage ditch | U | 85 | 70 | -17.6 | 1.37 | .15 | -89.0 |
| Gandy Boulevard drainage ditch | U | 87 | 88 | +1.1 | .64 | 1.45 | +126 |
| Allen Creek | U | 85 | 89 | +4.7 | .31 | 1.26 | +320 |
| Clower Creek | U | 95 | 90 | -5.3 | 1.61 | 3.10 | +92.5 |
| Urban Watersheds | | | | -3.5 | | | +88.5 |
| IMC Creek | N | 70 | 64 | -8.6 | .94 | 2.75 | +193 |
| Grace Creek | N | 72 | 72 | 0.0 | 2.08 | 5.25 | +152 |
| CFI-3 Creek | N | 73 | 53 | -27.4 | .76 | .74 | -2.6 |
| South Creek | N | 74 | 73 | -1.3 | 4.07 | 17.0 | +318 |
| Forked Creek | N | 72 | 88 | +22.2 | 1.95 | 12.0 | +515 |
| Natural Watersheds | | | | -3.0 | | | +235 |
| Walker Creek | M | 80 | 78 | -2.5 | 4.43 | 6.63 | +49.7 |
| Catfish Creek | M | 79 | 75 | -5.1 | 5.53 | 11.42 | +107 |
| Gottfried Creek | M | 74 | 80 | +8.1 | 3.93 | 23.75 | +504 |
| Mixed Watersheds | | | | +.2 | | | +220 |
| All Watersheds | | | | -2.5 | | | +169 |

sheds was a decrease of 3.5 percent, for all the natural watersheds was a decrease of 3 percent, and for all the mixed watersheds was an increase of 0.2 percent. The difference between the average initial and calibrated LTs ranged from an increase of 515 percent to a decrease of 89 percent. The average difference in LTs for all the storms in the urban watersheds was an increase of 88.5 percent. The average difference in LTs for all the natural watersheds was an increase of 235 percent, and the average difference for all the mixed watersheds was an increase of 220 percent. CNs and $T_c$s needed average changes of about 2.5 percent and 169 percent, respectively, to match observed peak discharges and runoff volumes for all the watersheds.

The average calibrated input parameters for each watershed were then used to recalculate the estimated peak discharge and runoff volume for each storm. Appendix E compares the observed peak discharges and runoff volumes to initial estimates and estimates made using calibrated CNs and LTs.

The initial input parameters produced mean errors of 105 percent for peak discharge and 26.8 percent for runoff volume for all the storms. The mean errors were reduced to 5.8 and 1.4 percent, respectively, using the average calibrated input parameters for each watershed. For the urban watersheds, the mean errors were reduced from 75.2 and 24.6 percent to less than 1 percent and 2.4 percent for peak discharge and runoff volume. Mean errors were reduced from 175 and 27.9 percent to 22 and 7.5 percent for the natural watersheds and from 84 and 29.4 percent to less than 1 percent and 6.5 percent for the mixed watersheds, for peak discharges and runoff volumes, respectively.

Although observed and estimated peak discharges and runoff volumes could be matched by adjusting CNs and LTs, the shape of the estimated flood hydrograph and timing of the peak could not. Calibrating the CNs and LTs, in most cases, caused greater error in the shape and timing of the peak of the estimated flood hydrograph. The input DUH would have to be changed to increase the accuracy of the HEC-1 model when used for estimating west-central Florida watersheds. The source code would have to be modified and recompiled to enter different DUHs into the program. It was assumed that most users would not go through this process before applying the model; therefore, no further modifications were made to the model. The HEC-1 model is probably not applicable to watersheds in west-central Florida, unless DUHs that are more representative of the area are used.

## The U.S. Environmental Protection Agency SWMM Model

The SWMM model, developed by the U.S. Environmental Protection Agency, can be used to make single-event or continuous simulations. For this study, the model was used only as a single-event model. It simulates storm events by using rainfall and watershed characterization. The model is organized in the form of "blocks". There are four computational blocks and six service blocks in the model. However, the model is usually run using only the executive block and one or two computational blocks. A detailed explanation of the model's properties, processes, and requirements are contained in the user's manual (Huber and Dickinson, 1988). The runoff and extended transport (extran) computational blocks and the executive and graph service blocks were used for this study.

The runoff block accepts rainfall and calculates infiltration, surface detention, and overland and channel flow. Rainfall depths from actual storms were used to make the estimates for this study. The SWMM model has two options for calculating infiltration. The first uses the Green-Ampt equation. The second uses an integrated form of Horton's equation. Both the Green-Ampt equation and Horton's equation were used in separate simulations. Except for the urban watersheds in Pinellas and western Hillsborough Counties and the Clower Creek watershed in Sarasota County, infiltration was also routed through subsurface pathways. Subsurface routing is calculated in the runoff block. Subsurface routing was not used in the urban watersheds because of the high percentage of impervious area and the presence of sewered drainage systems. Overland flow and channel routing are calculated in the runoff block by approximating the watersheds as nonlinear reservoirs and is accomplished by coupling a spatially lumped continuity equation with Manning's equation. A detailed description of the procedure is presented in appendix V of the user's manual (Huber and Dickinson, 1988).

The runoff block cannot simulate backwater effects on flood hydrographs being routed through watersheds with multiple subbasins. The equations used in the extran block, however, account for backwater effects as well as flow reversal, pressure flow, and surcharging (backup, storage, and slower release of water) at each junction (Roesner and others, 1988). Significant backwater and some surcharging occurs in the watersheds in Sarasota County. The Walker, Catfish, South, Forked, Gottfried, and Rock Creek watersheds in Sarasota County were modeled using multiple subbasins which allowed for a greater degree of spatial detail. Extran channel routing was used for all multiple subbasin watersheds. Channel routing was not used for single-basin watersheds.

Some runoff block input parameters and, where applicable, some ground-water input parameters were adjusted until the estimated and observed peak discharges and runoff volumes were calibrated. Parameters estimating ground-water levels and elevations of the channel bottom, land surface, and bottom of the surficial aquifer were not changed from the initial estimates. Only the ground-water flow coefficient ($A_1$), ground-water flow exponent ($B_1$), soil porosity (POR), and the initial upper zone moisture content ($TH_1$) parameters were adjusted. The remaining parameters of the runoff block had little or no effect on the estimations; therefore, these parameters were set to 0.0 which is the model default value. Calibrations were run for each storm, in each watershed. The calibrated input parameters were then averaged for each watershed.

The average initial and modified input parameters used with the Green-Ampt infiltration method are listed in tables 8 and 9. The average initial and modified input parameters used with the Horton infiltration method are listed in tables 10 and 11.

Simulations were rerun for each watershed using the calibrated average input parameters for that watershed. Appendix F compares observed peak discharges and runoff volumes to initial estimates and estimates made using the modified input parameters for the Green-Ampt infiltration method. Appendix G shows the same comparisons for the Horton infiltration method.

The initial input parameters produced a mean error for all storms of 46.5 percent for peak discharge and 6.8 percent for runoff volume using the Green-Ampt infiltration method. Mean errors were 48.8 percent for peak discharge and 9.5 percent for runoff volume using the Horton infiltration method. Initially, the peak discharge error was overestimated and the runoff volume error was underestimated using both infiltration methods. The mean errors were reduced to 18 and 0.3 percent, respectively, for the Green-Ampt method and to 20.9 and 7.2 percent, respectively, for the Horton method using the average calibrated input parameters for each watershed. Peak discharges and runoff volumes were overestimated using both infiltration methods.

**Table 8.** Selected average initial runoff block input parameters forthe U.S. Environmental Proctection Agency Storm Water Management model using the Green-Ampt infiltration method

[IMPV, impervious area Manning's number; PERVN, pervious area Manninig's number; IDS, impervious area depressional storage (in/impervious area); PDS, pervious area depressional storage (in/pervious area); SUCT, average capillary suction (in.); HYCON, saturated hydraulic conductivity (in/hour); IMD, initial soil moisture deficit (in/in); $A_1$, ground water flow coefficient (in/hr-ft); $B_1$, ground water flow exponent, POR, soil porosity (as a fraction);$TH_1$, initial upper zone moisture content (as a fraction); --, model default values used (0.0); U, urban; N, natural; M, mixed]

| Watershed name | Classification | IMPV | PERVN | IDS | PDS | SUCT | HYCON | IMD | $A_1$ | $B_1$ | POR | $TH_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arctic Street storm drain | U | 0.012 | 0.25 | 0.01 | 0.00 | 4.0 | 0.30 | 0.30 | -- | -- | -- | -- |
| Kirby Street drainage ditch | U | .100 | .35 | .05 | .10 | 4.0 | .30 | .30 | -- | -- | -- | -- |
| St. Louis Street drainage ditch | U | .010 | .16 | .00 | .00 | 8.0 | .10 | .25 | -- | -- | -- | -- |
| Gandy Boulevard drainage ditch | U | .010 | .29 | .00 | .00 | 8.0 | .10 | .25 | -- | -- | -- | -- |
| Allen Creek | U | .012 | .28 | .00 | .00 | 8.0 | .10 | .25 | -- | -- | -- | -- |
| Clower Creek | U | .012 | .35 | 1.00 | .50 | 4.0 | .10 | .20 | -- | -- | -- | -- |
| IMC Creek | N | .000 | .37 | .00 | .00 | 4.0 | .10 | .30 | 4.06E-06 | 2.0 | 0.40 | 0.24 |
| Grace Creek | N | .000 | .32 | .00 | .00 | 4.0 | .30 | .30 | 1.58E-06 | 2.0 | .40 | .26 |
| CFI-3 Creek | N | .000 | .37 | .00 | .00 | 4.0 | .30 | .25 | 1.58E-06 | 2.0 | .40 | .27 |
| South Creek | N | .005 | .37 | .00 | .10 | 4.0 | .12 | .20 | 2.00E-04 | 2.0 | .40 | .25 |
| Forked Creek | N | .000 | .33 | .00 | .10 | 4.0 | .05 | .20 | 1.00E-04 | 2.0 | .40 | .25 |
| Walker Creek | M | .015 | .45 | .20 | .20 | 4.0 | .30 | .30 | 5.00E-05 | 2.0 | .40 | .26 |
| Catfish Creek | M | .008 | .38 | .00 | .05 | 4.0 | .10 | .20 | 5.00E-05 | 2.0 | .40 | .27 |
| Gottfried Creek | M | .010 | .36 | .50 | .80 | 4.0 | .16 | .20 | 8.00E-03 | 2.0 | .40 | .25 |

**Table 9.** Selected average modified runoff block input parameters forthe U.S. Environmental Proctection Agency Storm Water Management model using the Green-Ampt infiltration method

[IMPV, impervious area Manning's number; PERVN, pervious area Manninig's number; IDS, impervious area depressional storage (in/impervious area);PDS, pervious area depressional storage (in/pervious area); SUCT, average capillary suction (in.); HYCON, saturated hydraulic conductivity (in/hour); IMD, initial soil moisture deficit (in/in.); $A_1$, ground water flow coefficient (in/hr-ft); $B_1$, ground water flow exponent; POR, soil porosity (as a fraction); $TH_1$, initial upper zone moisture content (as a fraction); --, model default values used (0.0); U, urban; N, natural; M, mixed]

| Watershed name | Classification | IMPV | PERVN | IDS | PDS | SUCT | HYCON | IMD | $A_1$ | $B_1$ | POR | $TH_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Artic Street storm drain | U | 0.020 | 0.30 | 0.02 | 0.00 | 4.0 | 0.30 | 0.30 | -- | -- | -- | -- |
| Kirby Street drainage ditch | U | .300 | .35 | .05 | .10 | 4.0 | .04 | .25 | -- | -- | -- | -- |
| St. Louis Street drainage ditch | U | .010 | .01 | .00 | .00 | 5.0 | 1.40 | .05 | -- | -- | -- | -- |
| Gandy Boulevard drainage ditch | U | .010 | .10 | .00 | .00 | 8.0 | .05 | .05 | -- | -- | -- | -- |
| Allen Creek | U | .015 | .20 | .00 | .00 | 5.0 | .03 | .05 | -- | -- | -- | -- |
| Clower Creek | U | .050 | .40 | 1.00 | .50 | 4.0 | .01 | .01 | -- | -- | -- | -- |
| IMC Creek | N | .000 | .50 | .00 | .00 | 4.0 | .15 | .13 | 2.00E-06 | 2.4 | 0.20 | 0.24 |
| Grace Creek | N | .000 | .37 | .00 | .00 | 3.8 | .38 | .35 | 2.00E-06 | 2.9 | .37 | .28 |
| CFI-3 Creek | N | .000 | .37 | .00 | .00 | 4.0 | .10 | .30 | 2.00E-06 | 4.0 | .37 | .20 |
| South Creek | N | .015 | .40 | .00 | .10 | 4.0 | .40 | .30 | 6.00E-04 | 5.5 | .39 | .10 |
| Forked Creek | N | .000 | .33 | .00 | .10 | 4.0 | .76 | .30 | 5.00E-03 | 2.7 | .38 | .09 |
| Walker Creek | M | .015 | .45 | .20 | .20 | 4.0 | .15 | .30 | 5.00E-05 | 4.2 | .40 | .11 |
| Catfish Creek | M | .008 | .38 | .00 | .05 | 4.0 | .05 | .30 | 3.00E-03 | 5.0 | .40 | .10 |
| Gottfried Creek | M | .015 | .40 | .50 | .80 | 4.0 | .80 | .30 | 6.00E-03 | 3.3 | .39 | .11 |

**Table 10.** Selected average initial runoff block input parameters forthe U.S. Environmental Proctection Agency Storm Water Management model using the Horton infiltration method

[IMPV, impervious area Manning's number; PERVN, pervious area Manninig's number; IDS, impervious area depressional storage (in/impervious area); PDS, pervious area depressional storage (in/pervious area); WLMAX, maximum infiltration rate (in/hr); WLMIN, minimum infiltration rate (in/hr); DECAY, rate of decay of the infiltration rate (in/hr); $A_1$, ground water flow coefficient (in/hr-ft); $B_1$, ground water flow exponent, POR, soil porosity (as a fraction); $TH_1$, initial upper zone moisture content (as a fraction); --, model default values used (0.0); U, urban; N, natural; M, mixed]

| Watershed Name | Classification | IMPV | PERVN | IDS | PDS | WLMAX | WLMIN | DECAY | $A_1$ | $B_1$ | POR | $TH_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arctic Street storm drain | U | 0.012 | 0.25 | 0.01 | 0.00 | 3.0 | 0.30 | 0.00115 | -- | -- | -- | -- |
| Kirby Street drainage ditch | U | .100 | .35 | .05 | .10 | 3.0 | .30 | 0.00115 | -- | -- | -- | -- |
| St. Louis Street drainage ditch | U | .010 | .16 | .00 | .00 | 1.0 | .10 | 0.00115 | -- | -- | -- | -- |
| Gandy Boulevard drainage ditch | U | .010 | .29 | .00 | .00 | 1.0 | .10 | 0.00115 | -- | -- | -- | -- |
| Allen Creek | U | .012 | .28 | .00 | .00 | 1.0 | .10 | 0.00115 | -- | -- | -- | -- |
| Clower Creek | U | .012 | .35 | 2.00 | .05 | 4.0 | .10 | 0.00115 | -- | -- | -- | -- |
| IMC Creek | N | .000 | .37 | .00 | .00 | 3.0 | .20 | 0.00115 | 4.06E-06 | 2.0 | 0.40 | 0.24 |
| Grace Creek | N | .000 | .32 | .00 | .00 | 3.0 | .30 | 0.00115 | 1.58E-06 | 2.0 | .40 | .26 |
| CFI-3 Creek | N | .000 | .37 | .00 | .00 | 2.0 | .30 | 0.00115 | 1.58E-06 | 2.0 | .40 | .27 |
| South Creek | N | .005 | .37 | .00 | .10 | 3.6 | .12 | 0.00115 | 2.00E-04 | 2.0 | .40 | .25 |
| Forked Creek | N | .000 | .33 | .00 | .10 | 3.7 | .16 | 0.00115 | 1.00E-04 | 2.0 | .40 | .25 |
| Walker Creek | M | .015 | .45 | .20 | .20 | 3.0 | .30 | 0.00115 | 5.00E-05 | 2.0 | .40 | .26 |
| Catfish Creek | M | .008 | .38 | .00 | .05 | 2.0 | .17 | 0.00115 | 5.00E-05 | 2.0 | .40 | .27 |
| Gottfried Creek | M | .010 | .36 | .50 | .80 | 4.0 | .14 | 0.00115 | 8.00E-03 | 2.0 | .40 | .25 |

**Table 11.** Selected average modified runoff block input parameters forthe U.S. Environmental Proctection Agency Storm Water Management model using the Horton infiltration method

[IMPV, impervious area Manning's number; PERVN, pervious area Manninig's number; IDS, impervious area depressional storage (in/impervious area); PDS, pervious area depressional storage (in/pervious area); WLMAX, maximum infiltration rate (in/hr); WLMIN, minimum infiltration rate (in/hr); DECAY, rate of decay of the infiltration rate (in/hr); $A_1$, ground water flow coefficient (in/hr-ft); $B_1$, ground water flow exponent, POR, soil porosity (as a fraction); $TH_1$, initial upper zone moisture content (as a fraction); --, model default values used (0.0); U, urban; N, natural; M, mixed]

| Watershed Name | Classification | IMPV | PERVN | IDS | PDS | WLMAX | WLMIN | DECAY | $A_1$ | $B_1$ | POR | $TH_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arctic Street storm drain | U | 0.012 | 0.25 | 0.01 | 0.00 | 3.0 | 0.20 | 0.00300 | -- | -- | -- | -- |
| Kirby Street drainage ditch | U | .100 | .35 | .05 | .10 | 3.0 | .07 | 0.00200 | -- | -- | -- | -- |
| St. Louis Street drainage ditch | U | .010 | .16 | .00 | .00 | 1.0 | 1.25 | 0.00500 | -- | -- | -- | -- |
| Gandy Boulevard drainage ditch | U | .010 | .29 | .00 | .00 | 1.0 | .20 | 0.00500 | -- | -- | -- | -- |
| Allen Creek | U | .012 | .28 | .00 | .00 | 1.5 | .03 | 0.00600 | -- | -- | -- | -- |
| Clower Creek | U | .012 | .35 | 2.00 | .05 | 4.0 | .01 | 0.00500 | -- | -- | -- | -- |
| IMC Creek | N | .000 | .37 | .00 | .00 | 3.0 | .20 | 0.00350 | 2.00E-06 | 2.4 | 0.20 | 0.24 |
| Grace Creek | N | .000 | .32 | .00 | .00 | 4.5 | .30 | 0.00100 | 2.00E-06 | 290 | .37 | .28 |
| CFI-3 Creek | N | .000 | .37 | .00 | .00 | 3.0 | .35 | 0.00100 | 2.00E-06 | 4.0 | .37 | .20 |
| South Creek | N | .005 | .37 | .00 | .10 | 3.0 | .05 | 0.00100 | 6.00E-04 | 5.5 | .39 | .10 |
| Forked Creek | N | .000 | .33 | .00 | .10 | 3.0 | .30 | 0.00100 | 5.00E-03 | 2.7 | .38 | .09 |
| Walker Creek | M | .015 | .45 | .20 | .20 | 3.0 | .20 | 0.00100 | 5.00E-05 | 4.2 | .40 | .11 |
| Catfish Creek | M | .008 | .38 | .00 | .05 | 2.0 | .15 | 0.00100 | 3.00E-03 | 5.0 | .40 | .10 |
| Gottfried Creek | M | .010 | .36 | .50 | .80 | 3.0 | .15 | 0.00100 | 6.00E-03 | 3.3 | .39 | .11 |

Using the average calibrated input parameters for each watershed with the Green-Ampt infiltration method produced reductions in the mean error from 19.6 and 27.6 percent to 7.7 and 2.1 percent for peak discharge and runoff volume, respectively, for all the storms in the urban watersheds. The mean errors were reduced from 54.3 and 18.9 percent to 51.4 and 1.3 percent for the natural watersheds. The mean error for peak discharge for the mixed watersheds was reduced from 83.1 percent to 1.7 percent; however, the mean error for runoff volume increased slightly from 1.7 percent to 3.7 percent.

Using the average calibrated input parameters for each watershed with the Horton infiltration method produced reductions in the mean error from 20.2 and 20.6 percent to 4.4 and 7.6 percent for peak discharge and runoff volume, respectively, for all the storms in the urban watersheds. The mean errors increased from 60 and 3.8 percent to 67.8 and 9.3 percent when the average calibrated input parameters were used for the natural watersheds. The mean error for peak discharge for the mixed watersheds was reduced from 84.9 percent to 7.4 percent; however, the mean error for runoff volume increased slightly from 3.0 percent to 4.4 percent.

## COMPARISON OF THE AVERAGE ERRORS FOR THE FIVE STORMWATER RUNOFF ESTIMATING TECHNIQUES

The average error for each technique, in percent, between the observed, and the initial and modified estimates of peak discharge and runoff volume for each watershed type are listed in table 12. All average errors were reduced using the modified input parameters or equations, for the rational method, the regression method, the TR-20 model and the HEC-1 model. However, increases in average errors were produced in some watershed types when modified input parameters were used in the SWMM model. Runoff volume increased from an underestimation of 1.7 percent to an underestimation of 3.7 percent for the mixed watersheds when average modified input parameters were used in the SWMM model with the Green-Ampt infiltration method. Peak discharge errors increased from an overestimation of 60 percent to an overestimation of 67.8 percent and runoff volume errors increased from an underestimation of 3.8 percent to an overestimation of 9.3 percent for the natural watersheds when average modified input parameters were used in the SWMM model with the Horton infiltration method. Runoff volume errors increased from an overestimation of 3 to 4.4 percent when this method was used for the mixed watersheds. Average errors decreased in all other applications of the SWMM model, using modified input parameters.

**Table 12.** Comparison of the average errors for the five stormwater runoff estimating techniques for each watershed type

[--, not applicable; -, negative values represent underestimations; <, less than; all values are in percent]

| | Peak discharge | | Runoff volume | |
|---|---|---|---|---|
| Rational method | Initial | Modified | Initial | Modified |
| Urban | 69.6 | 2.7 | -- | -- |
| Natural | 425 | -0.3 | -- | -- |
| Mixed | 287 | <-0.1 | -- | -- |
| Regression method | USGS | West-central Florida | USGS | West-central Florida |
| Urban | -25.3 | 19.9 | -31.8 | 19.2 |
| Natural | 277 | 14.5 | 67.7 | 20.7 |
| Mixed | -13.5 | 4.6 | 79.1 | 13.4 |
| TR-20 model | Initial | Modified | Initial | Modified |
| Urban | 12.3 | 3.3 | 31.1 | 6.2 |
| Natural | 95.9 | 41.7 | 55.6 | 39.9 |
| Mixed | 46.6 | 22.1 | 49.1 | 21.1 |
| HEC-1 model | Initial | Modified | Initial | Modified |
| Urban | 75.2 | -0.6 | 24.6 | -2.4 |
| Natural | 175 | 22.0 | 27.9 | -7.5 |
| Mixed | 84.0 | 0.1 | 29.4 | 6.5 |
| SWMM model (Green-Ampt) | Initial | Modified | Initial | Modified |
| Urban | 19.6 | 7.7 | -27.6 | 2.1 |
| Natural | 54.3 | 51.4 | 18.9 | 1.3 |
| Mixed | 83.1 | 1.7 | -1.7 | -3.7 |
| SWMM model (Horton) | Initial | Modified | Initial | Modified |
| Urban | 20.2 | 4.4 | -20.6 | 7.6 |
| Natural | 60.0 | 67.8 | -3.8 | 9.3 |
| Mixed | 84.9 | 7.4 | 3.0 | 4.4 |

Estimates of peak discharges and runoff volumes were initially made for watersheds in west-central Florida using recommended procedures, then compared to observed peak discharges and runoff volumes. Subsequently, they were modified to increase accuracy for this area. The same methods used during the study could be used in other parts of the country to evaluate the accuracy of standard methods for estimating stormwater runoff.

## SUMMARY AND CONCLUSIONS

Measured peak discharges and runoff volumes for 62 storms in 14 west-central Florida watersheds were compared to estimates made with five commonly used techniques applied with recommended or customary procedures and with estimates made using the same techniques with modified input parameters. The techniques used were: (1) the Rational Method; (2) the USGS Regional Regression Equations; (3) the Natural Resources Conservation Service TR-20 model; (4) the U.S. Army Corps of Engineers HEC-1 model; and (5)the U.S. Environmental Protection Agency SWMM model.

Comparison of the observed runoff volumes to the observed rainfall indicates that runoff ranged from 1.4 percent of rainfall for a storm in the IMC Creek watershed, a small natural watershed, to 99.3 percent of rainfall for a storm in the Clower Creek watershed, an urban watershed with about 85 percent impervious area. The average runoff for all watersheds included in this study was about 36 percent of rainfall. The average runoff for the urban, natural, and mixed land-use watersheds was about 41, 27, and 29 percent, respectively.

The Rational Method, as initially applied, produced average watershed errors in peak discharge that ranged from an underestimation of 50.4 percent to an overestimation of 767 percent. Initial estimates were made using values of C that ranged from 0.20 to 0.60.New values of C were calculated from the observed peak discharge, rainfall data and watershed area. The average calculated values of C ranged from 0.02 to 0.73 and produced average watershed errors that ranged from 1.1 to 480 percent. Further calibration of the technique produced average errors that ranged from an underestimation of 3.3 percent to an overestimation of 1.5 percent. The average calibrated values of C ranged from 0.02 to 0.72 for all the watersheds. The average values of C necessary to calibrate all the urban, natural, and mixed land-use watersheds were 0.39, 0.16, and 0.08, respectively. Watersheds that have control structures or use other management practices will have lower values of C than similar watersheds without management practices.

The USGS regional regression equation for determining peak discharge produced errors that ranged from an underestimation of 87.3 percent to an overestimation of 1,140 percent. Characteristics for the watersheds included in this study fall within the ranges of those used to develop the regression equations for peak discharge; however, they are near the extremes of these ranges, increasing the probability of error. The regression equations for determining runoff volume produced errors that ranged from an underestimation of 95.6 percent to an overestimation of 324 percent. The characteristics of many watersheds in west-central Florida are outside the limits of those used to develop the runoff volume equation; therefore, use of these equations may not produce reliable estimates for watersheds similar to those in west-central Florida. The assumption that rainfall frequency is equal to flow frequency also contributes to the probability of error.

Equations were developed during this study that were more specific to the types of watersheds located in west-central Florida. These equations reduced errors to about 20, 14, 5, and 14 percent for peak discharge and about 19, 21, 13, and 18 percent for runoff volume in the urban, natural, and mixed watersheds, and for all watersheds, respectively. Because of the simplicity of these equations, they could be used as preliminary estimates or as checks or guidelines to the appropriateness of more complicated methods.

Initial estimates of peak discharges and runoff volumes using the NRCS TR-20 model, produced average errors of 44.6 and 42.7 percent respectively, for all the watersheds. CNs and $T_c$s were adjusted until the best matches were obtained between estimated and observed peak discharges and runoff volumes. The average change in the CNs from initial to calibrated values for all the watersheds, was an increase of 2.8 percent. The average change in the $T_c$s was an increase of 59.2 percent. The NRCS procedures for calculating CNs are probably applicable to the study area, if detailed knowledge of the watershed is available and adjustments are made to account for wetlands and other depressional storage present in most watersheds in west-central Florida. The NRCS equations for calculating $T_c$s may not be as applicable in the study area. The shape of the input dimensionless unit hydrograph had to be adjusted also, to match the shape and time of the peak of the estimated and observed flood hydrograph.

Peak rate factors for the modified input dimensionless unit hydrographs ranged from 162 to 454. The mean errors for all watersheds were reduced to 18.9 and 19.5 percent, respectively, using the average calibrated input parameters for each watershed. For the urban watersheds, the mean errors were reduced to 3.3 and 6.2 percent for peak discharge and runoff volume. Mean errors were reduced to 22.1 and 21.1 percent for the mixed watersheds, and to 41.7 and 39.9 percent for the natural watersheds for peak discharges and runoff volumes, respectively. All mean errors were overestimations.

Initial estimates of peak discharges and runoff volumes using the U.S. Army Corps of Engineers HEC-1 model produced average errors of 105 and 26.8 percent, respectively, for all the watersheds. CNs and LTs were adjusted until the estimated and observed peak discharges and runoff volumes were equal. The average change in the CNs from initial to calibrated values for all the watersheds was a decrease of 2.5 percent. The average change in the LTs was an increase of 169 percent. Calibrated input parameters were averaged for each watershed and used to recalculate peak discharges and runoff volumes. The mean errors for all watersheds were reduced to 5.8 and 1.4 percent, respectively, peak discharge and runoff volume, for each watershed. For the urban watersheds, the mean errors were reduced to less than 1 and 2.4 percent. Mean errors were reduced to less than 1 and 6.5 percent for the mixed watersheds and to 22 and 7.5 percent for the natural watersheds.

The observed and estimated peak discharges and runoff volumes could be matched by adjusting CNs and LTs using the U.S. Army Corp of Engineers HEC-1 model; however, the shape of the estimated flood hydrograph and timing of the peak could not. Calibrating the CNs and LTs, in most cases, caused greater error in the shape and timing of the peak of the estimated flood hydrograph. The input DUH must also be changed to increase the accuracy of the HEC-1 model for watersheds in west-central Florida. The source code has to be modified and recompiled to enter different DUHs into the program. The HEC-1 model is probably not applicable to most watersheds in west-central Florida, unless DUHs that are more representative of the area are used.

The Environmental Protection Agency Storm Water Management model has two options for calculating infiltration, the Green-Ampt and the Horton method. Both methods were used in separate simulations for this study. Initial estimates of peak discharges and runoff volumes produced mean errors of 46.5 and 6.8 percent, respectively, for all the watersheds using the Green-Ampt infiltration method and 48.8 and 9.5 percent, respectively, using the Horton infiltration method. Peak discharges were initially overestimated and runoff volumes underestimated using both infiltration methods. The mean errors were reduced to 18 and 0.3 percent for the Green-Ampt method and to 20.9 and 7.2 percent for the Horton method using the average calibrated input parameters for each watershed. Peak discharges and runoff volumes were overestimated using both infiltration methods.

Mean errors were reduced to 7.7 and 2.1 percent for the urban watersheds and to 51.4 and 1.3 percent for the natural watersheds using calibrated input parameters and the Green-Ampt infiltration method. Peak discharges were reduced to 1.7 percent for the mixed watersheds: however, runoff volumes increased slightly, to 3.7 percent, using the calibrated input parameters and the Green-Ampt infiltration method. Mean errors were reduced to 4.4 and 7.6 percent for the urban watersheds using calibrated input parameters and the Horton infiltration method. Mean errors increased to 67.8 and 9.3 percent when the average calibrated input parameters and the Horton infiltration method were used for the natural watersheds. The mean error for peak discharge for the mixed watersheds was reduced to 7.4 percent; however, the mean error for runoff volume increased slightly to 4.4 percent.

With the exception of some applications of the SWMM model, the average errors for peak discharges and runoff errors decreased using the modified input parameters or equations. Peak discharge errors increased when the Horton infiltration method was used with modified input parameters for the natural watersheds. Runoff volume errors increased when the Green-Ampt infiltration method with modified input parameters was used for the mixed watersheds and when the Horton infiltration method with modified input parameters was used for the natural and mixed watersheds.

Estimates of peak discharges and runoff volumes were initially made for watersheds in west-central Florida using recommended procedures. The same methods used during this study could be used in other parts of the country to evaluate the accuracy of standard methods for estimating stormwater runoff.

## REFERENCES


Bridges, W. C., 1982, Technique for estimating magnitude and frequency of floods on natural-flow streams in Florida: U.S. Geological Survey Water-Resources Investigations Report 82-4012, 44 p.

Huber, W. C., and Dickinson, R. E., 1988, Storm water management model version 4, part A: User's manual: U.S. Environmental Protection Agency Report EPA/600/3-88/001a, 569 p.

Hydrologic Engineering Center, 1990, HEC-1 Flood hydrograph package user's manual: U.S. Army Corps of Engineers, Davis, California, 410 p.

Roesner, L. A., Aldrich, J. A., and Dickinson, R. E., 1988, Storm water management model, version 4, part B: Extran addendum: U.S. Environmental Protection Agency Report EPA/600/3-88/001b, 157 p.

Soil Conservation Service, 1983, TR-20 Project Formulation-Hydrology (1982 Version), Technical Release No. 20, 296 p.

Soil Conservation Service, 1985, National engineering handbook, section 4-hydrology: 210-VI-NEH-4, Amend 6, Washington, D. C.

Soil Conservation Service, 1986, Urban hydrology for small watersheds (2d ed.): Technical Release No. 55, 210-VI-TR-55, 156 p.

Soil Conservation Service, 1986, Technical Release No. 55: Florida Bulletin No. 210-7-2.

Stricker, V. A., and Sauer, V. B., 1982, Techniques for estimating flood hydrographs for ungaged urban watersheds: U.S. Geological Survey Open-File Report 82-365, 24 p.

Trommer, J. T., Loper, J. E., Hammett, K. M., 1996, Comparison of five estimating techniques for determining stormwater in west-central Florida: U.S. Geological Survey Open-File Report 96-129, 79 p.

Viessman, Warren, Jr., Lewis, G. L., and Knapp, J. W., 1989, Introduction to hydrology (3d ed.): New York, Harper and Row Publishers, Inc.

Williams, G. R., 1950, Hydrology: in Rouse, Hunter, ed., Engineering hydraulics, Proceedings of the Fourth Hydraulics Conference: Iowa Institute of Hydraulic Research, June 12-15, 1949, p. 229-320.

# Appendixes

**Appendix A. Comparison of observed peak discharges and peak discharges estimated using the initial, calulated, and calibrated input parameters, and a list of the rainfall intensities used for calculating peak discharges using the Rational Method**

[$ft^3/s$, cubic feet per second; in/hr, inches per hour; U, urban; N, natural; M, mixed; -, negative values represent underestimations; <, less than]

| | | Peak discharges | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Watershed name** | **Watershed classification** | **Observed ($ft^3/s$)** | **Initial ($ft^3/s$)** | **Error (percent)** | **Calculated ($ft^3/s$)** | **Error (percent)** | **Calibrated ($ft^3/s$)** | **Error (percent)** | **Rainfall intensity (in/hr)** | **Date of storm** |
| Arctic Street storm drain | U | 120 | 131 | 9.2 | 140 | 16.7 | 125 | 4.2 | 1.50 | 08/03/76 |
| | | 133 | 146 | 9.8 | 156 | 17.3 | 139 | 4.5 | 1.67 | 08/04/76 |
| | | 137 | 195 | 42.3 | 209 | 52.6 | 187 | 36.5 | 2.24 | 09/26/77 |
| | | 142 | 81 | -43.0 | 87 | -38.7 | 78 | -45.1 | 0.93 | 05/20/78 |
| Kirby Street drainage ditch | U | 57 | 689 | 618 | 117 | 21.9 | 110 | 14.6 | 3.12 | 07/19/75 |
| | | 95 | 400 | 321 | 68 | -28.4 | 64 | -32.6 | 1.81 | 08/30/75 |
| | | 96 | 420 | 637 | 71 | 24.6 | 67 | 17.5 | 1.90 | 08/15/78 |
| St. Louis St. drainage ditch | U | 357 | 140 | -60.8 | 205 | -42.6 | 203 | -43.0 | .86 | 05/15/76 |
| | | 226 | 202 | -10.6 | 296 | 31.0 | 293 | 29.6 | 1.24 | 06/18/76 |
| | | 326 | 256 | -21.5 | 375 | 15.0 | 371 | 13.8 | 1.57 | 06/29/77 |
| Gandy Blvd. drainage ditch | U | 223 | 380 | 70.4 | 445 | 99.6 | 284 | 27.3 | .92 | 06/18/75 |
| | | 301 | 182 | -39.5 | 213 | -29.2 | 136 | -53.2 | .44 | 07/11/75 |
| | | 207 | 644 | 211 | 754 | 264 | 482 | 133 | 1.56 | 08/07/75 |
| | | 692 | 202 | -70.8 | 411 | -40.6 | 263 | -62.0 | .49 | 05/15/76 |
| | | 410 | 318 | -22.4 | 372 | -9.3 | 238 | -42.0 | .77 | 05/17/76 |
| Allen Creek | U | 341 | 445 | 17.4 | 735 | 116 | 610 | 78.8 | .74 | 07/28/76 |
| | | 379 | 493 | -39.8 | 473 | 24.8 | 393 | 3.7 | .82 | 07/01/77 |
| | | 819 | 421 | 25.7 | 524 | -36.0 | 435 | -46.9 | .70 | 07/01/77 |
| | | 335 | 692 | 103 | 447 | 33.4 | 371 | 10.7 | 1.15 | 07/03/77 |
| | | 89 | 102 | 14.6 | 109 | 22.5 | 90 | <0.1 | .17 | 12/02/77 |
| | | 286 | 168 | -41.3 | 179 | -37.4 | 149 | -47.9 | .28 | 02/18/78 |
| Clower Creek | U | 77 | 105 | 36.4 | 77 | .0 | 70 | -10.0 | .78 | 02/05/92 |
| | | 205 | 19 | -90.7 | 210 | 2.4 | 190 | -7.3 | .14 | June 92 |
| | | 66 | 146 | 121 | 108 | 63.6 | 98 | 48.5 | 1.09 | 09/02/92 |
| | | 110 | 105 | -4.5 | 77 | -30.0 | 70 | -36.4 | .78 | 09/13/92 |
| | | 42 | 67 | 59.5 | 50 | 19.0 | 45 | 7.1 | .50 | 01/14/93 |
| | | 60 | 121 | 102 | 90 | 48.3 | 81 | 35.0 | .90 | 03/13/93 |
| | | 116 | 109 | -6.0 | 80 | -31.0 | 73 | -37.1 | .81 | 04/01/93 |
| Urban Watersheds | | | | 69.6 | | 19.6 | | 2.7 | | |
| IMC Creek | N | 11 | 10 | -9.1 | 4 | -63.6 | 2 | -81.8 | .31 | 11/23/88 |
| | | 5 | 78 | 1460 | 33 | 560 | 13 | 160 | 2.40 | 07/12/89 |
| | | 4 | 13 | 225 | 6 | 50.0 | 2 | -50.0 | .41 | 02/23/90 |
| | | 9 | 42 | 367 | 18 | 100 | 7 | -22.2 | 1.29 | 07/21/90 |

**Appendix A. Comparison of observed peak discharges and peak discharges estimated using the initial, calulated, and calibrated input parameters, and a list of the rainfall intensities used for calculating peak discharges using the Rational Method (Continued)**

[$ft^3/s$, cubic feet per second; in/hr, inches per hour; U, urban; N, natural; M, mixed; -, negative values represent underestimations; <, less than]

| | | Peak discharges | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Watershed name | Watershed classification | Observed ($ft^3/s$) | Initial ($ft^3/s$) | Error (percent) | Calculated ($ft^3/s$) | Error (percent) | Calibrated ($ft^3/s$) | Error (percent) | Rainfall intensity (in/hr) | Date of storm |
| Grace Creek | N | 59 | 59 | .0 | 30 | -49.1 | 22 | -62.7 | .70 | 08/07/88 |
| | | 40 | 84 | 110 | 42 | 5.0 | 32 | -20.0 | .99 | 08/23/88 |
| | | 16 | 101 | 531 | 51 | 219 | 38 | 137 | 1.20 | 07/12/90 |
| | | 25 | 28 | 12.0 | 14 | -44.0 | 11 | -56.0 | .33 | 07/14/90 |
| CFI-3 Creek | N | 19 | 8 | -57.9 | 16 | 15.8 | 15 | -21.0 | .28 | 07/05/89 |
| | | 7 | 4 | -42.9 | 9 | 28.6 | 8 | 14.3 | .15 | 02/23/90 |
| South Creek | N | 442 | 328 | -25.8 | 42 | -90.5 | 39 | -91.2 | .17 | June 92 |
| | | 143 | 928 | 549 | 116 | -18.9 | 107 | -25.2 | .47 | 09/06/92 |
| | | 96 | 849 | 784 | 106 | 10.4 | 98 | 2.0 | .43 | 09/13/92 |
| | | 94 | 1936 | 1960 | 242 | 157 | 223 | 137 | .98 | 03/13/93 |
| | | 168 | 1126 | 570 | 141 | -16.1 | 129 | -23.2 | .57 | 04/01/93 |
| Forked Creek | N | 287 | 125 | -56.4 | 146 | -49.1 | 25 | -91.3 | .24 | June 92 |
| | | 45 | 428 | 851 | 500 | 1011 | 85 | 88.9 | .82 | 08/09/92 |
| Natural Watersheds | | | | 425 | | 107 | | -0.3 | | |
| Walker Creek | M | 971 | 196 | -79.8 | 63 | -93.5 | 56 | -94.2 | .16 | June 92 |
| | | 438 | 1566 | 258 | 501 | 14.3 | 450 | 2.7 | 1.28 | 07/23/92 |
| | | 398 | 1738 | 337 | 556 | 39.7 | 500 | 25.6 | 1.42 | 08/07/92 |
| | | 334 | 1946 | 483 | 623 | 86.5 | 559 | 67.4 | 1.59 | 09/04/92 |
| | | 278 | 2386 | 758 | 764 | 175 | 686 | 147 | 1.95 | 09/05/92 |
| | | 199 | 563 | 183 | 180 | -9.5 | 162 | -18.6 | .46 | 09/25/92 |
| | | 292 | 795 | 172 | 255 | -12.7 | 229 | -21.6 | .65 | 09/26/92 |
| | | 235 | 502 | 114 | 161 | -27.9 | 144 | -38.7 | .41 | 01/15/93 |
| | | 319 | 600 | 88.1 | 192 | -39.8 | 172 | -46.1 | .49 | 04/01/93 |
| | | 237 | 649 | 174 | 208 | -12.2 | 186 | -21.5 | .53 | 07/01/93 |
| Catfish Creek | M | 70 | 513 | 633 | 145 | 107 | 111 | 58.5 | .56 | 01/14/93 |
| | | 76 | 201 | 164 | 57 | -25.0 | 44 | -42.1 | .22 | 01/15/93 |
| | | 140 | 833 | 495 | 236 | 68.6 | 181 | 29.3 | .91 | 03/13/93 |
| | | 300 | 742 | 147 | 210 | -30.0 | 161 | -46.3 | .81 | 04/01/93 |
| Gottfried Creek | M | 119 | 46 | -61.3 | 12 | -89.9 | 11 | -90.8 | .12 | June 92 |
| | | 21 | 207 | 886 | 55 | 161 | 49 | 133 | .54 | 08/11/92 |
| | | 18 | 42 | 133 | 11 | -38.9 | 10 | -44.4 | .11 | Oct 92 |
| Mixed Watersheds | | | | 287 | | 16.0 | | <-0.1 | | |
| All Watersheds | | | | 227 | | 42.7 | | 1.1 | | |

**Appendix B. Comparison of observed peak discharges and runoff volumes with estimates made using the regression equations developed for west-central Florida**

[$ft^3/s$, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | Runoff volume | | | |
|---|---|---|---|---|---|---|---|---|
| Watershed name | Watershed classification | Observed ($ft^3/s$) | Estimated ($ft^3/s$) | Error (percent) | Observed (inches) | Estimated (inches) | Error (percent) | Date of storm |
| Arctic Street Storm Drain | U | 120 | 103 | -14.2 | 0.76 | 1.03 | 35.5 | 08/03/76 |
| | | 133 | 95 | -28.6 | .97 | .84 | -13.4 | 08/04/76 |
| | | 137 | 91 | -33.6 | .58 | .74 | 27.6 | 09/26/77 |
| | | 142 | 117 | -17.6 | 1.30 | 1.51 | 16.1 | 05/20/78 |
| Kirby Street Drainage Ditch | U | 57 | 244 | 328 | .30 | .97 | 223 | 07/19/75 |
| | | 95 | 295 | 210 | .77 | 1.65 | 114 | 08/30/75 |
| | | 96 | 232 | 142 | .76 | .84 | 10.5 | 08/15/78 |
| St. Louis St. Drainage Ditch | U | 357 | 65 | -81.8 | .92 | 1.56 | 69.6 | 05/15/76 |
| | | 226 | 54 | -76.1 | .40 | .93 | 132 | 06/18/76 |
| | | 326 | 56 | -82.8 | .45 | 1.02 | 127 | 06/29/77 |
| Gandy Blvd.Drainage Ditch | U | 223 | 232 | 4.0 | .50 | .66 | 32.0 | 06/18/75 |
| | | 301 | 251 | -16.6 | 1.19 | .83 | -30.2 | 07/11/75 |
| | | 207 | 198 | -4.3 | .71 | .42 | -40.8 | 08/07/75 |
| | | 692 | 321 | -53.6 | 2.46 | 1.66 | -32.5 | 05/15/76 |
| | | 410 | 251 | -37.4 | .87 | .83 | -4.6 | 05/17/76 |
| Allen Creek | U | 341 | 224 | -34.3 | .69 | .31 | -55.1 | 07/28/76 |
| | | 379 | 288 | -24.0 | .60 | .63 | 5.0 | 07/01/77 |
| | | 819 | 330 | -59.7 | 1.64 | .92 | 43.9 | 07/01/77 |
| | | 335 | 226 | -32.5 | .51 | .32 | -37.2 | 07/03/77 |
| | | 89 | 248 | 179 | .18 | .41 | 128 | 12/02/77 |
| | | 286 | 314 | 9.8 | .71 | .79 | 11.3 | 02/18/78 |
| Clower Creek | U | 77 | 99 | 28.6 | 1.45 | .87 | -40.0 | 02/05/92 |
| | | 205 | 228 | 11.2 | 17.01 | 9.19 | -46.2 | June 92 |
| | | 66 | 88 | 33.3 | 1.07 | .64 | -40.2 | 09/02/92 |
| | | 110 | 114 | 3.6 | 2.31 | 1.32 | -42.9 | 09/13/92 |
| | | 42 | 91 | 117 | .67 | .69 | 3.0 | 01/14/93 |
| | | 60 | 104 | 73.3 | 1.37 | 1.02 | -25.5 | 03/13/93 |
| | | 116 | 133 | 14.6 | 2.90 | 2.00 | -31.0 | 04/01/93 |
| Urban Watersheds | | | | 19.9 | | | 19.2 | |
| IMC Creek | N | 11 | 7 | -36.4 | .66 | .19 | -71.2 | 11/23/88 |
| | | 5 | 11 | 120 | .17 | .58 | 241 | 07/12/89 |
| | | 4 | 10 | 150 | .36 | .48 | 33.3 | 02/23/90 |
| | | 9 | 9 | 0.0 | .47 | .41 | -12.8 | 07/21/90 |

**Appendix B. Comparison of observed peak discharges and runoff volumes with estimates made using the regression equations developed for west-central Florida (Continued)**

[$ft^3/s$, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| Watershed name | Watershed classification | Peak discharge: Observed ($ft^3/s$) | Peak discharge: Estimated ($ft^3/s$) | Peak discharge: Error (percent) | Runoff volume: Observed (inches) | Runoff volume: Estimated (inches) | Runoff volume: Error (percent) | Date of storm |
|---|---|---|---|---|---|---|---|---|
| Grace Creek | N | 59 | 24 | -59.3 | 1.00 | .58 | -42.0 | 08/07/88 |
| | | 40 | 20 | -50.0 | .72 | .35 | -51.4 | 08/23/88 |
| | | 16 | 21 | 31.2 | .23 | .38 | 65.2 | 07/12/90 |
| | | 25 | 25 | 0.0 | .54 | .63 | 16.7 | 07/14/90 |
| CFI-3 Creek | N | 19 | 8 | -57.9 | .44 | .34 | -22.7 | 07/05/89 |
| | | 7 | 9 | 28.6 | .29 | .59 | 103 | 02/23/90 |
| South Creek | N | 442 | 404 | 8.6 | 4.30 | 4.80 | 226 | June 92 |
| | | 143 | 107 | -25.2 | .13 | .19 | 46.1 | 09/06/92 |
| | | 96 | 133 | 38.5 | .39 | .32 | -17.9 | 09/13/92 |
| | | 94 | 168 | 78.7 | .69 | .57 | -17.4 | 03/13/93 |
| | | 168 | 178 | 5.9 | 1.27 | .65 | -48.8 | 04/01/93 |
| Forked Creek | N | 287 | 122 | -57.5 | 8.54 | 3.54 | -58.4 | June 92 |
| | | 45 | 77 | 71.1 | 1.85 | 1.16 | -37.3 | 08/09/92 |
| Natural Watersheds | | | | 14.5 | | | 20.7 | |
| Walker Creek | M | 971 | 971 | 0.0 | 6.89 | 6.18 | -10.3 | June 92 |
| | | 438 | 252 | -42.5 | 0.91 | .73 | -19.8 | 07/23/92 |
| | | 398 | 192 | -51.8 | .96 | .47 | -51.0 | 08/07/92 |
| | | 334 | 240 | -28.1 | . 77 | .67 | -13.0 | 09/04/92 |
| | | 278 | 206 | -25.9 | .41 | .43 | 29.3 | 09/05/92 |
| | | 199 | 223 | 12.1 | .56 | .60 | 7.1 | 09/25/92 |
| | | 292 | 166 | -43.1 | .74 | .37 | 50.0 | 09/26/92 |
| | | 235 | 221 | -6.0 | .76 | .59 | -22.4 | 01/15/93 |
| | | 319 | 288 | -9.7 | .94 | .90 | 4.2 | 04/01/93 |
| | | 237 | 249 | 3.1 | .46 | .71 | 54.3 | 07/01/93 |
| Catfish Creek | M | 70 | 194 | 177 | .21 | .48 | 129 | 01/14/93 |
| | | 76 | 149 | 96.0 | .25 | .32 | 28.0 | 01/15/93 |
| | | 140 | 247 | 76.4 | .49 | .71 | 44.9 | 03/13/93 |
| | | 300 | 381 | 27.0 | 1.41 | 1.41 | 0.0 | 04/01/93 |
| Gottfried Creek | M | 119 | 114 | -4.2 | 6.70 | 6.79 | 1.3 | June 92 |
| | | 21 | 16 | -23.8 | .32 | .31 | -3.1 | 08/11/92 |
| | | 18 | 24 | -77.8 | .57 | .57 | 0.0 | Oct 92 |
| Mixed Watersheds | | | | 4.6 | | | 13.4 | |
| All Watersheds | | | | 14.2 | | | 18.0 | |

**Appendix C. Dimensionless unit hydrographs developed for west-central Florida**

Peak rate factor = 150

| | | | | |
|---|---|---|---|---|
| 0.000 | 0.015 | 0.100 | 0.520 | 0.890 |
| 1.000 | .985 | .960 | .910 | .850 |
| .750 | .640 | .550 | .505 | .475 |
| .435 | .415 | .390 | .370 | .350 |
| .335 | .315 | .300 | .285 | .275 |
| .260 | .250 | .240 | .235 | .230 |
| .225 | .219 | .213 | .207 | .201 |
| .195 | .190 | .185 | .180 | .175 |
| .170 | .167 | .164 | .161 | .158 |
| .155 | .152 | .149 | .146 | .143 |

Peak rate factor = 200

| | | | | |
|---|---|---|---|---|
| 0.000 | 0.150 | 0.300 | 0.700 | 0.900 |
| 1.000 | .980 | .940 | .895 | .830 |
| .720 | .600 | .520 | .470 | .430 |
| .400 | .370 | .350 | .330 | .310 |
| .295 | .275 | .260 | .245 | .235 |
| .225 | .215 | .208 | .202 | .197 |
| .190 | .184 | .179 | .173 | .168 |
| .162 | .157 | .152 | .147 | .142 |
| .137 | .134 | .131 | .128 | .125 |
| .122 | .119 | .116 | .113 | .110 |

Peak rate factor = 250

| | | | | |
|---|---|---|---|---|
| 0.000 | 0.150 | 0.300 | 0.800 | 0.950 |
| 1.000 | .980 | .930 | .880 | .082 |
| .700 | .580 | .480 | .433 | .386 |
| .339 | .310 | .279 | .252 | .228 |
| .204 | .185 | .170 | .160 | .151 |
| .143 | .137 | .131 | .125 | .120 |
| .115 | .110 | .105 | .100 | .095 |
| .090 | .087 | .084 | .081 | .078 |
| .076 | .074 | .072 | .070 | .068 |
| .066 | .064 | .062 | .061 | .060 |

Peak rate factor = 300

| | | | | |
|---|---|---|---|---|
| 0.000 | 0.160 | 0.300 | 0.750 | 0.950 |
| 1.000 | .980 | .930 | .850 | .750 |
| .620 | .510 | .410 | .350 | .310 |
| .270 | .240 | .215 | .190 | .170 |
| .150 | .135 | .120 | .110 | .098 |
| .092 | .084 | .077 | .070 | .063 |
| .057 | .052 | .047 | .045 | .042 |
| .040 | .037 | .034 | .031 | .028 |
| .025 | .022 | .019 | .016 | .013 |
| .010 | .007 | .004 | .002 | .000 |

**Appendix C. Dimensionless unit hydrographs developed for west-central Florida (Continued)**

Peak rate factor = 350

| | | | | |
|---|---|---|---|---|
| 0.000 | 0.160 | 0.300 | 0.700 | 0.950 |
| 1.000 | .970 | .920 | .820 | .690 |
| .550 | .450 | .340 | .280 | .240 |
| .200 | .175 | .150 | .130 | .115 |
| .095 | .082 | .070 | .058 | .045 |
| .040 | .035 | .026 | .018 | .014 |
| .010 | .005 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |

Peak rate factor = 400

| | | | | |
|---|---|---|---|---|
| 0.000 | 0.160 | 0.300 | 0.700 | 0.950 |
| 1.000 | .970 | .900 | .780 | .600 |
| .430 | .350 | .270 | .210 | .165 |
| .130 | .100 | .085 | .070 | .060 |
| .050 | .040 | .030 | .020 | .015 |
| .010 | .008 | .006 | .004 | .002 |
| .001 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |

Peak rate factor = 450

| | | | | |
|---|---|---|---|---|
| 0.000 | 0.100 | 0.300 | 0.600 | 0.930 |
| 1.000 | .930 | .820 | .600 | .450 |
| .310 | .220 | .170 | .135 | .100 |
| .080 | .065 | .050 | .040 | .030 |
| .020 | .010 | .005 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |
| .000 | .000 | .000 | .000 | .000 |

**Appendix D. Comparison of observed peak discharges and runoff volumes with estimates made using the Natural Resources Conservation Service TR-20 model with initial and modified input parameters**

[$ft^3/s$, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed ($ft^3/s$) | Initial ($ft^3/s$) | Error (percent) | Modified ($ft^3/s$) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Arctic Street storm drain | U | 120 | 109 | -9.2 | 84 | -30.0 | 0.76 | 1.06 | 39.7 | 0.65 | -14.5 | 08/03/76 |
| | | 133 | 168 | 26.3 | 154 | 15.8 | .97 | 1.38 | 43.0 | 1.04 | 7.2 | 08/04/76 |
| | | 137 | 81 | -40.8 | 138 | 1.0 | .58 | 1.18 | 103 | .86 | 48.3 | 09/26/77 |
| | | 142 | 197 | 38.7 | 166 | 16.9 | 1.30 | 1.85 | 42.1 | 1.29 | -1.0 | 05/20/78 |
| Kirby Street drainage ditch | U | 57 | 38 | -33.3 | 38 | -33.3 | .30 | .39 | 30.0 | .30 | 0.0 | 07/19/75 |
| | | 95 | 114 | 20.0 | 125 | 31.5 | .77 | 1.19 | 54.0 | 1.01 | 31.2 | 08/30/75 |
| | | 96 | 27 | -71.9 | 98 | 2.1 | .76 | .85 | 11.8 | .76 | 0.0 | 08/15/78 |
| St. Louis St. drainage ditch | U | 357 | 168 | -52.9 | 395 | 10.6 | .92 | 2.10 | 129 | 1.07 | 16.3 | 05/15/76 |
| | | 226 | 89 | -60.6 | 312 | 38.1 | .40 | 1.00 | 150 | .35 | -12.5 | 06/18/76 |
| | | 326 | 100 | -69.3 | 176 | -46.0 | .45 | 1.15 | 156 | .44 | -2.2 | 06/29/77 |
| Gandy Blvd. drainage ditch | U | 223 | 290 | 30.0 | 300 | 34.5 | .50 | .67 | 33.7 | .72 | 44.0 | 06/18/75 |
| | | 301 | 266 | -11.6 | 278 | -7.6 | 1.19 | 1.06 | -10.9 | 1.13 | -5.0 | 07/11/75 |
| | | 207 | 144 | -30.4 | 155 | -25.1 | .71 | .39 | -45.4 | .34 | -52.1 | 08/07/75 |
| | | 692 | 812 | 17.3 | 811 | 17.2 | 2.46 | 2.45 | -0.4 | 2.53 | 3.7 | 05/15/76 |
| | | 410 | 413 | .7 | 420 | 2.4 | .87 | .95 | 9.2 | 1.01 | 16.1 | 05/17/76 |
| Allen Creek | U | 341 | 483 | 41.6 | 226 | -33.7 | .69 | .11 | -84.5 | .39 | -43.5 | 07/28/76 |
| | | 379 | 549 | 44.9 | 556 | 46.7 | .60 | .52 | 13.3 | 1.03 | 71.7 | 07/01/77 |
| | | 819 | 931 | 13.7 | 822 | 0.4 | 1.64 | .98 | 40.2 | 1.61 | - 1.8 | 07/01/77 |
| | | 335 | 398 | 18.8 | 222 | -33.7 | .51 | .12 | -76.5 | .39 | -23.5 | 07/03/77 |
| | | 89 | 196 | 120 | 88 | -1.1 | .18 | .23 | 27.8 | .20 | 11.1 | 12/02/77 |
| | | 286 | 866 | 203 | 327 | 14.3 | .71 | .78 | 9.9 | .73 | 2.8 | 02/18/78 |
| Clower Creek | U | 77 | 83 | 7.8 | 71 | -7.8 | 1.45 | 1.60 | 10.3 | 1.36 | -6.2 | 02/05/92 |
| | | 205 | 237 | 15.6 | 244 | 19.0 | 17.01 | 17.08 | <.1 | 16.64 | -2.6 | June 92 |
| | | 66 | 59 | -10.6 | 51 | -22.7 | 1.07 | 1.10 | 2.8 | .91 | -14.9 | 09/02/92 |
| | | 110 | 125 | 13.6 | 122 | 10.9 | 2.31 | 2.65 | 14.7 | 2.24 | -3.0 | 09/13/92 |
| | | 42 | 59 | 40.5 | 48 | 14.3 | .67 | 1.30 | 94.0 | 1.07 | 59.6 | 01/14/93 |
| | | 60 | 89 | 48.5 | 76 | 26.6 | 1.37 | .90 | 38.7 | 1.66 | 21.2 | 03/13/93 |
| | | 116 | 161 | 33.8 | 152 | 31.0 | 2.90 | 3.90 | 34.5 | 3.56 | 22.8 | 04/01/93 |

**Appendix D. Comparison of observed peak discharges and runoff volumes with estimates made using the Natural Resources Conservation Service TR-20 model with initial and modified input parameters (Continued)**

[ft$^3$/s, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed (ft$^3$/s) | Initial (ft$^3$/s) | Error (percent) | Modified (ft$^3$/s) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Urban Watersheds | | | | 12.3 | | 3.3 | | | 31.1 | | 6.2 | |
| IMC Creek | N | 11 | 1 | -90.9 | 1 | -90.9 | .66 | .02 | -97.0 | .04 | -93.9 | 11/23/88 |
| | | 5 | 30 | 500 | 16 | 220 | .17 | .71 | 318 | .77 | 353 | 07/12/89 |
| | | 4 | 10 | 150 | 6 | 50.0 | .36 | .52 | 44.4 | .58 | 61.1 | 02/23/90 |
| | | 9 | 14 | 55.6 | 8 | 11.1 | .47 | .34 | -27.7 | .34 | -27.7 | 07/21/90 |
| Grace Creek | N | 59 | 70 | 18.6 | 55 | -6.8 | 1.00 | .80 | 20.0 | 1.00 | 0.0 | 08/07/88 |
| | | 40 | 28 | -30.0 | 25 | -37.5 | .72 | .28 | -61.1 | .40 | -45.7 | 08/23/88 |
| | | 16 | 34 | 113 | 26 | 81.2 | .23 | .34 | 47.8 | .46 | 100 | 07/12/90 |
| | | 25 | 56 | 124 | 45 | 80.0 | .54 | .92 | 70.4 | 1.14 | 111 | 07/14/90 |
| CFI-3 Creek | N | 19 | 7 | -60.7 | 11 | -42.1 | .44 | .28 | -36.4 | .38 | -13.6 | 07/05/89 |
| | | 7 | 22 | 214 | 8 | 14.3 | .29 | .87 | 200 | .28 | -3.4 | 02/23/90 |
| South Creek | N | 442 | 1964 | 344 | 1967 | 345 | 4.30 | 14.23 | 231 | 14.00 | 226 | June 92 |
| | | 143 | 218 | 52.4 | 134 | -6.3 | .13 | .35 | 169 | .11 | -15.4 | 09/06/92 |
| | | 96 | 139 | 44.8 | 91 | -5.2 | .39 | .30 | -23.1 | .42 | 7.7 | 09/13/92 |
| | | 94 | 234 | 149 | 170 | 80.9 | .69 | .90 | 30.4 | 1.12 | 62.3 | 03/13/93 |
| | | 168 | 238 | 41.7 | 180 | 7.1 | 1.27 | .95 | -25.2 | 1.18 | -7.1 | 04/01/93 |
| Forked Creek | N | 287 | 277 | -3.5 | 292 | 1.7 | 8.54 | 9.12 | 6.8 | 8.99 | 5.3 | June 92 |
| | | 45 | 49 | 8.9 | 48 | 6.6 | 1.85 | 2.35 | 27.0 | 1.09 | -41.1 | 08/09/92 |
| Natural Watersheds | | | | 95.9 | | 41.7 | | | 55.6 | | 39.9 | |
| Walker Creek | M | 971 | 2058 | 112 | 2181 | 125 | 6.89 | 13.00 | 89.0 | 12.78 | 85.4 | June 92 |
| | | 438 | 380 | -13.2 | 411 | -6.2 | 0.91 | 1.01 | 11.0 | 0.93 | 2.2 | 07/23/92 |
| | | 398 | 189 | -53.7 | 199 | -50.0 | .96 | 0.49 | -49.0 | .44 | -54.2 | 08/07/92 |
| | | 334 | 330 | -1.2 | 356 | 6.6 | . 77 | .89 | 15.6 | .81 | 5.2 | 09/04/92 |
| | | 278 | 464 | 66.9 | 272 | 2.2 | .41 | 1.17 | 185 | .54 | 31.7 | 09/05/92 |
| | | 199 | 254 | 27.9 | 255 | 28.1 | .56 | .74 | 32.1 | .67 | 19.6 | 09/25/92 |
| | | 292 | 301 | 3.0 | 328 | 12.3 | .74 | .75 | 1.4 | .70 | -5.4 | 09/26/92 |
| | | 235 | 231 | -1.7 | 231 | -1.7 | .76 | .72 | -5.3 | .66 | -13.2 | 01/15/93 |
| | | 319 | 386 | 21.0 | 373 | 16.9 | .94 | 1.38 | 45.8 | 1.30 | 38.3 | 04/01/93 |
| | | 237 | 334 | 40.9 | 359 | 51.5 | .46 | .98 | 113 | .92 | 100 | 07/01/93 |

**Appendix D. Comparison of observed peak discharges and runoff volumes with estimates made using the Natural Resources Conservation Service TR-20 model with initial and modified input parameters (Continued)**

[ft$^3$/s, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed (ft$^3$/s) | Initial (ft$^3$/s) | Error (percent) | Modified (ft$^3$/s) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Catfish Creek | M | 70 | 127 | 81.4 | 56 | 20.0 | .21 | .48 | 129 | .20 | -4.8 | 01/14/93 |
| | | 76 | 119 | 56.6 | 84 | 10.5 | .25 | .58 | 132 | .35 | 40.0 | 01/15/93 |
| | | 140 | 215 | 53.6 | 138 | -1.4 | .49 | .88 | 79.6 | .47 | -4.1 | 03/13/93 |
| | | 300 | 509 | 69.6 | 416 | 38.7 | 1.41 | 2.41 | 70.9 | 1.68 | 19.1 | 04/01/93 |
| Gottfried Creek | M | 119 | 423 | 255 | 252 | 112 | 6.70 | 12.40 | 85.1 | 13.36 | 99.4 | June 92 |
| | | 21 | 18 | -14.3 | 14 | -33.3 | .32 | .08 | -75.0 | .24 | -25.0 | 08/11/92 |
| | | 18 | 34 | 88.9 | 26 | 44.4 | .57 | .42 | -26.3 | .71 | 24.6 | Oct 92 |
| Mixed Watersheds | | | | 46.6 | | 22.1 | | | 49.1 | | 21.1 | |
| All Watersheds | | | | 44.6 | | 18.9 | | | 42.7 | | 19.5 | |

**Appendix E. Comparison of observed peak discharges and runoff volumes with estimates made using the U.S. Army Corps of Engineers HEC-1 model with initial and modified input parameters**

[$ft^3/s$, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed ($ft^3/s$) | Initial ($ft^3/s$) | Error (percent) | Modified ($ft^3/s$) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Arctic Street storm drain | U | 120 | 154 | 28.3 | 113 | -5.8 | 0.76 | 1.06 | 39.7 | 0.90 | 18.4 | 08/03/76 |
| | | 133 | 301 | 126 | 100 | -24.8 | .97 | 1.40 | 44.3 | .63 | -35.0 | 08/04/76 |
| | | 137 | 147 | 7.3 | 83 | -39.4 | .58 | .61 | 5.2 | .49 | -15.5 | 09/26/77 |
| | | 142 | 339 | 139 | 232 | 63.4 | 1.30 | 1.86 | 43.1 | 1.65 | 26.9 | 05/20/78 |
| Kirby Street drainage ditch | U | 57 | 77 | 35.1 | 52 | -8.8 | .30 | .40 | 33.3 | .36 | -20.0 | 07/19/75 |
| | | 95 | 218 | 129 | 159 | 67.3 | .77 | 1.19 | 54.5 | 1.13 | -46.7 | 08/30/75 |
| | | 96 | 61 | -36.5 | 35 | -63.5 | .76 | .27 | -64.5 | .25 | -67.1 | 08/15/78 |
| St. Louis St. drainage ditch | U | 357 | 303 | -54.0 | 424 | 18.8 | .92 | 2.10 | 129 | 1.00 | 19.6 | 05/15/76 |
| | | 226 | 167 | -59.0 | 254 | 12.4 | .40 | 1.00 | 150 | .35 | 12.5 | 06/18/76 |
| | | 326 | 184 | -43.6 | 186 | -42.9 | .45 | 1.16 | 158 | .45 | 0.0 | 06/29/77 |
| Gandy Blvd. drainage ditch | U | 223 | 523 | 135 | 288 | -10.3 | .50 | .67 | 33.7 | .72 | 44.0 | 06/18/75 |
| | | 301 | 474 | 57.5 | 270 | -30.9 | 1.19 | 1.06 | -10.9 | 1.13 | -5.0 | 07/11/75 |
| | | 207 | 267 | 29.0 | 143 | 18.8 | .71 | .39 | -45.4 | .43 | -39.4 | 08/07/75 |
| | | 692 | 1407 | 103 | 822 | -3.3 | 2.46 | 2.45 | -.4 | 2.53 | 2.8 | 05/15/76 |
| | | 410 | 737 | 79.8 | 391 | | .87 | .95 | 9.2 | 1.01 | 16.1 | 05/17/76 |
| Allen Creek | U | 341 | 231 | -32.2 | 147 | -56.9 | .69 | .11 | -84.0 | .20 | -70.5 | 07/28/76 |
| | | 379 | 897 | 137 | 456 | 20.3 | .60 | .52 | -13.3 | .71 | 18.3 | 07/01/77 |
| | | 819 | 1433 | 75.0 | 765 | -6.6 | 1.64 | .98 | 40.2 | 1.24 | -24.4 | 07/01/77 |
| | | 335 | 170 | -49.2 | 138 | -58.8 | .51 | .12 | -76.5 | .21 | -58.8 | 07/03/77 |
| | | 89 | 267 | 220 | 215 | 1.4 | .18 | .23 | 27.8 | .35 | 94.4 | 12/02/77 |
| | | 286 | 1280 | 348 | 647 | 126 | .71 | .78 | 9.9 | 1.01 | 42.3 | 02/18/78 |
| Clower Creek | U | 77 | 136 | 76.6 | 63 | -18.2 | 1.45 | 1.63 | 12.4 | 1.22 | -15.9 | 02/05/92 |
| | | 205 | 309 | 50.7 | 221 | 7.8 | 17.01 | 17.19 | 1.1 | 16.54 | -2.8 | June 92 |
| | | 66 | 108 | 63.6 | 42 | -36.4 | 1.07 | 1.14 | 6.5 | .80 | -25.2 | 09/02/92 |
| | | 110 | 224 | 104 | 105 | -4.5 | 2.31 | 2.55 | 10.4 | 2.08 | -10.0 | 09/13/92 |
| | | 42 | 104 | 148 | 46 | 9.5 | .67 | 1.33 | 98.5 | .96 | 43.3 | 01/14/93 |
| | | 60 | 155 | 158 | 74 | 23.3 | 1.37 | 1.96 | 43.1 | 1.53 | 11.7 | 03/13/93 |
| | | 116 | 268 | 131 | 145 | 25.0 | 2.90 | 3.90 | 34.4 | 3.40 | 17.2 | 04/01/93 |
| Urban Watersheds | | | | 75.2 | | -0.6 | | | 24.6 | | -2.4 | |
| IMC Creek | N | 11 | 2 | -81.8 | 0 | -100 | .66 | .05 | -92.4 | .03 | -95.4 | 11/23/88 |
| | | 5 | 52 | 940 | 13 | 160 | .17 | .71 | 318 | .47 | 176 | 07/12/89 |
| | | 4 | 16 | 300 | 4 | 0.0 | .36 | .49 | 36.1 | .30 | -16.7 | 02/23/90 |
| | | 9 | 24 | 167 | 5 | -44.4 | .47 | .34 | 27.7 | .18 | -61.7 | 07/21/90 |

**Appendix E. Comparison of observed peak discharges and runoff volumes with estimates made using the U.S. Army Corps of Engineers HEC-1 model with initial and modified input parameters (Continued)**

[$ft^3/s$, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed ($ft^3/s$) | Initial ($ft^3/s$) | Error (percent) | Modified ($ft^3/s$) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Grace Creek | N | 59 | 101 | 71.2 | 46 | -22.0 | 1.00 | 0.80 | -20.0 | 0.80 | -20.0 | 08/07/88 |
| | | 40 | 41 | 2.5 | 17 | -57.5 | .72 | .28 | -61.1 | .28 | -61.1 | 08/23/88 |
| | | 16 | 48 | 200 | 20 | 25.0 | .23 | .34 | 47.8 | .34 | 47.8 | 07/12/90 |
| | | 25 | 71 | 184 | 38 | 52.0 | .54 | .92 | 70.4 | .92 | 70.4 | 07/14/90 |
| CFI-3 Creek | N | 19 | 10 | -52.6 | 0 | -100 | .44 | .28 | -36.4 | .00 | 100 | 07/05/89 |
| | | 7 | 34 | 386 | 4 | -42.8 | .29 | .87 | 200 | .15 | -48.3 | 02/23/90 |
| South Creek | N | 442 | 1710 | 287 | 1511 | 242 | 4.30 | 12.75 | 196 | 11.72 | 173 | June 92 |
| | | 143 | 138 | -3.5 | 129 | -9.8 | .13 | .04 | -69.2 | .03 | -76.9 | 09/06/92 |
| | | 96 | 142 | 47.9 | 46 | 52.1 | .39 | .23 | -41.0 | .19 | -51.3 | 09/13/92 |
| | | 94 | 245 | 161 | 157 | 67.0 | .69 | .74 | -7.2 | .63 | -8.7 | 03/13/93 |
| | | 68 | 244 | 259 | 162 | 138 | 1.27 | .83 | -34.6 | .75 | -40.9 | 04/01/93 |
| Forked Creek | N | 287 | 455 | 58.8 | 368 | 28.2 | 8.54 | 8.46 | -.5 | 10.67 | 24.9 | June 92 |
| | | 45 | 65 | 44.4 | 39 | -13.3 | .82 | .33 | -59.8 | .50 | -39.0 | 08/09/92 |
| Natural Watersheds | | | | 175 | | 22.0 | | | 27.9 | | -7.5 | |
| Walker Creek | M | 971 | 2463 | 154 | 2367 | 144 | 6.89 | 12.76 | 85.2 | 9.80 | 42.2 | June 92 |
| | | 438 | 553 | 26.3 | 340 | -22.4 | .91 | 1.01 | 9.9 | .89 | -2.2 | 07/23/92 |
| | | 398 | 250 | -37.2 | 152 | -61.8 | .96 | .49 | -48.9 | .41 | -52.1 | 08/07/92 |
| | | 334 | 446 | 33.5 | 281 | -15.8 | .77 | .89 | 15.6 | .77 | 0.0 | 09/04/92 |
| | | 278 | 328 | 18.0 | 208 | -25.2 | .41 | .60 | 46.3 | .50 | 21.9 | 09/05/92 |
| | | 199 | 336 | 68.8 | 216 | 8.5 | .56 | .74 | 32.1 | .63 | 12.5 | 09/25/92 |
| | | 292 | 408 | 39.7 | 106 | -63.7 | .74 | .31 | -58.1 | .25 | -66.2 | 09/26/92 |
| | | 235 | 285 | 21.3 | 206 | -12.3 | .76 | .72 | -5.3 | .62 | -18.4 | 01/15/93 |
| | | 319 | 508 | 59.2 | 361 | 13.2 | .94 | 1.38 | 46.8 | 1.23 | 30.8 | 04/01/93 |
| | | 237 | 459 | 93.7 | 293 | 23.6 | .46 | .98 | 113 | .87 | 89.1 | 07/01/93 |
| Catfish Creek | M | 70 | 200 | 186 | 78 | 11.4 | .21 | .46 | 119 | .27 | 28.6 | 01/14/93 |
| | | 76 | 85 | 11.8 | 38 | -50.0 | .25 | .20 | -20.0 | .10 | -60.0 | 01/15/93 |
| | | 140 | 354 | 153 | 147 | 5.0 | .49 | .86 | 75.5 | .55 | 12.2 | 03/13/93 |
| | | 300 | 837 | 179 | 407 | 35.7 | 1.41 | 2.34 | 65.9 | 1.66 | 17.7 | 04/01/93 |
| Gottfried Creek | M | 119 | 485 | 308 | 255 | 11.9 | 6.70 | 12.30 | 83.6 | 13.19 | 96.9 | June 92 |
| | | 21 | 19 | -9.5 | 12 | -42.9 | .32 | .08 | -75.0 | .14 | -56.2 | 08/11/92 |
| | | 18 | 40 | 122 | 25 | 38.8 | .57 | .42 | 16.0 | .57 | 14.0 | Oct 92 |
| Mixed Watersheds | | | | 84.0 | | 0.1 | | | 29.4 | | 6.5 | |
| All Watersheds | | | | 105 | | 5.8 | | | 26.8 | | -1.4 | |

**Appendix F. Comparison of observed peak discharges and runoff volumes with estimates made usingthe U.S. Environmental Protection Agency Storm Water Management model with the Green-Ampt infiltration method, with initial and modified input parameters**

[$ft^3/s$, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed ($ft^3/s$) | Initial ($ft^3/s$) | Error (percent) | Modified ($ft^3/s$) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Arctic Street storm drain | U | 120 | 121 | 0.8 | 109 | -9.2 | 0.76 | 1.01 | 32.9 | 0.98 | 28.9 | 08/03/76 |
| | | 133 | 174 | 30.8 | 133 | 0.0 | .97 | .84 | -13.4 | .82 | -15.5 | 08/04/76 |
| | | 137 | 182 | 32.8 | 133 | -3.9 | .58 | .73 | 25.9 | .68 | 17.2 | 09/26/77 |
| | | 142 | 241 | 69.7 | 207 | 45.8 | 1.30 | 1.49 | 14.6 | 1.44 | 10.8 | 05/20/78 |
| Kirby Street drainage ditch | U | 57 | 92 | 61.4 | 61 | 7.0 | .30 | .15 | -50.0 | .36 | 20.0 | 07/19/75 |
| | | 95 | 139 | 46.3 | 124 | 30.5 | .77 | .33 | -57.1 | 1.02 | 32.5 | 08/30/75 |
| | | 96 | 100 | 4.2 | 67 | -30.2 | .76 | .13 | -82.9 | .27 | -64.5 | 08/15/78 |
| St. Louis St. drainage ditch | U | 357 | 128 | -64.1 | 293 | 17.9 | .92 | .96 | 4.3 | .86 | -6.5 | 05/15/76 |
| | | 226 | 117 | -48.2 | 269 | 19.0 | .40 | .39 | -2.5 | .51 | 27.5 | 06/18/76 |
| | | 326 | 76 | -76.7 | 131 | -59.8 | .45 | .45 | .0 | .44 | -2.2 | 06/29/77 |
| Gandy Blvd. drainage ditch | U | 223 | 251 | 12.6 | 288 | 29.2 | .50 | .34 | -32.0 | .76 | 52.0 | 06/18/75 |
| | | 301 | 285 | -5.3 | 316 | 5.0 | 1.19 | .45 | -62.2 | 1.02 | -14.3 | 07/11/75 |
| | | 207 | 203 | -1.9 | 219 | 5.8 | .71 | .25 | -64.8 | .50 | -29.6 | 08/07/75 |
| | | 692 | 537 | -22.4 | 621 | -10.3 | 2.46 | .98 | -60.2 | 2.04 | -17.1 | 05/15/76 |
| | | 410 | 354 | -13.7 | 411 | .2 | .87 | .43 | -50.6 | .99 | 13.8 | 05/17/76 |
| Allen Creek | U | 341 | 171 | -49.9 | 154 | -54.8 | .69 | .16 | -76.8 | .21 | -69.6 | 07/28/76 |
| | | 379 | 362 | -4.5 | 453 | 19.5 | .60 | .32 | -.46.7 | .65 | 8.3 | 07/01/77 |
| | | 819 | 475 | -42.0 | 820 | .1 | 1.64 | .52 | -.68.7 | 1.78 | 8.5 | 07/01/77 |
| | | 335 | 156 | -53.4 | 132 | 60.6 | .51 | .17 | -66.7 | .21 | -58.8 | 07/03/77 |
| | | 89 | 125 | 40.4 | 120 | 34.8 | .18 | .21 | 16.7 | .26 | 44.4 | 12/02/77 |
| | | 286 | 374 | 30.8 | 370 | 29.4 | .71 | .40 | -43.7 | .65 | -8.4 | 02/18/78 |
| Clower Creek | U | 77 | 99 | 28.6 | 67 | -13.0 | 1.45 | .94 | -35.2 | 1.39 | -4.1 | 02/05/92 |
| | | 205 | 463 | 126 | 309 | 50.7 | 17.08 | 15.30 | -10.4 | 16.80 | -1.6 | June 92 |
| | | 66 | 89 | 34.8 | 41 | -37.8 | 1.07 | .68 | -36.4 | .91 | -15.0 | 09/02/92 |
| | | 110 | 227 | 106 | 131 | 19.1 | 2.31 | 1.84 | -20.3 | 2.33 | .9 | 09/13/92 |
| | | 42 | 75 | 78.6 | 40 | -4.8 | .67 | .75 | 11.9 | 1.02 | 52.2 | 01/14/93 |
| | | 60 | 105 | 75.0 | 73 | 11.7 | 1.37 | 1.26 | -8.0 | 1.67 | 21.9 | 03/13/93 |
| | | 116 | 294 | 153 | 178 | 53.4 | 2.90 | 3.15 | 8.6 | 3.67 | 26.6 | 04/01/93 |
| Urban Watersheds | | | | 19.6 | | 7.7 | | | -27.6 | | 2.1 | |
| IMC Creek | N | 11 | 2 | -81.8 | 5 | -54.5 | .66 | .03 | -95.5 | .10 | -84.8 | 11/23/88 |
| | | 5 | 29 | 480 | 34 | 580 | .17 | .39 | 129 | .82 | 382 | 07/12/89 |
| | | 4 | 4 | .0 | 4 | .0 | .36 | .06 | -83.3 | .08 | -77.8 | 02/23/90 |
| | | 9 | 13 | 44.4 | 23 | 155 | .47 | .13 | -72.3 | .45 | -4.3 | 07/21/90 |

**Appendix F. Comparison of observed peak discharges and runoff volumes with estimates made usingthe U.S. Environmental Protection Agency Storm Water Management model with the Green-Ampt infiltration method, with initial and modified input parameters (Continued)**

[ft³/s, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed (ft³/s) | Initial (ft³/s) | Error (percent) | Modified (ft³/s) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Grace Creek | N | 59 | 111 | 88.1 | 77 | 30.5 | 1.00 | 0.55 | -45.0 | .94 | -6.0 | 08/07/88 |
| | | 40 | 40 | 0.0 | 41 | 2.5 | .72 | .16 | -77.7 | .63 | -12.5 | 08/23/88 |
| | | 16 | 51 | 219 | 30 | 87.5 | .23 | .14 | -39.1 | .06 | -73.9 | 07/12/90 |
| | | 25 | 31 | 24.0 | 70 | 180 | .54 | .42 | -22.2 | 1.10 | 103 | 07/14/90 |
| CFI-3 Creek | N | 19 | .1 | -99.5 | 6 | -68.4 | .44 | .01 | -97.7 | .26 | -40.9 | 07/05/89 |
| | | 7 | 10 | 42.9 | 10 | 42.9 | .29 | .12 | -58.6 | .28 | -3.5 | 02/23/90 |
| South Creek | N | 442 | 651 | 47.3 | 446 | .9 | 4.30 | 9.29 | 116 | 4.63 | 7.7 | June 92 |
| | | 143 | 154 | 7.7 | 125 | -12.6 | .13 | .16 | 23.1 | .04 | -69.2 | 09/06/92 |
| | | 96 | 132 | 37.5 | 42 | -56.2 | .39 | .30 | -23.1 | .06 | -84.6 | 09/13/92 |
| | | 94 | 207 | 120 | 98 | 4.2 | .69 | .76 | 10.1 | .57 | -17.4 | 03/13/93 |
| | | 68 | 193 | 14.9 | 164 | -2.4 | 1.27 | .68 | -46.5 | 1.25 | 1.6 | 04/01/93 |
| Forked Creek | N | 287 | 263 | -8.4 | 263 | -8.4 | 8.54 | 8.84 | 3.5 | 8.96 | 4.9 | June 92 |
| | | 45 | 39 | -13.3 | 42 | -6.7 | .82 | 1.29 | 57.3 | .80 | -2.4 | 08/09/92 |
| Natural Watersheds | | | | 54.3 | | 51.4 | | | 18.9 | | 1.3 | |
| Walker Creek | M | 971 | 1650 | 69.9 | 1030 | 6.1 | 6.89 | 9.57 | 38.9 | 7.34 | 6.5 | June 92 |
| | | 438 | 1270 | 190 | 416 | -5.0 | .91 | .90 | -1.1 | .77 | -15.4 | 07/23/92 |
| | | 398 | 649 | 63.1 | 323 | -18.8 | .96 | .59 | -38.5 | .72 | -25.0 | 08/07/92 |
| | | 334 | 970 | 190 | 355 | 6.3 | .77 | .80 | 3.9 | .82 | 6.5 | 09/04/92 |
| | | 278 | 783 | 182 | 355 | 27.7 | .41 | .63 | 53.7 | .44 | 7.3 | 09/05/92 |
| | | 199 | 533 | 168 | 241 | 21.1 | .56 | .65 | 16.1 | .43 | -23.2 | 09/25/92 |
| | | 292 | 496 | 69.9 | 232 | -20.5 | .74 | .47 | -36.5 | .57 | -23.0 | 09/26/92 |
| | | 235 | 420 | 78.7 | 271 | 15.3 | .76 | .70 | -7.9 | .84 | 10.5 | 01/15/93 |
| | | 319 | 729 | 129 | 320 | .3 | .94 | .94 | .0 | .82 | -12.8 | 04/01/93 |
| | | 237 | 664 | 180 | 279 | 17.7 | .46 | .84 | 82.6 | .60 | -30.4 | 07/01/93 |
| Catfish Creek | M | 70 | 79 | 12.9 | 72 | 2.9 | .21 | .18 | -14.3 | .27 | 28.6 | 01/14/93 |
| | | 76 | 55 | -27.6 | 74 | -2.6 | .25 | .13 | -48.0 | .29 | 16.0 | 01/15/93 |
| | | 140 | 137 | -2.1 | 135 | -3.6 | .49 | .34 | -30.6 | .46 | -6.1 | 03/13/93 |
| | | 300 | 300 | .0 | 302 | .7 | 1.41 | 1.03 | -27.0 | 1.36 | -3.5 | 04/01/93 |
| Gottfried Creek | M | 119 | 244 | 105 | 123 | 3.4 | 6.70 | 11.70 | 74.6 | 6.54 | -2.4 | June 92 |
| | | 21 | 23 | 9.5 | 19 | -10.5 | .32 | .15 | -53.1 | .31 | -3.1 | 08/11/92 |
| | | 18 | 17 | -5.6 | 16 | -11.1 | .57 | .29 | -42.0 | .61 | 7.0 | Oct 92 |
| Mixed Watersheds | | | | 83.1 | | 1.7 | | | 1.7 | | -3.7 | |
| All Watersheds | | | | 46.5 | | 18.0 | | | -6.8 | | 0.3 | |

**Appendix G. Comparison of observed peak discharges and runoff volumes with estimates made using the U.S. Environmental Protection Agency Storm Water Management model with the Horton infiltration method, with initial and modified input parameters**

[ft$^3$/s, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed (ft$^3$/s) | Initial (ft$^3$/s) | Error (percent) | Modified (ft$^3$/s) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Arctic Street storm drain | U | 120 | 124 | 3.3 | 110 | -8.3 | 0.76 | 1.06 | 39.5 | 1.01 | 32.9 | 08/03/76 |
| | | 133 | 174 | 30.8 | 123 | -7.5 | .97 | .87 | -10.3 | .81 | -16.5 | 08/04/76 |
| | | 137 | 182 | 32.8 | 135 | -1.5 | .58 | .58 | 27.6 | .73 | 25.9 | 09/26/77 |
| | | 142 | 244 | 71.8 | 207 | 45.8 | 1.30 | 1.61 | 23.8 | 1.55 | 19.2 | 05/20/78 |
| Kirby Street drainage ditch | U | 57 | 92 | 61.4 | 55 | -35.1 | .30 | .17 | -43.3 | .29 | -3.3 | 07/19/75 |
| | | 95 | 142 | 49.5 | 110 | 15.8 | .77 | .42 | -45.5 | .90 | 16.9 | 08/30/75 |
| | | 96 | 99 | 3.1 | 141 | 46.9 | .76 | .14 | -81.6 | .22 | -71.0 | 08/15/78 |
| St. Louis St. drainage ditch | U | 357 | 144 | -59.7 | 324 | 9.4 | .92 | 1.59 | 72.8 | .97 | 5.4 | 05/15/76 |
| | | 226 | 125 | -44.7 | 268 | 18.6 | .40 | .76 | -90.0 | .50 | 25.0 | 06/18/76 |
| | | 326 | 86 | -73.6 | 123 | -62.3 | .45 | .88 | 95.6 | .44 | 2.2 | 06/29/77 |
| Gandy Blvd. drainage ditch | U | 223 | 256 | 14.8 | 271 | 21.5 | .50 | .41 | -17.8 | .43 | -14.0 | 06/18/75 |
| | | 301 | 289 | -4.0 | 305 | 13.3 | 1.19 | .57 | -52.1 | .59 | -50.4 | 07/11/75 |
| | | 207 | 208 | .5 | 207 | .0 | .71 | .28 | -60.6 | .28 | -60.6 | 08/07/75 |
| | | 692 | 544 | -21.4 | 571 | 17.5 | 2.46 | 1.22 | -50.4 | 1.32 | -46.3 | 05/15/76 |
| | | 410 | 361 | -12.0 | 391 | 19.0 | .87 | .55 | -36.8 | .60 | -31.0 | 05/17/76 |
| Allen Creek | U | 341 | 176 | -48.4 | 155 | -54.5 | .69 | .18 | -73.9 | .24 | -65.2 | 07/28/76 |
| | | 379 | 370 | -2.4 | 352 | -7.1 | .60 | .39 | -.34.6 | .48 | -20.0 | 07/01/77 |
| | | 819 | 488 | -40.4 | 986 | 20.4 | 1.64 | .69 | -.57.9 | 1.76 | 7.3 | 07/01/77 |
| | | 335 | 161 | -51.9 | 132 | -60.6 | .51 | .18 | -64.7 | .25 | -50.0 | 07/03/77 |
| | | 89 | 127 | 42.7 | 123 | 38.2 | .18 | .21 | 19.3 | .29 | 61.1 | 12/02/77 |
| | | 286 | 374 | 30.8 | 447 | 56.3 | .71 | .44 | -38.1 | .44 | -38.1 | 02/18/78 |
| Clower Creek | U | 77 | 96 | 24.7 | 65 | -15.6 | 1.45 | .91 | -37.2 | 1.35 | -6.9 | 02/05/92 |
| | | 205 | 463 | 126 | 309 | 50.7 | 17.08 | 15.30 | -10.4 | 16.80 | -1.6 | June 92 |
| | | 66 | 87 | 31.8 | 41 | -37.9 | 1.07 | .67 | -37.4 | .88 | -17.8 | 09/02/92 |
| | | 110 | 223 | 103 | 129 | 17.3 | 2.31 | 1.82 | -21.2 | 2.29 | -.9 | 09/13/92 |
| | | 42 | 74 | 76.1 | 39 | -7.1 | .67 | .74 | 10.4 | .95 | 42.8 | 01/14/93 |
| | | 60 | 102 | 70.0 | 70 | 16.7 | 1.37 | 1.24 | -9.5 | 1.63 | 19.0 | 03/13/93 |
| | | 116 | 290 | 150 | 177 | 13.2 | 2.90 | 3.13 | 7.9 | 3.63 | 25.2 | 04/01/93 |
| Urban Watersheds | | | | 20.2 | | 4.4 | | | -20.6 | | 7.6 | |
| IMC Creek | N | 11 | 3 | -72.7 | 5 | -54.5 | .66 | .05 | -92.4 | .09 | -86.4 | 11/23/88 |
| | | 5 | 33 | 560 | 36 | 620 | .17 | .60 | 252 | .94 | 453 | 07/12/89 |
| | | 4 | 3 | -25.0 | 5 | 25.0 | .36 | .06 | -83.3 | .10 | -72.2 | 02/23/90 |
| | | 9 | 16 | 77.8 | 20 | 122 | .47 | .23 | -51.1 | .48 | 2.1 | 07/21/90 |

**Appendix G. Comparison of observed peak discharges and runoff volumes with estimates made using the U.S. Environmental Protection Agency Storm Water Management model with the Horton infiltration method, with initial and modified input parameters (Continued)**

[$ft^3/s$, cubic feet per second; U, urban; N, natural; M, mixed; -, negative values represent underestimations]

| | | Peak discharge | | | | | Runoff volume | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Estimated | | | | | Estimated | | | | |
| Watershed name | Watershed classification | Observed ($ft^3/s$) | Initial ($ft^3/s$) | Error (percent) | Modified ($ft^3/s$) | Error (percent) | Observed (inches) | Initial (inches) | Error (percent) | Modified (inches) | Error (percent) | Date of storm |
| Grace Creek | N | 59 | 125 | 112 | 67 | 8.0 | 1.00 | 0.67 | -33.0 | .91 | -9.0 | 08/07/88 |
| | | 40 | 42 | 5.0 | 42 | 5.0 | .72 | .57 | -20.8 | .61 | -15.3 | 08/23/88 |
| | | 16 | 62 | 288 | 22 | 37.5 | .23 | .23 | .0 | .05 | -78.3 | 07/12/90 |
| | | 25 | 29 | 16.0 | 70 | 180 | .54 | .41 | -24.1 | 1.00 | 85.2 | 07/14/90 |
| CFI-3 Creek | N | 19 | 3 | -84.2 | 2 | -89.5 | .44 | .05 | -93.2 | .14 | -68.2 | 07/05/89 |
| | | 7 | 5 | -28.6 | 14 | 100 | .29 | .12 | -58.6 | .37 | 27.6 | 02/23/90 |
| South Creek | N | 442 | 662 | 49.8 | 655 | 48.2 | 4.30 | 9.24 | 115 | 6.45 | 50.0 | June 92 |
| | | 143 | 148 | 3.5 | 127 | -11.2 | .13 | .15 | 15.4 | .05 | -61.5 | 09/06/92 |
| | | 96 | 113 | 17.7 | 116 | 20.8 | .39 | .27 | -30.8 | .15 | -61.5 | 09/13/92 |
| | | 94 | 199 | 112 | 194 | 106 | .69 | .75 | 8.7 | .64 | -7.2 | 03/13/93 |
| | | 68 | 196 | 16.7 | 193 | 14.9 | 1.27 | .70 | -44.9 | .62 | -5.1 | 04/01/93 |
| Forked Creek | N | 287 | 264 | -8.0 | 257 | -10.4 | 8.54 | 8.88 | 4.0 | 8.48 | -.7 | June 92 |
| | | 45 | 36 | -20.0 | 57 | 26.7 | .82 | 1.41 | 72.3 | .86 | 4.9 | 08/09/92 |
| Natural Watersheds | | | | 60.0 | | 67.8 | | | -3.8 | | 9.3 | |
| Walker Creek | M | 971 | 1650 | 69.9 | 997 | 2.7 | 6.89 | 9.60 | 39.3 | 6.94 | .7 | June 92 |
| | | 438 | 1270 | 190 | 465 | 6.2 | .91 | .92 | 1.1 | .93 | 2.2 | 07/23/92 |
| | | 398 | 671 | 68.6 | 325 | -18.3 | .96 | .62 | -35.4 | .74 | -22.9 | 08/07/92 |
| | | 334 | 967 | 190 | 405 | 21.2 | .77 | .81 | 5.2 | .90 | 16.9 | 09/04/92 |
| | | 278 | 816 | 193 | 270 | -2.9 | .41 | .68 | 65.9 | .40 | 2.4 | 09/05/92 |
| | | 199 | 540 | 171 | 281 | 41.2 | .56 | .65 | 16.1 | .46 | 17.9 | 09/25/92 |
| | | 292 | 513 | 75.7 | 238 | -18.5 | .74 | .48 | -35.1 | .61 | -17.6 | 09/26/92 |
| | | 235 | 421 | 79.1 | 261 | 11.1 | .76 | .70 | -7.9 | .85 | 10.6 | 01/15/93 |
| | | 319 | 746 | 134 | 343 | 7.5 | .94 | .98 | 4.3 | .91 | -3.2 | 04/01/93 |
| | | 237 | 674 | 184 | 287 | 21.1 | .46 | .85 | 84.8 | .61 | 32.6 | 07/01/93 |
| Catfish Creek | M | 70 | 75 | 6.7 | 76 | 8.6 | .21 | .21 | .0 | .24 | 14.3 | 01/14/93 |
| | | 76 | 56 | -26.3 | 82 | 7.9 | .25 | .15 | -40.0 | .26 | 4.0 | 01/15/93 |
| | | 140 | 132 | -5.7 | 148 | 5.7 | .49 | .41 | -16.3 | .50 | 2.0 | 03/13/93 |
| | | 300 | 316 | 5.3 | 323 | 7.7 | 1.41 | 1.25 | -11.3 | 1.36 | -3.5 | 04/01/93 |
| Gottfried Creek | M | 119 | 244 | 105 | 122 | 2.5 | 6.70 | 11.80 | 76.1 | 6.95 | 3.7 | June 92 |
| | | 21 | 23 | 9.5 | 28 | 33.3 | .32 | .14 | -56.3 | .35 | 9.4 | 08/11/92 |
| | | 18 | 17 | -5.6 | 16 | -11.1 | .57 | .30 | -40.0 | .60 | 5.3 | Oct 92 |
| Mixed Watersheds | | | | 84.9 | | 7.4 | | | 3.0 | | 4.4 | |
| All Watersheds | | | | 48.8 | | 20.9 | | | -9.5 | | 7.2 | |