SMALL WATERSHED FLOOD FREQUENCY ANALYSIS FOR UTAH

by

Aaron Jacob Timpson

A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Civil and Environmental Engineering

The University of Utah

December 2012

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

The thesis of **Aaron Jacob Timpson**

has been approved by the following supervisory committee members:

Christine Pomeroy	, Chair	**10/09/12** Date Approved
Steven Burian	, Member	**10/09/12** Date Approved
Chris Pantelides	, Member	**10/11/12** Date Approved

and by **Chris Pantelides** , Chair of

the Department of **Civil and Environmental Engineering**

and by Charles A. Wight, Dean of The Graduate School.

ABSTRACT

Determining discharge in a stream is important to the design of culverts, bridges, and other structures pertaining to transportation systems. Currently in Utah regression equations exist to estimate recurrence flood year discharges for rural watersheds greater than 30 mi^2, and the rational method is used for areas smaller than 0.5 mi^2, however, there are no good methods available to estimate discharges for rural watersheds that fall between the two approaches. To solve this issue, flood frequency analyses were conducted for small rural watersheds with streamflow gaging station data within the state of Utah to develop regression equations for estimating flood flows for midsized watersheds. The watersheds selected range from 0.5 mi^2 to 30 mi^2, and have at least 10 years of annual peak discharges recorded by the United States Geological Survey (USGS). Flood frequency analyses were performed in accordance with the guidelines of Bulletin 17B (Interagency Advisory Committee on Water Data), using the USGS computer program PeakFQ. Computed flood year streamflows were regressed against multiple parameters (watershed geometries, soil characteristics, precipitation data, land use data, etc.) to estimate different recurrence flood year flows (i.e., 2-, 5-, 10-, 25-, 50-, 100-, 200-, 500-year). Regression equations were developed for seven regions in the state of Utah delineated according to hydrologic regions or climatic properties. Regression equations were developed in the format of the rational method where the runoff coefficient was regressed against appropriate determined data: basin characteristics, such as drainage basin area, max flow distance, sinuosity, composite curve number, saturated

hydraulic conductivity, and climatic characteristics including, the basin centroid 2-year, 24-hour precipitation, and basin centroid mean annual precipitation. The regression equations are presented within the document including errors associated with the regression processes. This document also summarizes the procedures a user should follow to use these equations in practice. Cautions are presented for the user to understand the limitations of the equations and to facilitate more efficient design of channel crossings.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

ACKNOWLEDGEMENTS

I would like to extend a great deal of appreciation to Dr. Christine Pomeroy, my graduate advisor, for all the labor she has extended to me in accomplishing this project. Without the opportunity she provided me, I would likely have done something else besides pushing myself for a Masters Degree. I would also like to extend my appreciation to the other members of my graduate committee, Dr. Steve Burian and Dr. Chris Pantelides, for their input on my project and giving me some direction.

I would like to acknowledge the technical advisory team (TAC) for their guidance and review of this project. Members of the TAC included Scott Stoddard of the United States Army Corps of Engineers, Terry Kenney of the Unites States Geological Survey, Scott Baird of Salt Lake County Flood Control, and Denis Stuhff, James Baird and Michael Fazio of the Utah Department of Transportation. Terry Kenny is acknowledged for his extensive review of the draft manuscript of this report, and for providing field data that was used for the time of concentration analysis. I would also like to acknowledge Matthew Stayner for the contribution of the skew map data used in the flood frequency analyses.

1 INTRODUCTION

The design of bridges and culverts crossing rivers, streams, and gullies requires knowledge of the possible peak flows to be conveyed through the respective channels. Often these structures are designed based on recurrence flood year discharges (typically the 1-percent chance (100 year) streamflow). Depending on the known parameters and data available for the site of interest, many different methods can be used to determine these recurrence year peak flows: a site specific analysis can be done using the rational method or constructing a watershed model; a statistical probability flood frequency analysis can be conducted if stream gage data are available; or peak flows can be computed using developed regional regression equations.

In the design of river crossings, estimating peak flood flows too low might lead to a structural failure of the bridge/culvert, whereas estimating the flows too high might lead to an over constructed bridge/culvert. In both scenarios the cost can be very expensive. Often times designers will use the rational method to estimate these flood flows, but only if the contributing watershed is smaller than 1 mi^2. For areas larger than 1 mi^2, regression equations are commonly consulted to estimate recurrence year peak flows. The literature shows that current regression equations for Utah generally represent drainage areas larger than 30 mi^2 statewide and 2 to 5 mi^2 in some locations within the state (Kenney et al. 2008, Perica and Stayner 2004). The objective of the research presented in this report was to develop regression equations to estimate different recurrence year runoff coefficients to use with the rational method, which provides a means of calculating these recurrence year peak discharges for ungaged rural watersheds in Utah ranging from 0.5 to 30 mi^2. These regression equations relate a recurrence year peak flow to statistically significant basin characteristics (e.g., basin area, precipitation, soil type, etc.).

The equations developed are for the entire state of Utah and portions of the surrounding states. Regression equations were developed in the form of the rational method, similar to those developed in a study performed for the Kansas Department of Transportation by McEnroe et al. (2007). The geographic boundaries of this project were chosen to coincide with the same geohydrologic region boundaries used in the development of the regression equations by the United States Geological Survey (USGS) (Kenney et al. 2008). A comparison between the results of this research and that of Kenney et al. (2008) was conducted to show which equations provide better results for the regions shown in Figure 1.1, which was developed by dividing the overall boundary into seven smaller regions based on geologic and hydrologic differences (Kenney et al. 2008).

Section 2 of this report presents a review of pertinent literature to the developing of the regression equations. Section 3 shows a discussion on the data used in the development of the regression equations. Section 4 provides the development of the extended rational method style regression equations. Section 5 discusses the equation and variable limitations. Section 6 contains the comparison between results of this research and Kenney et al. (2008). Section 7 gives the conclusions and recommendations for future research. Section 8 provides a step-by-step procedure on the application of the developed equations.

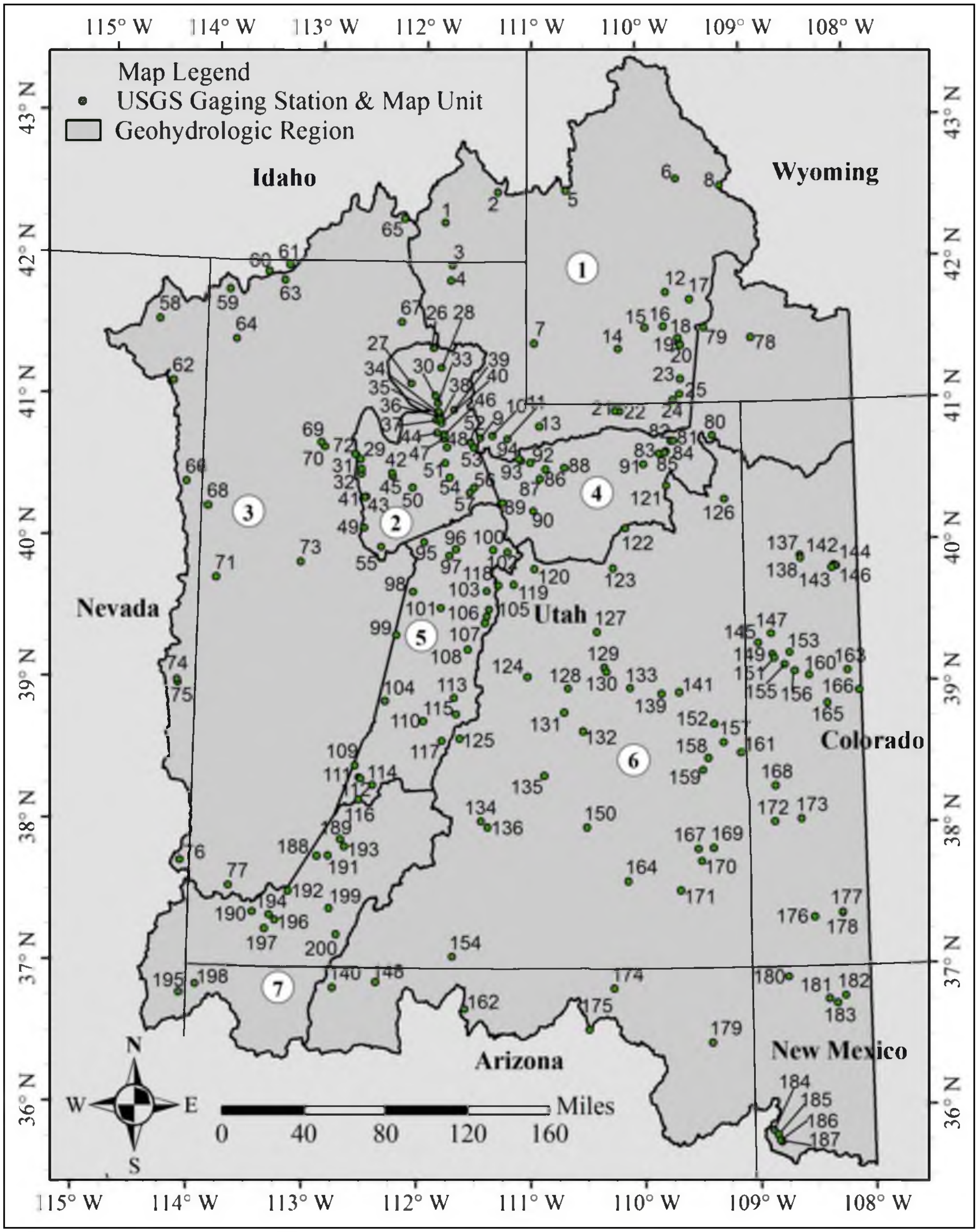

Figure 1.1: Geohydrologic regions, as defined by Kenney et al. (2008), and USGS gaging stations for study region. The east boundaries end at the 108th longitudinal line, where a change in soil and precipitation data was observed.

2 LITERATURE REVIEW

2.1 Use of Rational Method to Compute Flood Flows

The rational method is commonly used to estimate peak discharges for different recurrence storm years. This method is termed "rational" from a simple concept: for a set rainfall intensity over an area, the peak flow discharge off that area will be a fraction of the total rainfall intensity. The rational method is shown in equation 2.1.

$$Q = C_f CiA \qquad \textit{(Eq. 2.1)}$$

where,

Q = Peak flow discharge rate

C_f = Conversion unit

C = Unitless runoff coefficient

i = Rainfall intensity

A = Watershed area

David R. Maidment (1993) states that the American Society of Civil Engineers (ASCE) (1969) has published suggested ranges of runoff coefficients that are primarily suited for urbanized conditions, and only apply to watersheds under 0.5 mi^2. Maidment (1993) also suggests the "greatest difficulty and the major source of uncertainty" with using the rational method is in estimating a proper runoff coefficient, since published runoff coefficient design values are based more on judgment than actual data. Even though this is the case, the rational method can be applied to larger areas if proper runoff coefficients are available.

Choosing a proper runoff coefficient is not the only source of uncertainty with the rational method. In a discussion on the rational method, Alan Smith and Ken Lee (1984) agree with Maidment (1993) that peak flow estimations are far too "sensitive to the subjective choice of runoff coefficient" values, but add that the method assumes the rainfall intensity is constant over the watershed area. Smith and Lee (1984) also suggest the rational method formula assumes the rainfall event is represented as "an average uniform intensity" for the entire rainfall duration. Since rainfall intensity is not truly constant, the estimated peak flow is merely an approximation, and, in some cases, could be off considerably from real storm events in the watershed (Smith and Lee 1984).

According to Philip Bedient et al. (2008) the runoff coefficient accounts for all of the factors that contribute to losses of rainfall runoff volume throughout the watershed area, where the factors are primarily correlated with the soil type and land use of the area. Bedient et al. (2008) continues to explain that there is a volumetric amount of water the watershed will absorb before allowing runoff to occur. Because of this, the rainfall runoff from a watershed will be different under the same rainfall intensity due to the precondition water volume already absorbed by the watershed. So, Bedient et al. (2008) claims the rational method does not take into account the frequency, or elapsed time, between storm events.

As noted by Maidment (1993), the rational method is intended to be used for small watersheds less than 0.5 mi^2. At this size of land area, the runoff coefficients, rainfall intensities, and soil type/land use are much more uniform, and provide decent approximations of peak flows for practicing engineers (Smith and Lee 1984). However, when using the rational method to predict peak flows for larger watersheds, Bedient et al. (2008) suggests the watershed be divided into smaller areas to account for the deviations within the variables of equation 2.1.

2.2 Use of Regression Equations for Estimating Flood Flows in Utah

In the state of Utah it is often necessary to construct a crossing over a channel (or stream wash) that has no stream gage data, which means a site specific analysis is the only way to get peak discharge estimates. Regression equations provide a means to estimate the recurrence year peak flows in such ungaged sites; however, determining the variables to regress flood flows against is one of the primary challenges in developing regression equations. In most regression equations developed for Utah, area and mean watershed elevation are used as the primary explanatory variables, where these equations are intended for use on areas larger than 30 mi^2. A few studies were conducted to develop regression equations to estimate flood flows throughout various regions in Utah. These studies are briefly discussed below.

The Virgin River basin is located in the southwest corner of the state of Utah, which is the bottom half of Region #7 shown in Figure 1.1. Perica and Grenney (2003) developed regression equations to estimate recurrence year flood flows within this region, where the range of watersheds are between 50 and 2,000 mi^2. Many different watershed characteristics were considered for the development of these equations including drainage area, mean watershed elevation, slope and length of watershed, percent of watershed facing north and south, forested area, and watershed shape factor. All of the possible variables used by Perica and Grenney (2003) are watershed basin characteristics, where hydrologic characteristics, such as recurrent year storm events and mean annual precipitation, were not considered. Through the regression analysis process, Perica and Grenney (2003) found the variables of area and mean watershed elevation were the primary contributors to estimating flood flows, and were used in their equations.

The Weber River Basin is located in the north part of the state of Utah, which is the north part of Region #2 and southwest part of Region #1 shown in Figure 1.1 (where the whole basin is in the state of Utah). Perica and Stayner (2004) performed a regression analysis of this region to develop equations to estimate recurrence year flood flows for watersheds between 2 and 250 mi^2. The watershed characteristics used in this analysis are the same as from Perica and Grenney (2003), except they included hydrologic soil group, land use, and 24- hour recurrent year precipitation data as part of their possible explanatory variables. Even though soil and precipitation data were included, the resulting equations were still explained by the variables basin area and mean elevation, as was found with Perica and Grenney (2003).

In a study conducted by Thomas et al. (1997), the entire southwest portion of the United States was divided into 16 different hydrologic flood regions, where 7 include portions of the state of Utah. Recurrent year flood frequency regression equations were developed for each of the 16 hydrologic regions. In an effort to localize the equations to the state of Utah, Mason et al. (1999) prepared a document containing only the 7 flood regions pertaining to the state of Utah. In this document, Mason et al. (1999) discusses the equations are best used for watersheds less than 200 mi^2, and shows the equations were developed using the following explanatory variables: basin area, mean watershed elevation, and mean annual precipitation.

A later study conducted by Kenney et al. (2008) improved the equations developed by Thomas et al. (1997). To establish more proper boundaries for recurrence year flood frequency equations, Kenney et al. (2008) combined basin delineations of climatic regions of Utah (produced by the National Oceanic and Atmospheric Administration), physiographic regions of Utah (developed by USGS), and the flood regions developed by Thomas et al. (1997). These regions were compiled to form the geohydrologic regions shown in Figure 1.1. Also, in this study, Kenney et al. (2008) used all the possible explanatory variables discussed by Perica and Grenney (2003), and Perica and Stayner (2004), and Mason et al. (1999), and also considered many types of land cover ranging from forest to agricultural, barron to herbaceous, and developed to wetlands. The equations developed by Kenney et al. (2008) are for a wide range of watersheds that range from 1 to 1,600 mi^2. Due to the large sized watersheds used in the analysis, the equations are not likely to produce as accurate results watersheds smaller than 20 to 30 mi^2.

2.3 Use of Regression Equations with Rational Method Concept

Since it is difficult to develop proper runoff coefficients for the rational method, many engineers will turn to regression equations to estimate recurrence year peak flood flows. In a study conducted by McEnroe et al. (2007) for the state of Kansas, the concept of the rational method was combined with the idea of regression equations, by developing regression equations for the runoff coefficient. Since rainfall intensity and area are already in the rational method equation, these variables were excluded from the possible explanatory variables. McEnroe et al. (2007) used the following variables as possible explanatory variables to regress the runoff coefficients against: average slope of main channel, basin shape factor, soil permeability, runoff curve number, mean annual precipitation, and mean annual lake evaporation. Through the study, it was determined the mean annual precipitation provided the best explanation for the runoff coefficient equations, where the study is localized to watersheds less than 30 mi^2.

As part of the study performed by McEnroe et al. (2007), a results comparison was made between the rational method regression style equations and a traditional regression method style. To do this, McEnroe et al. (2007) also developed regression equations along the lines discussed in section 2.2, where flood flows were regressed against area, mean annual precipitation, and rainfall intensity. The results of the comparison showed there was very little difference between rational method regression equations and the traditional regression style equations. This is an expected result, since both sets of equations have the same variables. However, when McEnroe et al. (2007) performed the regression analysis of flood flows against just the area and mean annual precipitation, the errors in the results increased by roughly 10% across the recurrence year storm events.

Considering the analysis of McEnroe et al. (2007) is for the state of Kansas, where the climate is roughly the same throughout the state, and there are no mountain ranges to provide a wide range of hydrologic differences, the results show regression equations to determine runoff coefficients for the rational method perform better than traditional regression equations. Therefore, this method of developing regression equations is investigated for use within the state of Utah as shown and discussed in the following chapters.

3 DATA USED IN REGRESSION ANALYSES

3.1 USGS Streamflow-Gaging Stations

In order to develop any type of regression analysis, it is necessary to have recurrence year peak flow data. For over a century the USGS has recorded stream/river flows at locations across the nation. For most of these stations, annual peak flows are documented at active stream gages. Knowing this, a search was conducted on USGS's National Water Information System to extract all the steam gage stations that contain more than 10 years of peak flow records through water year 2008, and that were between 0.5 to 30 mi^2 located within the study region, which are shown in Figure 1.1. These stations were then sorted through to identify any two gages that contain nested data (i.e., the two gages have records of the same years of peak flow for the same stream). The stream gage having the least number of annul flow records was dropped from the analysis. From that, there were a total of 200 stations that fit the above criteria.

3.2 Recurrence Year Flood Discharges

Using the gathered data, flood-frequency analyses were performed for the records from each stream gage using the USGS *PeakFQ* program (Flynn et al. 2006). The *PeakFQ* program follows the Bulletin 17B (IACWD 1982) guidelines, using a log-Pearson Type III curve to fit data, and gives the resulting recurrence flood flows of 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year events (Flynn et al. 2006). According to Bulletin 17B guidelines, years of record showing zero flow through the gage should not be used for analysis. Years of record altered by local urbanization or flow regulations were also excluded from the analyses. (Flynn et al. 2006). Also, instead of using the nationwide map to determine the generalized skew for each station, a skew map was created by data generated by Perica and Stayner (2004) for the state of Utah. In order to use this skew map for the regions in the surrounding states, the map was modified as shown in Figure 3.1.

After the frequency analyses were performed for the streamflow gaging stations, results were reviewed to ensure all stations had more than 10 years of record (after eliminating the 0 year flood flows and years of streamflow regulation), and that the number of peaks dropped were fewer than allowed from the Bulletin 17B guidelines. Each of the geohydrologic regions had at least one station that could not be used. A summary of the number of useable stations for each region is provided in Table 3.1. Further explanation for the particular reasons stations were excluded from the regression analyses are provided in the footnotes in Appendix A, which also includes the recurrence flood year estimates for each station in the analysis.

Table 3.1: Summary of USGS stations available for regression analyses for each geohydrologic region.

Geohydrologic Region	Total Stations	Useable Stations	Unuseable Stations
1	25	19	6
2	32	29	3
3	20	14	6
4	17	16	1
5	23	21	2
6	70	58	12
7	13	12	1
Totals:	200	169	31

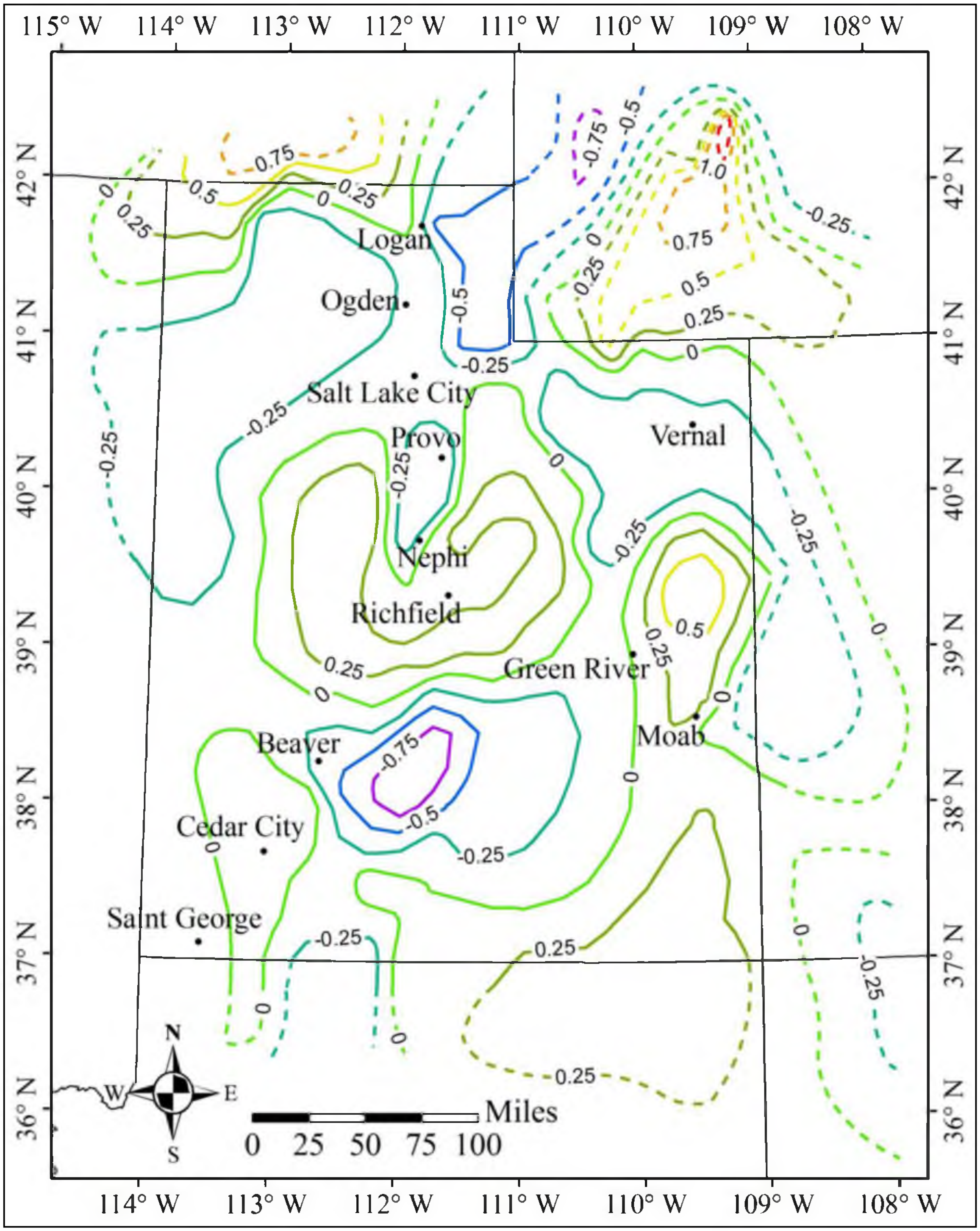

Figure 3.1: Generalized skew map for Utah showing contour lines of constant skew value for flood frequency analysis. Dashed lines show the approximated skew lines after modification.

3.3 Possible Explanatory Regression Variables

The next step taken in the regression equation development was to evaluate multiple explanatory variables with the potential to have strong correlations with the flood flows obtained in the frequency analyses. The explanatory variables evaluated included geometric characteristics of the watershed (i.e., area, slope, shape characteristics, etc.), an area weighted curve number, hydraulic conductivity of the soil, mean annual precipitation, 2-year, 24-hour precipitation, and rainfall intensity. A more in depth description of these possible explanatory variables is contained in the following sections.

3.3.1 Basin Geometric Characteristics

The geometric parameters of the watersheds were determined using Watershed Modeling Systems (WMS) software (Aquaveo, LLC 2009), which delineates the basins and provides multiple watershed characteristics. Digital Elevation Model (DEM) data were used to evaluate the terrain for the delineated watershed of each of the USGS gages evaluated in the study. Ten meter resolution DEM data were obtained from the USGS's Seamless Server (http://seamless.usgs.gov/index.php) for all stream gage locations. After delineation of the watersheds, the geometric parameters – basin area, basin slope, maximum flow distance, maximum flow distance slope, percent of basin facing south, basin length, basin shape-factor, basin sinuosity, and basin average elevation – were all compared and examined as possible geometric characteristics for regression. An explanation of each geometric characteristic is shown in Table 3.2, which includes a description of how WMS computes each characteristic. Also, the table shows the symbol describing each parameter used in the regression equations.

Table 3.2: Geometric parameters used as explanatory variables for regression equations.

Parameter	Symbol	Definition of WMS Computation*
Basin Area	*A*	Area enclosed by delineated watershed.
Basin Slope	*BS*	The average basin slope.
Max Flow Distance	*MFD*	The maximum flow distance within a basin including both overland and channel flow.
Max Flow Slope	*MFS*	The average slope of the MFD.
Percent Flow South	*FS*	The percentage of the basin whose aspect is directed south (where south is the negative Y-direction).
Basin Length	*BL*	The straight line distance from the outlet to the furthest remote point of the basin.
Basin Shape Factor	*SF*	The shape factor of the basin (computed by dividing basin length by basin width).
Basin Sinuosity	*SIN*	The sinuosity factor of the basin (computed by dividing the maximum stream length by the basin length).
Basin Mean Elevation	*ME*	The average elevation of the watershed.

*These definitions were taken from the WMS help manual (EMS-I 2010).

The WMS software calculated the geometric characteristics for each watershed used in the regression analyses, which data is shown in Appendix A. These values are provided for each of the delineated watersheds associated with the stream gage stations.

3.3.2 Composite Runoff Curve Number

A composite, or area weighted, Soil Conservation Service (SCS) runoff curve number for each watershed was calculated using the WMS software. This SCS runoff curve number is computed using the hydrologic soil group and land use/land cover (LULC) data. U.S. General Soil Map State Soil Geographic Database (STATSGO) data were obtained from the National Resources Conservation Service's (NRCS) "Soil Data Mart" (http://soildatamart.nrcs.usda.gov/USDGSM.aspx) for Utah and each of the surrounding states. The soil data were processed using a combination of *ArcGIS* (ESRI, Inc 2009) and *Soil Data Viewer* (NRCS 2009) (an extension for *ArcGIS* developed by

NRCS), to obtain statewide shapefiles of the soil's hydrologic group. LULC data were obtained from webgis.com, a site that is sponsored by Lakes Environmental Software, which has posted free processed LULC shapefiles obtained from USGS's Earth Resources Observation and Science (EROS) Data Center. The LULC and soils data were then combined to determine the curve numbers for each watershed. The STATSGO data have a minimum resolution of 2,500 acres (NRCS 2009), whereas the LULC data have a minimum resolution of 10 acres (USGS 2009). It should be noted the choice to use the STATSGO data over the Soil Survey Geospatial (SSURGO) data, which has a minimum resolution between 1 to 10 acres, was due to incomplete coverage of SSURGO data across the state of Utah.

Composite curve numbers for each gaging station's watershed were computed using WMS's shapefile overlay capabilities. A land use key (mapping each type of land use code with each type of hydrologic soil group) was used to extract the composite curve numbers. The land use key is shown in Appendix A, where the curve number values were obtained from SCS's Technical Release 55 (USDA 1986). The composite curve numbers determined for each basin are also shown in Appendix A.

3.3.3 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity values were also evaluated as possible explanatory variables. These values were also gathered using the STATSGO data, and processed using the *Soil Data Viewer*. The STATSGO data are a compilation of surveyed soils across the United States, where the soil characteristics have been mapped up to 60 in. deep, or until the bedrock (whichever comes first). Because soil types change throughout the depth of the soil, which affects the rate of percolation, composite saturated hydraulic conductivity values for each watershed were calculated for the surface layer of the soil, 12 in. into the soil, 24 in. into the soil, and the full depth (60 in. or until bedrock).

An area weighted hydraulic conductivity value was computed for each of the varying depths (in the cases where the soil had more than one soil type) using *ArcGIS*/*Soil Data Viewer* capabilities. To compute a saturated hydraulic conductivity value for each watershed, the delineated watersheds were exported from the WMS software as shapefiles and overlaid onto the soil data in *ArcGIS*. From the overlay, the watersheds were divided into different sections containing varying hydraulic conductivity values. Using an area-weighting procedure, an average saturated hydraulic conductivity value was calculated for each depth range for each watershed. These computed saturated hydraulic conductivity values are shown in Appendix A.

3.3.4 Mean Annual Precipitation

Mean annual precipitation (MAP) for the centroid of each gaging station's watershed was determined using data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group at Oregon State University (2009). Centroid MAP values, based on data from 1971 to 2000 (PRISM Climate Group 2009), were obtained using the PRISM digital gridded data explorer with the watershed's centroid location as an input (in latitude and longitude coordinates). The centroid of each watershed (computed from WMS) is a good location to approximate the MAP, since the watersheds are small (less than 30 mi^2) and do not have much variation in annual precipitation within the delineated boundaries. These MAP values for each watershed in the study are shown in Appendix A for reference.

3.3.5 2-year, 24-hour Precipitation Depth

Another chosen explanatory variable used to develop the desired regression equations is the 2-year, 24-hour storm depth. These data were collected from the National Oceanic and Atmospheric Administration (NOAA) using the centroid (in latitude and longitudinal coordinates) of the gaging station's watersheds (as discussed in section 3.3.4). The precipitation depths for watersheds located in Utah, Nevada, Arizona, and New Mexico were obtained from NOAA Atlas 14; and the precipitation for Idaho, Wyoming, and Colorado were obtained from NOAA Atlas 2. These determined depths are shown in Appendix A for each watershed in the study region.

3.3.6 Recurrence Year Rainfall Intensity

Since the rational method uses rainfall intensity as a means to calculate the flows, this parameter was necessary for developing the rational style regression equations. A time of concentration (which is the time required for runoff water to move from the hydraulically furthest remote point in the watershed to the outlet location (Maidment 1993)) is required to determine rainfall intensity from intensity duration frequency (IDF) data. Time of concentration is generally estimated using regression equations, or manually if stream channels are well defined (i.e., known channel widths, slopes, side slopes, etc.) using the methods outlined in the U.S. Department of Agriculture's (USDA) Technical Release 55 (USDA 1986).

Currently there are no regression equations specific for the state of Utah, and no process has been adopted state-wide to determine the time of concentration for rural watersheds. Many of the traditional equations used (i.e., SCS lag time, Espey lag time, Kirpich, etc.) to compute the time of concentration are included in WMS. Two of the pre-programmed equations were deemed appropriate for use in this project, as discussed in Appendix B: Arizona's Department of Transportation's (ADOT) time of concentration equation and the Riverside County (RC) lag time equation, where the lag time is estimated to be 60% of the time of concentration by the Soil Conservation Service (SCS). These empirical equations produced similar results, and were developed for semiarid regions with mountainous terrain (larger slopes) and similar watershed areas contained in this analysis. After developing the correlation matrices (discussed in section 4.3) for the explanatory variables and computing the regression equations, it was determined that the ADOT equation produced slightly better results than the RC lag time equation for each region in the analysis; therefore, it is necessary to only use the ADOT equation for computations. The ADOT time of concentration equation, taken from WMS 8.1, is shown in equation 3.1.

$$t_C = 2.4A^{0.1}L^{0.25}L_{CA}^{0.25}S^{-0.2} \qquad \textit{(Eq. 3.1)}$$

where,

t_C = Time of concentration (hrs)

A = Area of watershed (mi^2)

L = Length along main channel from outlet to upstream boundary (mi)

L_{CA} = Length along main channel from outlet to point opposite centroid (mi)

S = Slope along main channel from outlet to upstream boundary (ft/mi)

After computing the time of concentration for each watershed, rain intensity was determined using IDF tables produced by NOAA. The centroid of each watershed was used as the latitude and longitude coordinate to obtain the appropriate IDF tables from NOAA Atlas 14 and Atlas 2. The rain intensity values were then interpolated using the times of concentration computed for each watershed. These results are shown in Appendix A for each watershed within the study.

3.3.7 Summary of Explanatory Variables

A summary of all the explanatory variables examined in this study is provided in Table 3.3, which contains the symbol used in the regression equations and the units each parameter needs to be in.

Table 3.3: Summary of explanatory variables used in regression analyses with the units necessary for input into developed regression equations. Also, the variable symbol for each parameter is defined for regression analyses.

Parameter	Symbol	Units	Data Sets Used
Basin Geometric Characteristics			
Basin Area	A	mi^2	10-meter DEM
Basin Slope	BS	feet/feet	10-meter DEM
Max Flow Distance	MFD	feet	10-meter DEM
Max Flow Slope	MFS	feet/feet	10-meter DEM
Percent Flow South	FS	percent	10-meter DEM
Basin Length	BL	feet	10-meter DEM
Basin Shape Factor	SF	feet/feet	10-meter DEM
Basin Sinuosity	SIN	feet/feet	10-meter DEM
Basin Mean Elevation	ME	feet	10-meter DEM
Composite Runoff Curve Number	CN	dimensionless	LULC & STATSGO Soil
Area Weighted Saturated Hydraulic Conductivity			
Surface of Soil	$K_{SAT,SURF}$	inches/hour	STATSGO Soil
12” Deep in Soil	$K_{SAT,12}$	inches/hour	STATSGO Soil
24” Deep in Soil	$K_{SAT,24}$	inches/hour	STATSGO Soil
Full Depth of Soil	$K_{SAT,FULL}$	inches/hour	STATSGO Soil
Mean Annual Precipitation at centroid of watershed	MAP	inches	Prism Gridded Data Explorer
2-year, 24-hour Precipitation at centroid of watershed	$PREC$	inches	NOAA Atlas 14[1] & Atlas 2[2]
Rainfall Intensity at centroid of watershed	i	inches/hour	NOAA Atlas 14[1] & Atlas 2[2]

[1]Used for Utah, Nevada, Arizona, and New Mexico
[2]Used for Idaho, Wyoming, and Colorado

4 EXTENDED RATIONAL METHOD STYLE REGRESSION EQUATIONS

4.1 Recurrence Year Runoff Coefficients

The rational method is commonly used to compute peak flood flows for small watersheds (less than 0.5 mi^2). The method is based on the idea that the peak flow is computed by multiplying the peak rainfall intensity by a contributing watershed area, but only taking a percentage based on the ground cover of the watershed (Maidment 1993). Runoff coefficients have been determined for different ground cover conditions by ASCE, which are also dependent on recurrence storm intervals (Maidment 1993). The rational method equation takes the form as shown in equation 4.1:

$$Q = C_f CiA, \qquad \text{(Eq. 4.1)}$$

where,

Q = the peak discharge rate

C_f = a conversion unit

C = a unitless runoff coefficient

i = the rainfall intensity

A = the watershed area.

To develop the extended rational method regression equations it was necessary to associate the rational method runoff coefficient with the possible explanatory variables. This was accomplished by (1) computing a runoff coefficient for each watershed, (2) developing a correlation matrix for each recurrence flood year, and (3) using statistical software to generate regression equations using the best correlated variables. These processes are explained in the following sections.

Runoff coefficients for each watershed were determined for each recurrent flood year by rearranging the rational method equation into the form shown in equation 4.2 and applying the peak discharges, rainfall intensities, and watershed areas.

$$C_f C = Q/(iA) \qquad \textit{(Eq. 4.2)}$$

It is important to note that a conversion unit factor was not necessary for equation 3.2 because the units correct themselves through the terms in the regression equations. However, it is important to ensure the rain intensity and watershed area units are consistent with the units shown in Table 3.3. Calculated runoff coefficients were computed for each watershed within each region and are provided in Appendix C.

4.2 Form of Regression Equations

It was necessary to understand the relationship between the runoff coefficients and the predictor variables for the development of the regression equations. To explore this relationship, scatter plots of the runoff coefficients and the predictor variables were developed (indirectly and not reproduced in this report), which showed that runoff coefficients increase more rapidly as the predictor variable increases (i.e., they do not have a linear relationship with each other). McEnroe et al. (2007) also found this was the case when they evaluated the relationships between runoff flows and their explanatory variables. However, by taking the base 10 logarithm of the runoff coefficients and explanatory variables, a linear relationship was produced, yielding regression equations in the form shown in equation 4.3, which is a common method used in this type of analysis.

$$logY = a + b_1logX_1 + b_2logX_2 + ... + b_nlogX_n \qquad (Eq.\ 4.3)$$

where,

Y = dependent variable

X_i = independent variables

a = the regression constant

b_i = the regression coefficients for the independent variables

After performing a logarithmic transformation of equation 4.3, the resulting regression equation is a power function of the dependent variables, as shown in equation 4.4.

$$Y = 10^a (X_1)^{b_1} (X_2)^{b_2} ....(X_n)^{b_n} \qquad (Eq.\ 4.4)$$

Each of the regression equations developed for the rational method style equations and the traditional regression equations follow the format shown in equation 4.4.

4.3 Correlations between Runoff Coefficients and Explanatory Variables

A correlation analysis was performed on the runoff coefficients and the explanatory variables to determine which explanatory variables should be used for the regression. The computer program Minitab 15 (Minitab Inc. 2009) was used to compute the correlations and for developing the regression equations. Each of the recurrent year runoff coefficients were correlated with each of the possible explanatory variables. Also, the average correlation for each predictor variable was computed for easier interpretation. A cross-correlation of the variables was examined manually during the development of the regression equations. This ensured that variables of similar properties were not used in the same equations (e.g., basin length and stream length were not used together). These results are shown in Appendix D.

Before the correlations were determined, the logarithm of each variable was calculated, to produce the correlations relating the log(C) to the log(explanatory variables) (as discussed in section 4.2). These correlations were referred to when the regression equations were developed as a way to check the reasoning of the output. However, it should be noted the basin area and rainfall intensities were not included in the correlation analyses since they are contained within the computed runoff coefficients.

4.4 Developed Runoff Coefficient Regression Equations

A stepwise regression analysis was used to determine which set of predictor variables best explains the recurrence interval peak flows for each region. The stepwise regression assessed the significance of each predictor variable within the regression model, by comparing the statistical "*P*-value" for each variable with the specified statistical "α-value." The *P*-value is a statistical value used to compare how well a predicted variable fits in the regression equation (Minitab Inc 2009). If the *P*-value was less than the α-value, then the variable was identified as having statistical significance to the regression equation (Minitab Inc. 2009). An α-value of 0.05 (which means an explanatory variable will predict the regression equation output at a 95% confidence level) was used for the analyses, which is consistent with similar literature.

The computed regression equations, from the stepwise analyses, were of the form given in equation 4.3; a logarithmic transformation was performed to show the developed regression equations in the form of equation 4.4. Also, the R^2, R^2_{ADJ} (which accounts for the sample size), and R^2_{PRED} values (which indicates how well the equations "predict responses for new observations" (Minitab Inc. 2009)) for each regression equation were determined. In addition to the R^2 values, the square root of the mean standard error (S) for each predicted equation was given, which are in logarithm units. These error values were converted into errors in percentage units. The developed regression equations for the runoff coefficients, along with the associated fitting parameters, are later shown in Table 4.1.

4.5 Rational Style Regression Equations

To use the "extended rational method style" regression equations in practice, the runoff coefficient should be calculated for the location of interest and chosen recurrence storm, and then used with equation 4.5 (formatted like the rational method equation).

$$Q_X = C_X i_X A \qquad \text{(Eq. 4.5)}$$

where,

Q_X = Estimated peak flood flow at "x" recurrence year (ft^3/s)

C_X = Computed runoff coefficient at "x" recurrence year from Table 4.1 ((ft^3/s)/(in-mi^2/hr))

i_X = Rainfall intensity from time of concentration (Eq. 2.1) at "x" recurrence year (in/hr)

A = Area of watershed (mi^2)

It should be noted the reason some regions do not have predictive equations for the 200- and 500-year events is because NOAA Atlas 2 does not provide rain intensities past the 100-year event (for Colorado, Idaho, and Wyoming). Therefore, the rain intensity could not be determined for those stations, which restricted the computation of a runoff coefficient for those basins.

Table 4.1: Predictive runoff coefficient regression equations expressed with errors of fit, which represents the uncertainty in estimating the peak flows for rural streams in Utah. See Table 3.3 for predictor variable details.

Rational Style Runoff Coefficient Regression Equations	Square Root of Mean Standard Error, or S			Regression Fitting (%)		
	Log Units	Percentage Units		R^2	R^2_{ADJ}	R^2_{PRED}
Region #1 (equations based on 19 USGS gage stations)						
$C_2 = 10^{1.33} K_{SAT,SURF}{}^{0.462}$	0.239	+73%	-42%	15.3	10.3	0.0
$C_5 = 10^{1.34} K_{SAT,SURF}{}^{0.891}$	0.256	+80%	-45%	36.9	33.2	20.2
$C_{10} = 10^{1.32} K_{SAT,SURF}{}^{1.17}$	0.290	+95%	-49%	44.1	40.8	28.9
$C_{25} = 10^{1.27} K_{SAT,SURF}{}^{1.51}$	0.341	+119%	-54%	48.6	45.6	34.6
$C_{50} = 10^{1.23} K_{SAT,SURF}{}^{1.73}$	0.379	+139%	-58%	50.4	47.5	37.0
$C_{100} = 10^{1.19} K_{SAT,SURF}{}^{1.95}$	0.416	+161%	-62%	51.7	48.8	38.6
Region #2 (equations based on 29 USGS gage stations)						
$C_2 = 10^{2.74} FS^{-0.996}$	0.326	+112%	-53%	19.0	16.0	8.9
$C_5 = 10^{2.81} FS^{-0.949}$	0.272	+87%	-47%	23.5	20.6	12.4
$C_{10} = 10^{2.81} FS^{-0.919}$	0.259	+82%	-45%	24.1	21.3	12.2
$C_{25} = 10^{2.80} FS^{-0.889}$	0.262	+83%	-45%	22.4	19.6	10.0
$C_{50} = 10^{2.77} FS^{-0.869}$	0.276	+89%	-47%	20.0	17.0	7.2
$C_{100} = 10^{2.74} FS^{-0.848}$	0.296	+98%	-49%	17.1	14.1	4.3
$C_{200} = 10^{2.72} FS^{-0.833}$	0.320	+109%	-52%	14.6	11.4	1.8
$C_{500} = 10^{2.68} FS^{-0.814}$	0.356	+127%	-56%	11.6	8.4	0.0
Region #3 (equations based on 14 USGS gage stations)						
$C_2 = 10^{18.7} FS^{-2.69} MFD^{-2.91}$	0.527	+237%	-70%	39.9	29.0	0.0
$C_5 = 10^{17.6} FS^{-2.55} MFD^{-2.65}$	0.342	+120%	-55%	57.9	50.2	9.9
$C_{10} = 10^{16.6} FS^{-2.38} MFD^{-2.46}$	0.313	+106%	-51%	58.7	51.2	25.3
$C_{25} = 10^{15.3} FS^{-2.17} MFD^{-2.23}$	0.355	+126%	-56%	47.7	38.2	16.2
$C_{50} = 10^{14.3} FS^{-1.99} MFD^{-2.04}$	0.413	+159%	-61%	36.3	24.8	0.0
$C_{100} = 10^{13.2} FS^{-1.82} MFD^{-1.86}$	0.478	+201%	-67%	26.1	12.7	0.0
Region #4 (equations based on 16 USGS gage stations)						
$C_2 = 10^{0.831} BS^{-0.972}$	0.274	+88%	-47%	28.6	23.5	12.2
$C_5 = 10^{0.952} BS^{-0.894}$	0.226	+68%	-41%	33.3	28.5	16.8
$C_{10} = 10^{0.977} BS^{-0.878}$	0.216	+64%	-39%	34.5	29.8	11.4
$C_{25} = 10^{0.977} BS^{-0.876}$	0.216	+64%	-39%	34.5	29.8	11.4
$C_{50} = 10^{0.965} BS^{-0.879}$	0.226	+68%	-41%	32.4	27.6	5.6
$C_{100} = 10^{0.943} BS^{-0.888}$	0.246	+76%	-43%	29.4	24.4	0.0

Table 4.1: Continued.

Rational Style Runoff Coefficient Regression Equations	Square Root of Mean Standard Error, or *S*			Regression Fitting (%)		
	Log Units	Percentage Units		R^2	R^2_{ADJ}	R^2_{PRED}
Region #5 (equations based on 21 USGS gage stations)						
$C_2 = 10^{1.85} PREC^{-3.35}$	0.337	+117%	-54%	26.0	22.1	4.6
$C_5 = 10^{2.25} PREC^{-4.17}$	0.325	+111%	-53%	37.1	33.8	12.0
$C_{10} = 10^{2.45} PREC^{-4.66}$	0.332	+115%	-53%	41.3	38.2	15.8
$C_{25} = 10^{2.66} PREC^{-5.18}$	0.353	+125%	-56%	43.4	40.5	18.5
$C_{50} = 10^{2.79} PREC^{-5.55}$	0.373	+136%	-58%	44.2	41.2	20.2
$C_{100} = 10^{2.91} PREC^{-5.90}$	0.397	+149%	-60%	44.1	41.2	21.2
$C_{200} = 10^{3.01} PREC^{-6.23}$	0.422	+164%	-62%	43.7	40.7	21.9
$C_{500} = 10^{3.14} PREC^{-6.64}$	0.459	+188%	-65%	42.8	39.8	22.2
Region #6 (equations based on 58 USGS gage stations)						
$C_2 = 10^{4.89} MAP^{-2.43} BS^{0.43}$	0.416	+161%	-62%	54.6	52.9	49.7
$C_5 = 10^{7.48} MAP^{-2.58} BL^{-0.46} BS^{0.52}$	0.370	+134%	-57%	65.5	63.6	59.6
$C_{10} = 10^{8.64} MAP^{-2.64} BL^{-0.67} BS^{0.55}$	0.368	+133%	-57%	67.9	66.1	61.9
$C_{25} = 10^{9.88} MAP^{-2.68} BL^{-0.91} BS^{0.57}$	0.387	+144%	-59%	68.0	66.2	61.7
$C_{50} = 10^{10.72} MAP^{-2.70} BL^{-1.07} BS^{0.59}$	0.410	+157%	-61%	67.0	65.2	60.4
$C_{100} = 10^{11.49} MAP^{-2.71} BL^{-1.23} BS^{0.61}$	0.437	+174%	-63%	65.8	63.9	58.9
Region #7 (equations based on 12 USGS gage stations)						
$C_2 = 10^{0.564} K_{SAT,SURF}^{1.63}$	0.261	+82%	-45%	56.9	52.6	33.8
$C_5 = 10^{0.628} K_{SAT,SURF}^{2.36}$	0.281	+91%	-48%	70.5	67.5	57.9
$C_{10} = 10^{0.662} K_{SAT,SURF}^{2.69}$	0.315	+107%	-52%	71.2	68.3	59.1
$C_{25} = 10^{0.706} K_{SAT,SURF}^{3.00}$	0.362	+130%	-57%	69.8	66.8	56.9
$C_{50} = 10^{0.736} K_{SAT,SURF}^{3.17}$	0.397	+149%	-60%	68.4	65.2	54.4
$C_{100} = 10^{0.760} K_{SAT,SURF}^{3.33}$	0.430	+169%	-63%	66.9	63.6	51.9
$C_{200} = 10^{0.782} K_{SAT,SURF}^{3.46}$	0.462	+190%	-65%	65.4	62.0	49.4
$C_{500} = 10^{0.809} K_{SAT,SURF}^{3.60}$	0.502	+218%	-69%	63.4	59.8	46.0

5 EQUATION LIMITATIONS AND VARIABLES/ PREDICTION RANGES

The user of the equations presented in Table 4.1 should be aware of the limitations associated with the equations. These limitations are presented in the following sections. The equations derived for each region in the study area were developed based on specific ranges in the explanatory variables. The variable ranges and average expected ranges estimated from the developed equations are contained and discussed in the following sections.

5.1 Limitations of Rational Style Regression Equations

The predictive equations presented in Table 4.1 contain varying degrees of uncertainty. Many of the R^2 values are between 30% and 60%, which does not suggest a great fit to the data in many of the equations. Also, the S-value (square root of the mean standard error) primarily ranges between -60% to +150% throughout all the regions. The high error percentages, shown in Table 4.1, provide a typical range of accuracy to what the real recurrence peak flow for a rural watershed should be. Because of this, users of these methods should be cautious when using the presented equations for design purposes. The error values can provide a means to estimate the upper and lower limits (or the range) of likely peak flows.

Users of these equations should be aware of some exceptions associated with the statistical P-value of some explanatory variables in the developed runoff coefficient equations. These exceptions (where the P-value exceeded the α-value of 0.05) are shown in Table 5.1. Recall that a P-value greater than the α-value implies the predictor variable has no statistical bearing on the output of the equation. Each of the conditions presented in Table 5.1 were analyzed by estimating recurrence flood flows by including the explanatory variable or choosing the next closest equation outputted from the stepwise regression process. The estimations from the equations in question, shown in Table 5.1, showed there are slightly smaller standard deviations of predicted recurrence flood flows associated with leaving the variable in question in, rather than using an alternative equation. Therefore, it is the author's opinion the equations are better off used with the variables rather than using the other equation options. So the variables were left in the equations as shown in Table 4.1 for the equations listed in Table 5.1.

Table 5.1 shows the variables used for the 100-year runoff coefficient regression equation, for Region #3, both have P-values greater than the designated α-value of 0.05. This means the statistical significance of this equation does not contain a 95% confidence interval, but rather closer to an 85% confidence interval. The choice to use this equation rather than one with different variables is to maintain continuity for the user throughout the process of predicting all the recurrence year storm events.

Table 5.1: Exceptions to the α-value criterion for choosing the predictor runoff coefficient equations.

Region	Equation	Variable	P-value	Notes/Comments
#1	C_2	$K_{SAT,SURF}$	0.098	No variable produced an equation with $P < 0.05$
#3	C_{50}	MFD	0.059	Estimated flows have smaller standard deviation
#3	C_{100}	FS	0.089	No variable produced an equation with $P < 0.05$
#3	C_{100}	MFD	0.126	Variable used to provide continuity in estimations
#6	C_2	BS	0.074	Estimated flows have smaller standard deviation

In addition to maintaining continuity among the variables within the equations, if different variables are chosen to represent the 100-year runoff coefficient then it is likely the prediction of the 100-year flows can be less than the 50-year (and possibly the 25-year). This provides a significant issue to hydrologists, and therefore it is better to sacrifice the statistical significance of the equation to ensure the flows will be greater for the 100-year event than the 50-year event (in all cases). The user should be aware of this circumstance when using the equations for Region #3.

5.2 Explanatory Variable Input Ranges

Each of the equations presented in Table 4.1 were developed based on specific ranges of data for the explanatory variables used. These ranges, which are shown in Table 5.2, are provided to the user for a more detailed limitation of the developed equations. The ranges shown are only presented for the explanatory variables shown in the equations in Table 4.1, and include the range in area of the gaging station's watersheds.

Table 5.2: Ranges of explanatory variables used in the equations presented in Table 4.1.

Region	*A* (mi^2)	*BS* (ft/ft)	*BL* (ft)	*MFD* (ft)	*FS* (%)	$K_{SAT,SURF}$ (in/hr)	*MAP* (in)	*PREC* (in)
#1	1.3 - 28.5	---	---	---	---	0.97- 68.7	---	---
#2	0.83 - 28.3	---	---	---	11.4 - 68.7	---	---	---
#3	5.7 - 25.0	---	---	27,360 - 95,870	21.4 - 81.3	---	---	---
#4	1.4 - 26.4	0.093 - 0.387	---	---	---	---	---	---
#5	1.9 - 27.8	---	---	---	---	---	---	1.23 - 2.07
#6	0.72 - 27.3	0.031 - 0.426	6,650 - 71,630	---	---	---	6.7 - 33.9	---
#7	4.8 - 29.7	---	---	---	---	1.45 - 5.43	---	---

5.3 Average Predicted Ranges for Developed Equations

The equations presented in Table 4.1 were used to estimate the recurrence year runoff coefficients and predicted flood flows for each gaging station's watershed in the study. The values for the inputted explanatory variables are shown for each of the watersheds in Appendix A. The estimated ranges of predicted values are shown in Table 5.3 for each geohydrologic region in the study area. It should be noted the runoff coefficients are greater than one because of the units associated with the regression coefficient, as shown in Table 5.3. Typically runoff coefficients are between 0 and 1 (Maidment 1993), but that is when the coefficient is a unitless number. To make the coefficients unitless, the runoff coefficients can be divided by 640 acres/mi (since there is 1.008 ft^3/s per one acre-in/hr). The user should compare an estimated flood flow with the values presented in Table 5.3 as a means to determine where the estimated flow ranks within the provided range. This can be used as a check on how well the equations might be predicting the flood flows, and provide the user with a better understanding of the output from the equations for design purposes.

Table 5.3: Average values of prediction determined by equations presented in Table 4.1, with average minimum and maximum values determined by errors of equations.

Storm Event	Predicted Runoff Coefficients [Units are: $(ft^3/s)/(mi^2 \cdot in/hr)$]			Predicted Flood Flows [Units are: ft^3/s]		
	Average Minimum Error Value	Average Predicted Value	Average Maximum Error Value	Average Minimum Error Value	Average Predicted Value	Average Maximum Error Value
Geohydrologic Region #1						
2-year	19	33	56	58	99	172
5-year	28	51	92	108	197	354
10-year	34	66	129	150	293	572
25-year	40	86	188	209	455	995
50-year	42	101	242	256	611	1,459
100-year	45	120	312	310	816	2,130
Geohydrologic Region #2						
2-year	6	13	28	24	51	108
5-year	10	18	34	49	92	172
10-year	11	20	37	69	125	227
25-year	12	22	41	96	174	318
50-year	12	22	42	111	209	395
100-year	11	22	44	129	253	500
200-year	11	23	47	146	304	636
500-year	10	22	50	166	377	855
Geohydrologic Region #3						
2-year	4	12	41	14	47	160
5-year	11	25	54	57	127	280
10-year	16	34	69	104	212	438
25-year	18	40	91	144	328	740
50-year	22	57	148	216	554	1436
100-year	19	56	168	213	646	1943
Geohydrologic Region #4						
2-year	17	32	59	71	135	253
5-year	22	37	62	121	204	343
10-year	23	38	62	156	255	419
25-year	23	38	62	198	325	533
50-year	22	37	62	223	378	635
100-year	20	36	63	248	434	764

Table 5.3: Continued.

Storm Event	Predicted Runoff Coefficients [Units are: $(ft^3/s)/(mi^2 \cdot in/hr)$]			Predicted Flood Flows [Units are: ft^3/s]		
	Average Minimum Error Value	Average Predicted Value	Average Maximum Error Value	Average Minimum Error Value	Average Predicted Value	Average Maximum Error Value
Geohydrologic Region #5						
2-year	7	15	33	34	73	159
5-year	13	27	57	78	166	351
10-year	17	35	76	121	257	552
25-year	20	46	104	185	420	946
50-year	23	54	127	241	573	1,352
100-year	25	62	153	308	769	1,915
200-year	26	68	180	377	992	2,620
500-year	28	79	226	489	1,397	4,024
Geohydrologic Region #6						
2-year	33	86	224	78	206	539
5-year	81	188	439	231	537	1,256
10-year	117	271	632	381	886	2,065
25-year	156	380	927	602	1,468	3,582
50-year	194	496	1,275	848	2,175	5,590
100-year	211	570	1,562	1,040	2,812	7,705
Geohydrologic Region #7						
2-year	12	21	39	55	100	181
5-year	32	62	118	174	335	639
10-year	50	103	214	307	641	1,326
25-year	75	176	404	559	1,300	2,990
50-year	96	239	595	810	2,025	5,043
100-year	117	317	853	1,140	3,082	8,291
200-year	141	402	1,166	1,567	4,477	12,984
500-year	163	524	1,667	2,171	7,002	22,266

6 CASE STUDY COMPARISON

The equations developed in Table 4.1 are intended to be used on small watersheds between 0.5 to 30 mi^2, whereas the equations from Kenney et al. (2008) are better suited for larger sized watersheds. Comparing the predicted flood flows between the developed equations shown in Table 4.1 and those of Kenney et al. (2008) provides a more objective evaluation of the usefulness of both sets of equations. This analysis is provided in the sections below.

6.1 Description and Reason Behind Analysis

Regression equations are frequently used by engineers as a quick way to produce a desired quantity in the process of design. However, regression equations are also sometimes used "outside" the limits of the equations for design purposes. Because of this, it was determined that a comparison between Kenney et al. (2008) and the equations of Table 4.1, for watersheds less than 30 mi^2 and from 30 to 50 mi^2 would show the usefulness of each type of equation and provide suggestions for which equations are better suited for use in each geohydrologic region (shown in Figure 1.1). (It should be noted that the equations developed by Kenney et al. (2008) are also divided by the same geohydrologic regions for equations in Table 4.1).

When evaluating the prediction accuracy of the peak flows obtained by using equations from Table 4.1, it is best to use watersheds that are within the same guidelines (i.e., less than 30 mi^2 with 10 years of recorded stream gage data) used to produce the equations, while also having streamflow data to compare results against. However, there was a restriction on the number of watersheds that were available when developing the equations, so all watersheds that could be used were. Because of this, it was determined that the watersheds should be chosen at random from each geohydrologic region, and that the number of watersheds in the analysis would be 20% of those used to derive the equations of Table 4.1. The gage stations were chosen at random for the analysis, and the necessary data pertaining to the equations of Table 4.1 and Kenney et al. (2008) was gathered for computation purposes. These data are shown in Appendix E.

For the analysis comparison of watersheds between 30 and 50 mi^2, the same processes were used to gather the basin data, hydrologic data, and soil data as detailed in section 3. It was also decided to use the same number of watersheds per geohydrologic region as the analysis for watersheds less than 30 mi^2 if possible. However, in Region #2 there were only 4 watersheds instead of 6 and Region #5 only had 1 watershed instead of 4. This was due to the lack of gage station data (no less than 10 years of peak flow data) for the watershed size range. Also, for each of these gage stations, a flood frequency analysis was conducted to provide a basis for comparison between Kenney et al. (2008) and equations of Table 4.1. A summary of these collected data are shown in Appendix E. The selected USGS gage station locations for this analysis are shown in Figure 6.1 for spatial reference.

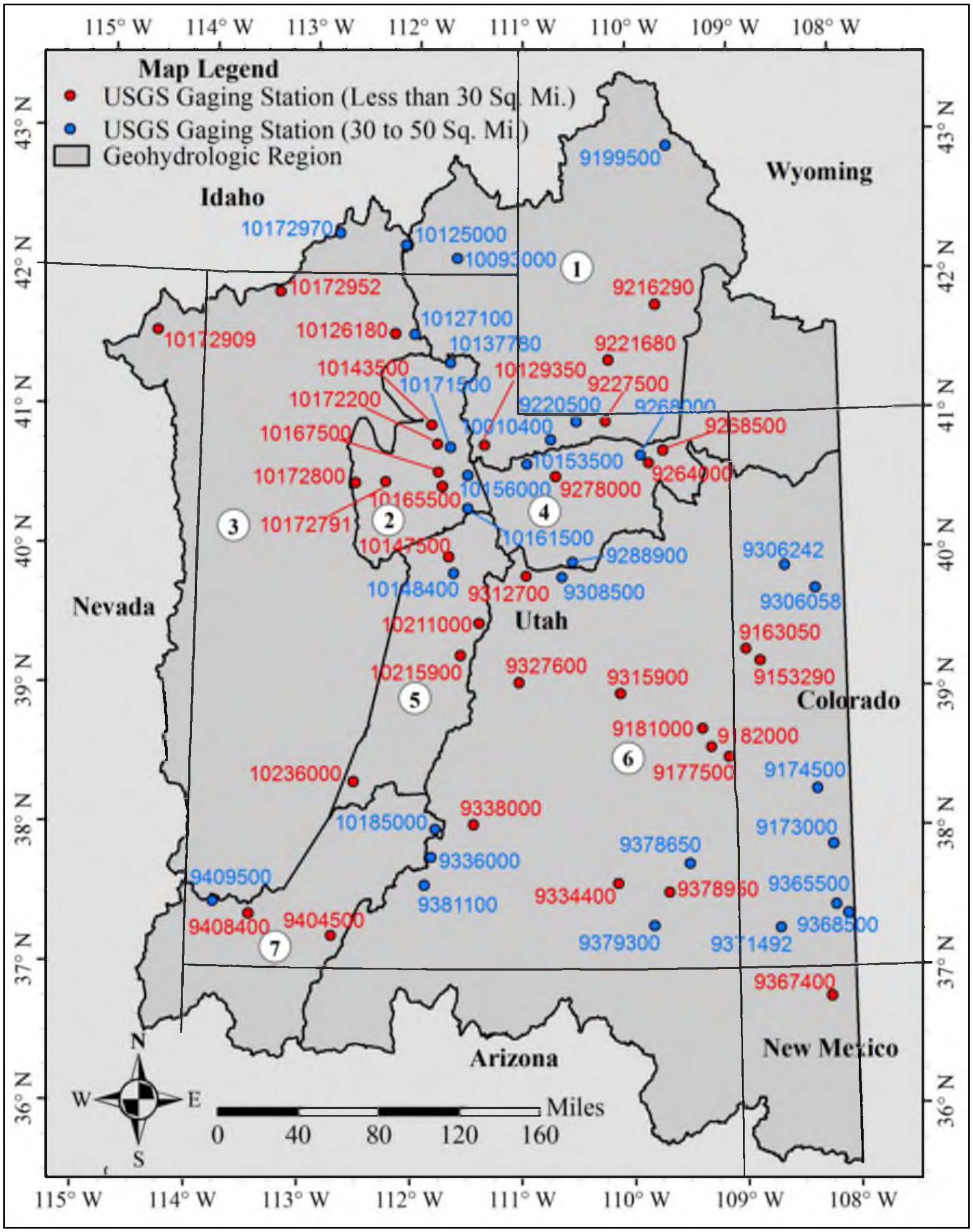

Figure 6.1: Selected USGS gaging stations for analysis per geohydrologic region. The gage station in red are for the analysis comparison of watersheds less than 30 mi^2, where the blue stations are for watersheds between 30 and 50 mi^2.

6.2 Equation Comparison for Watersheds Less than 30 mi^2

For each selected gage station, the recurrence year flood flows were predicted by a flood frequency analysis, equations from Kenney et al. (2008), and from Table 4.1. The predicted flood flows computed by equations from Kenney et al. (2008) and equations from Table 4.1 were compared to the flood flows from the flood frequency analysis. This was done by figuring a percent difference in the flood flows for each recurrence year. The average percent difference per recurrence year was calculated along with an overall average percent difference of all recurrence year results. However, looking at straight averages does not provide proper insight to the "accuracy" of prediction for the equations, because the range of percent difference might be from -50% to +100%, which could give an average difference around 40%. Because of this, the average of the absolute value of the percent differences was calculated. This provides a different picture of how far off the equations predict from the targeted value (the flood frequency analysis in this case). The results are summarized in Table 6.1, where the more detailed numbers per station ID are shown in Appendix E.

6.3 Results of Comparison of Equations

The results in Table 6.1 show which equations best match the flood flows predicted by the flood frequency analyses. It is interesting to observe the differences between the values produced by "averaging the percent differences" and "averaging the absolute value of percent differences." For each region, the average that produces the closest value to a zero percent difference was bolded as a means to visually represent which set of equations offer the more accurate prediction of flood flows. In all but two instances, the values for the same set of equations are bolded regardless which average is

Table 6.1: Summary of the equation prediction accuracy comparison between Kenney et al. (2008) and equations of Table 4.1. Comparison is done by averages of percent differences.

Storm Event	Watershed Sizes Less than 30 mi²				Watershed Sizes between 30 and 50 mi²			
	Average of Percent Differences (%)		*Average of Absolute Value of Percent Differences (%)*		*Average of Percent Differences (%)*		*Average of Absolute Value of Percent Differences (%)*	
	Kenney et al. (2008)	Table 4.1 Equations	Kenney et al. (2008)	Table 4.1 Equations	Kenney et al. (2008)	Table 4.1 Equations	Kenney et al. (2008)	Table 4.1 Equations
Region #1	**Averages Based on 4 Watersheds**				**Averages Based on 4 Watersheds**			
2-year	37.2	8.0	56.5	21.6	-21.2	-75.6	21.8	75.6
5-year	30.2	24.2	68.4	33.5	-11.0	-59.7	20.5	59.7
10-year	18.8	38.0	71.9	51.3	-11.7	-45.1	22.7	45.1
25-year	16.7	55.5	80.8	75.2	-4.9	-22.6	27.4	43.9
50-year	18.3	67.9	88.4	91.3	2.0	-2.9	31.6	44.0
100-year	16.3	84.1	91.7	110.1	6.1	22.0	34.5	51.4
Averages	**22.9**	46.3	76.3	**63.8**	**-6.8**	-30.7	**26.4**	53.3
Region #2	**Averages Based on 6 Watersheds**				**Averages Based on 4 Watersheds**			
2-year	22.8	55.1	70.5	105.2	-29.3	20.2	33.9	66.6
5-year	37.4	41.3	71.1	85.8	-9.6	42.3	25.6	76.1
10-year	4.2	36.1	45.9	77.3	-19.7	54.2	24.5	84.8
25-year	7.8	32.9	41.9	69.9	-10.1	69.7	26.8	95.9
50-year	10.1	27.8	40.5	62.7	-3.7	74.5	28.1	98.2
100-year	12.2	26.5	39.1	58.5	2.5	83.5	29.1	104.1
200-year	-3.4	27.0	27.4	55.7	-3.6	95.9	31.6	112.9
500-year	-16.3	26.7	27.9	51.2	-10.1	110.7	36.9	123.1
Averages	**9.4**	34.2	**45.6**	70.8	**-10.4**	68.9	**29.6**	95.2
Region #3	**Averages Based on 3 Watersheds**				**Averages Based on 3 Watersheds**			
2-year	897.4	72.2	971.2	178.6	-53.5	-80.6	53.5	80.6
5-year	360.6	-4.4	393.2	76.9	-29.7	-66.9	52.9	66.9
10-year	208.5	-19.7	223.3	37.1	-8.9	-56.3	59.3	62.4
25-year	123.0	26.8	123.0	26.8	20.8	-10.2	76.9	77.8
50-year	103.6	32.9	103.6	39.9	45.6	-1.7	103.5	81.2
100-year	103.7	47.6	103.7	78.2	71.3	3.7	130.9	81.8
Averages	299.4	**25.9**	319.7	**72.9**	**7.6**	-35.3	79.5	**75.1**
Region #4	**Averages Based on 3 Watersheds**				**Averages Based on 3 Watersheds**			
2-year	68.4	20.0	68.4	20.0	23.4	33.1	31.7	77.3
5-year	63.7	28.0	63.7	28.0	8.2	-3.8	17.1	30.8
10-year	108.6	34.4	108.6	34.4	30.9	-13.9	41.1	13.9
25-year	63.1	43.9	63.1	43.9	-0.6	-20.3	30.9	20.3
50-year	62.1	50.6	62.1	50.6	-3.6	-22.9	33.6	24.2
100-year	70.1	57.5	70.1	57.5	-0.5	-23.7	38.0	29.2
Averages	72.7	**39.1**	72.7	**39.1**	**9.6**	-8.6	**32.1**	32.6

Table 6.1: Continued.

Storm Event	Watershed Sizes Less than 30 mi²				Watershed Sizes between 30 and 50 mi²			
	Average of Percent Differences (%)		*Average of Absolute Value of Percent Differences (%)*		*Average of Percent Differences (%)*		*Average of Absolute Value of Percent Differences (%)*	
	Kenney et al. (2008)	Table 4.1 Equations	Kenney et al. (2008)	Table 4.1 Equations	Kenney et al. (2008)	Table 4.1 Equations	Kenney et al. (2008)	Table 4.1 Equations
Region #5	**Averages Based on 4 Watersheds**				**Averages Based on 1 Watershed**			
2-year	-14.0	-19.0	16.5	43.5	127.9	56.4	127.9	56.4
5-year	-7.3	-4.2	16.4	31.1	105.6	84.2	105.6	84.2
10-year	-7.4	6.4	18.3	25.1	86.4	98.4	86.4	98.4
25-year	-8.5	23.1	20.5	34.9	65.3	120.5	65.3	120.5
50-year	-6.3	34.4	20.9	46.0	58.3	132.6	58.3	132.6
100-year	-7.1	48.5	22.1	59.8	45.1	146.3	45.1	146.3
200-year	-5.4	60.5	22.5	72.4	37.7	155.8	37.7	155.8
500-year	-1.7	83.6	24.9	95.6	30.2	174.8	30.2	174.8
Averages	**-7.2**	29.2	**20.3**	51.1	**69.6**	121.1	**69.6**	121.1
Region #6	**Averages Based on 12 Watersheds**				**Averages Based on 12 Watersheds**			
2-year	55.7	48.8	109.3	102.4	211.7	399.1	277.4	440.7
5-year	114.8	82.3	162.7	123.0	181.2	254.8	240.5	303.2
10-year	154.7	108.4	198.0	144.6	160.3	190.0	217.8	243.6
25-year	215.4	136.8	250.7	172.0	144.8	120.5	199.2	184.0
50-year	262.8	176.6	296.4	207.8	134.8	97.4	186.6	163.5
100-year	319.3	191.3	352.4	223.4	135.0	60.8	181.6	133.8
Averages	187.1	**124.0**	228.3	**162.2**	**161.3**	187.1	**217.2**	244.8
Region #7	**Averages Based on 2 Watersheds**				**Averages Based on 2 Watersheds**			
2-year	2.2	63.8	69.5	104.9	-8.4	-41.3	8.5	41.3
5-year	17.1	122.2	97.8	168.1	1.2	-51.2	44.6	51.2
10-year	26.4	157.7	111.0	204.6	16.0	-54.5	70.3	54.5
25-year	35.5	202.9	122.9	248.8	41.9	-55.6	105.9	55.6
50-year	40.5	228.1	129.3	273.5	66.6	-55.3	135.9	55.3
100-year	44.7	256.4	134.4	299.2	96.9	-53.3	170.3	53.3
200-year	47.8	280.5	138.2	321.1	131.3	-50.3	208.1	50.3
500-year	50.4	305.9	141.5	343.7	185.8	-43.9	266.3	43.9
Averages	**33.1**	202.2	**118.1**	245.5	**66.4**	-50.7	126.2	**50.7**

considered. The cases where they differ are in Region #1 for watersheds less than 30 mi^2, and in Region #7 for watersheds between 30 and 50 mi^2. Also for both of these cases, the equations of Table 4.1 more closely predict the flood flows of the flood frequency analysis because there is less variation in the percent difference errors than that of Kenney et al. (2008).

For the watershed sizes less than 30 mi^2, the equations produced by Kenney et al. (2008) better predict flood flows for the geohydrologic regions 2, 5, and 7, whereas the equations shown in Table 4.1 provide better estimates for geohydrologic regions 1, 3, 4, and 6. For the watershed sizes between 30 and 50 mi^2, the equations produced by Kenney et al. (2008) better predict flood flows for all geohydrologic regions, except region 7. However, the equations of Kenney et al. (2008) closely match the differences computed using equations of Table 4.1 for Region #7. These results are better quantified in Table 6.2, which shows a recommendation for which equations to use in each region based on results of Table 6.1.

Table 6.2: Recommended set of equations to mitigate error of predicted flood flows for the different geohydrologic regions.

	Less Than 30 mi^2		***Between 30 to 50 mi^2***	
Geohydrologic Region	**Table 4.1 Equations**	**Kenney et al. (2008)**	**Table 4.1 Equations**	**Kenney et al. (2008)**
#1	X			X
#2		X		X
#3	X			X
#4	X			X
#5		X		X
#6	X			X
#7		X		X

In further evaluating the results, it is interesting to note the equations for Kenney et al. (2008) are better suited to use in all regions than those from Table 4.1 for watersheds between 30 and 50 mi^2 (and likely better for watersheds greater than 50 mi^2). Also, for the watersheds less than 30 mi^2, the equations from Kenney et al. (2008) better predict flood flows for watersheds inside the regions containing Interstate-15, which happens to house the majority of population in the state of Utah. Also, these ranges are comprised of very mountainous landscape that often times contain a lot of snow pack. This leaves the equations of Table 4.1 better suited for the other regions of Utah that have a more barren desert landscape and lower average elevations.

7 CONCLUSIONS AND RECOMMENDATIONS

Developing regression equations to predict recurrence year flood flows is by no means an exact science and often involves a substantial amount of error in the equation predictions. The equations developed and presented in this document contain errors that are consistent with the results presented by Kenney et al. (2008), Perica and Stayner (2004), and McEnroe et al. (2007), which range from ~ -50% to +200%, so accurate predictions are not likely to be acquired. However, using them to approximate flows through ungaged rural streams and washes provides useful information for design of roadway crossings as a way to obtain “ball-park” estimations. Since many engineers are familiar with the rational method, the regression equations developed in this document coincide with methods they are accustomed to for determining peak runoff flows.

One method that may provide better equations than developed in this analysis, and that might create an interesting future study, is the use of a more modern flood frequency analysis than the Bulletin 17B guidelines. This more recent method is a regional frequency analysis, which is a method based on L-moments and associates each gage station’s peak runoff data with similar climate locations and characteristics throughout the region. By doing this, gages with more years of record would be used to better predict recurrence year flood flows of smaller years of record. Doing this would be very useful in this analysis, since many of the streamflow gages have fewer than 20 years of peak flow data.

A similar study in the future would have the advantage of using more USGS stream gage stations than were available for this study, since more data will be collected as the years pass. There were a large number of stations that were not used in this analysis because the records were fewer than 10 years of peak flow data. Within the next 5 years, some of these stations may fit the criteria used to select the gaging stations (which was a minimum of 10 years of record). An increase in the gaging stations used in the analysis provides more coverage of the state, which will likely refine the correlations between the predicted flood frequency flows and the explanatory variables.

Even though the developed regression equations might be improved in the future, the equations presented in this study will provide recurrence year flood flow estimations within errors shown in similar reports. However, the equations should be used with caution and common sense. The user should determine the level of accuracy desired for the estimation and decide if the equations developed should be used. It is the author's suggestion that these equations should be used as an approximation for recurrence peak flows within the study region, and in many design situations, a more detailed analysis should be conducted for comparison purposes.

8 APPLICATION OF THE DEVELOPED EQUATIONS

8.1 Step-By-Step Procedure

The rational style regression equations presented in Table 4.1 should be used to estimate recurrence year flood flows for rural streams with drainage areas less than 30 mi^2 in Utah. Estimates can be made for the 2-year through 100-year events, and in some regions up to the 500-year events. The step-by-step process the user should follow to make these estimates is outlined below:

1. Obtain 10 m DEM data from the USGS Seamless Server for a region large enough to encompass the local watershed. (http://seamless.usgs.gov/index.php).
2. Import DEM data into WMS and delineate the watershed using a selected outlet point (usually the location of a culvert or any point of interest). Note: different programs are available that can delineate watersheds and provide the necessary variables discussed in Table 3.3, but the user should make sure the output variables are defined the same way as WMS (as presented in Table 3.2).
3. Identify the geohydrologic region the delineated watershed is located within using Figure 1.1. Consult Tables 4.1 and 5.1 for required input variables to regression equations for desired recurrence year calculations. Consult Table 3.3 for identification of the dataset used to determine the needed predictor variables. A list of internet locations that provide these data are shown below. The user should follow the processes outlined in sections 3.3.1 through 3.3.6 for specific details on

how to determine each of the specific parameters needed, a summary for each is presented in Step 4.

a. For LULC Data: http://www.webgis.com/lulcdata.html.

b. For STATSGO Data: http://soildatamart.nrcs.usda.gov/USDGSM.aspx (A statewide mapping of K_{SAT} variables is available through UDOT to eliminate processing of data).

c. For PRISM Data: http://prismmap.nacse.org/nn/

d. For NOAA's Atlas Data: Atlas 14 http://hdsc.nws.noaa.gov/hdsc/pfds/ Atlas 2 http://hydrology.nws.noaa.gov/oh/hdsc/noaaatlas2.htm.

4. To determine the specific parameters needed for input to the regression equations, the user should follow the following processes:

a. The "basin geometric parameters" can be obtained directly after the delineation of the watershed in WMS. Select the watershed and consult the properties box for the values, or save the delineated watershed as an Arc GIS shapefile and view the table using Arc MAP or Arc Catalog.

b. The composite curve number can be calculated directly in WMS using coverages or GIS layers in conjunction with curve number values shown in Appendix A. It is recommended that the curve number values in Appendix A be used since the regression equations were developed using those values. For further information on this process go to WMS Help Online (http://www.ems-i.com/wmshelp/Hydrologic_Models/Calculators/Composite_Runoff_Coefficients/Selecting_the_Method.htm). This is also achievable by overlaying the LULC and STATSGO data sets in *ArcGIS*.

c. Saturated hydraulic conductivity, K_{SAT}, should be computed by overlaying the STATSGO data on the delineated watershed in *ArcGIS*, which will provide the areas of the watershed that are comprised of different K_{SAT} values. Then an area weighting technique should be applied to determine the appropriate value to use, which can be done using Excel or other similar software.

d. Mean Annual Precipitation for the centroid is determined by inputting the watershed centroid location (in latitude and longitude coordinates) into the PRISM Data Explorer. The centroid coordinates are computed by the delineation of the watershed, and can be accessed as described in Step 4a (they will likely need to be converted into latitude and longitude coordinates).

e. 2-year, 24-hour precipitation for the centroid is determined by inputting the watershed centroid location (in latitude and longitude coordinates) into NOAA's Atlas 14 or Atlas 2. See Step 4d for obtaining centroid location.

f. The rainfall intensity is calculated using traditional rational method procedures. The only difference in this methodology is the computation of the time of concentration. Time of concentration can be calculated using the following equation, which is the same as equation 3.1:

$$t_C = 2.4A^{0.1}L^{0.25}L_{CA}^{0.25}S^{-0.2} \qquad \textit{(Eq. 8.1)}$$

or by WMS by choosing the "ADOT Method [Desert/Mountain]" option in the basin data module (linked to HEC-HMS module). After the time of concentration is determined, the rainfall intensity is obtained by entering the intensity duration frequency (IDF) table obtained from NOAA Atlas 14 or Atlas 2 (as described in Step 4e).

5. Apply values for the determined parameters to equations identified in Step 3, from Table 4.1. Noting that the equations in Table 4.1 only calculate the runoff coefficient for the rational style equations, so to obtain the estimated recurrence year flow it is necessary to use equation 8.2, as reproduced from equation 4.5.

$$Q_X = C_X i_X A \qquad \textit{(Eq. 8.2)}$$

6. The user should compare the predicted flood flow with the prediction ranges presented in Table 5.3. Then engineering judgment should be used to determine if the estimation makes sense from a design perspective.

8.2 Example Problem

8.2.1 Problem Statement

A road crossing an ephemeral rural wash is to be constructed to provide access to a camping ground 25 mi northeast of Moab, Utah. The crossing occurs at the coordinates of 38.798 north latitude and 109.207 west longitude. The road crossing should be designed to convey the 50-year peak flow discharge. Estimate the peak flow discharge using the rational style equations in Table 4.1. The delineation of the watershed is shown in Figure 8.1, which also provides the details on the relative location of the site.

8.2.2 Solution

1. A 10 m DEM was obtained from the USGS Seamless Server in GRIDFLOAT file format, which is used with WMS. The DEM was imported into WMS and converted to UTM, NAD83, Zone 12 North coordinates.

2. The outlet location was selected at the coordinates provided in the problem statement, where the river crossing occurs.
3. The location of the delineated basin resides in geohydrologic Region #6, identified using Figure 1.1. The regression equation to be used in this problem is obtained from Table 4.1. This is shown below for identification of which predictor variables need to be determined. Also, the rational style equation has been written as a combination of equation 8.2 and the 50-year regression runoff coefficient regression equation.

$$Q_{50} = C_{50} i_{50} A = 10^{10.72} MAP^{-2.70} BL^{-1.07} BS^{0.59} (i_{50} A) \qquad \text{(From Table 4.1)}$$

Therefore, the parameters that need to be determined are: MAP, BL, BS, i_{50}, and A.

4. WMS automatically computes the "basin geometric parameters." From WMS, the following values were obtained for these predictor variables:

Area, $A = 11.522$ mi^2

Basin Length, $BL = 31{,}481.2$ ft

Basin Slope, $BS = 0.27549$ ft/ft

The rain intensity, i_{50}, was then calculated using the following steps:

a. The time of concentration was calculated by using one of two methods: (1) WMS and (2) equation 8.1 (which is also equation 3.1). Both methods are shown below, but only one is necessary.

(1) WMS provided the time of concentration for this watershed as: t_c = 2.26 hrs.

(2) For equation 8.1, the necessary parameters were provided from the delineation of the watershed, which are presented below:

Figure 8.1: Watershed delineation and for example problem located 25 mi northeast of Moab, UT.

$$t_C = 2.4A^{0.1}L^{0.25}L_{CA}^{0.25}S^{-0.2} \quad \textit{(Eq. 8.1)}$$

Where,

$A = 11.522$ mi^2

$L = 7.955$ mi

$L_{CA} = 4.216$ mi

$S = 370.1$ft/mi

Therefore,

$t_C = 2.4(11.522)^{0.1}(7.955)^{0.25}(4.216)^{0.25}(370.1)^{-0.2} = t_C = 2.56$ hrs

b. With the time of concentration computed for the watershed, the centroid location is then obtained from the watershed. The basin delineation from WMS provided the centroid in the "x" and "y" directions (which was in meters since the chosen projected coordinates were UTM Zone 12 North). Using *ArcGIS*, the following were reported for the centroid location:

Centroid: Latitude = 38.752767 Longitude = -109.232206

The centroid latitude and longitude were then used to obtain an intensity duration frequency table from NOAA Atlas 14. Some of the values reported for this location are reproduced in Table 8.1.

c. Since the time of concentration value was between 2 and 3 hrs, linear interpolation was used to obtain the rainfall intensity. The values shown in bold print in Table 8.1 are the lower and upper bound limits that were used in the interpolation. Since the 50-year peak flow was desired, the 50-year rain intensity was calculated. This interpolation calculation is shown below:

Table 8.1: Rainfall intensity values obtained from NOAA Atlas 14 for centroid of delineated watershed. The values presented in bold were used with the linear interpolation procedure.

Recurrence Year	1-hr (in/hr)	2-hr (in/hr)	3-hr (in/hr)	6-hr (in/hr)	12-hr (in/hr)	24-hr (in/hr)
1	0.36	0.22	0.16	0.10	0.06	0.04
2	0.46	0.27	0.20	0.13	0.08	0.05
5	0.63	0.37	0.26	0.16	0.10	0.06
10	0.78	0.45	0.32	0.19	0.11	0.07
25	1.02	0.59	0.41	0.23	0.14	0.09
50	1.24	**0.72**	**0.46**	0.27	0.16	0.10
100	1.49	0.87	0.59	0.32	0.18	0.11

$$i_{50} = \frac{2.26\,hrs - 2.0\,hrs}{3.0\,hrs - 2.0\,hrs}\left(0.49\frac{in}{hr} - 0.72\frac{in}{hr}\right) + 0.72\frac{in}{hr} \Rightarrow \qquad i_{50} = 0.652\frac{in}{hr}$$

d. The final variable to be determined was the mean annual precipitation (MAP). This was done by entering the centroid of the watershed (in latitude and longitude) into PRISM's Gridded Data Explorer. By doing this, the following value was reported for this location:

$$MAP = 12.62 \text{ in.}$$

5. Now that all the needed values are determined, they are implemented into the predictor equation from Table 4.1. This computation is shown below:

$$Q_{50} = 10^{10.72}(12.62\,in)^{-2.70}(31{,}481.2\,ft)^{-1.07}\left(0.27549\frac{ft}{ft}\right)^{0.59}\left(0.652\frac{in}{hr}\right)(11.522\,mi^2)$$
$$Q_{50} = 3{,}018\,cfs$$

6. From Table 5.3 the applicable range of values for the 50-year flood flow are between 848 and 5,590 cfs, with an average value of 2,175 cfs. The estimated flow is 3,018 cfs, which is between the average and upper average error value for this equation. Because of this, the computed value might be conservative and

would be appropriate for preliminary design. For comparison purposes, a watershed analysis could be performed using software, such as Hec-HMS, as a means for verification or refined design.

8.3 Addendum to Example Problem

The example problem in section 8.2 does not provide an example of how to compute the area weighted saturated hydraulic conductivity for the watershed. Since this is a variable that is contained in the equations developed for geohydrologic Regions #1 and #7, it is worthwhile to show the steps to compute this value. For simplicity purposes, the watershed used in section 8.2 will be used for this additional step (even though this is not necessary for Region #6).

The saturated hydraulic conductivity for the surface layer of the soil, $K_{SAT,SURF}$ was obtained by performing an overlay of the watershed polygon onto the STATSGO soil data for Utah in *ArcGIS*. From the overlay, there were four intersecting polygons from the STATSGO data with the delineated watershed. Area was computed for each of these soil sections within the watershed, and recorded in tabular form shown in Table 8.2.

From the computations in Table 8.2, the weighted average $K_{SAT,SURF}$ value was calculated using equation 8.3:

$$K_{SAT,SURF} = \frac{\sum \left(K_{SAT,SURF} \cdot A\right)_i}{\sum A_i} \qquad \textit{(Eq. 8.3)}$$

Therefore,

$$K_{SAT,SURF} = \frac{50.76}{11.522} \Rightarrow \qquad K_{SAT,SURF} = 4.405 \frac{in}{hr}$$

8.4 Different Processes to Computing Geometric Characteristics

The geometric characteristics for this project were determined using the WMS software. Many practicing engineers likely do not have access (or the money) for WMS, so the objective of these equations was to ensure that the common engineer would be able to obtain all the variables needed for the equations. All of the geometric characteristic variables can be determined manually from a topography map (or similar material), as well as using the WMS and StreamStats (created by USGS) softwares. ArcHydro is another software that can be used to delineate watersheds and obtain these geometric characteristic variables; however, the author has not been able to determine if the FS (flow south) parameter can be determined using ArcHydro. Table 8.3 shows the different methods that can be used to obtain the various basin geometric characteristics used in the equations of Table 4.1.

Table 8.2: Weighted average computation for $K_{SAT,SURF}$.

Watershed Soil Section	$K_{SAT,SURF}$ (in/hr)	Area (mi^2)	$K_{SAT} \cdot A$ (in-mi^2/hr)
1	4.00	7.266	29.07
2	10.46	0.636	6.66
3	11.00	0.078	0.86
4	4.00	3.542	14.17
	Σ =	11.522	50.76

Table 8.3: Different Methods Available to Compute the Basin Geometric Characteristics

Geometric Characteristic	Manually	WMS	ArcHydro	StreamStats
A	x	x	x	x
BS	x	x	x	x
BL	x	x	x	x
MFD	x	x	x	x
FS	x	x	?	x
Centroid	x	x	x	x

APPENDIX A: COMPUTED AND GATHERED DATA

Table A.1: Peak flows at selected streamflow gaging stations in the geohydrologic regions within the study area. Spaces containing "ND" indicates not determined values due to errors in flood frequency analysis.

Map Unit ID	Gage Station Number	Peak Flow Flood Frequency Analyses, for Recurrence Year								
		2 Year (cfs)	5 Year (cfs)	10 Year (cfs)	25 Year (cfs)	50 Year (cfs)	100 Year (cfs)	200 Year (cfs)	500 Year (cfs)	Number of Annual Peak Flows
Geohydrologic Region #1										
1	10090800	45	96	138	198	247	299	354	431	19
2	10069000	51	69	82	100	114	129	145	167	17
3	10099000	214	335	418	524	603	682	761	865	22
4	10102300	147	212	252	300	334	366	397	436	18
5	9208000	131	164	183	204	218	231	242	257	33
[1]6	9204700	10	27	46	77	108	145	190	260	18
[2]7	10019700	45	84	116	163	202	245	291	358	17
[5]8	9214000	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	10130000	122	236	326	454	558	668	783	945	14
10	10129350	90	123	143	167	184	201	217	237	10
11	10128200	197	226	242	261	273	284	295	308	10
12	9216290	142	305	477	798	1,140	1,580	2,170	3,230	16
[5]13	10011200	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	9221680	55	188	367	763	1,240	1,920	2,890	4,790	20
[5]15	9224600	101	191	279	432	583	774	1,010	1,420	9
[1]16	9224800	23	88	182	404	681	1,100	1,700	2,930	18
[4]17	9216350	15	45	93	222	412	745	1,320	2,770	11
[3]18	9224810	17	64	128	274	451	708	1,080	1,790	17
[1]19	9224820	18	68	142	320	547	893	1,410	2,470	20
[1]20	9224840	11	23	36	58	79	106	139	194	17
21	9227500	163	251	321	422	508	604	710	868	14
22	9226500	308	487	622	810	963	1,130	1,300	1,550	22
23	9225200	103	229	351	560	759	1,000	1,300	1,780	20
[4]24	9229450	22	96	210	491	859	1,430	2,290	4,080	10
[1,2]25	9225300	214	971	2,070	4,530	7,410	11,400	16,900	26,900	21

Table A.1: Continued.

Map Unit ID	Gage Station Number	Peak Flow Flood Frequency Analyses, for Recurrence Year: 2 Year (cfs)	5 Year (cfs)	10 Year (cfs)	25 Year (cfs)	50 Year (cfs)	100 Year (cfs)	200 Year (cfs)	500 Year (cfs)	Number of Annual Peak Flows
					Geohydrologic Region #2					
26	10137680	91	120	138	160	176	191	206	226	11
27	10141400	175	231	265	303	329	354	377	406	13
28	10139300	104	224	330	492	632	789	962	1,220	37
[4]29	10172810	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	10141500	18	31	41	55	67	79	91	109	17
31	10172805	26	54	80	123	163	210	265	353	13
32	10172800	32	56	75	102	124	147	172	208	48
33	10142000	154	247	315	407	479	553	631	739	34
34	10142500	19	40	58	87	114	144	178	230	17
35	10143000	14	23	30	38	44	50	56	63	19
36	10143500	14	26	36	50	63	78	94	118	40
37	10145126	27	49	68	96	121	148	179	226	36
38	10144000	25	72	131	256	402	611	907	1,480	16
39	10135000	246	364	436	518	574	626	674	733	29
40	10145000	42	77	105	143	175	208	244	294	19
[1]41	10172760	13	40	71	129	189	264	357	513	14
42	10172791	18	41	62	94	123	155	191	244	10
43	10172765	16	30	40	55	68	82	96	117	17
44	10172500	64	96	118	146	167	188	209	236	70
[4]45	10172790	21	63	108	188	265	359	471	648	11
46	10172200	15	32	48	72	95	120	150	196	45
47	10172000	25	46	63	89	111	137	166	210	57
48	10170000	50	75	91	113	129	146	162	184	63
[4]49	10172720	ND	ND	ND	ND	ND	ND	ND	ND	ND
50	10166430	31	86	154	295	458	689	1,010	1,640	33
51	10167500	387	512	595	699	776	853	930	1,030	51
52	10133700	10	15	18	23	26	30	33	39	13
53	10133600	64	107	138	180	212	245	279	326	12
54	10165500	201	279	332	401	453	507	561	636	23
55	10172700	21	69	136	289	481	770	1,200	2,080	49
56	10160000	61	88	104	123	137	150	162	178	11
57	10160800	106	148	176	212	240	267	296	334	10
					Geohydrologic Region #3					
58	10172909	1	8	24	86	204	457	980	2,540	21
59	10172920	3	17	42	119	244	475	893	1,970	10

Table A.1: Continued.

Map Unit ID	Gage Station Number	Peak Flow Flood Frequency Analyses, for Recurrence Year 2 Year (cfs)	5 Year (cfs)	10 Year (cfs)	25 Year (cfs)	50 Year (cfs)	100 Year (cfs)	200 Year (cfs)	500 Year (cfs)	Number of Annual Peak Flows
Geohydrologic Region #3 (continued)										
60	13077700	68	108	142	195	242	298	363	466	30
61	13079000	114	180	234	313	381	457	542	671	28
62	10172913	10	92	270	796	1,550	2,740	4,550	8,190	18
63	10172952	45	78	105	144	177	213	253	312	32
[4]64	10172925	8	129	520	2,170	5,260	11,400	22,900	51,700	12
65	10122500	64	109	146	202	250	304	365	457	23
[4]66	10172902	3	237	1,580	9,290	25,700	59,200	119,000	256,000	18
67	10126180	175	235	273	320	355	389	423	467	15
68	10172900	71	376	837	1,860	3,040	4,640	6,730	10,400	15
[4]69	10172905	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]70	10172835	0	1	3	12	29	62	120	265	12
71	10172870	44	83	112	152	183	215	249	294	43
[4]72	10172830	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]73	10172885	3	148	992	6,890	22,900	65,500	167,000	499,000	12
74	10243260	24	49	72	111	148	192	245	330	19
75	10243240	75	137	187	258	317	381	449	547	28
76	10242460	21	121	273	607	979	1,470	2,090	3,120	18
77	10242440	147	395	668	1,180	1,700	2,380	3,230	4,710	11
Geohydrologic Region #4										
78	9216600	90	185	282	459	641	877	1,180	1,720	22
79	9216900	12	24	34	49	62	77	93	116	24
80	9235600	62	126	182	271	351	444	549	712	35
81	9264000	433	561	638	726	787	844	898	967	11
82	9264500	313	414	474	543	592	637	681	735	12
83	9268500	76	116	143	178	204	231	258	294	44
84	9268900	187	281	342	419	475	529	583	654	29
85	9269000	129	191	229	272	302	329	355	386	18
86	9273500	75	108	129	154	172	190	206	227	19
87	9276000	50	73	88	107	121	134	148	165	38
88	9278000	93	138	167	202	227	252	275	305	38
89	9280400	69	102	124	150	169	188	207	231	21
90	9287500	28	60	91	143	194	256	331	454	26
91	9298000	88	174	239	327	395	463	532	623	31
[7]92	10153500	503	632	710	802	866	928	988	1,060	20
93	10153800	395	546	639	749	826	899	970	1,060	33
94	10154000	178	203	218	236	248	259	270	284	10

Table A.1: Continued.

Map Unit ID	Gage Station Number	Peak Flow Flood Frequency Analyses, for Recurrence Year: 2 Year (cfs)	5 Year (cfs)	10 Year (cfs)	25 Year (cfs)	50 Year (cfs)	100 Year (cfs)	200 Year (cfs)	500 Year (cfs)	Number of Annual Peak Flows
Geohydrologic Region #5										
[1]95	10146900	181	712	1,380	2,690	4,060	5,790	7,920	11,400	12
96	10147500	140	259	350	476	577	683	793	946	15
97	10147000	73	123	157	201	234	267	300	343	19
[1]98	10220300	64	158	255	425	592	799	1,050	1,470	14
99	10224100	19	42	65	104	142	189	246	339	31
100	10148300	151	392	672	1,240	1,870	2,740	3,940	6,190	14
101	10219200	46	132	230	419	618	879	1,210	1,790	33
102	10148200	23	79	166	388	696	1,210	2,040	3,970	33
103	10208500	145	283	413	632	842	1,100	1,410	1,930	25
104	10233000	52	104	150	223	287	360	444	572	11
105	10210000	159	332	509	830	1,160	1,580	2,130	3,090	21
106	10211000	68	132	194	298	399	523	675	929	12
107	10215700	91	150	195	258	310	366	426	514	25
108	10215900	315	456	552	678	773	870	969	1,100	40
109	10237500	33	70	104	160	212	274	347	462	13
[3]110	10204200	2	18	57	181	375	711	1,260	2,500	11
111	10236000	40	77	106	149	185	223	265	324	18
112	10236500	174	468	771	1,300	1,800	2,410	3,140	4,300	11
113	10205070	25	101	220	521	925	1,570	2,570	4,740	10
[5]114	10234000		ND	ND	ND	ND	ND	ND	ND	ND
115	10205300	12	23	33	47	59	71	84	104	12
116	10235000	33	80	126	204	277	364	466	628	12
117	10187300	57	79	92	107	117	127	135	146	18
Geohydrologic Region #6										
118	9310000	217	308	365	434	483	530	575	633	65
119	9310700	104	196	272	386	483	593	714	894	26
120	9312700	42	83	119	177	229	288	357	464	29
121	9271800	92	301	529	925	1,300	1,730	2,230	2,990	15
[1]122	9308200	92	1,000	3,010	8,740	16,500	28,000	44,300	74,500	11
123	9309100	177	726	1,410	2,680	3,960	5,500	7,310	10,100	12
124	9327600	106	337	624	1,210	1,880	2,780	4,000	6,230	12
125	9329050	183	268	319	376	414	449	481	520	35
126	9263800	302	802	1,310	2,170	2,990	3,950	5,090	6,860	14
127	9314400	254	607	948	1,510	2,040	2,670	3,400	4,550	10
[1]128	9328300	437	1,190	1,960	3,310	4,610	6,170	8,020	11,000	15

Table A.1: Continued.

Map Unit ID	Gage Station Number	Peak Flow Flood Frequency Analyses, for Recurrence Year 2 Year (cfs)	5 Year (cfs)	10 Year (cfs)	25 Year (cfs)	50 Year (cfs)	100 Year (cfs)	200 Year (cfs)	500 Year (cfs)	Number of Annual Peak Flows
Geohydrologic Region #6 (continued)										
129	9315150	816	2,250	3,780	6,520	9,220	12,600	16,600	23,200	15
130	9315200	990	2,530	3,980	6,260	8,250	10,500	12,900	16,500	15
131	9328600	215	592	1,000	1,750	2,500	3,440	4,610	6,570	14
132	9328720	263	936	1,730	3,220	4,710	6,550	8,770	12,300	10
133	9315900	206	608	1,070	1,970	2,930	4,180	5,790	8,610	15
134	9338000	203	304	369	447	502	555	606	671	20
135	9330300	991	2,390	3,620	5,470	7,020	8,700	10,500	13,000	15
136	9338500	22	66	117	217	321	457	630	928	20
[1]137	9306235	14	69	160	397	716	1,220	1,990	3,600	14
138	9306240	14	57	120	268	454	733	1,140	1,960	11
139	9328900	418	1,110	1,930	3,590	5,430	7,990	11,500	18,000	10
[1]140	9403800	135	567	1,150	2,360	3,710	5,490	7,790	11,800	14
141	9182600	262	713	1,220	2,200	3,240	4,600	6,370	9,500	15
[1]142	9306042	7	48	135	416	871	1,700	3,160	6,730	18
[4]143	9306052	6	11	16	24	32	41	51	68	11
[1]144	9306039	3	23	79	311	772	1,780	3,900	10,300	11
145	9163050	111	202	279	397	502	622	759	969	10
[1]146	9306036	11	59	146	380	709	1,240	2,080	3,890	12
[4]147	9163300	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]148	9403750	ND	ND	ND	ND	ND	ND	ND	ND	ND
149	9153290	156	209	245	292	328	365	403	455	25
150	9333900	420	758	1,030	1,410	1,730	2,080	2,450	2,980	16
[5]151	9153300	ND	ND	ND	ND	ND	ND	ND	ND	ND
152	9181000	730	1,390	1,920	2,660	3,260	3,910	4,590	5,550	13
[4]153	9153200	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]154	9379820	10	70	208	692	1,540	3,190	6,310	14,600	10
155	9152900	133	181	210	245	270	293	316	344	11
[6]156	9152650	238	376	476	610	715	823	936	1,090	10
157	9182000	9	19	27	38	46	55	65	77	24
158	9183500	188	404	611	960	1,290	1,700	2,190	2,990	26
159	9185200	529	842	1,070	1,370	1,610	1,850	2,110	2,460	15
160	9106200	60	113	156	219	271	327	387	474	10
161	9177500	114	265	400	608	787	985	1,200	1,520	23
[4]162	9379980	ND	ND	ND	ND	ND	ND	ND	ND	ND
163	9104500	40	59	74	96	113	132	153	183	24

Table A.1: Continued.

Map Unit ID	Gage Station Number	2 Year (cfs)	5 Year (cfs)	10 Year (cfs)	25 Year (cfs)	50 Year (cfs)	100 Year (cfs)	200 Year (cfs)	500 Year (cfs)	Number of Annual Peak Flows
		Peak Flow Flood Frequency Analyses, for Recurrence Year								
		Geohydrologic Region #6 (continued)								
164	9334400	412	1,910	4,090	8,890	14,400	22,100	32,300	50,500	15
[4]165	9151700	ND	ND	ND	ND	ND	ND	ND	ND	ND
166	9137800	44	68	84	104	118	133	147	166	12
[5]167	9185800	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]168	9169800	ND	ND	ND	ND	ND	ND	ND	ND	ND
169	9378170	39	82	123	193	259	338	434	589	23
170	9378630	12	36	62	111	162	227	308	448	42
171	9378950	732	1,430	2,100	3,250	4,380	5,790	7,540	10,500	10
[4]172	9168700	41	131	233	424	617	858	1,160	1,640	12
173	9175800	151	546	1,040	2,020	3,060	4,410	6,130	9,050	11
174	9379560	455	939	1,410	2,240	3,060	4,080	5,350	7,500	14
[1]175	9379100	170	1,140	3,080	8,810	17,300	31,700	55,100	107,000	15
[4]176	9371300	51	353	957	2,750	5,400	9,890	17,200	33,300	11
177	9369500	105	196	267	367	449	534	625	752	15
178	9369000	107	183	244	335	413	500	596	741	15
[1]179	9379060	13	51	105	225	368	572	857	1,400	14
[1]180	9368020	124	308	502	850	1,200	1,640	2,200	3,130	23
[1]181	9367550	136	472	893	1,740	2,670	3,910	5,520	8,350	21
182	9367400	62	179	313	570	840	1,190	1,650	2,440	27
[1]183	9367530	110	249	384	612	830	1,090	1,410	1,920	35
[1]184	9367840	273	610	912	1,380	1,790	2,250	2,760	3,520	37
[1]185	9367860	1,090	2,430	3,680	5,710	7,570	9,760	12,300	16,300	29
[1]186	9367880	1,710	3,010	4,050	5,570	6,830	8,220	9,730	11,900	18
[1]187	9367900	429	1,050	1,650	2,640	3,560	4,640	5,890	7,820	53
		Geohydrologic Region #7								
188	10241600	68	216	412	847	1,370	2,140	3,260	5,480	23
189	10241400	36	126	245	509	824	1,280	1,920	3,170	21
190	9408400	68	152	235	378	518	692	904	1,260	49
191	10241470	57	142	232	399	571	792	1,070	1,560	23
192	9406300	140	366	611	1,060	1,530	2,120	2,880	4,170	23
193	10241430	14	25	33	45	55	65	76	93	11
194	9406700	199	549	927	1,610	2,300	3,160	4,210	5,960	16
[1]195	9415100	44	344	968	2,820	5,510	9,970	17,000	31,900	18
196	9406800	192	468	743	1,220	1,670	2,220	2,880	3,950	14
197	9408000	155	673	1,460	3,330	5,690	9,220	14,400	24,600	45

Table A.1: Continued.

Map Unit ID	Gage Station Number	Peak Flow Flood Frequency Analyses, for Recurrence Year: 2 Year (cfs)	5 Year (cfs)	10 Year (cfs)	25 Year (cfs)	50 Year (cfs)	100 Year (cfs)	200 Year (cfs)	500 Year (cfs)	Number of Annual Peak Flows
Geohydrologic Region #7 (continued)										
[3]198	9415050	2	32	133	587	1,490	3,410	7,160	17,300	13
199	9405420	207	410	598	907	1,200	1,550	1,960	2,630	11
200	9404500	202	1,040	2,330	5,270	8,750	13,600	20,100	31,900	14

[1]Years with zero peak flows and flows below gage height were taken out, but there were still more than 10 years of peak flow data. Stations were used.
[2]Historic peaks were discounted from analyses. Stations used in analyses.
[3]Years with zero peak flows and flows below gage height were removed. Number of peaks dropped exceeded Bulletin 17B Specs. Stations were dropped.
[4]Years with zero peak flows and flows below gage height were taken out. Number of peaks dropped below 10 years of record. Stations were dropped.
[5]Urbanization or flow regulation occurred, years dropped. Number of peaks dropped below 10 years of record. Stations were dropped.
[6]Urbanization or flow regulation occurred, years dropped. Number of peaks remained above 10 years of record. Stations used in analyses.
[7]Basins were delineated to have an area larger than 30 mi^2. Stations were dropped from analyses.

Table A.2: Determined geometric characteristics from basin delineation where the outlet point is the streamflow gaging stations. The footnotes provide explanation of whether or not the basin was used in the analysis.

		Basin Geometric Characteristics								
Map Unit ID	**Gage Station Number**	**Basin Area**	**Basin Slope**	**Max Flow Distance**	**Max Flow Slope**	**Percent Flow South**	**Basin Length**	**Shape Factor**	**Basin Sinuosity**	**Average Elevation**
		(mi^2)	**(ft/ft)**	**(ft)**	**(ft/ft)**	**(%)**	**(ft)**	**(ft/ft)**	**(ft/ft)**	**(ft)**
					Geohydrologic Region #1					
1	10090800	4.8	0.1783	22,478	0.0618	50.9	17,612	2.330	1.143	5,839
2	10069000	21.9	0.4159	56,578	0.0405	48.4	43,922	3.161	1.238	7,825
3	10099000	16.1	0.5518	37,054	0.1037	46.3	28,655	1.832	1.234	7,663
4	10102300	11.7	0.5979	38,165	0.1142	55.8	29,004	2.583	1.254	7,592
5	9208000	6.7	0.2862	39,894	0.0364	55.1	34,550	6.391	1.088	8,999
[1]6	9204700	2.2	0.0421	17,116	0.0116	42.1	14,788	3.584	1.031	7,339
[2]7	10019700	8.9	0.1664	35,170	0.0362	38.5	27,372	3.009	1.183	7,307
[5]8	9214000	20.3	0.2763	88,826	0.0497	66.2	66,115	7.732	1.292	9,770
9	10130000	27.1	0.1753	77,249	0.0450	30.7	57,252	4.332	1.313	7,126
10	10129350	12.1	0.2702	37,811	0.0834	51.5	32,056	3.058	1.115	7,689
11	10128200	19.2	0.3812	42,992	0.0853	35.9	34,144	2.173	1.188	8,732
12	9216290	17.2	0.0503	54,558	0.0125	31.7	42,559	3.771	1.234	6,445
[5]13	10011200	7.0	0.2381	23,583	0.0495	32.9	20,806	2.205	1.001	9,797
14	9221680	9.4	0.0726	42,076	0.0149	26.6	32,698	4.084	1.218	6,740
[5]15	9224600	2.5	0.0188	17,958	0.0096	5.1	14,514	3.073	1.090	6,416
[1]16	9224800	4.2	0.0343	14,796	0.0200	36.0	12,384	1.318	1.010	6,333
[4]17	9216350	15.9	0.0689	56,817	0.0183	19.3	48,317	5.266	1.128	6,955
[3]18	9224810	12.0	0.0963	41,049	0.0247	33.2	34,772	3.609	1.100	6,647
[1]19	9224820	3.7	0.1055	23,161	0.0334	32.7	21,139	4.287	1.005	6,561
[1]20	9224840	1.3	0.1399	16,949	0.0409	49.7	15,116	6.375	0.991	6,544
21	9227500	22.3	0.2378	67,470	0.0672	24.4	57,633	5.352	1.110	10,674
22	9226500	28.5	0.2104	68,873	0.0574	22.7	46,553	2.730	1.421	10,464
23	9225200	6.8	0.1353	34,083	0.0489	44.9	26,483	3.708	1.199	6,644
[4]24	9229450	3.1	0.1606	20,999	0.0325	53.8	16,593	3.218	1.183	6,596
[1,2]25	9225300	12.0	0.1090	45,339	0.0211	40.6	36,137	3.906	1.196	6,577
					Geohydrologic Region #2					
26	10137680	6.0	0.3955	23,031	0.1051	51.5	19,921	2.373	1.050	7,116
27	10141400	18.9	0.0175	50,411	0.0115	28.1	38,372	2.794	1.202	4,382
28	10139300	11.1	0.3423	35,244	0.1247	39.3	25,331	2.069	1.275	6,577
[4]29	10172810	2.9	0.4805	17,070	0.2024	56.3	12,559	1.936	1.200	7,205
30	10141500	2.5	0.5300	16,851	0.2410	55.3	14,104	2.906	1.040	7,601
31	10172805	5.5	0.4714	23,509	0.1909	43.8	20,756	2.834	1.038	7,595
32	10172800	4.2	0.5828	23,355	0.1780	35.8	19,599	3.269	1.040	8,426

Table A.2: Continued.

Map Unit ID	Gage Station Number	Basin Area (mi²)	Basin Slope (ft/ft)	Max Flow Distance (ft)	Max Flow Slope (ft/ft)	Percent Flow South (%)	Basin Length (ft)	Shape Factor (ft/ft)	Basin Sinuosity (ft/ft)	Average Elevation (ft)
		Basin Geometric Characteristics								
Geohydrologic Region #2 (continued)										
33	10142000	10.1	0.4134	42,147	0.0962	49.5	30,991	3.413	1.306	7,464
34	10142500	2.4	0.4617	19,348	0.2108	59.5	16,373	4.048	1.048	7,360
35	10143000	2.1	0.4493	22,044	0.1873	68.5	18,533	5.736	1.072	7,084
36	10143500	3.2	0.4701	23,564	0.1622	54.0	20,219	4.639	1.069	6,936
37	10145126	0.8	0.1241	20,035	0.1075	11.4	17,865	13.814	0.992	4,854
38	10144000	4.5	0.4225	24,006	0.1454	52.9	18,947	2.877	1.134	7,074
39	10135000	28.3	0.3972	44,879	0.0709	42.2	37,289	1.762	1.154	7,200
40	10145000	8.8	0.4441	31,784	0.1195	52.9	26,928	2.941	1.106	7,399
[1]41	10172760	3.5	0.2366	16,705	0.0817	52.3	13,634	1.930	1.061	6,400
42	10172791	16.7	0.4949	39,452	0.1214	42.9	34,890	2.620	1.068	7,407
43	10172765	6.6	0.2949	33,089	0.1393	68.7	27,527	4.116	1.116	6,805
44	10172500	17.0	0.4783	59,240	0.0640	58.3	50,365	5.345	1.139	6,897
[4]45	10172790	12.3	0.5135	30,646	0.1460	42.1	28,001	2.284	1.018	7,676
46	10172200	7.2	0.5072	26,787	0.1056	59.0	23,205	2.666	1.066	6,808
47	10172000	18.6	0.4098	55,949	0.0719	60.8	43,210	3.609	1.245	6,429
48	10170000	21.7	0.5459	63,230	0.0720	43.6	50,821	4.264	1.207	7,691
[4]49	10172720	1.2	0.2723	11,082	0.1106	49.8	9,070	2.534	0.993	6,213
50	10166430	26.9	0.4253	43,172	0.1012	49.0	36,858	1.814	1.105	7,547
51	10167500	27.4	0.5642	67,644	0.0841	42.9	55,314	4.003	1.184	8,851
52	10133700	2.7	0.3871	15,727	0.1573	35.1	12,749	2.147	1.005	7,349
53	10133600	8.8	0.2971	36,349	0.0880	27.7	28,848	3.397	1.199	7,735
54	10165500	9.6	0.4764	31,583	0.1821	68.5	28,384	3.002	1.048	8,833
55	10172700	25.5	0.2103	59,888	0.0337	46.2	36,702	1.895	1.566	7,082
56	10160000	27.0	0.3643	63,725	0.0692	59.9	53,101	3.744	1.159	7,403
57	10160800	12.3	0.5118	35,002	0.1784	54.1	25,753	1.937	1.277	8,103
Geohydrologic Region #3										
58	10172909	11.1	0.2322	52,057	0.0632	55.0	43,820	6.222	1.124	6,347
59	10172920	19.3	0.2221	46,067	0.0561	55.2	36,416	2.466	1.202	6,521
60	13077700	8.0	0.3193	27,362	0.1003	38.7	21,369	2.054	1.161	8,486
61	13079000	19.9	0.3281	49,358	0.0704	28.8	38,935	2.738	1.181	8,136
62	10172913	23.3	0.1512	52,619	0.0330	26.7	43,869	2.961	1.159	6,466
63	10172952	8.6	0.3436	30,370	0.1246	81.3	25,531	2.708	1.086	8,181
[4]64	10172925	10.0	0.2176	41,871	0.0640	63.2	34,744	4.320	1.157	5,989
65	10122500	12.5	0.1796	34,303	0.0737	44.6	24,885	1.772	1.272	5,987
[4]66	10172902	4.5	0.1886	23,996	0.0461	60.6	16,476	2.148	1.249	6,398

Table A.2: Continued.

Map Unit ID	Gage Station Number	Basin Area	Basin Slope	Max Flow Distance	Max Flow Slope	Percent Flow South	Basin Length	Shape Factor	Basin Sinuosity	Average Elevation
		Basin Geometric Characteristics								
		(mi^2)	(ft/ft)	(ft)	(ft/ft)	(%)	(ft)	(ft/ft)	(ft/ft)	(ft)
Geohydrologic Region #3 (continued)										
67	10126180	25.0	0.0577	95,867	0.0268	21.4	76,104	8.302	1.232	4,457
68	10172900	12.8	0.1090	47,271	0.0368	24.5	36,299	3.701	1.238	5,456
[4]69	10172905	1.5	0.3288	13,018	0.0942	38.6	8,588	1.717	1.301	5,846
[4]70	10172835	1.4	0.2947	11,647	0.0938	47.8	7,996	1.670	1.223	5,948
71	10172870	8.2	0.5350	31,209	0.1493	64.3	26,888	3.160	1.094	9,248
[4]72	10172830	1.7	0.5096	12,063	0.1791	45.3	10,164	2.200	1.006	7,006
[4]73	10172885	6.8	0.2517	26,039	0.0509	32.9	20,473	2.222	1.184	5,505
74	10243260	12.7	0.3390	45,337	0.1320	39.9	35,328	3.527	1.207	9,116
75	10243240	16.7	0.4174	42,917	0.1267	45.5	34,060	2.491	1.193	9,535
76	10242460	6.8	0.1434	28,920	0.0438	61.8	24,189	3.103	1.103	6,663
77	10242440	5.7	0.2072	27,867	0.0484	35.6	23,913	3.586	1.050	6,103
Geohydrologic Region #4										
78	9216600	8.7	0.1268	38,898	0.0272	61.4	23,281	2.229	1.541	6,983
79	9216900	1.4	0.2871	15,061	0.0848	76.2	12,321	3.992	1.054	6,874
80	9235600	25.6	0.1825	44,786	0.0296	49.4	31,443	1.384	1.357	8,129
81	9264000	26.4	0.0930	57,342	0.0486	62.7	45,142	2.770	1.157	9,920
82	9264500	20.1	0.1680	61,959	0.0432	52.1	51,575	4.744	1.133	10,480
83	9268500	8.9	0.2280	31,558	0.0815	78.5	25,383	2.604	1.114	10,155
84	9268900	7.4	0.1656	34,644	0.0787	59.2	24,898	2.992	1.276	10,031
85	9269000	10.7	0.1803	40,732	0.0795	62.1	27,388	2.507	1.382	9,792
86	9273500	7.4	0.3869	30,628	0.1297	63.7	26,167	3.336	1.099	10,070
87	9276000	10.6	0.2694	39,544	0.0533	68.2	31,634	3.383	1.177	9,155
88	9278000	14.3	0.3445	42,821	0.0838	54.6	33,994	2.909	1.185	10,144
89	9280400	3.1	0.1783	16,674	0.0893	47.6	14,786	2.565	0.994	9,029
90	9287500	13.8	0.3628	55,966	0.0564	49.9	46,917	5.706	1.137	8,480
91	9298000	14.7	0.3077	49,374	0.0632	60.6	43,826	4.698	1.064	9,179
[7]92	10153500	35.7	0.1888	64,470	0.0501	61.6	50,040	2.516	1.226	9,710
93	10153800	24.8	0.2528	58,369	0.0674	63.0	49,213	3.507	1.121	9,447
94	10154000	7.9	0.2633	34,114	0.0931	66.1	28,239	3.602	1.114	9,333
Geohydrologic Region #5										
[1]95	10146900	4.7	0.1903	25,127	0.0734	43.0	18,976	2.748	1.191	5,506
96	10147500	18.7	0.2782	34,013	0.0808	30.1	28,662	1.574	1.096	7,674
97	10147000	14.7	0.4479	36,664	0.0960	42.4	29,961	2.197	1.164	8,383
[1]98	10220300	17.9	0.1655	50,789	0.0371	58.4	42,118	3.554	1.161	6,106
99	10224100	5.6	0.3984	20,833	0.1301	36.8	14,916	1.422	1.245	7,726

Table A.2: Continued.

Map Unit ID	Gage Station Number	Basin Area (mi²)	Basin Slope (ft/ft)	Max Flow Distance (ft)	Max Flow Slope (ft/ft)	Percent Flow South (%)	Basin Length (ft)	Shape Factor (ft/ft)	Basin Sinuosity (ft/ft)	Average Elevation (ft)
		Basin Geometric Characteristics								
Geohydrologic Region #5 (continued)										
100	10148300	11.0	0.2703	33,636	0.0849	32.6	26,324	2.264	1.201	6,877
101	10219200	27.8	0.3312	60,433	0.0459	45.6	46,409	2.774	1.268	7,390
102	10148200	19.7	0.3930	41,245	0.0746	59.8	36,257	2.391	1.076	7,548
103	10208500	12.0	0.3451	44,679	0.0576	46.4	32,619	3.186	1.306	8,504
104	10233000	12.4	0.4892	41,241	0.1036	49.2	31,990	2.950	1.230	8,286
105	10210000	16.4	0.4410	32,922	0.1215	39.0	27,880	1.699	1.096	8,877
106	10211000	6.5	0.4536	30,836	0.1265	46.6	27,665	4.199	1.039	8,998
107	10215700	8.3	0.3951	28,286	0.1338	32.4	20,711	1.846	1.237	9,169
108	10215900	25.8	0.2844	47,097	0.0850	36.6	38,973	2.108	1.131	9,150
109	10237500	18.6	0.4240	49,600	0.0901	50.2	41,685	3.356	1.137	8,389
[3]110	10204200	18.6	0.2032	58,899	0.0703	25.0	47,488	4.355	1.176	7,744
111	10236000	14.1	0.4386	47,219	0.1152	51.9	38,880	3.838	1.160	8,399
112	10236500	23.2	0.4634	60,268	0.0712	49.7	47,561	3.500	1.232	9,194
113	10205070	8.0	0.2791	36,484	0.0912	55.0	28,833	3.736	1.138	7,536
[5]114	10234000	19.1	0.2666	43,189	0.0735	44.5	30,744	1.776	1.325	9,827
115	10205300	1.9	0.2203	18,199	0.1425	9.6	15,516	4.541	0.965	9,171
116	10235000	14.5	0.2982	46,935	0.0836	50.9	38,013	3.570	1.180	8,724
117	10187300	23.7	0.2655	53,075	0.0792	43.0	41,399	2.592	1.174	9,557
Geohydrologic Region #6										
118	9310000	16.7	0.1684	47,905	0.0277	27.8	37,228	2.969	1.224	8,922
119	9310700	27.3	0.3650	52,638	0.0517	39.7	45,614	2.736	1.116	8,963
120	9312700	26.2	0.2851	85,640	0.0268	39.6	66,327	6.034	1.246	8,673
121	9271800	5.1	0.1650	39,952	0.0604	67.5	35,144	8.717	1.088	6,435
[1]122	9308200	15.9	0.0710	71,840	0.0196	24.3	55,770	7.014	1.232	6,096
123	9309100	5.6	0.2355	25,402	0.0452	53.4	19,517	2.461	1.212	6,874
124	9327600	0.7	0.0978	9,780	0.0371	20.2	6,652	2.204	1.185	6,166
125	9329050	24.4	0.2018	48,115	0.0503	54.1	34,795	1.783	1.294	10,198
126	9263800	1.5	0.3781	18,980	0.1264	68.1	14,643	5.100	1.151	5,981
127	9314400	3.8	0.1261	30,705	0.0326	55.0	23,629	5.260	1.214	5,531
[1]128	9328300	19.0	0.1295	61,249	0.0159	24.6	43,976	3.657	1.314	6,396
129	9315150	9.0	0.0768	36,469	0.0665	38.4	27,820	3.085	1.248	4,848
130	9315200	5.2	0.1762	28,323	0.0849	51.8	22,881	3.589	1.142	4,953
131	9328600	6.7	0.1109	29,587	0.0165	35.0	24,586	3.247	1.126	6,988
132	9328720	18.1	0.1916	58,050	0.0217	50.3	36,903	2.699	1.514	5,429
133	9315900	3.5	0.0399	21,649	0.0142	12.1	17,649	3.180	1.030	4,303

Table A.2: Continued.

Map Unit ID	Gage Station Number	Basin Area (mi²)	Basin Slope (ft/ft)	Max Flow Distance (ft)	Max Flow Slope (ft/ft)	Percent Flow South (%)	Basin Length (ft)	Shape Factor (ft/ft)	Basin Sinuosity (ft/ft)	Average Elevation (ft)
		Basin Geometric Characteristics								
Geohydrologic Region #6 (continued)										
134	9338000	20.3	0.1010	52,786	0.0376	51.6	43,223	3.305	1.165	10,702
135	9330300	22.0	0.0669	39,988	0.0348	31.6	32,107	1.684	1.156	4,809
136	9338500	2.5	0.1770	24,024	0.0941	72.4	20,242	5.976	1.068	10,235
[1]137	9306235	8.7	0.2640	28,668	0.0552	47.7	24,385	2.452	1.118	7,758
138	9306240	10.5	0.2583	34,875	0.0484	45.1	27,768	2.632	1.178	7,813
139	9328900	22.6	0.3439	69,068	0.0412	50.9	59,603	5.626	1.120	6,109
[1]140	9403800	2.4	0.2175	18,261	0.0708	75.0	16,510	4.004	0.989	5,206
141	9182600	2.8	0.0766	22,108	0.0534	44.9	18,171	4.195	1.039	5,136
[1]142	9306042	1.1	0.1472	11,915	0.0452	19.9	11,156	4.196	0.894	6,669
[4]143	9306052	7.9	0.1841	46,919	0.0329	26.0	40,965	7.626	1.104	7,207
[1]144	9306039	1.2	0.1332	13,605	0.0450	16.7	12,373	4.692	0.923	6,743
145	9163050	5.5	0.0701	27,360	0.0191	46.4	24,297	3.872	1.046	4,939
[1]146	9306036	3.7	0.1372	29,724	0.0375	15.2	27,618	7.437	0.971	6,935
[4]147	9163300	1.4	0.1263	17,730	0.0905	63.2	15,690	6.244	1.028	5,298
[4]148	9403750	0.7	0.0351	9,762	0.0225	11.0	7,883	3.073	0.821	5,274
149	9153290	15.9	0.0312	37,948	0.0125	42.2	32,034	2.319	1.123	4,715
150	9333900	13.8	0.2787	40,939	0.0418	57.2	32,445	2.731	1.165	5,163
[5]151	9153300	28.7	0.0289	50,668	0.0103	37.3	40,871	2.089	1.191	4,669
152	9181000	19.2	0.3947	65,882	0.0593	35.8	46,157	3.978	1.360	5,585
[4]153	9153200	2.5	0.0410	21,774	0.0180	33.7	18,891	5.199	0.969	4,964
[4]154	9379820	4.8	0.0844	31,620	0.0317	12.9	27,867	5.825	1.019	5,002
155	9152900	15.7	0.1310	87,994	0.0328	42.9	71,633	11.709	1.200	5,228
[6]156	9152650	14.9	0.1355	66,605	0.0373	48.3	57,044	7.843	1.137	5,151
157	9182000	8.7	0.3892	29,599	0.1756	22.0	22,939	2.164	1.198	9,388
158	9183500	26.8	0.3384	69,012	0.1045	51.5	53,582	3.841	1.233	8,664
159	9185200	17.6	0.2266	67,083	0.0907	39.7	50,406	5.168	1.277	6,530
160	9106200	4.9	0.1408	42,387	0.0406	51.6	37,548	10.368	1.062	5,068
161	9177500	15.5	0.1508	40,352	0.0780	36.4	27,105	1.706	1.397	8,979
[4]162	9379980	0.8	0.0523	13,377	0.0246	25.0	11,104	5.495	0.996	6,138
163	9104500	6.5	0.1886	35,979	0.0847	19.4	25,251	3.527	1.279	9,893
164	9334400	20.1	0.1888	42,190	0.0561	32.1	33,788	2.035	1.168	6,171
[4]165	9151700	4.7	0.1456	35,547	0.0650	51.1	28,908	6.404	1.162	5,974
166	9137800	9.2	0.1747	37,719	0.0948	76.2	28,522	3.171	1.205	9,596
[5]167	9185800	2.3	0.4414	13,659	0.1427	52.2	11,150	1.901	0.948	10,074

Table A.2: Continued.

Map Unit ID	Gage Station Number	Basin Area (mi²)	Basin Slope (ft/ft)	Max Flow Distance (ft)	Max Flow Slope (ft/ft)	Percent Flow South (%)	Basin Length (ft)	Shape Factor (ft/ft)	Basin Sinuosity (ft/ft)	Average Elevation (ft)
		Basin Geometric Characteristics								
Geohydrologic Region #6 (continued)										
[4]168	9169800	4.7	0.1699	22,480	0.0635	13.4	18,507	2.640	1.039	5,646
169	9378170	8.5	0.2618	35,514	0.1163	49.1	29,066	3.555	1.151	8,610
170	9378630	3.9	0.3354	30,058	0.1186	71.6	25,270	5.865	1.109	8,652
171	9378950	10.2	0.2587	37,850	0.0616	50.5	27,976	2.747	1.252	5,789
[4]172	9168700	1.9	0.0795	17,949	0.0336	59.8	15,869	4.701	1.005	5,821
173	9175800	5.4	0.1975	38,925	0.0506	17.9	29,373	5.713	1.257	7,111
174	9379560	6.0	0.1387	24,308	0.0337	29.9	20,698	2.576	1.096	5,651
[1]175	9379100	1.3	0.2263	11,624	0.0680	30.3	7,352	1.535	1.158	6,970
[4]176	9371300	4.0	0.1436	30,692	0.0531	33.4	23,566	4.930	1.216	6,726
177	9369500	12.2	0.2376	42,677	0.1035	54.9	33,087	3.206	1.202	9,363
178	9369000	11.1	0.4255	59,196	0.0912	53.2	46,960	7.127	1.215	9,776
[1]179	9379060	1.4	0.0316	14,531	0.0181	5.8	12,286	3.851	0.975	5,832
[1]180	9368020	2.2	0.0543	15,799	0.0499	43.6	13,311	2.866	0.968	5,330
[1]181	9367550	4.6	0.0548	26,062	0.0163	48.9	21,405	3.558	1.129	5,462
182	9367400	1.1	0.1271	17,853	0.0336	48.9	16,094	8.436	0.974	5,646
[1]183	9367530	2.9	0.0649	25,193	0.0176	44.0	21,230	5.481	1.063	5,503
[1]184	9367840	2.0	0.2099	17,761	0.0519	59.4	14,595	3.730	1.114	7,208
[1]185	9367860	9.9	0.1990	43,044	0.0452	58.8	34,749	4.393	1.170	7,357
[1]186	9367880	26.4	0.1866	54,750	0.0319	47.1	41,974	2.389	1.253	7,078
[1]187	9367900	7.1	0.1571	40,773	0.0326	37.6	33,296	5.600	1.168	6,789
Geohydrologic Region #7										
188	10241600	23.4	0.3451	51,041	0.0758	34.2	40,702	2.536	1.218	8,385
189	10241400	16.0	0.2728	41,133	0.0579	39.2	34,626	2.682	1.122	7,983
190	9408400	18.7	0.4167	38,241	0.0827	38.5	28,197	1.526	1.277	8,631
191	10241470	13.3	0.3540	45,773	0.0938	26.8	37,389	3.768	1.167	8,813
192	9406300	9.8	0.3623	35,971	0.0914	39.4	26,753	2.620	1.233	7,758
193	10241430	5.2	0.2278	23,854	0.0900	21.9	17,938	2.200	1.197	8,952
194	9406700	11.1	0.4500	27,452	0.1701	59.3	23,017	1.712	1.073	7,189
[1]195	9415100	4.8	0.1827	23,552	0.0388	54.5	20,396	3.081	1.037	1,897
196	9406800	13.8	0.4230	53,583	0.1104	59.0	42,159	4.604	1.205	6,767
197	9408000	15.4	0.3700	46,146	0.1285	72.9	36,824	3.150	1.173	6,352
[3]198	9415050	8.1	0.0316	46,625	0.0115	31.5	39,414	6.921	1.083	2,209

Table A.2: Continued.

Map Unit ID	Gage Station Number	Basin Area (mi²)	Basin Slope (ft/ft)	Max Flow Distance (ft)	Max Flow Slope (ft/ft)	Percent Flow South (%)	Basin Length (ft)	Shape Factor (ft/ft)	Basin Sinuosity (ft/ft)	Average Elevation (ft)
		Basin Geometric Characteristics								
Geohydrologic Region #7 (continued)										
199	9405420	29.7	0.3115	44,686	0.0790	60.4	35,447	1.517	1.195	7,825
200	9404500	7.6	0.1294	35,786	0.0468	54.8	26,982	3.435	1.235	5,992

1Years with zero peak flows and flows below gage height were taken out, but there were still more than 10 years of peak flow data. Stations were used.

2Historic peaks were discounted from analyses. Stations used in analyses.

3Years with zero peak flows and flows below gage height were taken out. Number of peaks dropped exceeded Bulletin 17B Specs. Stations were dropped.

4Years with zero peak flows and flows below gage height were taken out. Number of peaks dropped below 10 years of record. Stations were dropped.

5Urbanization or flow regulation occurred, years dropped. Number of peaks dropped below 10 years of record. Stations dropped from analyses.

6Urbanization or flow regulation occurred, years dropped. Number of peaks remained above 10 years of record. Stations used in analyses.

7Basins were delineated to have an area larger than 30 mi^2. Stations were dropped from analyses.

Table A.3: Curve numbers used to develop the composite curve numbers for each watershed. The polygons for the LULC data and STATSGO data provided the Land Use Code and Hydrologic Soil Group, which this table was used with for the overlays in WMS.

Land Use Code	Land Use Description	Hydrologic Soil Group* A	B	C	D
11	"Residential"	57	72	81	86
12	"Commercial and Services"	89	92	94	95
13	"Industrial"	81	88	91	93
14	"Transportation, Communications, & Util."	83	89	92	93
15	"Industrial and Commercial Complexes"	84	90	92	94
16	"Mixed Urban or Built-up Land"	81	88	91	93
17	"Other Urban or Built-up Land"	63	77	85	88
21	"Cropland and Pasture"	49	69	79	84
22	"Orchards, Vineyards, Nurseries, etc."	45	66	77	83
23	"Confined Feeding Operations"	68	79	86	89
24	"Other Agricultural Land"	59	74	82	86
31	"Herbaceous Rangeland"	49	69	79	84
32	"Shrub and Brush Rangeland"	35	56	70	77
33	"Mixed Rangeland"	35	56	70	77
41	"Deciduous Forest Land"	36	60	73	79
42	"Evergreen Forest Land"	36	60	73	79
43	"Mixed Forest Land"	36	60	73	79
51	"Streams and Canals"	100	100	100	100
52	"Lakes"	100	100	100	100
53	"Reservoirs"	100	100	100	100
54	"Bays and Estuaries"	100	100	100	100
61	"Forested Wetland"	30	55	70	77
62	"Nonforested Wetland"	30	58	71	78
71	"Dry Salt Flats"	74	84	90	92
72	"Beaches"	50	50	50	50
73	"Sandy Areas other than Beaches"	63	77	85	88
74	"Bare Exposed Rock"	98	98	98	98
75	"Strip Mines, Quarries, & Gravel"	77	86	91	94
76	"Transitional Areas"	77	86	91	94
77	"Mixed Barren Land"	77	86	91	94
81	"Shrub and Brush Tundra"	48	67	77	83
82	"Herbaceous Tundra"	68	79	86	89
83	"Bare Ground Tundra"	77	86	91	94
84	"Wet Tundra"	35	56	70	77
85	"Mixed Tundra"	35	56	70	77
91	"Perennial Snowfields"	100	100	100	100
92	"Glaciers"	100	100	100	100

*Values taken from USDA - TR55 (1986)

Table A.4: Calculated composite curve numbers and saturated hydraulic conductivity for each station in analyses. Also the mean annual precipitation and 2-year, 24-hour precipitation for each basin is presented.

		Composite CN	*Weighted Saturated Hydraulic Conductivity, K_{SAT}*				*MAP*	*PREC*
Map Unit ID	**Gage Station Number**	**Area weighted Curve Number**	**Surface of Soil (in/hr)**	**0" to 12" into Soil (in/hr)**	**0" to 24" into Soil (in/hr)**	**Full Depth (max of 60") of Soil (in/hr)**	**Mean Annual Precipitation (in/year)**	**2-year, 24-hour Precipitation (in)**
				Geohydrologic Region #1				
1	10090800	67.1	1.30	1.30	1.56	1.07	20.92	1.39
2	10069000	59.2	1.29	1.29	1.43	1.29	34.12	1.85
3	10099000	62.2	1.38	1.36	1.37	1.31	35.15	2.72
4	10102300	70.7	1.43	1.44	1.65	1.55	34.51	2.78
5	9208000	58.8	2.47	2.14	2.71	2.20	35.68	1.65
[1]6	9204700	56.0	2.96	2.48	3.34	2.34	11.69	1.07
[2]7	10019700	77.0	0.97	0.86	0.91	0.85	15.99	1.05
[5]8	9214000	70.0	4.42	4.44	5.04	4.57	29.29	1.65
9	10130000	70.4	1.62	1.66	2.18	1.60	22.08	1.48
10	10129350	64.9	1.47	1.40	1.25	1.24	24.66	1.57
11	10128200	70.0	1.98	1.77	1.93	1.48	34.64	1.87
12	9216290	78.2	4.59	3.97	3.93	3.95	8.19	0.86
[5]13	10011200	60.0	3.97	3.56	5.17	2.99	36.37	1.73
14	9221680	77.0	3.91	3.52	3.46	3.48	8.37	0.91
[5]15	9224600	77.0	4.88	4.16	4.12	4.14	8.49	0.89
[1]16	9224800	77.0	3.91	3.52	3.46	3.48	8.25	0.86
[4]17	9216350	77.0	3.64	3.29	3.22	3.23	9.13	0.99
[3]18	9224810	77.0	3.81	3.44	3.37	3.39	8.59	0.94
[1]19	9224820	75.5	3.89	3.52	3.47	3.48	8.71	0.90
[1]20	9224840	77.0	3.91	3.52	3.46	3.48	8.70	0.90
21	9227500	67.8	2.95	3.05	3.00	2.83	30.68	1.60
22	9226500	65.5	3.09	3.16	3.28	3.01	30.58	1.56
23	9225200	77.3	2.95	2.91	3.20	3.00	10.15	1.00
[4]24	9229450	77.0	3.90	3.52	3.46	3.47	10.41	1.05
[1,2]25	9225300	77.0	3.89	3.51	3.46	3.47	10.59	1.03
				Geohydrologic Region #2				
26	10137680	69.2	1.46	0.70	0.87	1.61	50.68	3.80
27	10141400	76.1	5.39	10.46	10.95	12.61	19.61	1.58
28	10139300	66.4	1.21	0.59	0.66	1.27	37.58	2.62
[4]29	10172810	78.3	1.93	3.04	2.26	3.23	27.9	1.67
30	10141500	72.0	1.30	1.38	1.65	3.67	43.91	2.56
31	10172805	78.1	1.85	1.09	0.70	0.67	33.38	2.01

Table A.4: Continued.

Map Unit ID	Gage Station Number	*Composite CN* Area weighted Curve Number	*Weighted Saturated Hydraulic Conductivity, K_{SAT}* Surface of Soil (in/hr)	0" to 12" into Soil (in/hr)	0" to 24" into Soil (in/hr)	Full Depth (max of 60") of Soil (in/hr)	*MAP* Mean Annual Precipitation (in/year)	*PREC* 2-year, 24-hour Precipitation (in)
Geohydrologic Region #2 (continued)								
32	10172800	78.7	1.81	0.58	0.44	0.44	39.72	2.36
33	10142000	65.4	3.61	5.64	5.04	4.52	44.02	2.74
34	10142500	60.7	5.90	22.54	19.94	15.71	47.59	2.88
35	10143000	58.3	5.84	33.27	34.73	43.72	45.98	2.81
36	10143500	60.5	5.54	22.60	23.60	29.70	39.73	2.69
37	10145126	71.3	2.57	89.31	92.64	113.27	23.27	1.78
38	10144000	57.2	6.17	11.97	10.59	8.34	38.49	2.56
39	10135000	60.0	4.58	2.08	1.83	1.60	30.02	2.38
40	10145000	57.8	5.93	7.48	6.77	5.59	39.15	2.48
[1]41	10172760	77.2	2.32	1.87	1.38	2.19	19.67	1.52
42	10172791	72.5	1.45	0.31	0.19	0.16	28.8	2.02
43	10172765	73.7	2.03	1.35	1.00	1.43	21.22	1.73
44	10172500	73.0	2.20	4.02	3.57	2.75	33.05	2.24
[4]45	10172790	72.1	1.32	0.41	0.26	0.22	29.56	2.08
46	10172200	76.3	3.35	2.02	1.94	1.82	31.45	2.07
47	10172000	75.1	2.70	1.14	1.10	1.30	28.14	1.97
48	10170000	58.5	2.43	0.86	0.85	0.73	32.99	2.16
[4]49	10172720	79.0	2.36	5.55	4.10	6.51	16.88	1.26
50	10166430	69.7	1.44	0.67	0.55	0.63	26.43	1.85
51	10167500	79.4	2.87	5.53	5.70	6.27	39.72	2.67
52	10133700	61.8	2.31	5.31	5.13	4.21	27.95	1.85
53	10133600	66.8	1.94	1.89	1.81	1.73	25.38	1.65
54	10165500	69.9	3.99	5.30	5.76	7.46	40.15	2.47
55	10172700	77.2	2.17	0.23	0.15	0.14	24.12	1.80
56	10160000	71.3	1.35	0.23	0.30	0.62	36.2	2.08
57	10160800	66.6	2.34	3.42	3.91	5.48	41.22	2.61
Geohydrologic Region #3								
58	10172909	77.5	1.69	1.30	1.43	1.25	10.47	1.11
59	10172920	58.8	3.34	3.57	4.20	3.68	13.9	1.38
60	13077700	62.1	3.06	3.33	4.27	3.53	27.27	1.66
61	13079000	63.5	3.06	3.34	4.26	3.54	27.58	1.56
62	10172913	78.4	2.72	1.60	1.49	1.38	11.98	1.13
63	10172952	63.2	3.06	3.33	4.27	3.53	25.33	1.60
[4]64	10172925	72.8	2.23	2.19	2.56	2.38	12.95	1.20
65	10122500	68.6	1.29	1.18	1.03	0.89	20.64	1.68

Table A.4: Continued.

Map Unit ID	Gage Station Number	*Composite CN* Area weighted Curve Number	*Weighted Saturated Hydraulic Conductivity, K_{SAT}* Surface of Soil (in/hr)	0" to 12" into Soil (in/hr)	0" to 24" into Soil (in/hr)	Full Depth (max of 60") of Soil (in/hr)	*MAP* Mean Annual Precipitation (in/year)	*PREC* 2-year, 24-hour Precipitation (in)
			Geohydrologic Region #3 (continued)					
[4]66	10172902	78.7	1.29	1.16	1.02	1.03	10.76	1.19
67	10126180	76.8	0.79	0.73	0.81	0.63	16.89	1.41
68	10172900	71.0	3.36	3.29	3.84	3.22	10.75	1.28
[4]69	10172905	78.4	3.17	2.94	3.02	2.62	18.13	1.33
[4]70	10172835	79.0	2.95	2.55	2.57	2.28	17.53	1.32
71	10172870	79.0	1.82	1.35	1.37	1.37	23.95	1.67
[4]72	10172830	78.9	2.08	1.41	1.36	1.35	24.36	1.71
[4]73	10172885	78.0	3.17	2.94	3.02	2.62	12.18	1.21
74	10243260	72.5	1.99	1.90	1.97	1.73	21.17	1.69
75	10243240	73.3	2.69	2.46	2.35	2.29	23.32	1.81
76	10242460	77.9	2.80	1.35	1.42	1.12	17.08	1.70
77	10242440	59.9	2.12	1.07	1.01	1.00	16.47	1.80
			Geohydrologic Region #4					
78	9216600	77.2	2.92	2.79	2.82	2.95	9.13	1.03
79	9216900	77.0	2.13	2.27	2.40	2.69	8.94	1.03
80	9235600	50.0	2.58	2.83	3.41	3.75	19.20	1.54
81	9264000	61.0	2.56	2.83	3.70	5.35	28.65	1.69
82	9264500	65.9	3.45	3.71	4.46	5.98	31.65	1.81
83	9268500	63.4	3.41	3.73	4.57	6.03	30.57	1.87
84	9268900	61.5	3.47	3.82	4.69	6.10	30.69	1.77
85	9269000	56.0	3.37	3.92	5.04	6.24	29.93	1.74
86	9273500	67.5	5.53	5.91	6.61	7.62	38.34	1.92
87	9276000	59.5	1.89	1.86	1.97	2.38	30.56	1.82
88	9278000	66.7	5.07	5.41	6.10	7.25	34.17	1.78
89	9280400	73.0	1.29	1.35	2.57	4.18	34.30	1.92
90	9287500	58.5	2.09	1.96	1.79	1.60	23.53	1.52
91	9298000	37.5	3.38	4.66	6.65	7.01	26.49	1.67
[7]92	10153500	61.0	2.98	3.25	4.06	5.66	38.55	2.06
93	10153800	64.8	2.92	3.10	3.67	4.87	37.20	1.98
94	10154000	65.1	3.09	3.29	3.91	5.19	37.42	1.88
			Geohydrologic Region #5					
[1]95	10146900	67.6	2.94	2.81	2.62	2.83	14.49	1.23
96	10147500	58.1	1.30	1.29	1.27	1.56	25.84	1.63
97	10147000	59.6	1.33	1.31	1.34	1.51	26.10	1.76
[1]98	10220300	73.6	2.44	2.27	2.01	2.24	15.21	1.37

Table A.4: Continued.

Map Unit ID	Gage Station Number	*Composite CN* Area weighted Curve Number	*Weighted Saturated Hydraulic Conductivity, K_{SAT}* Surface of Soil (in/hr)	0" to 12" into Soil (in/hr)	0" to 24" into Soil (in/hr)	Full Depth (max of 60") of Soil (in/hr)	*MAP* Mean Annual Precipitation (in/year)	*PREC* 2-year, 24-hour Precipitation (in)
Geohydrologic Region #5 (continued)								
99	10224100	79.0	7.53	7.46	7.39	7.58	20.47	1.56
100	10148300	58.6	2.36	2.00	1.82	1.87	22.25	1.49
101	10219200	59.1	1.42	1.32	1.31	1.35	21.29	1.45
102	10148200	58.4	2.49	2.11	1.93	2.01	20.23	1.52
103	10208500	59.1	1.39	1.36	1.29	1.30	26.59	1.57
104	10233000	65.0	1.81	1.43	1.31	1.45	30.36	2.07
105	10210000	59.3	1.39	1.31	1.15	1.04	27.87	1.51
106	10211000	59.4	1.42	1.33	1.15	0.92	28.84	1.60
107	10215700	59.5	1.42	1.32	1.14	0.85	27.63	1.55
108	10215900	66.2	1.38	1.17	1.03	1.09	26.63	1.47
109	10237500	63.3	1.68	1.56	1.38	1.45	25.21	1.87
[3]110	10204200	66.2	1.23	1.23	1.27	1.84	19.99	1.29
111	10236000	64.5	2.22	2.10	1.98	2.13	24.59	1.85
112	10236500	61.3	3.34	3.20	3.28	3.47	27.77	2.07
113	10205070	76.6	1.32	1.20	1.25	2.21	22.92	1.45
[5]114	10234000	59.9	2.48	2.42	2.33	2.51	32.43	2.18
115	10205300	70.3	1.93	1.93	1.71	1.78	33.13	1.72
116	10235000	62.7	2.85	2.79	2.74	3.19	25.27	1.88
117	10187300	58.9	3.85	3.84	3.82	3.90	30.07	1.79
Geohydrologic Region #6								
118	9310000	58.3	1.37	1.41	1.34	2.12	27.98	1.55
119	9310700	60.3	1.59	1.75	1.47	1.40	25.06	1.55
120	9312700	60.5	1.73	1.85	1.55	1.51	20.00	1.39
121	9271800	57.7	1.82	1.46	1.43	1.57	11.70	1.18
[1]122	9308200	75.5	2.89	2.89	2.74	2.81	9.97	1.02
123	9309100	77.6	2.22	2.21	2.03	2.05	13.41	1.18
124	9327600	60.0	0.91	0.70	0.49	0.38	8.91	1.10
125	9329050	62.0	3.55	3.77	3.74	3.78	27.23	1.72
126	9263800	67.8	3.00	2.72	2.40	2.62	10.19	1.08
127	9314400	56.0	4.07	2.80	2.45	2.44	10.42	1.22
[1]128	9328300	78.4	4.00	3.40	2.64	3.56	10.25	1.12
129	9315150	63.0	1.03	0.81	0.67	0.65	8.44	1.06
130	9315200	67.7	1.02	0.91	0.82	0.83	8.56	1.11

Table A.4: Continued.

Map Unit ID	Gage Station Number	*Composite CN* Area weighted Curve Number	*Weighted Saturated Hydraulic Conductivity, K_{SAT}* Surface of Soil (in/hr)	0" to 12" into Soil (in/hr)	0" to 24" into Soil (in/hr)	Full Depth (max of 60") of Soil (in/hr)	*MAP* Mean Annual Precipitation (in/year)	*PREC* 2-year, 24-hour Precipitation (in)
Geohydrologic Region #6 (continued)								
131	9328600	78.6	4.00	3.40	2.64	3.56	11.17	1.13
132	9328720	74.2	4.33	4.28	4.05	4.56	8.67	1.03
133	9315900	77.0	0.61	0.50	0.44	0.49	7.72	0.97
134	9338000	63.3	1.27	1.92	2.58	3.29	29.07	1.60
135	9330300	79.2	1.96	1.73	1.55	1.56	6.73	0.94
136	9338500	73.0	1.29	1.30	1.27	1.34	27.31	1.51
[1]137	9306235	72.0	2.16	2.15	2.24	2.32	19.67	1.25
138	9306240	67.3	1.98	1.95	2.02	2.05	20.12	1.25
139	9328900	71.6	3.12	1.96	1.85	1.89	11.60	1.30
[1]140	9403800	50.3	9.62	9.97	9.54	8.54	12.45	1.37
141	9182600	67.8	1.37	1.03	0.94	1.61	9.81	1.18
[1]142	9306042	73.0	3.19	2.99	2.47	2.39	16.38	1.16
[4]143	9306052	74.2	2.63	2.57	2.50	2.56	17.22	1.20
[1]144	9306039	73.0	3.19	2.99	2.47	2.39	16.24	1.16
145	9163050	75.0	0.62	0.54	0.49	1.31	11.04	1.00
[1]146	9306036	75.4	3.01	2.88	2.57	2.57	16.61	1.18
[4]147	9163300	60.2	2.58	1.85	1.78	2.35	11.14	1.10
[4]148	9403750	70.0	1.30	1.75	1.94	1.94	11.69	1.47
149	9153290	71.2	0.82	0.65	0.62	0.95	9.51	0.99
150	9333900	69.9	8.70	8.60	8.53	8.72	7.96	1.01
[5]151	9153300	68.8	0.87	0.68	0.65	0.89	9.39	0.98
152	9181000	77.3	8.98	6.31	5.96	5.82	13.07	1.25
[4]153	9153200	77.0	0.55	0.49	0.44	1.27	9.69	1.00
[4]154	9379820	79.5	7.41	7.26	6.68	5.97	8.52	1.12
155	9152900	74.3	1.18	1.08	1.04	1.51	9.61	1.00
[6]156	9152650	76.7	0.97	0.90	0.86	1.49	9.86	1.07
157	9182000	59.6	3.41	3.52	3.66	4.89	28.35	1.67
158	9183500	66.4	4.27	4.35	4.50	5.30	27.45	1.81
159	9185200	74.5	4.77	5.08	5.40	5.50	13.51	1.32
160	9106200	76.3	0.76	0.68	0.64	1.34	10.08	1.09
161	9177500	61.1	1.74	1.70	1.64	2.61	29.25	1.74
[4]162	9379980	77.9	3.55	3.67	3.67	3.67	9.68	1.25
163	9104500	59.8	0.94	0.85	0.73	0.59	33.91	1.52

Table A.4: Continued.

Map Unit ID	Gage Station Number	*Composite CN* Area weighted Curve Number	*Weighted Saturated Hydraulic Conductivity, K_{SAT}* Surface of Soil (in/hr)	0" to 12" into Soil (in/hr)	0" to 24" into Soil (in/hr)	Full Depth (max of 60") of Soil (in/hr)	*MAP* Mean Annual Precipitation (in/year)	*PREC* 2-year, 24-hour Precipitation (in)
Geohydrologic Region #6 (continued)								
164	9334400	78.4	3.95	5.41	5.96	6.01	10.41	1.22
[4]165	9151700	61.3	1.79	1.35	1.27	1.27	14.18	1.02
166	9137800	49.5	3.65	3.90	3.74	3.66	32.64	1.70
[5]167	9185800	60.0	2.98	2.90	3.10	4.93	33.85	2.38
[4]168	9169800	64.0	2.00	1.90	1.70	1.34	13.21	1.15
169	9378170	60.0	2.50	2.09	2.10	3.49	26.40	2.01
170	9378630	59.9	2.19	1.85	1.83	3.47	25.78	2.05
171	9378950	83.6	3.80	5.02	5.53	5.67	10.96	1.36
[4]172	9168700	73.0	0.33	0.33	0.37	0.37	12.83	1.14
173	9175800	66.4	2.35	2.11	1.70	1.60	16.24	1.20
174	9379560	56.7	6.74	6.74	6.61	6.57	7.86	1.08
[1]175	9379100	79.0	3.12	3.19	3.09	2.73	12.17	1.35
[4]176	9371300	70.7	0.96	0.52	0.50	0.47	16.01	1.42
177	9369500	60.7	16.43	4.20	3.18	2.43	30.62	1.67
178	9369000	67.0	44.37	10.17	6.77	4.88	33.12	1.80
[1]179	9379060	56.0	5.98	3.78	2.84	2.39	8.86	1.18
[1]180	9368020	56.0	2.18	1.98	1.83	1.82	9.15	1.17
[1]181	9367550	62.4	2.43	2.42	2.39	3.80	9.10	1.08
182	9367400	63.1	2.60	2.46	2.37	3.61	9.70	1.11
[1]183	9367530	63.7	2.66	2.61	2.57	3.92	9.23	1.07
[1]184	9367840	36.0	10.00	6.47	5.82	6.02	13.84	1.36
[1]185	9367860	54.4	7.06	4.93	4.42	4.50	12.78	1.35
[1]186	9367880	44.4	8.44	5.61	5.06	5.22	11.74	1.30
[1]187	9367900	50.0	7.23	4.87	4.43	4.62	11.09	1.28
Geohydrologic Region #7								
188	10241600	74.8	2.01	1.08	0.88	0.79	27.63	1.81
189	10241400	65.3	1.45	0.95	0.78	2.73	26.59	1.62
190	9408400	78.9	2.84	2.29	2.46	2.44	19.99	2.10
191	10241470	72.3	1.72	1.01	0.77	0.63	28.84	1.79
192	9406300	60.7	2.43	1.37	1.27	1.69	25.84	1.88
193	10241430	71.7	1.70	0.98	0.70	0.83	27.87	1.85
194	9406700	79.0	2.87	2.78	2.88	2.86	20.23	1.96
[1]195	9415100	77.0	5.43	6.68	7.16	7.50	33.13	1.07

Table A.4: Continued.

Map Unit ID	Gage Station Number	*Composite CN* Area weighted Curve Number	*Weighted Saturated Hydraulic Conductivity, K_{SAT}* Surface of Soil (in/hr)	0" to 12" into Soil (in/hr)	0" to 24" into Soil (in/hr)	Full Depth (max of 60") of Soil (in/hr)	*MAP* Mean Annual Precipitation (in/year)	*PREC* 2-year, 24-hour Precipitation (in)
Geohydrologic Region #7 (continued)								
196	9406800	79.0	3.25	3.06	3.07	3.05	22.25	1.88
197	9408000	78.0	3.03	3.00	3.06	3.04	30.07	1.85
[3]198	9415050	77.0	8.37	11.74	12.07	9.89	22.92	1.11
199	9405420	67.9	2.06	1.41	1.04	0.85	26.10	1.86
200	9404500	78.8	4.66	3.86	3.66	3.46	14.49	1.60

[1]Years with zero peak flows and flows below gage height were taken out, but there were still more than 10 years of peak flow data. Stations were used.

[2]Historic peaks were discounted from analyses. Stations used in analyses.

[3]Years with zero peak flows and flows below gage height were removed. Number of peaks dropped exceeded Bulletin 17B Specs. Stations were dropped.

[4]Years with zero peak flows and flows below gage height were removed. Number of peaks dropped below 10 years of record. Stations were dropped.

[5]Urbanization or flow regulation occurred, years dropped. Number of peaks dropped below 10 years of record. Stations were dropped.

[6]Urbanization or flow regulation occurred, years dropped. Number of peaks remained above 10 years of record. Stations used in analyses.

[7]Basins were delineated to have an area larger than 30 mi^2. Stations were dropped from analyses.

Table A.5: Computed recurrence year rainfall intensities for each basin contained in the analyses. Values showing "NA" indicate values are not available due to using NOAA Atlas 2.

Map Unit ID	Gage Station Number	***Recurrence Year Rainfall Intensity using ADOT Time of Concentration Equation***							
		2 year (in/hr)	**5 year (in/hr)**	**10 year (in/hr)**	**25 year (in/hr)**	**50 year (in/hr)**	**100 year (in/hr)**	**200 year (in/hr)**	**500 year (in/hr)**
Geohydrologic Region #1									
1	10090800	0.35	0.49	0.57	0.70	0.80	0.92	NA	NA
2	10069000	0.26	0.32	0.37	0.42	0.47	0.52	NA	NA
3	10099000	0.38	0.50	0.61	0.77	0.91	1.08	1.28	1.58
4	10102300	0.39	0.50	0.61	0.77	0.92	1.09	1.29	1.60
5	9208000	0.25	0.35	0.42	0.51	0.58	0.66	NA	NA
[1]6	9204700	0.23	0.34	0.41	0.50	0.58	0.67	NA	NA
[2]7	10019700	0.19	0.28	0.34	0.42	0.49	0.55	NA	NA
[5]8	9214000	0.20	0.28	0.32	0.38	0.44	0.49	NA	NA
9	10130000	0.22	0.27	0.32	0.41	0.48	0.57	0.67	0.85
10	10129350	0.31	0.41	0.50	0.65	0.79	0.95	1.15	1.47
11	10128200	0.33	0.43	0.53	0.68	0.82	0.98	1.18	1.49
12	9216290	0.14	0.20	0.24	0.29	0.34	0.38	NA	NA
[5]13	10011200	0.40	0.54	0.66	0.86	1.04	1.25	1.50	1.90
14	9221680	0.16	0.23	0.28	0.34	0.39	0.44	NA	NA
[5]15	9224600	0.20	0.23	0.28	0.34	0.39	0.44	NA	NA
[1]16	9224800	0.25	0.39	0.48	0.60	0.70	0.81	NA	NA
[4]17	9216350	0.15	0.21	0.25	0.31	0.35	0.40	NA	NA
[3]18	9224810	0.17	0.25	0.30	0.36	0.42	0.48	NA	NA
[1]19	9224820	0.23	0.35	0.42	0.52	0.61	0.70	NA	NA
[1]20	9224840	0.28	0.44	0.54	0.67	0.78	0.90	NA	NA
21	9227500	0.29	0.38	0.45	0.57	0.68	0.80	0.94	1.18
22	9226500	0.28	0.35	0.43	0.54	0.63	0.75	0.88	1.09
23	9225200	0.20	0.30	0.36	0.44	0.52	0.59	NA	NA
[4]24	9229450	0.24	0.36	0.44	0.55	0.64	0.73	NA	NA
[1,2]25	9225300	0.17	0.24	0.29	0.36	0.41	0.47	NA	NA
Geohydrologic Region #2									
26	10137680	0.60	0.79	0.96	1.22	1.46	1.74	2.07	2.60
27	10141400	0.22	0.28	0.33	0.40	0.48	0.57	0.67	0.85
28	10139300	0.50	0.65	0.78	1.01	1.20	1.45	1.73	2.20
[4]29	10172810	0.52	0.71	0.89	1.15	1.39	1.68	2.00	2.51
30	10141500	0.71	0.97	1.19	1.54	1.87	2.25	2.72	3.47
31	10172805	0.48	0.65	0.80	1.02	1.23	1.47	1.75	2.20
32	10172800	0.54	0.72	0.89	1.14	1.36	1.62	1.92	2.39
33	10142000	0.47	0.61	0.74	0.94	1.13	1.36	1.62	2.05
34	10142500	0.70	0.93	1.15	1.48	1.79	2.16	2.59	3.29

Table A.5: Continued.

Map Unit ID	Gage Station Number	*Recurrence Year Rainfall Intensity using ADOT Time of Concentration Equation* 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	200 year (in/hr)	500 year (in/hr)
Geohydrologic Region #2 (continued)									
34	10142500	0.70	0.93	1.15	1.48	1.79	2.16	2.59	3.29
35	10143000	0.64	0.85	1.04	1.35	1.63	1.96	2.36	3.00
36	10143500	0.57	0.76	0.93	1.20	1.46	1.75	2.11	2.69
37	10145126	0.52	0.70	0.87	1.15	1.41	1.72	2.09	2.69
38	10144000	0.53	0.70	0.86	1.11	1.35	1.63	1.96	2.49
39	10135000	0.35	0.45	0.54	0.69	0.82	0.98	1.17	1.48
40	10145000	0.44	0.58	0.71	0.92	1.11	1.33	1.60	2.03
[1]41	10172760	0.43	0.58	0.72	0.94	1.14	1.37	1.63	2.06
42	10172791	0.37	0.48	0.59	0.75	0.90	1.07	1.27	1.58
43	10172765	0.39	0.51	0.63	0.81	0.98	1.17	1.39	1.74
44	10172500	0.31	0.39	0.47	0.59	0.69	0.83	0.99	1.25
[4]45	10172790	0.43	0.57	0.69	0.89	1.07	1.28	1.52	1.90
46	10172200	0.43	0.56	0.69	0.89	1.09	1.32	1.59	2.02
47	10172000	0.30	0.38	0.45	0.57	0.68	0.81	0.97	1.23
48	10170000	0.31	0.39	0.46	0.58	0.68	0.82	0.97	1.23
[4]49	10172720	0.53	0.73	0.91	1.20	1.46	1.77	2.12	2.67
50	10166430	0.31	0.40	0.49	0.62	0.73	0.87	1.03	1.29
51	10167500	0.35	0.44	0.52	0.64	0.76	0.89	1.05	1.32
52	10133700	0.56	0.76	0.95	1.25	1.53	1.87	2.26	2.90
53	10133600	0.33	0.43	0.53	0.69	0.84	1.02	1.22	1.56
54	10165500	0.45	0.59	0.72	0.93	1.12	1.35	1.61	2.05
55	10172700	0.24	0.31	0.37	0.46	0.53	0.63	0.74	0.91
56	10160000	0.28	0.35	0.42	0.53	0.62	0.74	0.87	1.10
57	10160800	0.41	0.53	0.65	0.84	1.01	1.22	1.45	1.83
Geohydrologic Region #3									
58	10172909	0.24	0.32	0.38	0.49	0.57	0.67	0.79	0.96
59	10172920	0.29	0.38	0.45	0.57	0.67	0.78	0.91	1.12
60	13077700	0.46	0.61	0.73	0.93	1.10	1.31	1.57	1.95
61	13079000	0.28	0.37	0.44	0.56	0.66	0.77	0.91	1.12
62	10172913	0.23	0.29	0.34	0.43	0.50	0.59	0.69	0.83
63	10172952	0.40	0.54	0.65	0.83	0.99	1.17	1.38	1.72
[4]64	10172925	0.26	0.34	0.42	0.52	0.62	0.74	0.86	1.06
65	10122500	0.32	0.43	0.50	0.60	0.69	0.78	0.00	0.00
[4]66	10172902	0.31	0.42	0.51	0.66	0.80	0.94	1.12	1.39
67	10126180	0.25	0.34	0.42	0.56	0.69	0.83	1.01	1.27
68	10172900	0.27	0.36	0.46	0.60	0.72	0.86	1.02	1.30

Table A.5: Continued.

Map Unit ID	Gage Station Number	*Recurrence Year Rainfall Intensity using ADOT Time of Concentration Equation* 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	200 year (in/hr)	500 year (in/hr)
Geohydrologic Region #3 (continued)									
[4]69	10172905	0.49	0.69	0.86	1.14	1.40	1.70	2.05	2.62
[4]70	10172835	0.50	0.70	0.87	1.16	1.41	1.72	2.08	2.65
71	10172870	0.41	0.54	0.66	0.84	1.00	1.18	1.38	1.71
[4]72	10172830	0.66	0.90	1.13	1.49	1.83	2.21	2.63	3.30
[4]73	10172885	0.33	0.43	0.53	0.68	0.82	0.98	1.16	1.45
74	10243260	0.39	0.52	0.63	0.80	0.95	1.12	1.32	1.63
75	10243240	0.43	0.57	0.69	0.87	1.03	1.21	1.42	1.76
76	10242460	0.38	0.51	0.62	0.79	0.94	1.10	1.29	1.57
77	10242440	0.44	0.59	0.71	0.90	1.06	1.25	1.46	1.77
Geohydrologic Region #4									
78	9216600	0.18	0.26	0.31	0.38	0.44	0.50	0.00	0.00
79	9216900	0.29	0.47	0.60	0.75	0.89	1.03	0.00	0.00
80	9235600	0.30	0.39	0.47	0.60	0.71	0.84	0.99	1.25
81	9264000	0.28	0.37	0.45	0.57	0.67	0.80	0.95	1.19
82	9264500	0.28	0.36	0.44	0.55	0.65	0.77	0.91	1.14
83	9268500	0.42	0.55	0.67	0.86	1.04	1.24	1.48	1.87
84	9268900	0.39	0.51	0.63	0.81	0.97	1.16	1.38	1.74
85	9269000	0.37	0.50	0.60	0.77	0.93	1.11	1.33	1.68
86	9273500	0.43	0.57	0.70	0.91	1.09	1.31	1.57	1.98
87	9276000	0.33	0.43	0.53	0.68	0.82	0.99	1.18	1.49
88	9278000	0.35	0.46	0.57	0.74	0.88	1.06	1.27	1.61
89	9280400	0.50	0.68	0.84	1.09	1.32	1.59	1.89	2.38
90	9287500	0.27	0.35	0.43	0.55	0.66	0.79	0.93	1.18
91	9298000	0.31	0.40	0.50	0.63	0.75	0.90	1.08	1.37
[7]92	10153500	0.28	0.35	0.42	0.53	0.63	0.74	0.87	1.10
93	10153800	0.28	0.37	0.44	0.56	0.66	0.78	0.92	1.16
94	10154000	0.35	0.47	0.57	0.74	0.90	1.08	1.30	1.66
Geohydrologic Region #5									
[1]95	10146900	0.35	0.48	0.59	0.77	0.93	1.11	1.32	1.65
96	10147500	0.37	0.48	0.58	0.74	0.88	1.05	1.23	1.53
97	10147000	0.37	0.49	0.60	0.76	0.91	1.07	1.26	1.56
[1]98	10220300	0.23	0.30	0.36	0.46	0.54	0.64	0.75	0.93
99	10224100	0.48	0.66	0.81	1.03	1.23	1.45	1.71	2.10
100	10148300	0.35	0.46	0.57	0.73	0.88	1.05	1.24	1.54
101	10219200	0.25	0.31	0.37	0.46	0.53	0.63	0.74	0.90
102	10148200	0.30	0.40	0.49	0.63	0.75	0.89	1.06	1.33

Table A.5: Continued.

Map Unit ID	Gage Station Number	*Recurrence Year Rainfall Intensity using ADOT Time of Concentration Equation* 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	200 year (in/hr)	500 year (in/hr)
Geohydrologic Region #5 (continued)									
103	10208500	0.35	0.46	0.56	0.71	0.83	0.98	1.15	1.42
104	10233000	0.44	0.59	0.71	0.90	1.07	1.26	1.48	1.83
105	10210000	0.38	0.51	0.62	0.80	0.94	1.12	1.32	1.62
106	10211000	0.42	0.56	0.69	0.87	1.04	1.23	1.45	1.79
107	10215700	0.41	0.55	0.67	0.86	1.02	1.21	1.43	1.76
108	10215900	0.31	0.40	0.48	0.60	0.71	0.84	0.98	1.21
109	10237500	0.43	0.56	0.67	0.84	1.00	1.17	1.38	1.70
[3]110	10204200	0.26	0.34	0.41	0.51	0.61	0.71	0.85	1.06
111	10236000	0.47	0.61	0.74	0.94	1.11	1.31	1.54	1.90
112	10236500	0.42	0.54	0.64	0.79	0.93	1.09	1.29	1.59
113	10205070	0.35	0.47	0.57	0.73	0.88	1.04	1.23	1.53
[5]114	10234000	0.49	0.63	0.76	0.96	1.14	1.33	1.57	1.94
115	10205300	0.66	0.90	1.11	1.40	1.67	1.96	2.30	2.85
116	10235000	0.42	0.54	0.66	0.83	0.98	1.15	1.35	1.67
117	10187300	0.38	0.48	0.59	0.73	0.86	1.02	1.19	1.47
Geohydrologic Region #6									
118	9310000	0.32	0.40	0.49	0.61	0.72	0.85	0.99	1.22
119	9310700	0.27	0.34	0.41	0.52	0.61	0.72	0.85	1.06
120	9312700	0.18	0.23	0.27	0.34	0.39	0.46	0.54	0.67
121	9271800	0.26	0.35	0.44	0.57	0.69	0.84	1.01	1.29
[1]122	9308200	0.16	0.20	0.24	0.31	0.36	0.43	0.51	0.65
123	9309100	0.31	0.42	0.51	0.67	0.81	0.98	1.17	1.48
124	9327600	0.45	0.64	0.79	1.05	1.28	1.55	1.86	2.36
125	9329050	0.37	0.48	0.58	0.73	0.86	1.01	1.18	1.46
126	9263800	0.44	0.61	0.76	1.00	1.22	1.48	1.78	2.26
127	9314400	0.28	0.37	0.46	0.60	0.73	0.88	1.06	1.35
[1]128	9328300	0.16	0.21	0.25	0.32	0.38	0.45	0.54	0.69
129	9315150	0.24	0.33	0.40	0.54	0.65	0.80	0.97	1.24
130	9315200	0.29	0.39	0.49	0.65	0.79	0.96	1.17	1.50
131	9328600	0.24	0.32	0.39	0.51	0.62	0.74	0.90	1.14
132	9328720	0.17	0.22	0.27	0.34	0.41	0.50	0.60	0.77
133	9315900	0.24	0.33	0.41	0.55	0.67	0.83	1.01	1.31
134	9338000	0.32	0.41	0.50	0.63	0.75	0.89	1.05	1.33
135	9330300	0.19	0.25	0.31	0.41	0.50	0.61	0.74	0.95
136	9338500	0.48	0.65	0.80	1.04	1.24	1.49	1.78	2.24
[1]137	9306235	0.39	0.53	0.61	0.73	0.84	0.95	0.00	0.00
138	9306240	0.35	0.48	0.55	0.66	0.75	0.85	0.00	0.00

Table A.5: Continued.

Map Unit ID	Gage Station Number	*Recurrence Year Rainfall Intensity using ADOT Time of Concentration Equation*							
		2 year (in/hr)	**5 year (in/hr)**	**10 year (in/hr)**	**25 year (in/hr)**	**50 year (in/hr)**	**100 year (in/hr)**	**200 year (in/hr)**	**500 year (in/hr)**
Geohydrologic Region #6 (continued)									
139	9328900	0.19	0.25	0.30	0.38	0.46	0.55	0.66	0.85
[1]140	9403800	0.49	0.67	0.83	1.07	1.29	1.54	1.83	2.29
141	9182600	0.33	0.44	0.56	0.73	0.89	1.08	1.31	1.67
[1]142	9306042	0.60	0.84	1.00	1.20	1.38	1.58	0.00	0.00
[4]143	9306052	0.29	0.39	0.45	0.54	0.61	0.69	0.00	0.00
[1]144	9306039	0.56	0.78	0.93	1.11	1.28	1.46	0.00	0.00
145	9163050	0.30	0.41	0.48	0.57	0.65	0.75	0.00	0.00
[1]146	9306036	0.37	0.51	0.60	0.71	0.82	0.93	0.00	0.00
[4]147	9163300	0.48	0.69	0.82	0.99	1.14	1.31	0.00	0.00
[4]148	9403750	0.60	0.83	1.04	1.35	1.64	1.96	2.35	2.97
149	9153290	0.22	0.30	0.35	0.42	0.47	0.54	0.00	0.00
150	9333900	0.21	0.29	0.35	0.46	0.56	0.68	0.82	1.05
[5]151	9153300	0.18	0.24	0.27	0.32	0.37	0.42	0.00	0.00
152	9181000	0.20	0.27	0.32	0.41	0.50	0.60	0.72	0.92
[4]153	9153200	0.36	0.49	0.57	0.68	0.77	0.88	0.00	0.00
[4]154	9379820	0.27	0.37	0.46	0.61	0.74	0.89	1.08	1.39
155	9152900	0.19	0.25	0.29	0.34	0.38	0.43	0.00	0.00
[6]156	9152650	0.20	0.27	0.32	0.37	0.43	0.48	0.00	0.00
157	9182000	0.43	0.57	0.70	0.90	1.07	1.28	1.52	1.90
158	9183500	0.28	0.36	0.43	0.55	0.65	0.78	0.93	1.17
159	9185200	0.25	0.33	0.39	0.51	0.61	0.73	0.88	1.11
160	9106200	0.26	0.36	0.42	0.51	0.58	0.66	0.00	0.00
161	9177500	0.33	0.44	0.53	0.68	0.82	0.98	1.16	1.46
[4]162	9379980	0.46	0.62	0.78	1.03	1.25	1.51	1.82	2.31
163	9104500	0.49	0.63	0.71	0.83	0.93	1.04	0.00	0.00
164	9334400	0.27	0.36	0.44	0.57	0.68	0.81	0.96	1.20
[4]165	9151700	0.34	0.46	0.53	0.63	0.72	0.81	0.00	0.00
166	9137800	0.48	0.62	0.71	0.83	0.94	1.06	0.00	0.00
[5]167	9185800	0.79	1.04	1.27	1.57	1.83	2.11	2.42	2.89
[4]168	9169800	0.44	0.59	0.68	0.81	0.92	1.04	0.00	0.00
169	9378170	0.43	0.57	0.69	0.88	1.03	1.21	1.40	1.70
170	9378630	0.50	0.66	0.81	1.01	1.18	1.37	1.59	1.91
171	9378950	0.33	0.44	0.53	0.68	0.80	0.95	1.11	1.36
[4]172	9168700	0.47	0.62	0.71	0.84	0.95	1.07	0.00	0.00
173	9175800	0.35	0.47	0.54	0.64	0.72	0.82	0.00	0.00
174	9379560	0.32	0.44	0.54	0.69	0.84	1.00	1.18	1.48
[1]175	9379100	0.66	0.88	1.09	1.40	1.66	1.97	2.31	2.84

Table A.5: Continued.

Map Unit ID	Gage Station Number	*Recurrence Year Rainfall Intensity using ADOT Time of Concentration Equation* 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	200 year (in/hr)	500 year (in/hr)
Geohydrologic Region #6 (continued)									
[4]176	9371300	0.39	0.56	0.67	0.81	0.93	1.07	0.00	0.00
177	9369500	0.41	0.57	0.66	0.79	0.91	1.03	0.00	0.00
178	9369000	0.37	0.50	0.59	0.70	0.80	0.91	0.00	0.00
[1]179	9379060	0.47	0.63	0.77	0.97	1.14	1.33	1.54	1.85
[1]180	9368020	0.51	0.68	0.82	1.03	1.20	1.39	1.59	1.88
[1]181	9367550	0.30	0.39	0.47	0.59	0.69	0.80	0.92	1.10
182	9367400	0.47	0.63	0.76	0.96	1.13	1.30	1.49	1.77
[1]183	9367530	0.32	0.43	0.52	0.65	0.76	0.88	1.02	1.22
[1]184	9367840	0.55	0.74	0.90	1.11	1.29	1.48	1.69	1.98
[1]185	9367860	0.34	0.45	0.54	0.66	0.77	0.88	1.01	1.19
[1]186	9367880	0.27	0.35	0.42	0.52	0.60	0.69	0.79	0.93
[1]187	9367900	0.33	0.44	0.53	0.65	0.76	0.87	0.99	1.17
Geohydrologic Region #7									
188	10241600	0.41	0.53	0.64	0.80	0.95	1.12	1.32	1.64
189	10241400	0.35	0.45	0.55	0.70	0.83	0.99	1.17	1.46
190	9408400	0.48	0.63	0.76	0.95	1.11	1.30	1.50	1.82
191	10241470	0.43	0.56	0.68	0.87	1.03	1.22	1.45	1.80
192	9406300	0.47	0.62	0.75	0.96	1.13	1.33	1.57	1.93
193	10241430	0.59	0.80	0.98	1.25	1.49	1.77	2.10	2.61
194	9406700	0.53	0.70	0.86	1.08	1.27	1.49	1.74	2.12
[1]195	9415100	0.33	0.44	0.54	0.70	0.83	0.98	1.14	1.39
196	9406800	0.37	0.47	0.57	0.71	0.83	0.97	1.12	1.36
197	9408000	0.41	0.53	0.64	0.80	0.94	1.10	1.28	1.54
[3]198	9415050	0.20	0.27	0.32	0.40	0.47	0.54	0.63	0.76
199	9405420	0.34	0.44	0.54	0.68	0.81	0.96	1.14	1.43
200	9404500	0.35	0.46	0.57	0.73	0.88	1.06	1.27	1.60

[1]Years with zero peak flows and flows below gage height were taken out, but there were still more than 10 years of peak flow data. Stations were used.
[2]Historic peaks were discounted from analyses. Stations used in analyses.
[3]Years with zero peak flows and flows below gage height were removed. Number of peaks dropped exceeded Bulletin 17B Specs. Stations were dropped.
[4]Years with zero peak flows and flows below gage height were removed. Number of peaks dropped below 10 years of record. Stations were dropped.
[5]Urbanization or flow regulation occurred, years dropped. Number of peaks dropped below 10 years of record. Stations were dropped.
[6]Urbanization or flow regulation occurred, years dropped. Number of peaks remained above 10 years of record. Stations used in analyses.
[7]Basins were delineated to have an area larger than 30 mi^2. Stations were dropped from analyses.

APPENDIX B: ANALYSIS OF TIME OF CONCENTRATION EQUATIONS

Memorandum

To: UDOT Staff and the Technical Advisory Committee for the UTRAC Project: *Improving Design Discharge Estimates in Utah*

From: Aaron Timpson and Christine Pomeroy

Date: July 17, 2009

Subject: Proposed method to calculate time of concentration for rural watersheds

---

The time of concentration is the primary quantity used in figuring the rainfall intensity in a watershed for use with the Rational Method equation. The process of determining the time of concentration for each watershed used in the analysis can be done two different ways: (1) using an empirical equation or (2) summing the travel times of overland flow, shallow concentrated flow, and channel flow. This memorandum summarizes results from analysis of these two methods and provides a recommendation for calculating time of concentration in the UTRAC project *Improving Design Discharge Estimates in Utah*. Thirteen watersheds in Region 4 were used in this evaluation.

B.1 Possible Empirical Time of Concentration Equations for Analysis

The Watershed Modeling System (WMS) software has pre-programmed equations used to empirically calculate the time of concentration for different types of watersheds. Since this research is concerned with rural areas and watersheds between 0.5 and 30 mi^2, most of the equations in WMS are not applicable because they are primarily for urban areas and watersheds with shallow slopes. Also, a number of equations are used to calculate lag time, which is the time difference between the "centroid of rainfall excess to the peak of the unit hydrograph," as shown in Figure B.1. Lag time (T_{LAG}) is then converted to time of concentration (T_C) through the relationship developed by SCS, which is $T_{LAG} = 0.6*T_C$ (Maidment 1993). A summary of these empirical equations is shown in Table B.1 (on the next page), including descriptions of their limiting factors and if each equation is applicable to the watersheds analyzed in this study.

In addition to evaluating the equations available in WMS, a brief literature review was conducted to see if other equations are available that are appropriate for Utah watersheds. The literature review did not yield additional equations that would be appropriate for the watersheds included in this study. Discussions with UDOT personnel, the technical advisory committee for this project and Brian McInerney at NOAA indicated that no equation exists to empirically estimate the time of concentration for rural watersheds in the state of Utah. However, since the Riverside County and ADOT equations were developed for similar watershed slopes and areas, these two equations were used to estimate time of concentration for the 13 watersheds in this preliminary analysis.

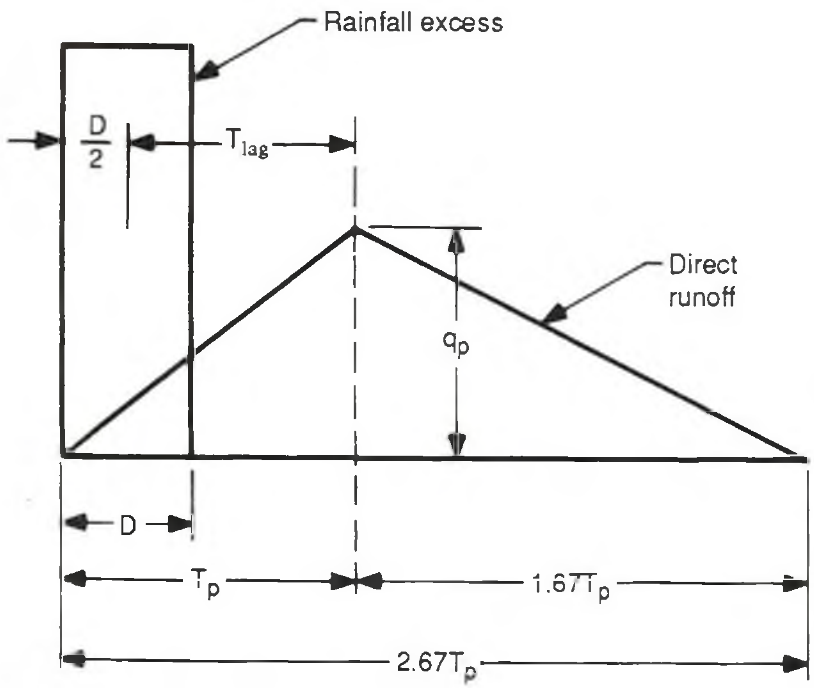

Figure B.1: SCS triangular hydrograph detailing lag time

Table B.1: List of empirical equations included in WMS*

Empirical equations already programmed into WMS		
Equation	**Limiting Factors**	**Applys to Rural Utah?**
Lag Time Equations		
Colorado State	Valid for > 10% impervious area	No
Denver	Valid for urban area and < 5 mi^2	No
Eagleson	Valid for urban area and < 7 mi^2	No
Espey	Valid for impervious area from 25 to 40%	No
Putnam	Valid for very shallow slopes (U.S. Great Planes)	Yes
Riverside County	Valid for mountainous/foothills/valley areas and < 650 mi^2	No
SCS	Valid for areas less than 2,000 acres	No
Taylor Schwartz	Developed for N.E. United States	No
Tulsa District	Valid for slopes under 90 ft/mi	No
Time of Concentration Equations		
Fort Bend	Valid for slopes under 33 ft/mi	No
Kerby	Valid for overland flow between 300 and 500 ft	No
Kirpich	Valid for small, agricultural watersheds and overland flows	No
Ramser	Valid for well-defined channels	No
ADOT	Valid for desert/mountainous large region areas	Yes

*Information taken from WMS help site: http://www.ems-i.com/wmshelp/Hydrologic_Models/Calculators/Computing_Travel_Times/Using_Basin_Data/Equations/Overview_of_Basin_Data_Equations.htm

B.2 Computing T_C by Travel Time Summation Method

Another way to compute the time of concentration is to sum the overall travel time from three basic water flow conditions: overland flow, shallow concentrated flow, and channel flow. WMS uses the program TR-55 to compute each travel time from the different types of flow conditions. However, the use of this method requires knowledge of the channel geometric characteristics (shape of cross-section, depth of flowing water calculated from an input discharge, and the channel slope) along with a Manning's roughness coefficient. Since the watersheds in this study are less than 30 mi^2, the streams/rivers within the watersheds are relatively small. In looking at the 13 Region 4 streams on Google Earth, most of the streams were found to be between 10 to 20 feet in width. With a stream this small and a DEM with only a 10 meter resolution, it is not possible to electronically compute accurate channel geometry. This would require manual surveys, which is not feasible for this project. Therefore, for the purpose of this analysis, the channel geometries were approximated as trapezoidal in shape with a 2:1 side slope; the base width of the channel was estimated based off aerial photography by averaging the upstream, middle, and downstream widths. In an average sized watershed (almost 15 mi^2) a 3:1 side slope was used as a comparison to the 2:1 side slope. However, the results appeared to have very little difference in rainfall intensity estimates (an average of 0.8%) compared to the effects a change in Manning's roughness (2.7%) and runoff flows (7.2%) had. Since the difference was very small, a 2:1 side slope was used for all of the river channels.

The 2-year and 100-year runoff flows estimated from the PeakFQ program were used to get the depth of water in the channel for each watershed. The depth of water in the channel was calculated by Manning's equation using the WMS-TR55 interface (since the flow was a known parameter). For Manning's equation, two different Manning's numbers were used (n = 0.065 and n = 0.080) to evaluate the impact of the selected roughness value on the results. These two roughness values were used because: (1) a natural mountain stream with steep sides, trees and brush along the banks, and larger cobble stones have a range of Manning's roughness from 0.04 to 0.07 (Chow 1959). (2) It is assumed that in the event of larger storms (possibly even the 2-year storm) the water level will raise into the overbanks where the roughness values can be 0.07 to 0.11. (3) Using a higher Manning's value will give a longer time of concentration.

B.3 Rainfall Intensities

Rainfall intensities were determined for each storm year (i.e., 1, 2, 5, 10, 25, 50, 100, 200, 500, 1000) using NOAA Atlas 14. Precipitation depths were obtained for respective time of concentration values; rainfall intensity was computed by dividing the rainfall depth by the time of concentration in hours to give rainfall intensity with units of in/hr.

B.4 Results from Analysis

The time of concentration was calculated by WMS using the travel time summation method for comparison to the time of concentration values computed from the selected empirical equation's values for 13 watersheds. Table B.2 summarizes the time of concentration values obtained from each approach. As expected, the results from Table B.2 show that a longer time of concentration returns a lower rainfall intensity. Also, the rainfall intensities for the empirical equations are closest to the 2-year flood flow with a

Manning's number of 0.08, which is a common pattern among the 13 watersheds in the study.

Tables B.3 and B.4 detail computed rainfall intensities for additional watersheds of different drainage area and channel slope. After investigating results from each of the watersheds, it was found that the size of the watershed and slope of the channel did not significantly impact differences in rainfall intensities derived from t_c computed by the empirical equations or the summation of flow travel time method.

Tables B.2, B.3, and B.4 show common trends for the 13 watersheds in the study, which are: (1) the ADOT equation has a slightly shorter time of concentration value than the Riverside County equation; (2) the ADOT and Riverside County equations generally estimate time of concentration values that are longer than the four geometric channel conditions; and (3) the lower flow (Q_2) and higher Manning's value (0.08) always produce the longest time of concentration (as expected). The ADOT equation typically estimated a time of concentration close to the longest value produced by the travel time summation method. Lastly, higher Manning's numbers produce longer times of concentration. Due to overbank flow conditions, it is possible that the Manning's number could be even higher than 0.08 under flood flows, which means the Riverside County equation may be more accurate than these results show.

Table B.2: Typical rainfall intensity results for a larger sized watershed

Watershed Geometric Properties	Empirical Equations		Travel Time Summation Method (Q is in cfs)			
Area = 20.11 mi^2 Channel Slope = 217.9 ft/mi. Bottom Width = 20 ft	ADOT	Riverside County	$Q_2 = 310$ n = 0.065	$Q_2 = 310$ n = 0.08	$Q_{100} = 640$ n = 0.065	$Q_{100} = 640$ n = 0.08
Time of Concentration, T_C (hr)	3.16	3.57	2.84	3.23	2.30	2.62
1-year Rain Intensity (in/hr)	0.23	0.21	0.24	0.22	0.27	0.25
2-year Rain Intensity (in/hr)	0.28	0.26	0.30	0.28	0.35	0.32
5-year Rain Intensity (in/hr)	0.36	0.33	0.39	0.36	0.45	0.41
10-year Rain Intensity (in/hr)	0.44	0.40	0.47	0.43	0.55	0.50
25-year Rain Intensity (in/hr)	0.55	0.50	0.60	0.54	0.71	0.64
50-year Rain Intensity (in/hr)	0.65	0.59	0.71	0.64	0.84	0.76
100-year Rain Intensity (in/hr)	0.77	0.69	0.84	0.76	1.01	0.90
200-year Rain Intensity (in/hr)	0.91	0.81	1.00	0.89	1.20	1.07
500-year Rain Intensity (in/hr)	1.13	1.02	1.25	1.11	1.51	1.34
1,000-year Rain Intensity (in/hr)	1.34	1.20	1.49	1.32	1.80	1.59

Table B.3: Typical rainfall intensity results for a medium sized watershed

Watershed Geometric Properties	Empirical Equations		Travel Time Summation Method (Q is in cfs)			
Area = 8.88 mi^2 Channel Slope = 432.5 ft/mi. Bottom Width = 10 ft	ADOT	Riverside County	$Q_2 = 75$ n = 0.065	$Q_2 = 75$ n = 0.08	$Q_{100} = 230$ n = 0.065	$Q_{100} = 230$ n = 0.08
Time of Concentration, T_C (hr)	1.85	1.93	1.65	1.87	1.22	1.38
1-year Rain Intensity (in/hr)	0.33	0.32	0.35	0.32	1.44	0.40
2-year Rain Intensity (in/hr)	0.42	0.41	0.45	0.41	0.57	0.52
5-year Rain Intensity (in/hr)	0.55	0.53	0.60	0.55	0.77	0.69
10-year Rain Intensity (in/hr)	0.67	0.65	0.73	0.66	0.94	0.85
25-year Rain Intensity (in/hr)	0.86	0.83	0.94	0.85	1.21	1.09
50-year Rain Intensity (in/hr)	1.04	1.00	1.13	1.03	1.44	1.30
100-year Rain Intensity (in/hr)	1.24	1.20	1.35	1.23	1.72	1.55
200-year Rain Intensity (in/hr)	1.48	1.43	1.61	1.47	2.04	1.84
500-year Rain Intensity (in/hr)	1.87	1.81	2.03	1.85	2.55	2.32
1,000-year Rain Intensity (in/hr)	2.22	2.16	2.41	2.21	3.04	2.75

Table B.4: Typical rainfall intensity results for a smaller sized watershed

Watershed Geometric Properties	Empirical Equations		Travel Time Summation Method (Q is in cfs)			
Area = 3.06 mi^2 Channel Slope = 474.1 ft/mi. Bottom Width = 10 ft	ADOT	Riverside County	Q_2 = 70 n = 0.065	Q_2 = 70 n = 0.08	Q_{100} = 190 n = 0.065	Q_{100} = 190 n = 0.08
Time of Concentration, T_C (hr)	1.21	1.20	0.93	1.04	0.73	0.82
1-year Rain Intensity (in/hr)	0.39	0.40	0.47	0.44	0.55	0.51
2-year Rain Intensity (in/hr)	0.50	0.50	0.60	0.55	0.70	0.65
5-year Rain Intensity (in/hr)	0.68	0.69	0.83	0.76	0.97	0.90
10-year Rain Intensity (in/hr)	0.84	0.85	1.02	0.95	1.20	1.11
25-year Rain Intensity (in/hr)	1.09	1.10	1.33	1.23	1.56	1.45
50-year Rain Intensity (in/hr)	1.32	1.33	1.61	1.49	1.88	1.75
100-year Rain Intensity (in/hr)	1.59	1.60	1.93	1.79	2.26	2.10
200-year Rain Intensity (in/hr)	1.89	1.91	2.31	2.13	2.70	2.51
500-year Rain Intensity (in/hr)	2.38	2.40	2.91	2.68	3.41	3.17
1,000-year Rain Intensity (in/hr)	2.84	2.85	3.46	3.20	4.05	3.76

B.5 Conclusions and Recommendations

The ADOT and Riverside County empirical equations consistently produce results similar to those obtained from the travel time summation method. Although the empirical equations consistently produce rainfall intensities lower than those generated by the travel time summation method, short of conducting field experiments, it is not possible to know that the empirical equations are overestimating time of concentration. Additionally, there is a significant amount of uncertainty in the methods used to estimate the channel geometric characteristics in this analysis, so it is not possible to determine if the computed time of concentration values are accurate. It is recommended that future research be conducted to create empirical time of concentration equations specific for Utah.

Given that time of concentration values generated by the empirical equations and the travel time summation method produce results that are “in the same ballpark”, it suggested the empirical equations should be used for calculating the time of concentration of the watersheds. Reasons for this are: (1) The equations are included in WMS and can be used by UDOT staff and other engineers in an automated manner; (2) Professional judgment is required to estimate geometric characteristics for the channels, this has the potential to be done incorrectly, or inconsistent with the methods used in this study which could create a lot of variability in resulting discharge estimates.

At this time it is not possible to distinguish whether the ADOT or Riverside County equations will produce the better results for this project. Both methods for computing time of concentration will be evaluated in this project; the equation that produces the better regression equations will be included in the final methodology.

B.6 References

Chow, V.T. (1959). *Open-channel hydraulics*. McGraw-Hill.

Maidment, D.R. (1993). *Handbook of Hydrology*. McGraw-Hill.

APPENDIX C: CALCULATED RUNOFF COEFFICIENTS FOR WATERSHEDS

Table C.1: Computed runoff coefficients associated with each rain gage station using the relationship: *C = Q/(iA)*. Values showing "ND" indicated values that are not determined due to insufficient data.

Map Unit ID	Gage Station Number	***Computed Recurrence Year Runoff Coefficients for Each Gage Station*** **[cfs/(in-mi^2/hr)]**							
		C_2 year	**C_5 year**	**C_{10} year**	**C_{25} year**	**C_{50} year**	**C_{100} year**	**C_{200} year**	**C_{500} year**
					Geohydrologic Region #1				
1	10090800	27	41	50	60	64	68	ND	ND
2	10069000	9	10	10	11	11	11	ND	ND
3	10099000	35	41	43	42	41	39	37	34
4	10102300	33	36	35	33	31	29	26	23
5	9208000	79	70	65	60	56	52	ND	ND
[1]6	9204700	20	37	51	71	84	99	ND	ND
[2]7	10019700	27	34	38	44	47	50	ND	ND
[5]8	9214000	ND	ND	ND	ND	ND	ND	ND	ND
9	10130000	21	32	37	41	43	43	43	41
10	10129350	24	25	24	21	19	18	16	13
11	10128200	31	27	24	20	17	15	13	11
12	9216290	59	88	115	160	197	241	ND	ND
[5]13	10011200	ND	ND	ND	ND	ND	ND	ND	ND
14	9221680	36	86	140	241	338	461	ND	ND
[5]15	9224600	201	340	411	523	607	709	ND	ND
[1]16	9224800	22	54	91	162	232	327	ND	ND
[4]17	9216350	6	13	23	46	73	117	ND	ND
[3]18	9224810	8	21	36	63	89	123	ND	ND
[1]19	9224820	20	52	90	164	240	343	ND	ND
[1]20	9224840	29	41	52	67	78	92	ND	ND
21	9227500	25	30	32	33	34	34	34	33
22	9226500	39	48	51	53	53	53	52	50
23	9225200	77	114	143	186	216	249	ND	ND
[4]24	9229450	30	86	154	292	437	636	ND	ND
[1,2]25	9225300	107	333	588	1,059	1,491	2,017	ND	ND

Table C.1: Continued.

Map Unit ID	Gage Station Number	*Computed Recurrence Year Runoff Coefficients for Each Gage Station* [cfs/(in-mi^2/hr)]							
		C_2 year	C_5 year	C_{10} year	C_{25} year	C_{50} year	C_{100} year	C_{200} year	C_{500} year
Geohydrologic Region #2									
26	10137680	25	25	24	22	20	18	17	14
27	10141400	42	44	43	40	36	33	30	25
28	10139300	19	31	38	44	47	49	50	50
[4]29	10172810	ND	ND	ND	ND	ND	ND	ND	ND
30	10141500	10	13	14	15	14	14	14	13
31	10172805	10	15	18	22	24	26	28	29
32	10172800	14	19	20	21	22	22	21	21
33	10142000	32	40	42	43	42	40	39	36
34	10142500	11	18	21	25	27	28	29	29
35	10143000	10	13	13	13	13	12	11	10
36	10143500	8	11	12	13	14	14	14	14
37	10145126	63	85	94	101	103	104	103	101
38	10144000	11	23	34	51	66	84	103	133
39	10135000	24	29	29	27	25	23	20	17
40	10145000	11	15	17	18	18	18	17	16
[1]41	10172760	9	20	28	40	48	56	63	72
42	10172791	3	5	6	8	8	9	9	9
43	10172765	6	9	10	10	10	11	10	10
44	10172500	12	14	15	15	14	13	12	11
[4]45	10172790	4	9	13	17	20	23	25	28
46	10172200	5	8	10	11	12	13	13	13
47	10172000	4	6	7	8	9	9	9	9
48	10170000	7	9	9	9	9	8	8	7
[4]49	10172720	ND	ND	ND	ND	ND	ND	ND	ND
50	10166430	4	8	12	18	23	29	36	47
51	10167500	40	43	42	40	37	35	32	28
52	10133700	7	7	7	7	6	6	5	5
53	10133600	22	28	30	30	29	27	26	24
54	10165500	47	49	48	45	42	39	36	32
55	10172700	3	9	15	25	35	48	64	89
56	10160000	8	9	9	9	8	8	7	6
57	10160800	21	23	22	21	19	18	17	15
Geohydrologic Region #3									
58	10172909	0	2	6	16	32	61	112	238
59	10172920	1	2	5	11	19	31	51	91
60	13077700	18	22	24	26	28	29	29	30

Table C.1: Continued.

Map Unit ID	Gage Station Number	*Computed Recurrence Year Runoff Coefficients for Each Gage Station* [cfs/(in-mi²/hr)]							
		C_2 year	C_5 year	C_{10} year	C_{25} year	C_{50} year	C_{100} year	C_{200} year	C_{500} year
Geohydrologic Region #3 (continued)									
61	13079000	20	25	27	28	29	30	30	30
62	10172913	2	14	34	79	132	199	285	422
63	10172952	13	17	19	20	21	21	21	21
[4]64	10172925	3	38	124	413	842	1,547	2,644	4,863
65	10122500	16	20	23	27	29	31	ND	ND
[4]66	10172902	2	125	677	3,084	7,123	13,830	23,462	40,601
67	10126180	28	28	26	23	21	19	17	15
68	10172900	21	83	142	244	330	423	516	628
[4]69	10172905	ND	ND	ND	ND	ND	ND	ND	ND
[4]70	10172835	0	1	3	8	15	26	42	73
71	10172870	13	19	21	22	22	22	22	21
[4]72	10172830	ND	ND	ND	ND	ND	ND	ND	ND
[4]73	10172885	1	51	275	1,492	4,142	9,902	21,293	50,776
74	10243260	5	7	9	11	12	13	15	16
75	10243240	10	14	16	18	18	19	19	19
76	10242460	8	35	65	113	154	197	240	294
77	10242440	58	118	164	228	280	333	387	465
Geohydrologic Region #4									
78	9216600	58	82	104	139	167	200	ND	ND
79	9216900	31	37	42	48	51	55	ND	ND
80	9235600	8	13	15	18	19	21	22	22
81	9264000	58	57	54	48	44	40	36	31
82	9264500	55	57	54	49	45	41	37	32
83	9268500	21	24	24	23	22	21	20	18
84	9268900	65	74	73	70	66	62	57	50
85	9269000	32	36	36	33	30	28	25	21
86	9273500	24	26	25	23	21	20	18	16
87	9276000	14	16	16	15	14	13	12	10
88	9278000	19	21	21	19	18	17	15	13
89	9280400	46	49	48	45	42	39	36	32
90	9287500	7	12	15	19	21	24	26	28
91	9298000	19	29	33	35	36	35	34	31
[7]92	10153500	51	50	47	42	38	35	32	27
93	10153800	56	60	59	54	50	46	42	37
94	10154000	64	55	48	40	35	30	26	22

Table C.1: Continued.

Map Unit ID	Gage Station Number	*Computed Recurrence Year Runoff Coefficients for Each Gage Station* [cfs/(in-mi²/hr)]							
		C_2 year	C_5 year	C_{10} year	C_{25} year	C_{50} year	C_{100} year	C_{200} year	C_{500} year
Geohydrologic Region #5									
[1]95	10146900	110	315	496	745	931	1,112	1,278	1,473
96	10147500	20	29	32	34	35	35	34	33
97	10147000	13	17	18	18	18	17	16	15
[1]98	10220300	15	29	39	52	61	70	78	89
99	10224100	7	11	14	18	21	23	26	29
100	10148300	39	77	108	154	194	238	290	365
101	10219200	7	15	22	33	41	50	59	71
102	10148200	4	10	17	31	47	69	98	152
103	10208500	34	51	62	75	84	93	102	114
104	10233000	9	14	17	20	22	23	24	25
105	10210000	25	40	50	64	75	86	99	116
106	10211000	25	36	43	52	59	65	71	80
107	10215700	27	33	35	36	36	36	36	35
108	10215900	40	44	45	43	42	40	38	35
109	10237500	4	7	8	10	11	13	14	15
[3]110	10204200	0	3	7	19	33	54	80	127
111	10236000	6	9	10	11	12	12	12	12
112	10236500	18	38	52	71	83	96	105	117
113	10205070	9	27	48	89	132	189	262	388
[5]114	10234000	ND	ND	ND	ND	ND	ND	ND	ND
115	10205300	9	14	16	18	18	19	19	19
116	10235000	5	10	13	17	20	22	24	26
117	10187300	6	7	7	6	6	5	5	4
Geohydrologic Region #6									
118	9310000	41	46	45	42	40	37	35	31
119	9310700	14	21	24	27	29	30	31	31
120	9312700	9	14	17	20	22	24	25	27
121	9271800	69	168	239	320	369	407	435	458
[1]122	9308200	37	310	776	1,789	2,845	4,079	5,447	7,246
123	9309100	102	313	495	723	879	1,013	1,125	1,225
124	9327600	325	736	1,090	1,607	2,039	2,492	2,982	3,669
125	9329050	20	23	23	21	20	18	17	15
126	9263800	453	875	1,136	1,439	1,618	1,770	1,892	2,009
127	9314400	241	431	544	659	734	798	843	884
[1]128	9328300	145	305	414	553	646	725	784	845
129	9315150	375	758	1,040	1,351	1,567	1,758	1,905	2,074

Table C.1: Continued.

Map Unit ID	Gage Station Number	*Computed Recurrence Year Runoff Coefficients for Each Gage Station* [cfs/(in-mi^2/hr)]							
		C_2 year	C_5 year	C_{10} year	C_{25} year	C_{50} year	C_{100} year	C_{200} year	C_{500} year
Geohydrologic Region #6 (continued)									
130	9315200	656	1,232	1,557	1,844	1,993	2,084	2,112	2,100
131	9328600	134	280	382	513	606	692	768	860
132	9328720	86	235	357	517	627	723	805	884
133	9315900	245	531	746	1,028	1,239	1,440	1,625	1,864
134	9338000	31	36	36	35	33	31	28	25
135	9330300	239	428	528	608	637	651	646	622
136	9338500	18	41	59	85	105	125	144	168
[1]137	9306235	4	15	30	62	98	148	ND	ND
138	9306240	4	11	21	39	58	82	ND	ND
139	9328900	96	197	282	412	520	639	764	937
[1]140	9403800	113	349	570	902	1,180	1,459	1,742	2,107
141	9182600	283	570	778	1,066	1,294	1,509	1,728	2,014
[1]142	9306042	11	53	127	326	593	1,012	ND	ND
[4]143	9306052	2	4	4	6	7	7	ND	ND
[1]144	9306039	4	25	73	239	516	1,041	ND	ND
145	9163050	68	90	106	127	140	153	ND	ND
[1]146	9306036	8	32	66	145	236	363	ND	ND
[4]147	9163300	ND	ND	ND	ND	ND	ND	ND	ND
[4]148	9403750	ND	ND	ND	ND	ND	ND	ND	ND
149	9153290	44	44	44	44	44	43	ND	ND
150	9333900	142	189	210	220	222	221	215	204
[5]151	9153300	ND	ND	ND	ND	ND	ND	ND	ND
152	9181000	185	270	309	335	341	341	331	314
[4]153	9153200	ND	ND	ND	ND	ND	ND	ND	ND
[4]154	9379820	7	39	94	238	437	747	1,220	2,202
155	9152900	45	47	47	46	45	43	ND	ND
[6]156	9152650	79	93	101	110	113	115	ND	ND
157	9182000	3	4	4	5	5	5	5	5
158	9183500	25	42	53	66	74	81	88	95
159	9185200	121	147	154	154	150	143	136	126
160	9106200	47	64	76	89	96	102	ND	ND
161	9177500	22	39	49	58	62	65	67	67
[4]162	9379980	ND	ND	ND	ND	ND	ND	ND	ND
163	9104500	13	15	16	18	19	20	ND	ND
164	9334400	74	261	459	779	1,055	1,357	1,668	2,091
[4]165	9151700	ND	ND	ND	ND	ND	ND	ND	ND

Table C.1: Continued.

Map Unit ID	Gage Station Number	*Computed Recurrence Year Runoff Coefficients for Each Gage Station* [cfs/(in-mi^2/hr)]							
		C_2 year	C_5 year	C_{10} year	C_{25} year	C_{50} year	C_{100} year	C_{200} year	C_{500} year
Geohydrologic Region #6 (continued)									
166	9137800	10	12	13	14	14	14	ND	ND
[5]167	9185800	ND	ND	ND	ND	ND	ND	ND	ND
[4]168	9169800	ND	ND	ND	ND	ND	ND	ND	ND
169	9378170	10	17	21	26	29	33	36	41
170	9378630	6	14	20	28	35	42	50	60
171	9378950	220	321	386	470	534	599	664	758
[4]172	9168700	46	111	170	263	338	416	ND	ND
173	9175800	79	216	355	585	782	996	ND	ND
174	9379560	235	361	439	542	614	687	759	851
[1]175	9379100	205	1,020	2,240	4,982	8,251	12,732	18,854	29,803
[4]176	9371300	32	155	354	840	1,430	2,282	ND	ND
177	9369500	21	28	33	38	40	42	ND	ND
178	9369000	26	33	37	43	46	49	ND	ND
[1]179	9379060	20	58	98	165	229	305	395	538
[1]180	9368020	109	205	276	373	450	533	624	751
[1]181	9367550	100	262	411	640	836	1,059	1,298	1,648
182	9367400	120	259	372	538	676	833	1,005	1,250
[1]183	9367530	116	198	252	321	369	418	467	532
[1]184	9367840	241	401	497	606	678	743	798	869
[1]185	9367860	324	550	695	872	998	1,119	1,238	1,390
[1]186	9367880	238	322	362	403	427	449	468	486
[1]187	9367900	182	337	441	569	661	751	835	939
Geohydrologic Region #7									
188	10241600	7	17	28	45	62	82	106	142
189	10241400	7	17	28	46	62	81	103	136
190	9408400	7	13	17	21	25	29	32	37
191	10241470	10	19	25	34	42	49	56	65
192	9406300	31	60	83	113	138	162	188	221
193	10241430	5	6	6	7	7	7	7	7
194	9406700	34	70	97	134	163	191	218	254
[1]195	9415100	28	160	367	830	1,370	2,106	3,073	4,723
196	9406800	38	71	94	124	145	165	186	210
197	9408000	25	82	148	268	393	543	731	1,033
[3]198	9415050	1	15	51	181	397	781	1,416	2,841
199	9405420	21	31	38	45	50	54	58	62

Table C.1: Continued.

Map Unit ID	Gage Station Number	*Computed Recurrence Year Runoff Coefficients for Each Gage Station* [cfs/(in-mi^2/hr)]							
		C_2 year	C_5 year	C_{10} year	C_{25} year	C_{50} year	C_{100} year	C_{200} year	C_{500} year
Geohydrologic Region #7 (continued)									
200	9404500	76	296	542	949	1,308	1,687	2,088	2,629

[1]Years with zero peak flows and flows below gage height were taken out, but there were still more than 10 years of peak flow data. Stations were used.

[2]Historic peaks were discounted from analyses. Stations used in analyses.

[3]Years with zero peak flows and flows below gage height were removed. Number of peaks dropped exceeded Bulletin 17B Specs. Stations were dropped.

[4]Years with zero peak flows and flows below gage height were removed. Number of peaks dropped below 10 years of record. Stations were dropped.

[5]Urbanization or flow regulation occurred, years dropped. Number of peaks dropped below 10 years of record. Stations were dropped.

[6]Urbanization or flow regulation occurred, years dropped. Number of peaks remained above 10 years of record. Stations used in analyses.

[7]Basins were delineated to have an area larger than 30 mi^2. Stations were dropped from analyses.

APPENDIX D: CORRELATION MATRICES FOR DATA RELATIONSHIPS

Table D.1: Correlation relationships between the recurrence year runoff coefficients and the explanatory variables in the regression analyses. Note that "ND" indicates that correlations couldn't be made for the recurrence year in question.

Explanatory Variable	Correlations of Each Recurrence Year Runoff Coefficient with Explanatory Variables								
	Log (C_2)	Log (C_5)	Log (C_{10})	Log (C_{25})	Log (C_{50})	Log (C_{100})	Log (C_{200})	Log (C_{500})	Average Correlation
Geohydrologic Region #1									
Log(Basin Slope)	-0.102	-0.453	-0.574	-0.659	-0.694	-0.719	ND	ND	-0.534
Log(MF Distance)	0.133	-0.072	-0.161	-0.231	-0.260	-0.284	ND	ND	-0.146
Log(MF Slope)	-0.126	-0.430	-0.538	-0.615	-0.647	-0.670	ND	ND	-0.504
Log(Flow South)	0.035	-0.121	-0.170	-0.203	-0.221	-0.232	ND	ND	-0.152
Log(Basin Length)	0.125	-0.079	-0.167	-0.234	-0.262	-0.284	ND	ND	-0.150
Log(Shape Factor)	0.227	0.177	0.155	0.141	0.134	0.130	ND	ND	0.161
Log(Sinuosity)	0.168	-0.001	-0.085	-0.156	-0.187	-0.214	ND	ND	-0.079
Log(Mean Elevation)	-0.045	-0.341	-0.441	-0.508	-0.534	-0.552	ND	ND	-0.404
Log(Composite CN)	0.318	0.503	0.548	0.573	0.582	0.587	ND	ND	0.519
Log(Ksat Surface)	0.391	0.608	0.664	0.697	0.710	0.719	ND	ND	0.632
Log(Ksat [0 to 12])	0.377	0.591	0.645	0.677	0.689	0.697	ND	ND	0.613
Log(Ksat [0 to 24])	0.373	0.577	0.627	0.655	0.665	0.671	ND	ND	0.595
Log(Ksat Full Depth)	0.393	0.605	0.658	0.689	0.702	0.710	ND	ND	0.626
Log(MAP)	-0.189	-0.553	-0.674	-0.759	-0.793	-0.818	ND	ND	-0.631
Log(2yr, 24hr Prec.)	-0.163	-0.478	-0.591	-0.672	-0.706	-0.731	ND	ND	-0.557
Geohydrologic Region #2									
Log(Basin Slope)	-0.318	-0.366	-0.380	-0.375	-0.359	-0.338	-0.314	-0.282	-0.342
Log(MF Distance)	-0.034	-0.077	-0.098	-0.118	-0.123	-0.128	-0.131	-0.134	-0.105
Log(MF Slope)	-0.087	-0.109	-0.122	-0.128	-0.130	-0.126	-0.119	-0.109	-0.116
Log(Flow South)	-0.436	-0.484	-0.491	-0.474	-0.447	-0.414	-0.382	-0.341	-0.434
Log(Basin Length)	-0.020	-0.082	-0.117	-0.153	-0.167	-0.179	-0.188	-0.195	-0.138
Log(Shape Factor)	0.291	0.244	0.196	0.129	0.079	0.036	-0.002	-0.044	0.116

Table D.1: Continued.

Explanatory Variable	Correlations of Each Recurrence Year Runoff Coefficient with Explanatory Variables								
	Log (C_2)	Log (C_5)	Log (C_{10})	Log (C_{25})	Log (C_{50})	Log (C_{100})	Log (C_{200})	Log (C_{500})	Average Correlation
Geohydrologic Region #2 (continued)									
Log(Sinuosity)	-0.072	-0.011	0.040	0.095	0.132	0.159	0.179	0.197	0.090
Log(Mean Elevation)	-0.154	-0.215	-0.243	-0.257	-0.256	-0.249	-0.239	-0.222	-0.229
Log(Composite CN)	-0.025	0.009	0.036	0.069	0.089	0.104	0.115	0.125	0.065
Log(Ksat Surface)	0.230	0.244	0.243	0.225	0.205	0.184	0.164	0.138	0.204
Log(Ksat [0 to 12])	0.486	0.485	0.459	0.403	0.351	0.302	0.256	0.202	0.368
Log(Ksat [0 to 24])	0.525	0.507	0.467	0.395	0.333	0.275	0.223	0.163	0.361
Log(Ksat Full Depth)	0.561	0.536	0.491	0.410	0.341	0.278	0.221	0.155	0.374
Log(MAP)	0.192	0.103	0.038	-0.036	-0.084	-0.121	-0.151	-0.181	-0.030
Log(2yr, 24hr Prec.)	0.264	0.187	0.128	0.053	0.003	-0.039	-0.074	-0.110	0.052
Geohydrologic Region #3									
Log(Basin Slope)	-0.086	-0.283	-0.377	-0.439	-0.450	-0.444	ND	ND	-0.347
Log(MF Distance)	-0.240	-0.261	-0.258	-0.230	-0.199	-0.167	ND	ND	-0.226
Log(MF Slope)	0.026	-0.267	-0.431	-0.567	-0.618	-0.639	ND	ND	-0.416
Log(Flow South)	-0.312	-0.401	-0.409	-0.372	-0.325	-0.278	ND	ND	-0.350
Log(Basin Length)	-0.264	-0.265	-0.249	-0.207	-0.170	-0.133	ND	ND	-0.215
Log(Shape Factor)	-0.099	-0.040	0.000	0.044	0.071	0.093	ND	ND	0.012
Log(Sinuosity)	-0.050	-0.150	-0.211	-0.252	-0.265	-0.266	ND	ND	-0.199
Log(Mean Elevation)	-0.032	-0.223	-0.332	-0.425	-0.458	-0.474	ND	ND	-0.324
Log(Composite CN)	-0.193	-0.087	-0.030	0.018	0.036	0.046	ND	ND	-0.035
Log(Ksat Surface)	-0.155	0.009	0.112	0.217	0.270	0.299	ND	ND	0.125
Log(Ksat [0 to 12])	-0.128	-0.158	-0.167	-0.151	-0.131	-0.112	ND	ND	-0.141
Log(Ksat [0 to 24])	-0.114	-0.159	-0.177	-0.170	-0.154	-0.137	ND	ND	-0.152
Log(Ksat Full Depth)	-0.121	-0.164	-0.179	-0.168	-0.149	-0.130	ND	ND	-0.152
Log(MAP)	0.518	0.163	-0.096	-0.381	-0.539	-0.649	ND	ND	-0.164
Log(2yr, 24hr Prec.)	0.632	0.398	0.199	-0.048	-0.201	-0.316	ND	ND	0.111
Geohydrologic Region #4									
Log(Basin Slope)	-0.535	-0.577	-0.594	-0.587	-0.569	-0.542	ND	ND	-0.567
Log(MF Distance)	-0.118	-0.089	-0.092	-0.101	-0.098	-0.102	ND	ND	-0.100
Log(MF Slope)	0.130	0.011	-0.090	-0.218	-0.301	-0.364	ND	ND	-0.139
Log(Flow South)	0.198	0.140	0.111	0.078	0.049	0.029	ND	ND	0.101
Log(Basin Length)	-0.148	-0.141	-0.164	-0.198	-0.208	-0.224	ND	ND	-0.181

Table D.1: Continued.

Explanatory Variable	Correlations of Each Recurrence Year Runoff Coefficient with Explanatory Variables								
	Log (C_2)	Log (C_5)	Log (C_{10})	Log (C_{25})	Log (C_{50})	Log (C_{100})	Log (C_{200})	Log (C_{500})	Average Correlation
Geohydrologic Region #4 (continued)									
Log(Shape Factor)	0.020	0.012	-0.004	-0.028	-0.041	-0.056	ND	ND	-0.016
Log(Sinuosity)	0.011	0.097	0.172	0.263	0.318	0.360	ND	ND	0.204
Log(Mean Elevation)	0.141	0.019	-0.115	-0.297	-0.405	-0.499	ND	ND	-0.193
Log(Composite CN)	0.449	0.400	0.389	0.374	0.359	0.349	ND	ND	0.387
Log(Ksat Surface)	0.066	0.038	0.000	-0.052	-0.084	-0.111	ND	ND	-0.024
Log(Ksat [0 to 12])	0.073	0.051	0.010	-0.049	-0.088	-0.123	ND	ND	-0.021
Log(Ksat [0 to 24])	0.203	0.170	0.107	0.011	-0.056	-0.117	ND	ND	0.053
Log(Ksat Full Depth)	0.383	0.316	0.222	0.081	-0.018	-0.106	ND	ND	0.146
Log(MAP)	0.065	-0.069	-0.208	-0.392	-0.500	-0.590	ND	ND	-0.282
Log(2yr, 24hr Prec.)	0.037	-0.094	-0.230	-0.410	-0.515	-0.603	ND	ND	-0.303
Geohydrologic Region #5									
Log(Basin Slope)	-0.293	-0.355	-0.365	-0.358	-0.347	-0.333	-0.318	-0.297	-0.333
Log(MF Distance)	-0.283	-0.260	-0.243	-0.221	-0.205	-0.193	-0.183	-0.170	-0.220
Log(MF Slope)	-0.050	-0.167	-0.215	-0.251	-0.269	-0.279	-0.284	-0.287	-0.225
Log(Flow South)	-0.162	-0.048	0.012	0.072	0.108	0.137	0.160	0.185	0.058
Log(Basin Length)	-0.312	-0.291	-0.272	-0.248	-0.230	-0.215	-0.202	-0.187	-0.245
Log(Shape Factor)	-0.212	-0.124	-0.082	-0.040	-0.019	-0.001	0.010	0.022	-0.056
Log(Sinuosity)	0.120	0.142	0.143	0.136	0.130	0.122	0.114	0.104	0.126
Log(Mean Elevation)	-0.292	-0.489	-0.565	-0.619	-0.641	-0.653	-0.659	-0.660	-0.572
Log(Composite CN)	-0.112	-0.022	0.021	0.060	0.078	0.093	0.104	0.112	0.042
Log(Ksat Surface)	-0.227	-0.171	-0.141	-0.113	-0.099	-0.086	-0.077	-0.068	-0.123
Log(Ksat [0 to 12])	-0.224	-0.178	-0.154	-0.132	-0.122	-0.113	-0.107	-0.101	-0.141
Log(Ksat [0 to 24])	-0.248	-0.191	-0.162	-0.136	-0.124	-0.113	-0.106	-0.099	-0.147
Log(Ksat Full Depth)	-0.307	-0.204	-0.155	-0.109	-0.087	-0.067	-0.054	-0.041	-0.128
Log(MAP)	-0.189	-0.384	-0.464	-0.525	-0.552	-0.570	-0.580	-0.587	-0.481
Log(2yr, 24hr Prec.)	-0.510	-0.609	-0.642	-0.659	-0.665	-0.664	-0.661	-0.654	-0.633
Geohydrologic Region #6									
Log(Basin Slope)	-0.236	-0.269	-0.277	-0.279	-0.278	-0.275	ND	ND	-0.269
Log(MF Distance)	-0.095	-0.238	-0.309	-0.376	-0.415	-0.446	ND	ND	-0.313
Log(MF Slope)	-0.249	-0.279	-0.286	-0.287	-0.284	-0.280	ND	ND	-0.278
Log(Flow South)	0.155	0.036	-0.030	-0.094	-0.132	-0.163	ND	ND	-0.038

Table D.1: Continued.

Explanatory Variable	Correlations of Each Recurrence Year Runoff Coefficient with Explanatory Variables								
	Log (C_2)	Log (C_5)	Log (C_{10})	Log (C_{25})	Log (C_{50})	Log (C_{100})	Log (C_{200})	Log (C_{500})	Average Correlation
Geohydrologic Region #6 (continued)									
Log(Basin Length)	-0.133	-0.271	-0.337	-0.398	-0.432	-0.460	ND	ND	-0.339
Log(Shape Factor)	-0.051	-0.047	-0.039	-0.027	-0.020	-0.013	ND	ND	-0.033
Log(Sinuosity)	0.124	0.010	-0.059	-0.134	-0.180	-0.219	ND	ND	-0.076
Log(Mean Elevation)	-0.626	-0.665	-0.664	-0.648	-0.631	-0.613	ND	ND	-0.641
Log(Composite CN)	-0.017	0.061	0.100	0.135	0.152	0.164	ND	ND	0.099
Log(Ksat Surface)	0.048	0.062	0.066	0.069	0.070	0.071	ND	ND	0.064
Log(Ksat [0 to 12])	0.018	0.055	0.068	0.078	0.082	0.086	ND	ND	0.065
Log(Ksat [0 to 24])	0.001	0.032	0.042	0.048	0.051	0.054	ND	ND	0.038
Log(Ksat Full Depth)	-0.013	-0.010	-0.014	-0.018	-0.020	-0.022	ND	ND	-0.016
Log(MAP)	-0.720	-0.776	-0.777	-0.759	-0.739	-0.717	ND	ND	-0.748
Log(2yr, 24hr Prec.)	-0.507	-0.584	-0.605	-0.611	-0.607	-0.599	ND	ND	-0.586
Geohydrologic Region #7									
Log(Basin Slope)	-0.217	-0.369	-0.403	-0.420	-0.423	-0.423	-0.419	-0.413	-0.386
Log(MF Distance)	-0.009	-0.074	-0.085	-0.086	-0.084	-0.081	-0.075	-0.068	-0.070
Log(MF Slope)	-0.011	-0.220	-0.282	-0.327	-0.347	-0.361	-0.371	-0.381	-0.288
Log(Flow South)	0.759	0.762	0.747	0.729	0.718	0.708	0.700	0.690	0.727
Log(Basin Length)	-0.003	-0.036	-0.036	-0.029	-0.022	-0.015	-0.006	0.005	-0.018
Log(Shape Factor)	0.321	0.406	0.425	0.438	0.441	0.444	0.445	0.446	0.421
Log(Sinuosity)	-0.124	-0.280	-0.324	-0.358	-0.375	-0.388	-0.397	-0.407	-0.332
Log(Mean Elevation)	-0.423	-0.630	-0.682	-0.716	-0.730	-0.741	-0.747	-0.752	-0.678
Log(Composite CN)	0.250	0.306	0.315	0.317	0.316	0.314	0.312	0.309	0.305
Log(Ksat Surface)	0.754	0.839	0.844	0.836	0.827	0.818	0.809	0.797	0.816
Log(Ksat [0 to 12])	0.717	0.810	0.818	0.814	0.808	0.802	0.794	0.784	0.793
Log(Ksat [0 to 24])	0.703	0.795	0.804	0.801	0.796	0.790	0.784	0.776	0.781
Log(Ksat Full Depth)	0.551	0.697	0.728	0.744	0.749	0.752	0.753	0.753	0.716
Log(MAP)	-0.458	-0.334	-0.278	-0.225	-0.193	-0.166	-0.142	-0.116	-0.239
Log(2yr, 24hr Prec.)	-0.214	-0.464	-0.535	-0.585	-0.608	-0.625	-0.637	-0.648	-0.540

APPENDIX E: COLLECTED DATA FOR EQUATION COMPARISON TO KENNEY ET AL. (2008)

Table E.1: Parameters required when using equations from Table 4.1 and Kenney et al. (2008) are listed for each gage station in each geohydrologic region. Values were compiled from those shown in the tables in Appendix A. Watersheds in this table are less than 30 mi^2.

Geohydrologic Region #1

USGS Gage Station	Equations of Table 4.1								Kenney et al. (2008)	
	Basin Characteristics		Rainfall Intensity from Computed Time of Concentration						Basin Characteristics	
	Area (mi^2)	$K_{SAT,SURF}$ (in/hr)	2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	Area (mi^2)	ME (ft)
10129350	12.1	1.47	0.31	0.41	0.50	0.65	0.79	0.95	12.1	7,689
9216290	17.2	4.59	0.14	0.20	0.24	0.29	0.34	0.38	17.2	6,445
9227500	22.3	2.95	0.29	0.38	0.45	0.57	0.68	0.80	22.3	10,674
9221680	9.4	3.91	0.16	0.23	0.28	0.34	0.39	0.44	9.4	6,740

Geohydrologic Region #2

USGS Gage Station	Equations of Table 4.1										Kenney et al. (2008)	
	Basin Characteristics		Rainfall Intensity from Computed Time of Concentration								Basin Characteristics	
	Area (mi^2)	FS (%)	2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	200 year (in/hr)	500 year (in/hr)	Area (mi^2)	MAP (in/year)
10172800	4.2	35.8	0.54	0.72	0.89	1.14	1.36	1.62	1.92	2.39	4.2	39.72
10167500	27.4	42.9	0.35	0.44	0.52	0.64	0.76	0.89	1.05	1.32	27.4	39.72
10172791	16.7	42.9	0.37	0.48	0.59	0.75	0.90	1.07	1.27	1.58	16.7	28.8
10143500	3.2	54.0	0.57	0.76	0.93	1.20	1.46	1.75	2.11	2.69	3.2	39.73
10172200	7.2	59.0	0.43	0.56	0.69	0.89	1.09	1.32	1.59	2.02	7.2	31.45
10165500	9.6	68.5	0.45	0.59	0.72	0.93	1.12	1.35	1.61	2.05	9.6	40.15

Table E.1: Continued.

Geohydrologic Region #3

USGS Gage Station	Equations of Table 4.1										Kenney et al. (2008)
	Basin Characteristics				Rainfall Intensity from Computed Time of Concentration						Basin Characteristic
	Area	FS	MFD	MFS	2 year	5 year	10 year	25 year	50 year	100 year	Area
	(mi^2)	(%)	(ft)	(ft/ft)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(mi^2)
10126180	25	21.4	95,867	0.0268	0.25	0.34	0.42	0.56	0.69	0.83	25
10172952	8.6	81.3	30,370	0.1246	0.40	0.54	0.65	0.83	0.99	1.17	8.6
10172909	11.1	55.0	52,057	0.0632	0.24	0.32	0.38	0.49	0.57	0.67	11.1

Geohydrologic Region #4

USGS Gage Station	Equations of Table 4.1								Kenney et al. (2008)		
	Basin Characteristics		Rainfall Intensity from Computed Time of Concentration						Basin Characteristics		
	Area	BS	2 year	5 year	10 year	25 year	50 year	100 year	Area	BS	ME
	(mi^2)	(ft/ft)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(mi^2)	(%)	(ft)
9278000	14.3	0.3445	0.35	0.46	0.57	0.74	0.88	1.06	14.3	34.45	10,144
9268500	8.9	0.2280	0.42	0.55	0.67	0.86	1.04	1.24	8.9	22.80	10,155
9264000	26.4	0.0930	0.28	0.37	0.45	0.57	0.67	0.80	26.4	9.30	9,920

Geohydrologic Region #5

USGS Gage Station	Equations of Table 4.1										Kenney et al. (2008)	
	Basin Characteristics		Rainfall Intensity from Computed Time of Concentration								Basin Characteristics	
	Area	PREC	2 year	5 year	10 year	25 year	50 year	100 year	200 year	500 year	Area	Herb Upland
	(mi^2)	(in)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(mi^2)	(%)
10211000	6.5	1.60	0.42	0.56	0.69	0.87	1.04	1.23	1.45	1.79	6.5	21.43
10236000	14.1	1.85	0.47	0.61	0.74	0.94	1.11	1.31	1.54	1.90	14.1	2.44
10215900	25.8	1.47	0.31	0.40	0.48	0.60	0.71	0.84	0.98	1.21	25.8	30.44
10147500	18.7	1.63	0.37	0.48	0.58	0.74	0.88	1.05	1.23	1.53	18.7	17.02

Geohydrologic Region #6

USGS Gage Station	Equations of Table 4.1										Kenney et al. (2008)	
	Basin Characteristics				Rainfall Intensity from Computed Time of Concentration						Basin Characteristics	
	Area	BL	BS	MAP	2 year	5 year	10 year	25 year	50 year	100 year	Area	ME
	(mi^2)	(ft)	(ft/ft)	(in/yr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(mi^2)	(ft)
9327600	0.7	6,652	0.0978	8.91	0.45	0.64	0.79	1.05	1.28	1.55	0.7	6,166
9315900	3.5	17,649	0.0399	7.72	0.24	0.33	0.41	0.55	0.67	0.83	3.5	4,303
9182000	8.7	22,939	0.3892	28.35	0.43	0.57	0.70	0.90	1.07	1.28	8.7	9,388
9181000	19.2	46,157	0.3947	13.07	0.20	0.27	0.32	0.41	0.50	0.60	19.2	5,585
9312700	26.2	66,327	0.2851	20.00	0.18	0.23	0.27	0.34	0.39	0.46	26.2	8,673
9177500	15.5	27,105	0.1508	29.25	0.33	0.44	0.53	0.68	0.82	0.98	15.5	8,979
9367400	1.1	16,094	0.1271	9.70	0.47	0.63	0.76	0.96	1.13	1.30	1.1	5,646

Table E.1: Continued.

USGS Gage Station	Area (mi²)	BL (ft)	BS (ft/ft)	MAP (in/yr)	2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	Area (mi²)	ME (ft)
Geohydrologic Region #6 (continued)												
	Equations of Table 4.1										**Kenney et al. (2008)**	
	Basin Characteristics				**Rainfall Intensity from Computed Time of Concentration**						**Basin Characteristics**	
9163050	5.5	24,297	0.0701	11.04	0.30	0.41	0.48	0.57	0.65	0.75	5.5	4,939
9153290	15.9	32,034	0.0312	9.51	0.22	0.30	0.35	0.42	0.47	0.54	15.9	4,715
9378950	10.2	27,976	0.2587	10.96	0.33	0.44	0.53	0.68	0.80	0.95	10.2	5,789
9334400	20.1	33,788	0.1888	10.41	0.27	0.36	0.44	0.57	0.68	0.81	20.1	6,171
9338000	20.3	43,223	0.1010	29.07	0.32	0.41	0.50	0.63	0.75	0.89	20.3	10,702

USGS Gage Station	Area (mi²)	$K_{SAT,SURF}$ (in/hr)	2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	200 year (in/hr)	500 year (in/hr)	Area (mi²)
Geohydrologic Region #7											
	Equations of Table 4.1										**Kenney et al. (2008)**
	Basin Characteristics		**Rainfall Intensity from Computed Time of Concentration**								**Basin Characteristic**
9404500	7.6	4.66	0.35	0.46	0.57	0.73	0.88	1.06	1.27	1.60	7.6
9408400	18.7	2.84	0.48	0.63	0.76	0.95	1.11	1.30	1.50	1.82	18.7

Table E.2: Parameters required when using equations from Table 4.1 and Kenney et al. (2008) are listed for each gage station in each geohydrologic region. Values were compiled using same methods to compile those found in the tables in Appendix A. Watersheds in this table are between 30 and 50 mi^2.

Geohydrologic Region #1

USGS Gage Station	Equations of Table 4.1: Basin Characteristics: Area (mi^2)	$K_{SAT,SURF}$ (in/hr)	Rainfall Intensity from Computed Time of Concentration: 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	Kenney et al. (2008) Basin Characteristics: Area (mi^2)	ME (ft)
9199500	39.6	3.98	0.20	0.26	0.30	0.36	0.40	0.46	39.6	9,347
9220500	37.0	2.38	0.26	0.33	0.40	0.50	0.59	0.70	37.0	9,808
10010400	35.2	4.17	0.29	0.37	0.44	0.54	0.64	0.75	35.2	10,374
10093000	31.4	0.99	0.31	0.39	0.44	0.51	0.57	0.63	31.4	7,338

Geohydrologic Region #2

USGS Gage Station	Equations of Table 4.1: Basin Characteristics: Area (mi^2)	FS (%)	Rainfall Intensity from Computed Time of Concentration: 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	200 year (in/hr)	500 year (in/hr)	Kenney et al. (2008) Basin Characteristics: Area (mi^2)	MAP (in/year)
10137780	31.4	55.4	0.32	0.40	0.48	0.59	0.70	0.82	0.97	1.21	31.4	36.09
10156000	31.5	63.5	0.27	0.34	0.40	0.50	0.60	0.71	0.83	1.06	31.5	25.50
10161500	33.4	43.3	0.29	0.38	0.45	0.58	0.68	0.81	0.96	1.20	33.4	23.35
10171500	50.5	46.2	0.25	0.31	0.36	0.45	0.53	0.62	0.74	0.93	50.5	25.71

Geohydrologic Region #3

USGS Gage Station	Equations of Table 4.1: Basin Characteristics: Area (mi^2)	FS (%)	MFD (ft)	MFS (ft/ft)	Rainfall Intensity from Computed Time of Concentration: 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	Kenney et al. (2008) Basin Characteristic: Area (mi^2)
10125000	31.4	52.6	48,844	0.0734	0.32	0.42	0.48	0.56	0.64	0.72	31.4
10127100	36.9	53.2	68,159	0.0756	0.26	0.33	0.39	0.49	0.58	0.69	36.9
10172970	43.6	64.2	68,559	0.0375	0.23	0.31	0.35	0.41	0.47	0.53	43.6

Geohydrologic Region #4

USGS Gage Station	Equations of Table 4.1: Basin Characteristics: Area (mi^2)	BS (ft/ft)	Rainfall Intensity from Computed Time of Concentration: 2 year (in/hr)	5 year (in/hr)	10 year (in/hr)	25 year (in/hr)	50 year (in/hr)	100 year (in/hr)	Kenney et al. (2008) Basin Characteristics: Area (mi^2)	BS (%)	ME (ft)
9268000	44.1	0.1959	0.24	0.31	0.37	0.46	0.54	0.63	44.1	19.59	10,340
9288900	40.5	0.4067	0.22	0.28	0.33	0.42	0.49	0.58	40.5	40.67	8,128
10153500	35.7	0.1888	0.27	0.35	0.42	0.53	0.62	0.73	35.7	18.88	9,710

Table E.2: Continued.

Geohydrologic Region #5												
USGS Gage Station	Equations of Table 4.1										Kenney et al. (2008)	
	Basin Characteristics		Rainfall Intensity from Computed Time of Concentration								Basin Characteristics	
	Area	PREC	2 year	5 year	10 year	25 year	50 year	100 year	200 year	500 year	Area	Herb Upland
	(mi^2)	(in)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(mi^2)	(%)
10148400	36.9	1.55	0.28	0.36	0.43	0.54	0.64	0.75	0.88	1.09	36.9	35.12

Geohydrologic Region #6												
USGS Gage Station	Equations of Table 4.1										Kenney et al. (2008)	
	Basin Characteristics				Rainfall Intensity from Computed Time of Concentration						Basin Characteristics	
	Area	BL	BS	MAP	2 year	5 year	10 year	25 year	50 year	100 year	Area	ME
	(mi^2)	(ft)	(ft/ft)	(in/yr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(mi^2)	(ft)
9173000	40.6	53,463	0.2219	32.62	0.26	0.35	0.40	0.48	0.54	0.62	40.6	10,082
9174500	38.4	44,561	0.1540	17.09	0.30	0.40	0.46	0.54	0.61	0.69	38.4	7,642
9306058	48.3	79,172	0.2736	17.88	0.19	0.25	0.29	0.34	0.38	0.43	48.3	7,474
9306242	31.6	47,026	0.2319	18.65	0.25	0.33	0.39	0.46	0.52	0.59	31.6	7,541
9308500	31.9	48,797	0.3321	22.12	0.24	0.31	0.37	0.47	0.56	0.66	31.9	8,392
9336000	35.2	56,164	0.2750	14.47	0.26	0.33	0.40	0.50	0.59	0.70	35.2	8,391
9365500	34.5	62,259	0.4558	39.49	0.34	0.44	0.50	0.59	0.66	0.74	34.5	10,174
9368500	39.6	60,636	0.2486	32.56	0.31	0.39	0.45	0.52	0.58	0.65	39.6	9,715
9371492	33.7	35,321	0.1325	12.63	0.33	0.45	0.53	0.63	0.72	0.82	33.7	6,336
9378650	54.8	61,840	0.2110	17.75	0.25	0.32	0.38	0.47	0.55	0.63	54.8	7,619
9379300	36.0	67,273	0.1516	7.86	0.16	0.21	0.25	0.31	0.36	0.42	36.0	5,335
9381100	33.4	57,034	0.2844	12.64	0.20	0.26	0.31	0.39	0.46	0.54	33.4	7,067

Geohydrologic Region #7											
USGS Gage Station	Equations of Table 4.1										Kenney et al. (2008)
	Basin Characteristics		Rainfall Intensity from Computed Time of Concentration								Basin Characteristic
	Area	$K_{SAT,SURF}$	2 year	5 year	10 year	25 year	50 year	100 year	200 year	500 year	Area
	(mi^2)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(mi^2)
9409500	34.0	2.62	0.30	0.39	0.46	0.57	0.66	0.76	0.87	1.04	34.0
10185000	59.0	1.30	0.21	0.26	0.31	0.38	0.44	0.51	0.60	0.74	59.0

Table E.3: Estimated flood flows using Flood Frequency Analysis, equations produced by Kenney et al. (2008), and equations in Table 4.1. The percent difference between both types of equations and the Flood Frequency Analysis is also computed for comparison purposes. Watersheds are less than 30 mi^2.

Station ID	Calculation type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #1												
10129350	Calculated Peak Flows	F. F. Analysis	90	123	143	167	184	201	---	---		
		Kenney et al.	103	191	244	334	414	484	---	---		
		Table 4.1 Eqs.	96	152	199	263	316	379	---	---		
	Percent Difference	Kenney et al.	14%	55%	71%	100%	125%	141%	---	---	84%	84%
		Table 4.1 Eqs.	6%	24%	39%	57%	72%	89%	---	---	48%	48%
9216290	Calculated Peak Flows	F. F. Analysis	142	305	477	798	1,140	1,580	---	---		
		Kenney et al.	87	171	227	319	401	477	---	---		
		Table 4.1 Eqs.	104	293	513	928	1370	1981	---	---		
	Percent Difference	Kenney et al.	-39%	-44%	-52%	-60%	-65%	-70%	---	---	-55%	55%
		Table 4.1 Eqs.	-27%	-4%	7%	16%	20%	25%	---	---	6%	17%
9227500	Calculated Peak Flows	F. F. Analysis	163	251	321	422	508	604	---	---		
		Kenney et al.	418	608	677	823	958	1,058	---	---		
		Table 4.1 Eqs.	232	481	745	1,213	1,659	2,260	---	---		
	Percent Difference	Kenney et al.	156%	142%	111%	95%	89%	75%	---	---	111%	111%
		Table 4.1 Eqs.	42%	92%	132%	188%	227%	274%	---	---	159%	159%
9221680	Calculated Peak Flows	F. F. Analysis	55	188	367	763	1,240	1,920	---	---		
		Kenney et al.	64	127	170	243	307	367	---	---		
		Table 4.1 Eqs.	61	161	269	462	659	920	---	---		
	Percent Difference	Kenney et al.	17%	-32%	-54%	-68%	-75%	-81%	---	---	-49%	54%
		Table 4.1 Eqs.	11%	-14%	-27%	-39%	-47%	-52%	---	---	-28%	32%
		Average of Percent Differences										
		Kenney et al.	37%	30%	19%	17%	18%	16%	---	---	23%	
		Table 4.1 Eqs.	8%	24%	38%	55%	68%	84%	---	---	46%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	57%	68%	72%	81%	88%	92%	---	---		76%
		Table 4.1 Eqs.	22%	33%	51%	75%	91%	110%	---	---		64%
Geohydrologic Region #2												
10172800	Calculated Peak Flows	F. F. Analysis	32	56	75	102	124	147	172	208		
		Kenney et al.	29	67	70	105	135	169	172	185		
		Table 4.1 Eqs.	35	66	90	125	150	180	214	261		
	Percent Difference	Kenney et al.	-10%	19%	-7%	2%	9%	15%	0%	-11%	2%	9%
		Table 4.1 Eqs.	10%	16%	20%	23%	21%	22%	25%	26%	20%	20%

Table E.3: Continued.

Station ID	Calculation type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #2 (continued)												
10167500	Calculated Peak Flows	F. F. Analysis	387	512	595	699	776	853	930	1030		
		Kenney et al.	142	272	260	361	444	533	523	523		
		Table 4.1 Eqs.	125	219	290	394	466	555	660	814		
	Percent Difference	Kenney et al.	-63%	-47%	-56%	-48%	-43%	-38%	-44%	-49%	-49%	49%
		Table 4.1 Eqs.	-68%	-57%	-51%	-44%	-40%	-35%	-29%	-21%	-43%	43%
10172791	Calculated Peak Flows	F. F. Analysis	18	41	62	94	123	155	191	244		
		Kenney et al.	45	90	97	138	172	208	218	233		
		Table 4.1 Eqs.	81	147	201	280	337	405	485	594		
	Percent Difference	Kenney et al.	148%	118%	57%	46%	39%	34%	14%	-4%	57%	58%
		Table 4.1 Eqs.	349%	258%	225%	197%	174%	161%	154%	143%	208%	208%
10143500	Calculated Peak Flows	F. F. Analysis	14	26	36	50	63	78	94	118		
		Kenney et al.	23	55	58	87	114	143	147	159		
		Table 4.1 Eqs.	19	36	49	70	86	105	128	160		
	Percent Difference	Kenney et al.	62%	112%	62%	73%	80%	84%	56%	35%	71%	71%
		Table 4.1 Eqs.	33%	38%	38%	39%	36%	35%	36%	36%	36%	36%
10172200	Calculated Peak Flows	F. F. Analysis	15	32	48	72	95	120	150	196		
		Kenney et al.	26	57	63	92	117	145	152	166		
		Table 4.1 Eqs.	29	55	75	108	133	164	201	252		
	Percent Difference	Kenney et al.	70%	77%	31%	27%	24%	21%	2%	-15%	30%	33%
		Table 4.1 Eqs.	88%	69%	58%	50%	41%	37%	34%	29%	51%	51%
10165500	Calculated Peak Flows	F. F. Analysis	201	279	332	401	453	507	561	636		
		Kenney et al.	60	128	128	185	234	287	288	299		
		Table 4.1 Eqs.	35	66	92	131	161	197	241	302		
	Percent Difference	Kenney et al.	-70%	-54%	-62%	-54%	-48%	-43%	-49%	-53%	-54%	54%
		Table 4.1 Eqs.	-83%	-76%	-72%	-67%	-64%	-61%	-57%	-53%	-67%	67%
		Average of Percent Differences										
		Kenney et al.	23%	37%	4%	8%	10%	12%	-3%	-16%	9%	
		Table 4.1 Eqs.	55%	41%	36%	33%	28%	26%	27%	27%	34%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	70%	71%	46%	42%	41%	39%	27%	28%		46%
		Table 4.1 Eqs.	105%	86%	77%	70%	63%	58%	56%	51%		71%
Geohydrologic Region #3												
10126180	Calculated Peak Flows	F. F. Analysis	175	235	273	320	355	389	---	---		
		Kenney et al.	42	120	212	386	568	796	---	---		
		Table 4.1 Eqs.	26	85	158	390	656	1001	---	---		
	Percent Difference	Kenney et al.	-76%	-49%	-22%	21%	60%	105%	---	---	6%	55%
		Table 4.1 Eqs.	-85%	-64%	-42%	22%	85%	157%	---	---	12%	76%

Table E.3: Continued.

Station ID	Calculation type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #3 (continued)												
10172952	Calculated Peak Flows	F. F. Analysis	45	78	105	144	177	213	---	---		
		Kenney et al.	29	88	156	281	412	576	---	---		
		Table 4.1 Eqs.	11	33	60	161	220	280	---	---		
	Percent Difference	Kenney et al.	-34%	13%	48%	95%	133%	170%	---	---	71%	82%
		Table 4.1 Eqs.	-75%	-58%	-43%	12%	24%	31%	---	---	-18%	41%
10172909	Calculated Peak Flows	F. F. Analysis	1	8	24	86	204	457	---	---		
		Kenney et al.	32	95	168	303	445	622	---	---		
		Table 4.1 Eqs.	5	16	30	126	183	247	---	---		
	Percent Difference	Kenney et al.	2803%	1118%	599%	253%	118%	36%	---	---	821%	821%
		Table 4.1 Eqs.	376%	109%	26%	47%	-10%	-46%	---	---	84%	102%
		Average of Percent Differences										
		Kenney et al.	897%	361%	208%	123%	104%	104%	---	---	299%	
		Table 4.1 Eqs.	72%	-4%	-20%	27%	33%	48%	---	---	26%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	971%	393%	223%	123%	104%	104%	---	---		320%
		Table 4.1 Eqs.	179%	77%	37%	27%	40%	78%	---	---		73%
Geohydrologic Region #4												
9278000	Calculated Peak Flows	F. F. Analysis	93	138	167	202	227	252	---	---		
		Kenney et al.	150	219	346	331	376	462	---	---		
		Table 4.1 Eqs.	96	153	196	254	297	343	---	---		
	Percent Difference	Kenney et al.	61%	59%	107%	64%	66%	83%	---	---	73%	73%
		Table 4.1 Eqs.	3%	11%	17%	26%	31%	36%	---	---	21%	21%
9268500	Calculated Peak Flows	F. F. Analysis	76	116	143	178	204	231	---	---		
		Kenney et al.	161	225	344	322	358	416	---	---		
		Table 4.1 Eqs.	106	165	207	265	312	360	---	---		
	Percent Difference	Kenney et al.	112%	94%	140%	81%	76%	80%	---	---	97%	97%
		Table 4.1 Eqs.	39%	42%	45%	49%	53%	56%	---	---	47%	47%
9264000	Calculated Peak Flows	F. F. Analysis	433	561	638	726	787	844	---	---		
		Kenney et al.	573	774	1,137	1,050	1,141	1,242	---	---		
		Table 4.1 Eqs.	512	733	901	1,140	1,323	1,525	---	---		
	Percent Difference	Kenney et al.	32%	38%	78%	45%	45%	47%	---	---	48%	48%
		Table 4.1 Eqs.	18%	31%	41%	57%	68%	81%	---	---	49%	49%
		Average of Percent Differences										
		Kenney et al.	68%	64%	109%	63%	62%	70%	---	---	73%	
		Table 4.1 Eqs.	20%	28%	34%	44%	51%	58%	---	---	39%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	68%	64%	109%	63%	62%	70%	---	---		73%
		Table 4.1 Eqs.	20%	28%	34%	44%	51%	58%	---	---		39%

Table E.3: Continued.

Station ID	Calculation type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #5												
10211000	Calculated Peak Flows	F. F. Analysis	68	132	194	298	399	523	675	929		
		Kenney et al.	66	129	174	236	293	352	423	535		
		Table 4.1 Eqs.	40	91	141	227	306	405	514	708		
	Percent Difference	Kenney et al.	-2%	-2%	-10%	-21%	-27%	-33%	-37%	-42%	-22%	22%
		Table 4.1 Eqs.	-41%	-31%	-27%	-24%	-23%	-23%	-24%	-24%	-27%	27%
10236000	Calculated Peak Flows	F. F. Analysis	40	77	106	149	185	223	265	324		
		Kenney et al.	42	91	129	185	239	290	356	458		
		Table 4.1 Eqs.	59	118	168	250	318	397	481	622		
	Percent Difference	Kenney et al.	5%	18%	22%	24%	29%	30%	34%	41%	25%	25%
		Table 4.1 Eqs.	49%	54%	58%	68%	72%	78%	81%	92%	69%	69%
10215900	Calculated Peak Flows	F. F. Analysis	315	456	552	678	773	870	969	1,100		
		Kenney et al.	185	328	426	557	686	796	937	1,156		
		Table 4.1 Eqs.	154	366	578	969	1,331	1,810	2,350	3,338		
	Percent Difference	Kenney et al.	-41%	-28%	-23%	-18%	-11%	-9%	-3%	5%	-16%	17%
		Table 4.1 Eqs.	-51%	-20%	5%	43%	72%	108%	143%	203%	63%	81%
10147500	Calculated Peak Flows	F. F. Analysis	140	259	350	476	577	683	793	946		
		Kenney et al.	115	215	287	385	480	566	674	843		
		Table 4.1 Eqs.	94	207	315	503	675	892	1,126	1,540		
	Percent Difference	Kenney et al.	-18%	-17%	-18%	-19%	-17%	-17%	-15%	-11%	-16%	16%
		Table 4.1 Eqs.	-33%	-20%	-10%	6%	17%	31%	42%	63%	12%	28%
		Average of Percent Differences										
		Kenney et al.	-14%	-7%	-7%	-8%	-6%	-7%	-5%	-2%	-7%	
		Table 4.1 Eqs.	-19%	-4%	6%	23%	34%	49%	61%	84%	29%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	17%	16%	18%	20%	21%	22%	22%	25%		20%
		Table 4.1 Eqs.	43%	31%	25%	35%	46%	60%	72%	96%		51%
Geohydrologic Region #6												
9327600	Calculated Peak Flows	F. F. Analysis	106	337	624	1,210	1,880	2,780	---	---		
		Kenney et al.	40	130	236	445	663	916	---	---		
		Table 4.1 Eqs.	44	248	577	1,395	2,640	4,295	---	---		
	Percent Difference	Kenney et al.	-63%	-61%	-62%	-63%	-65%	-67%	---	---	-64%	64%
		Table 4.1 Eqs.	-58%	-26%	-8%	15%	40%	54%	---	---	3%	34%
9315900	Calculated Peak Flows	F. F. Analysis	206	608	1,070	1,970	2,930	4,180	---	---		
		Kenney et al.	232	678	1,172	2,125	3,102	4,348	---	---		
		Table 4.1 Eqs.	113	369	686	1,319	2,119	2,943	---	---		
	Percent Difference	Kenney et al.	13%	12%	10%	8%	6%	4%	---	---	9%	9%
		Table 4.1 Eqs.	-45%	-39%	-36%	-33%	-28%	-30%	---	---	-35%	35%

Table E.3: Continued.

Station ID	Calculation type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #6 (continued)												
9182000	Calculated Peak Flows	F. F. Analysis	9	19	27	38	46	55	---	---		
		Kenney et al.	57	156	256	436	611	829	---	---		
		Table 4.1 Eqs.	57	161	276	475	724	968	---	---		
	Percent Difference	Kenney et al.	505%	719%	854%	1063%	1225%	1405%	---	---	962%	962%
		Table 4.1 Eqs.	502%	744%	930%	1168%	1471%	1656%	---	---	1078%	1078%
9181000	Calculated Peak Flows	F. F. Analysis	730	1,390	1,920	2,660	3,260	3,910	---	---		
		Kenney et al.	314	811	1,310	2,223	3,112	4,317	---	---		
		Table 4.1 Eqs.	397	902	1,378	2,055	2,870	3,475	---	---		
	Percent Difference	Kenney et al.	-57%	-42%	-32%	-16%	-5%	10%	---	---	-23%	27%
		Table 4.1 Eqs.	-46%	-35%	-28%	-23%	-12%	-11%	---	---	-26%	26%
9312700	Calculated Peak Flows	F. F. Analysis	42	83	119	177	229	288	---	---		
		Kenney et al.	127	322	507	837	1,149	1,566	---	---		
		Table 4.1 Eqs.	148	251	335	436	547	607	---	---		
	Percent Difference	Kenney et al.	205%	288%	326%	373%	402%	444%	---	---	340%	340%
		Table 4.1 Eqs.	254%	202%	182%	146%	139%	111%	---	---	172%	172%
9177500	Calculated Peak Flows	F. F. Analysis	114	265	400	608	787	985	---	---		
		Kenney et al.	87	230	369	618	857	1,166	---	---		
		Table 4.1 Eqs.	49	116	183	296	431	553	---	---		
	Percent Difference	Kenney et al.	-23%	-13%	-8%	2%	9%	18%	---	---	-3%	12%
		Table 4.1 Eqs.	-57%	-56%	-54%	-51%	-45%	-44%	---	---	-51%	51%
9367400	Calculated Peak Flows	F. F. Analysis	62	179	313	570	840	1,190	---	---		
		Kenney et al.	63	201	358	668	990	1,372	---	---		
		Table 4.1 Eqs.	66	236	445	834	1,317	1,776	---	---		
	Percent Difference	Kenney et al.	1%	12%	14%	17%	18%	15%	---	---	13%	13%
		Table 4.1 Eqs.	6%	32%	42%	46%	57%	49%	---	---	39%	39%
9163050	Calculated Peak Flows	F. F. Analysis	111	202	279	397	502	622	---	---		
		Kenney et al.	213	602	1,019	1,811	2,608	3,636	---	---		
		Table 4.1 Eqs.	119	334	542	859	1,221	1,507	---	---		
	Percent Difference	Kenney et al.	92%	198%	265%	356%	420%	485%	---	---	303%	303%
		Table 4.1 Eqs.	7%	65%	94%	116%	143%	142%	---	---	95%	95%
9153290	Calculated Peak Flows	F. F. Analysis	156	209	245	292	328	365	---	---		
		Kenney et al.	429	1,121	1,831	3,147	4,445	6,207	---	---		
		Table 4.1 Eqs.	260	603	904	1,317	1,759	2,039	---	---		
	Percent Difference	Kenney et al.	175%	436%	647%	978%	1255%	1600%	---	---	849%	849%
		Table 4.1 Eqs.	67%	189%	269%	351%	436%	459%	---	---	295%	295%
9378950	Calculated Peak Flows	F. F. Analysis	732	1,430	2,100	3,250	4,380	5,790	---	---		
		Kenney et al.	203	549	905	1,567	2,219	3,073	---	---		
		Table 4.1 Eqs.	428	1,243	2,124	3,556	5,258	6,746	---	---		
	Percent Difference	Kenney et al.	-72%	-62%	-57%	-52%	-49%	-47%	---	---	-56%	56%
		Table 4.1 Eqs.	-42%	-13%	1%	9%	20%	17%	---	---	-1%	17%

Table E.3: Continued.

Station ID	Calculation type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #6 (continued)												
9334400	Calculated Peak Flows	F. F. Analysis	412	1,910	4,090	8,890	14,400	22,100	---	---		
		Kenney et al.	253	650	1045	1764	2459	3397	---	---		
		Table 4.1 Eqs.	706	1819	2957	4742	6834	8547	---	---		
	Percent Difference	Kenney et al.	-39%	-66%	-74%	-80%	-83%	-85%	---	---	-71%	71%
		Table 4.1 Eqs.	71%	-5%	-28%	-47%	-53%	-61%	---	---	-20%	44%
9338000	Calculated Peak Flows	F. F. Analysis	203	304	369	447	502	555	---	---		
		Kenney et al.	66	170	269	445	610	824	---	---		
		Table 4.1 Eqs.	52	95	134	189	252	296	---	---		
	Percent Difference	Kenney et al.	-68%	-44%	-27%	-1%	21%	48%	---	---	-12%	35%
		Table 4.1 Eqs.	-74%	-69%	-64%	-58%	-50%	-47%	---	---	-60%	60%
		Average of Percent Differences										
		Kenney et al.	56%	115%	155%	215%	263%	319%	---	---	187%	
		Table 4.1 Eqs.	49%	82%	108%	137%	177%	191%	---	---	124%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	109%	163%	198%	251%	296%	352%	---	---		228%
		Table 4.1 Eqs.	102%	123%	145%	172%	208%	223%	---	---		162%
Geohydrologic Region #7												
9404500	Calculated Peak Flows	F. F. Analysis	202	1040	2330	5270	8750	13600	20100	31900		
		Kenney et al.	66	201	360	664	984	1403	1937	2859		
		Table 4.1 Eqs.	119	563	1237	2849	4776	7781	11943	19867		
	Percent Difference	Kenney et al.	-67%	-81%	-85%	-87%	-89%	-90%	-90%	-91%	-85%	85%
		Table 4.1 Eqs.	-41%	-46%	-47%	-46%	-45%	-43%	-41%	-38%	-43%	43%
9408400	Calculated Peak Flows	F. F. Analysis	68	152	235	378	518	692	904	1260		
		Kenney et al.	116	327	558	976	1398	1932	2586	3678		
		Table 4.1 Eqs.	182	593	1086	2085	3116	4537	6342	9445		
	Percent Difference	Kenney et al.	72%	115%	137%	158%	170%	179%	186%	192%	151%	151%
		Table 4.1 Eqs.	169%	290%	362%	452%	502%	556%	602%	650%	448%	448%
		Average of Percent Differences										
		Kenney et al.	2%	17%	26%	35%	41%	45%	48%	50%	33%	
		Table 4.1 Eqs.	64%	122%	158%	203%	228%	256%	280%	306%	202%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	70%	98%	111%	123%	129%	134%	138%	141%		118%
		Table 4.1 Eqs.	105%	168%	205%	249%	274%	299%	321%	344%		245%

Table E.4: Estimated flood flows using Flood Frequency Analysis, equations produced by Kenney et al. (2008), and equations in Table 4.1. The percent difference between both types of equations and the Flood Frequency Analysis is also computed for comparison purposes. Watersheds between 30 and 50 mi^2.

Station ID	Calculation Type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #1												
9199500	Calculated Peak Flows	F. F. Analysis	430	551	617	687	732	772	---	---		
		Kenney et al.	399	611	703	876	1,028	1,153	---	---		
		Table 4.1 Eqs.	96	152	199	263	316	379	---	---		
	Percent Difference	Kenney et al.	-7%	11%	14%	27%	40%	49%	---	---	22%	25%
		Table 4.1 Eqs.	-78%	-72%	-68%	-62%	-57%	-51%	---	---	-65%	65%
9220500	Calculated Peak Flows	F. F. Analysis	438	703	911	1,210	1,470	1,750	---	---		
		Kenney et al.	443	661	749	921	1,074	1,197	---	---		
		Table 4.1 Eqs.	104	293	513	928	1,370	1,981	---	---		
	Percent Difference	Kenney et al.	1%	-6%	-18%	-24%	-27%	-32%	---	---	-18%	18%
		Table 4.1 Eqs.	-76%	-58%	-44%	-23%	-7%	13%	---	---	-33%	37%
10010400	Calculated Peak Flows	F. F. Analysis	560	688	764	851	911	968	---	---		
		Kenney et al.	516	744	826	999	1,155	1,276	---	---		
		Table 4.1 Eqs.	232	481	745	1,213	1,659	2,260	---	---		
	Percent Difference	Kenney et al.	-8%	8%	8%	17%	27%	32%	---	---	14%	17%
		Table 4.1 Eqs.	-59%	-30%	-3%	43%	82%	133%	---	---	28%	58%
10093000	Calculated Peak Flows	F. F. Analysis	601	727	801	886	944	999	---	---		
		Kenney et al.	175	312	392	525	641	746	---	---		
		Table 4.1 Eqs.	61	161	269	462	659	920	---	---		
	Percent Difference	Kenney et al.	-71%	-57%	-51%	-41%	-32%	-25%	---	---	-46%	46%
		Table 4.1 Eqs.	-90%	-78%	-66%	-48%	-30%	-8%	---	---	-53%	53%
		Average of Percent Differences										
		Kenney et al.	-21%	-11%	-12%	-5%	2%	6%	---	---	-7%	
		Table 4.1 Eqs.	-76%	-60%	-45%	-23%	-3%	22%	---	---	-31%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	22%	21%	23%	27%	32%	35%	---	---		26%
		Table 4.1 Eqs.	76%	60%	45%	44%	44%	51%	---	---		53%
Geohydrologic Region #2												
10137780	Calculated Peak Flows	F. F. Analysis	457	560	623	698	751	802	852	917		
		Kenney et al.	125	235	232	320	392	469	467	473		
		Table 4.1 Eqs.	103	181	242	332	396	472	562	690		
	Percent Difference	Kenney et al.	-73%	-58%	-63%	-54%	-48%	-42%	-45%	-48%	-54%	54%
		Table 4.1 Eqs.	-78%	-68%	-61%	-52%	-47%	-41%	-34%	-25%	-51%	51%

Table E.4: Continued.

Station ID	Calculation Type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #2 (continued)												
10156000	Calculated Peak Flows	F. F. Analysis	87	109	122	137	149	160	170	184		
		Kenney et al.	61	115	125	173	212	253	265	283		
		Table 4.1 Eqs.	74	133	180	250	301	363	435	544		
	Percent Difference	Kenney et al.	-30%	6%	3%	26%	42%	58%	56%	54%	27%	34%
		Table 4.1 Eqs.	-15%	22%	47%	83%	102%	127%	156%	196%	90%	93%
10161500	Calculated Peak Flows	F. F. Analysis	51	83	108	148	182	221	264	332		
		Kenney et al.	55	104	115	159	194	232	245	263		
		Table 4.1 Eqs.	126	227	306	427	509	609	728	894		
	Percent Difference	Kenney et al.	9%	26%	7%	7%	7%	5%	-7%	-21%	4%	11%
		Table 4.1 Eqs.	147%	175%	184%	189%	180%	176%	176%	169%	174%	174%
10171500	Calculated Peak Flows	F. F. Analysis	121	190	238	298	343	388	433	493		
		Kenney et al.	92	166	177	239	289	343	355	371		
		Table 4.1 Eqs.	153	265	350	477	562	671	806	999		
	Percent Difference	Kenney et al.	-24%	-12%	-26%	-20%	-16%	-12%	-18%	-25%	-19%	19%
		Table 4.1 Eqs.	26%	39%	47%	60%	64%	73%	86%	103%	62%	62%
		Average of Percent Differences										
		Kenney et al.	-29%	-10%	-20%	-10%	-4%	3%	-4%	-10%	-10%	
		Table 4.1 Eqs.	20%	42%	54%	70%	75%	84%	96%	111%	69%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	34%	26%	25%	27%	28%	29%	32%	37%		30%
		Table 4.1 Eqs.	67%	76%	85%	96%	98%	104%	113%	123%		95%
Geohydrologic Region #3												
10125000	Calculated Peak Flows	F. F. Analysis	54	95	129	181	227	278	---	---		
		Kenney et al.	45	128	227	413	609	852	---	---		
		Table 4.1 Eqs.	27	80	141	365	498	635	---	---		
	Percent Difference	Kenney et al.	-17%	35%	76%	128%	168%	207%	---	---	99%	105%
		Table 4.1 Eqs.	-50%	-15%	9%	101%	119%	128%	---	---	49%	71%
10127100	Calculated Peak Flows	F. F. Analysis	184	258	307	367	411	455	---	---		
		Kenney et al.	47	134	237	434	639	895	---	---		
		Table 4.1 Eqs.	9	30	58	176	243	316	---	---		
	Percent Difference	Kenney et al.	-74%	-48%	-23%	18%	56%	97%	---	---	4%	53%
		Table 4.1 Eqs.	-95%	-89%	-81%	-52%	-41%	-31%	---	---	-65%	65%
10172970	Calculated Peak Flows	F. F. Analysis	163	583	1,220	2,850	5,110	8,810	---	---		
		Kenney et al.	50	140	249	455	671	940	---	---		
		Table 4.1 Eqs.	6	20	38	569	851	1,181	---	---		
	Percent Difference	Kenney et al.	-69%	-76%	-80%	-84%	-87%	-89%	---	---	-81%	81%
		Table 4.1 Eqs.	-96%	-97%	-97%	-80%	-83%	-87%	---	---	-90%	90%

Table E.4: Continued.

Station ID	Calculation Type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #3 (continued)												
		Average of Percent Differences										
		Kenney et al.	-53%	-30%	-9%	21%	46%	71%	---	---	8%	
		Table 4.1 Eqs.	-81%	-67%	-56%	-10%	-2%	4%	---	---	-35%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	53%	53%	59%	77%	104%	131%	---	---		79%
		Table 4.1 Eqs.	81%	67%	62%	78%	81%	82%	---	---		75%
Geohydrologic Region #4												
9268000	Calculated Peak Flows	F. F. Analysis	526	745	886	1,060	1,190	1,310	---	---		
		Kenney et al.	770	1,028	1,530	1,386	1,506	1,692	---	---		
		Table 4.1 Eqs.	354	524	647	801	917	1,036	---	---		
	Percent Difference	Kenney et al.	46%	38%	73%	31%	27%	29%	---	---	41%	41%
		Table 4.1 Eqs.	-33%	-30%	-27%	-24%	-23%	-21%	---	---	-26%	26%
9288900	Calculated Peak Flows	F. F. Analysis	54	161	284	521	772	1,100	---	---		
		Kenney et al.	74	140	241	275	342	465	---	---		
		Table 4.1 Eqs.	144	226	282	353	404	457	---	---		
	Percent Difference	Kenney et al.	36%	-13%	-15%	-47%	-56%	-58%	---	---	-25%	38%
		Table 4.1 Eqs.	166%	41%	-1%	-32%	-48%	-58%	---	---	11%	58%
10153500	Calculated Peak Flows	F. F. Analysis	503	632	710	802	866	928	---	---		
		Kenney et al.	440	632	962	920	1,026	1,179	---	---		
		Table 4.1 Eqs.	333	493	611	767	883	1,005	---	---		
	Percent Difference	Kenney et al.	-13%	0%	35%	15%	18%	27%	---	---	14%	18%
		Table 4.1 Eqs.	-34%	-22%	-14%	-4%	2%	8%	---	---	-11%	14%
		Average of Percent Differences										
		Kenney et al.	23%	8%	31%	-1%	-4%	-1%	---	---	10%	
		Table 4.1 Eqs.	33%	-4%	-14%	-20%	-23%	-24%	---	---	-9%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	32%	17%	41%	31%	34%	38%	---	---		32%
		Table 4.1 Eqs.	77%	31%	14%	20%	24%	29%	---	---		33%
Geohydrologic Region #5												
10148400	Calculated Peak Flows	F. F. Analysis	109	208	294	429	550	689	849	1,100		
		Kenney et al.	248	428	548	709	871	1,000	1,169	1,433		
		Table 4.1 Eqs.	170	383	583	946	1,279	1,697	2,172	3,023		
	Percent Difference	Kenney et al.	128%	106%	86%	65%	58%	45%	38%	30%	70%	
		Table 4.1 Eqs.	56%	84%	98%	121%	133%	146%	156%	175%	121%	
		Average of Percent Differences										
		Kenney et al.	128%	106%	86%	65%	58%	45%	38%	30%	70%	
		Table 4.1 Eqs.	56%	84%	98%	121%	133%	146%	156%	175%	121%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	128%	106%	86%	65%	58%	45%	38%	30%		70%
		Table 4.1 Eqs.	56%	84%	98%	121%	133%	146%	156%	175%		121%

Table E.4: Continued.

Station ID	Calculation Type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #6												
9173000	Calculated Peak Flows	F. F. Analysis	238	458	633	878	1,080	1,290	---	---		
		Kenney et al.	112	275	425	687	931	1,261	---	---		
		Table 4.1 Eqs.	90	162	214	273	341	373	---	---		
	Percent Difference	Kenney et al.	-53%	-40%	-33%	-22%	-14%	-2%	---	---	-27%	27%
		Table 4.1 Eqs.	-62%	-65%	-66%	-69%	-68%	-71%	---	---	-67%	67%
9174500	Calculated Peak Flows	F. F. Analysis	124	237	324	446	543	644	---	---		
		Kenney et al.	214	527	822	1,346	1,841	2,522	---	---		
		Table 4.1 Eqs.	406	838	1,178	1,589	2,044	2,297	---	---		
	Percent Difference	Kenney et al.	73%	122%	154%	202%	239%	292%	---	---	180%	180%
		Table 4.1 Eqs.	227%	254%	264%	256%	276%	257%	---	---	256%	256%
9306058	Calculated Peak Flows	F. F. Analysis	14	35	59	105	153	216	---	---		
		Kenney et al.	256	620	961	1,564	2,130	2,920	---	---		
		Table 4.1 Eqs.	372	610	767	905	1,071	1,107	---	---		
	Percent Difference	Kenney et al.	1759%	1652%	1518%	1389%	1292%	1252%	---	---	1,477%	1,477%
		Table 4.1 Eqs.	2595%	1623%	1191%	762%	600%	412%	---	---	1,197%	1,197%
9306242	Calculated Peak Flows	F. F. Analysis	27	110	232	522	890	1,450	---	---		
		Kenney et al.	199	495	779	1,284	1,764	2,418	---	---		
		Table 4.1 Eqs.	269	558	781	1,047	1,345	1,512	---	---		
	Percent Difference	Kenney et al.	625%	350%	236%	146%	98%	67%	---	---	254%	254%
		Table 4.1 Eqs.	882%	407%	237%	101%	51%	4%	---	---	280%	280%
9308500	Calculated Peak Flows	F. F. Analysis	107	356	655	1,240	1,850	2,640	---	---		
		Kenney et al.	153	383	600	985	1,348	1,840	---	---		
		Table 4.1 Eqs.	202	399	578	818	1,094	1,285	---	---		
	Percent Difference	Kenney et al.	43%	8%	-8%	-21%	-27%	-30%	---	---	-6%	23%
		Table 4.1 Eqs.	89%	12%	-12%	-34%	-41%	-51%	---	---	-6%	40%
9336000	Calculated Peak Flows	F. F. Analysis	424	1,030	1,620	2,570	3,450	4,470	---	---		
		Kenney et al.	162	402	627	1,026	1,402	1,913	---	---		
		Table 4.1 Eqs.	618	1,203	1,719	2,368	3,118	3,580	---	---		
	Percent Difference	Kenney et al.	-62%	-61%	-61%	-60%	-59%	-57%	---	---	-60%	60%
		Table 4.1 Eqs.	46%	17%	6%	-8%	-10%	-20%	---	---	5%	18%
9365500	Calculated Peak Flows	F. F. Analysis	411	695	904	1,190	1,410	1,640	---	---		
		Kenney et al.	100	249	386	628	853	1,155	---	---		
		Table 4.1 Eqs.	86	145	184	224	273	293	---	---		
	Percent Difference	Kenney et al.	-76%	-64%	-57%	-47%	-40%	-30%	---	---	-52%	52%
		Table 4.1 Eqs.	-79%	-79%	-80%	-81%	-81%	-82%	---	---	-80%	80%
9368500	Calculated Peak Flows	F. F. Analysis	321	587	799	1,110	1,360	1,630	---	---		
		Kenney et al.	121	297	461	746	1,013	1,374	---	---		
		Table 4.1 Eqs.	109	179	228	277	335	357	---	---		
	Percent Difference	Kenney et al.	-62%	-49%	-42%	-33%	-26%	-16%	---	---	-38%	38%
		Table 4.1 Eqs.	-66%	-69%	-72%	-75%	-75%	-78%	---	---	-73%	73%

Table E.4: Continued.

Station ID	Calculation Type	Method for Calculation	2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	Avg. of % Diff.	Avg. of Absolute Value of % Diff.
Geohydrologic Region #6 (continued)												
9371492	Calculated Peak Flows	F. F. Analysis	78	192	316	549	795	1,120	---	---		
		Kenney et al.	315	781	1,232	2,042	2,815	3,885	---	---		
		Table 4.1 Eqs.	752	1,859	2,826	4,131	5,591	6,580	---	---		
	Percent Difference	Kenney et al.	305%	307%	290%	272%	254%	247%	---	---	279%	279%
		Table 4.1 Eqs.	867%	868%	794%	653%	603%	487%	---	---	712%	712%
9378650	Calculated Peak Flows	F. F. Analysis	114	327	565	1,010	1,470	2,050	---	---		
		Kenney et al.	262	628	969	1,569	2,131	2,919	---	---		
		Table 4.1 Eqs.	495	873	1,186	1,572	1,988	2,186	---	---		
	Percent Difference	Kenney et al.	130%	92%	72%	55%	45%	42%	---	---	73%	73%
		Table 4.1 Eqs.	334%	167%	110%	56%	35%	7%	---	---	118%	118%
9379300	Calculated Peak Flows	F. F. Analysis	1,610	4,110	6,750	11,500	16,400	22,400	---	---		
		Kenney et al.	498	1,227	1,941	3,232	4,473	6,216	---	---		
		Table 4.1 Eqs.	1,350	2,510	3,509	4,660	5,867	6,421	---	---		
	Percent Difference	Kenney et al.	-69%	-70%	-71%	-72%	-73%	-72%	---	---	-71%	71%
		Table 4.1 Eqs.	-16%	-39%	-48%	-59%	-64%	-71%	---	---	-50%	50%
9381100	Calculated Peak Flows	F. F. Analysis	873	2,070	3,320	5,550	7,800	10,700	---	---		
		Kenney et al.	240	596	937	1,547	2,126	2,922	---	---		
		Table 4.1 Eqs.	644	1,274	1,835	2,535	3,315	3,803	---	---		
	Percent Difference	Kenney et al.	-73%	-71%	-72%	-72%	-73%	-73%	---	---	-72%	72%
		Table 4.1 Eqs.	-26%	-38%	-45%	-54%	-58%	-64%	---	---	-48%	48%
		Average of Percent Differences										
		Kenney et al.	212%	181%	160%	145%	135%	135%	---	---	161%	
		Table 4.1 Eqs.	399%	255%	190%	121%	97%	61%	---	---	187%	
		Average of Absolute Value of Percent Differences										
		Kenney et al.	277%	241%	218%	199%	187%	182%	---	---		217%
		Table 4.1 Eqs.	441%	303%	244%	184%	164%	134%	---	---		245%
Geohydrologic Region #7												
9409500	Calculated Peak Flows	F. F. Analysis	204	796	1,630	3,500	5,740	8,970	13500	22200		
		Kenney et al.	170	451	746	1,261	1,764	2,387	3,132	4,347		
		Table 4.1 Eqs.	181	544	9,58	1,763	2,574	3,669	5,024	7,321		
	Percent Difference	Kenney et al.	-17%	-43%	-54%	-64%	-69%	-73%	-77%	-80%	-60%	60%
		Table 4.1 Eqs.	-11%	-32%	-41%	-50%	-55%	-59%	-63%	-67%	-47%	47%
10185000	Calculated Peak Flows	F. F. Analysis	240	416	524	645	723	791	851	919		
		Kenney et al.	240	607	976	1,598	2,187	2,904	3,739	5,074		
		Table 4.1 Eqs.	69	122	168	248	322	415	529	727		
	Percent Difference	Kenney et al.	0%	46%	86%	148%	203%	267%	339%	452%	193%	193%
		Table 4.1 Eqs.	-71%	-71%	-68%	-62%	-55%	-47%	-38%	-21%	-54%	54%

Table E.4: Continued.

Station ID	**Calculation Type**	**Method for Calculation**	**2 year (cfs)**	**5 year (cfs)**	**10 year (cfs)**	**25 year (cfs)**	**50 year (cfs)**	**100 year (cfs)**	**200 year (cfs)**	**500 year (cfs)**	**Avg. of % Diff.**	**Avg. of Absolute Value of % Diff.**
Geohydrologic Region #7 (continued)												
	Average of Percent Differences											
		Kenney et al.	-8%	1%	16%	42%	67%	97%	131%	186%	66%	
		Table 4.1 Eqs.	-41%	-51%	-55%	-56%	-55%	-53%	-50%	-44%	-51%	
	Average of Absolute Value of Percent Differences											
		Kenney et al.	8%	45%	70%	106%	136%	170%	208%	266%		126%
		Table 4.1 Eqs.	41%	51%	55%	56%	55%	53%	50%	44%		51%

REFERENCES

ASCE (1969). “Design and construction of sanitary storm sewers.” *American Society of Civil Engineers (ASCE) and Water Pollution Control Federation (WPCF)*. ASCE Manuals and Reports on Engineering Practice No. 37 and WPCF Manual of Practice No. 9.

Aquaveo, LLC. (2009). “Watershed modeling system (WMS) software package.” *Aquaveo, LLC*. Available from http://www.aquaveo.com/downloads (March, 2010).

Bedient, P. B., Huber, W. C., and Vieux, B. E. (2008). *Hydrology and floodplain analysis, fourth Ed.* Upper Saddle River, NJ: Prentice Hall.

EMS-I. (2010). “Watershed modeling systems (WMS) help.” *Environmental Modeling Systems, Incorporated*. Accessed from http://www.ems-i.com/wmshelp/wms80.htm (March, 2010).

ESRI, Inc. (2010). “ArcGIS software.” *Environmental Systems Research Institute, Inc. (ESRI)*. Available from http://www.esri.com/products/index.html (April, 2010).

Flynn, K. M., Kirby, W. H., Hummel, P. R. (2006). “User’s manual for program PeakFQ, annual flood-frequency analysis using bulletin 17B guidelines.” *United States Geological Survey (USGS)*. Techniques and Methods 4-B4.

Kenney, T. A., Wilkowske, C. D., and Wright, S. J. (2008). “Methods for estimating magnitude and frequency of peak flows for natural streams in Utah.” *United States Geological Survey (USGS)*. Scientific Investigations Report 2007-5158. Available at *http://pubs.usgs.gov/sir/2007/5158/*

Maidment, D.R. (1993). *Handbook of hydrology*. McGraw-Hill.

Mason, R. R., Ries III, K. G., King, J. N., and Thomas Jr., W. O. (1999). “The National Flood-Frequency Program—Methods for estimating flood magnitude and frequency in rural areas in Utah.” *United States Geological Survey (USGS)*. USGS Fact Sheet 124-96. Available at http://pubs.usgs.gov/fs/fs-124-98/pdf/utahfinal.pdf

McEnroe, B. M., Young, C. B., and Rome, A. C. (2007). “Flood frequency relationships for small watersheds in Kansas.” *Kansas Department of Transportation (KDOT)*. Report No. K-Tran: KU-0604.

Minitab, Inc. (2009). "Minitab StatGuide." (2009) Contained in Minitab 15 Software. *Minitab Inc*. Available at http://www.minitab.com/en-US/Products/ (March, 2010).

NRCS. (2009). "Soil data viewer software." *National Resources Conservation Service*. Available from http://soils.usda.gov/sdv (March, 2010).

NRCS. (2009). "STATSGO and SSURGO soils data description." *NRCS Soil Data Mart*. Available at http://soildatamart.nrcs.usda.gov/USDGSM.aspx (March, 2010).

Perica, S., and Grenney, W. (2003). "Virgin River Basin regional flood frequency analysis." *Utah Department of Transportation (UDOT)*. Report No. UT-3.06

Perica, S., and Stayner, M. (2004). "Regional flood frequency analysis for selected basins in Utah: Part II: Weber River Basin." *Utah Department of Transportation (UDOT)*. Report No. UT-4.12.

PRISM Climate Group. (2009). "PRISM Data Extractor." *Parameter-elevation Regressions on Independent Slopes Model Climate Group*. Accessed from http://prismmap.nacse.org/nn/ (March, 2010).

Smith, A. A., and Lee, K. B. (1984). "The rational method revisited." *Canadian Journal of Civil Engineering*. Volume 11, pp 854-862.

Thomas, B.E., Hjalmarson, H.W., and Waltemeyer, S.D., (1997), "Methods for estimating magnitude and frequency of floods in the Southwestern United States." *United States Geological Survey (USGS)*. Water-Supply Paper 2433. Available at http://pubs.er.usgs.gov/publication/wsp2433

USDA. (1986). "Urban hydrology for small watersheds." *United States Department of Agriculture*. Technical Release 55.

IACWD. (1982). "Guidelines for determining flood flow frequency." *Interagency Advisory Committee on Water Data (IACWD)*. Bulletin #17B of the Hydrology Subcommittee.

USGS. (2009). "Land use and land cover (LULC) data." *United States Geological Survey*. Accessed from http://www.webgis.com/lulcdata.html (March, 2010).

USGS. (2009). "The national map seamless server." *United States Geological Survey*. Accessed at http://seamless.usgs.gov/index.php (March, 2010).