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Report No. UT-10.11

METHODS FOR ESTIMATING MAGNITUDE AND FREQUENCY OF PEAK FLOWS FOR SMALL WATERSHEDS IN UTAH

Prepared For:

Utah Department of Transportation Research Division

Submitted By:

University of Utah
Department of Civil & Environmental Engineering

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Aaron J. Timpson, E.I.T.

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16. 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 mid-sized 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 (Flynn et al 2006). 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.

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TABLE OF CONTENTS

LIST OF TABLES

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LIST OF FIGURES

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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 gauging station data within the state of Utah to develop regression equations for estimating flood flows for mid-sized 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 (Flynn et al 2006). 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.

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1.0 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.

The rational method is commonly used to estimate peak discharges for different recurrence storm years. The rational method is in the form $Q = C_f C i A$, where Q is the peak discharge rate, C_f is a conversion unit, C is a unitless runoff coefficient, i is the rainfall intensity, and A is the watershed area. David R. Maidment (1993) states 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 half a square mile. 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. 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 ungauged sites; however, literature shows 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 2007, 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 peak discharges for ungauged rural watersheds in Utah ranging from 0.5 to 30 square miles. These regression equations relate a recurrence year peak flow to statistically significant basin characteristics (e.g. basin area, precipitation, soil type, etc.).

This report summarizes methods and regression equations developed 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 geo-hydrologic region boundaries used in the development of the regression equations for watersheds greater than 30 mi^2 performed by the United States Geological Survey (USGS) (Kenney et al 2008). The overall boundary is divided into seven smaller regions based on geologic and hydrologic differences, which is shown in Figure 1.1.

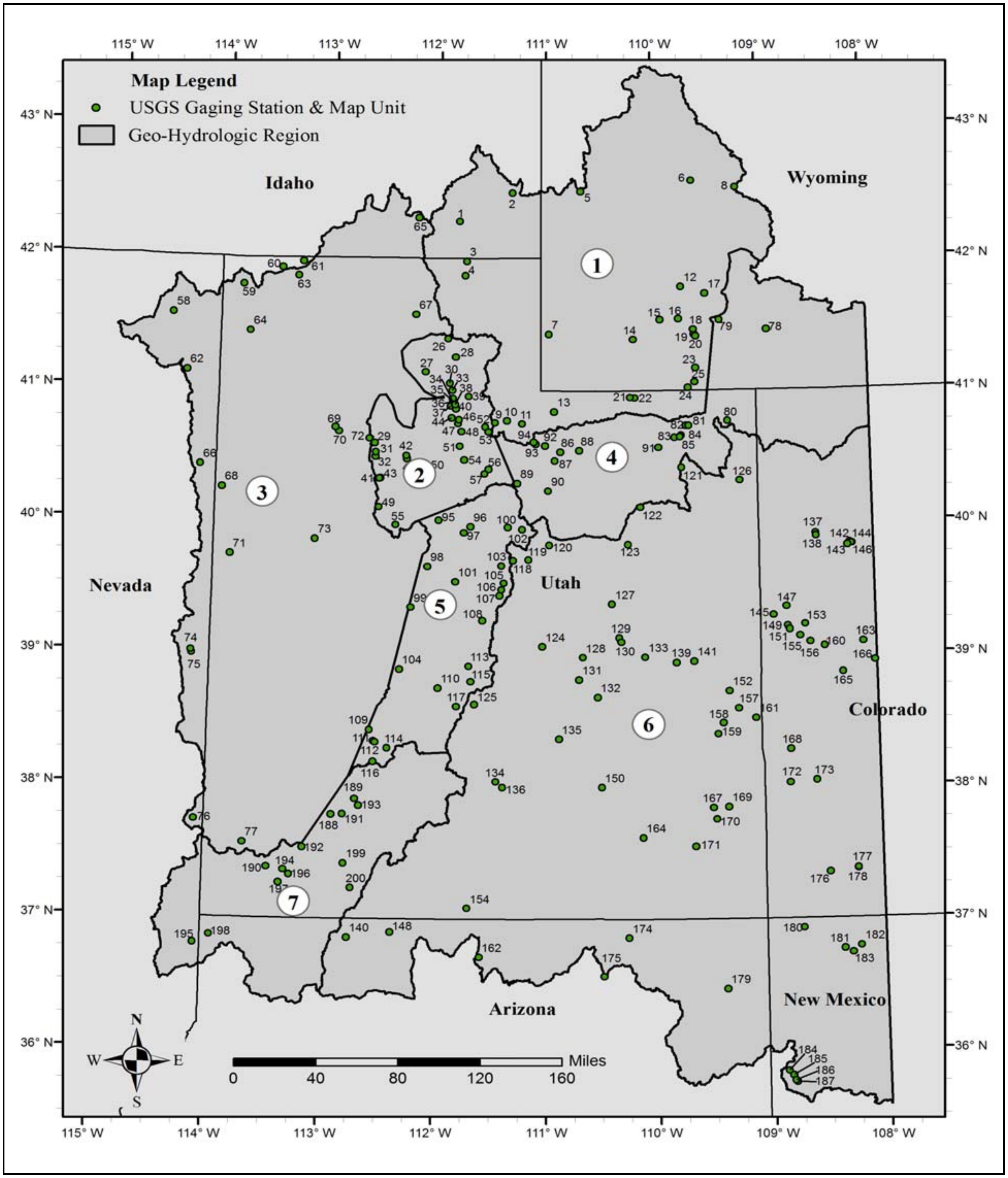

Figure 1.1: Geo-Hydrologic regions, as defined by Kenney et al (2008), and USGS gaging stations for study region. The East boundaries end at the 108th longitudinal line, where a change in soil and precipitation data was observed.

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2.0 DATA USED IN REGRESSION ANALYSES

2.1 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 ten years of peak flow records through water year 2008, and that were between one half to thirty square miles 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.

2.2 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 developed by Perica and Stayner (2004) for the state of Utah was consulted. In order to use this skew map for the regions in the surrounding states, the map was modified as shown in Figure 2.1.

After the frequency analyses were performed for the streamflow gaging stations, results were reviewed to ensure all stations had more than ten years of record (after eliminating the zero 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 geo-hydrologic 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 2.1. Further explanation for the particular reasons stations were excluded from the regression analyses are provided in the footnotes to Table A.1 in Appendix A, which also includes the recurrence flood year estimates for each station in the analysis.

Table 2.1: Summary of USGS stations available for regression analyses for each geo-hydrologic region.

Geo-Hydrologic Region	Total Stations	Useable Stations	Un-useable 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

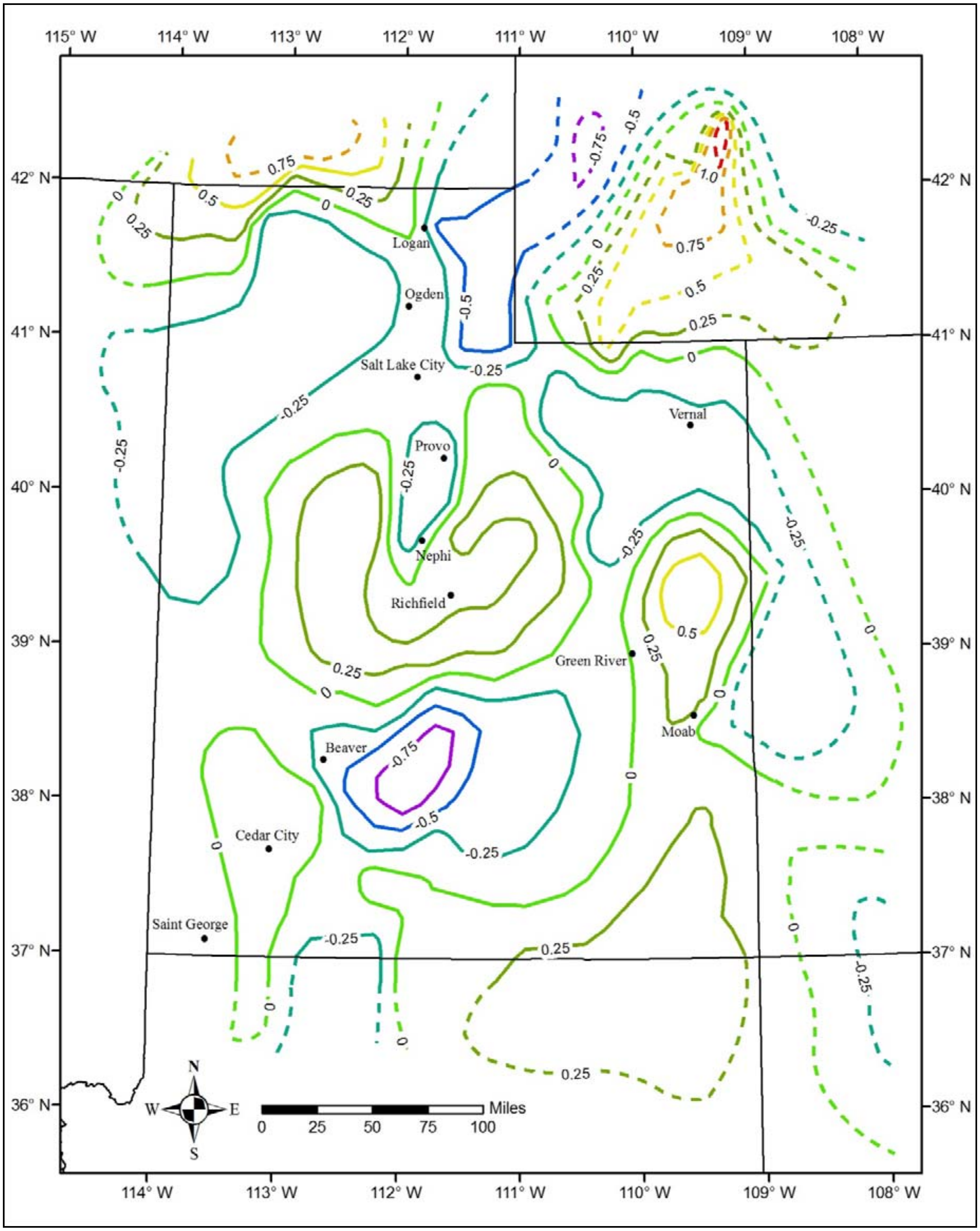

Figure 2.1: Generalized skew map for Utah showing contour lines of constant skew value for flood frequency analysis (modified from Perica and Stayner (2004) using a preliminary skew map detailing skew contour lines as shown above). Dashed lines show the approximated skew lines after modification.

2.3 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.

2.3.1 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 2.2, which includes a description of how WMS computes each characteristic. Also, the table shows the symbol describing each parameter used in the regression equations.

The WMS software calculated the geometric characteristics for each watershed used in the regression analyses, which data is shown in Appendix A in Table A.2. These values are provided for each of the delineated watersheds associated with the stream gage stations.

Table 2.2: 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).

2.3.2 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 is 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 t 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 ten 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 one to ten acres, was due to incomplete coverage of SSURGO data across the state of Utah.

Composite curve numbers for each gauging 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 in Table A.3, where the curve number values were obtained from SCS's Technical Release 55 (USDA 1986). The composite curve numbers determined for each basin are shown in Appendix A in Table A.4.

2.3.3 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 inches 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 inches into the soil, 24 inches into the soil, and the full depth (60 inches 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 in Table A.4.

2.3.4 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 square miles) 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 in Table A.4 for reference.

2.3.5 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 gauging station's watersheds (as discussed in section 2.3.4). 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 in Table A.4 for each watershed in the study region.

2.3.6 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 semi-arid regions with mountainous terrain (larger slopes) and similar watershed areas contained in this analysis. After developing the correlation matrices (discussed in Section 3.3) 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 2.1.

(Eq. 2.1)

$$-$$

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/mile)

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 in Table A.5 for each watershed within the study.

2.3.7 Summary of Explanatory Variables

A summary of all the explanatory variables examined in this study is provided in Table 2.3, which contains the symbol used in the regression equations and the units each parameter needs to be in.

Table 2.3: 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	square miles	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

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3.0 EXTENDED RATIONAL METHOD STYLE REGRESSION EQUATIONS

The rational method is commonly used to compute peak flood flows for small watersheds (less than half a square mile). 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 3.1:

$$Q = C_f C i A, \qquad \textit{(Eq. 3.1)}$$

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.

3.1 Recurrence Year Runoff Coefficients

Runoff coefficients for each watershed were determined for each recurrent flood year by rearranging the rational method equation into the form shown in Equation 3.2 and applying the peak discharges, rainfall intensities, and watershed areas.

$$C_f C = Q/(iA) \qquad \textit{(Eq. 3.2)}$$

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 2.3. Calculated runoff coefficients were computed for each watershed within each region and are provided in Appendix C in Table C.1.

3.2 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 3.3, which is a common method used in this type of analysis.

$$logY = a + b_1 logX_1 + b_2 logX_2 + ... + b_n logX_n \qquad (Eq.\ 3.3)$$

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 3.3, the resulting regression equation is a power function of the dependent variables, as shown in Equation 3.4.

(Eq. 3.4)

–

Each of the regression equations developed for the rational method style equations and the traditional regression equations follow the format shown in Equation 3.4.

3.3 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 in Table D.1.

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 3.2). 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.

3.4 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 3.3; a logarithmic transformation was performed to show the developed regression equations in the form of Equation 3.4. Also, the R^2, R^2_{adjusted} (which accounts for the sample size), and $R^2_{predicted}$ 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 shown in Table 3.1.

3.5 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 3.5 (which is the form of the rational method equation).

$$Q_x = C_x i_x A \qquad \textit{(Eq. 3.5)}$$

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 3.1 ((ft^3/s)/(in-$mile^2$/hr))
i_x = Rainfall intensity from time of concentration (Eq. 2.1) at "x" recurrence year (in/hr)
A = Area of watershed ($mile^2$)

It should be noted the reason some regions don't 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 couldn't be determined for those stations, which restricted the computation of a runoff coefficient for those basins.

Table 3.1: 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 2.3 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 3.1: 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 2.3 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 #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

4.0 EQUATION LIMITATIONS AND VARIABLES/PREDICTION RANGES

The user of the equations presented in Table 3.1 should be aware of the limitations associated with the equations. These limitations are presented in the following sections. Each of the equations developed 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.

4.1 Limitations of Rational Style Regression Equations

The predictive equations presented in Table 3.1 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 3.1, 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 4.1. 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 4.1 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 4.1, 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 authors' opinion the equations are better off using the variables, rather than using the other equation options. Therefore, the variables were left in the equations as shown in Table 3.1 for the equations listed in Table 4.1.

Table 4.1: 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

Table 4.1 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 closer to an 85% confidence interval. The choice to use this equation rather than choosing different variables is to maintain continuity throughout the prediction of all the recurrence year storm events. 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.

4.2 Explanatory Variable Input Ranges

Each of the equations presented in Table 3.1 were developed based on specific ranges of data for the explanatory variables used. These ranges, which are shown in Table 4.2, 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 3.1, and include the range in area of the gauging station's watersheds.

Table 4.2: Ranges of explanatory variables used in the equations presented in Table 3.1.

Region	*A* (mi^2)	*BS* (ft/ft)	*BL* (ft)	*MFD* (ft)	*FS* (%)	*Ksat,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	---	---

4.3 Average Predicted Ranges for Developed Equations

The equations presented in Table 3.1 were used to estimate the recurrence year runoff coefficients and predicted flood flows for each gauging station's watershed in the study. The values for the inputted explanatory variables are shown for each of the watersheds in Appendix A in Tables A.1 through A.5. The estimated ranges of predicted values are shown in Table 4.3 for each geo-hydrologic 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 4.3. Typically runoff coefficients are between zero and one (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 per mile (since there is 1.008 ft^3/s per one acre-inch per hour). The user should compare an estimated flood flow with the values presented in Table 4.3 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 4.3: Average values of prediction determined by equations presented in Table 3.1, 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
Geo-Hydrologic 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
Geo-Hydrologic 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
Geo-Hydrologic 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
Geo-Hydrologic 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 4.3: Average values of prediction determined by equations presented in Table 3.1, 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
Geo-Hydrologic 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
Geo-Hydrologic 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
Geo-Hydrologic 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

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5.0 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 aren't likely to be made with them. However, using them to approximate flows through ungauged 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 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. This might prove to be useful in this analysis, since many of the streamflow gauges have fewer than twenty years of peak flow data.

A similar study in the future would have the advantage of using more USGS stream gauge 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 weren't used in this analysis because the records were fewer than ten years of peak flow data. Within the next five years, some of these stations may fit the criteria used to select the gauging stations (which was a minimum of ten years of record). An increase in the gauging 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 authors' 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.

6.0 APPLICATION OF THE DEVELOPED EQUATIONS

6.1 Step-By-Step Procedure

The rational style regression equations presented in Table 3.1 should be used to estimate recurrence year flood flows for rural streams with drainage areas less than 30 square miles 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-meter 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 2.3, but the user should make sure the output variables are defined the same way as WMS (as presented in Table 2.2).

3. Identify the geo-hydrologic region the delineated watershed is located within using Figure 1.1. Consult Tables 3.1 and 4.1 for required input variables to regression equations for desired recurrence year calculations. Consult Table 2.3 for identification of the dataset used to determine the needed predictor variables. A list of internet locations that provide these data is shown below. The user should follow the processes outlined in sections 2.3.1 through 2.3.6 for specific details 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://gisdev.nacse.org/prism/nn/index.phtml.

    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 Table A.3 in Appendix A. This table should be used since it was used in the development of the regression equations. For more 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 can also be done by overlaying the LULC data on the STATSGO data 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 2.1:

$$t_c = 2.4 A^{0.1} L^{0.25} L_{ca}^{0.25} S^{-0.2} \qquad \textit{(Eq. 6.1)}$$

   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 3.1. Remember the equations in Table 3.1 only calculate the runoff coefficient for the rational style equations, so to obtain the estimated recurrence year flow it is necessary to use Equation 6.2, as reproduced from Equation 3.5.

$$Q_x = C_x i_x A \qquad \text{(Eq. 6.2)}$$

6. The user should compare the predicted flood flow with the prediction ranges presented in Table 4.3. Then engineering judgment should be used to determine if the estimation makes sense from a design perspective.

6.2 Example Problem

Problem Statement:

A road crossing an ephemeral rural wash is to be constructed to provide access to a campground 25 miles north east 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 3.1. The delineation of the watershed is shown in Figure 6.1, which also provides the details on the relative location of the site.

Solution:

1. A 10-meter 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 geo-hydrologic Region 6, identified using Figure 1.1. The regression equation to be used in this problem is obtained from Table 3.1. 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 3.3 and the 50-year regression runoff coefficient regression equation.

(From Table 3.1)

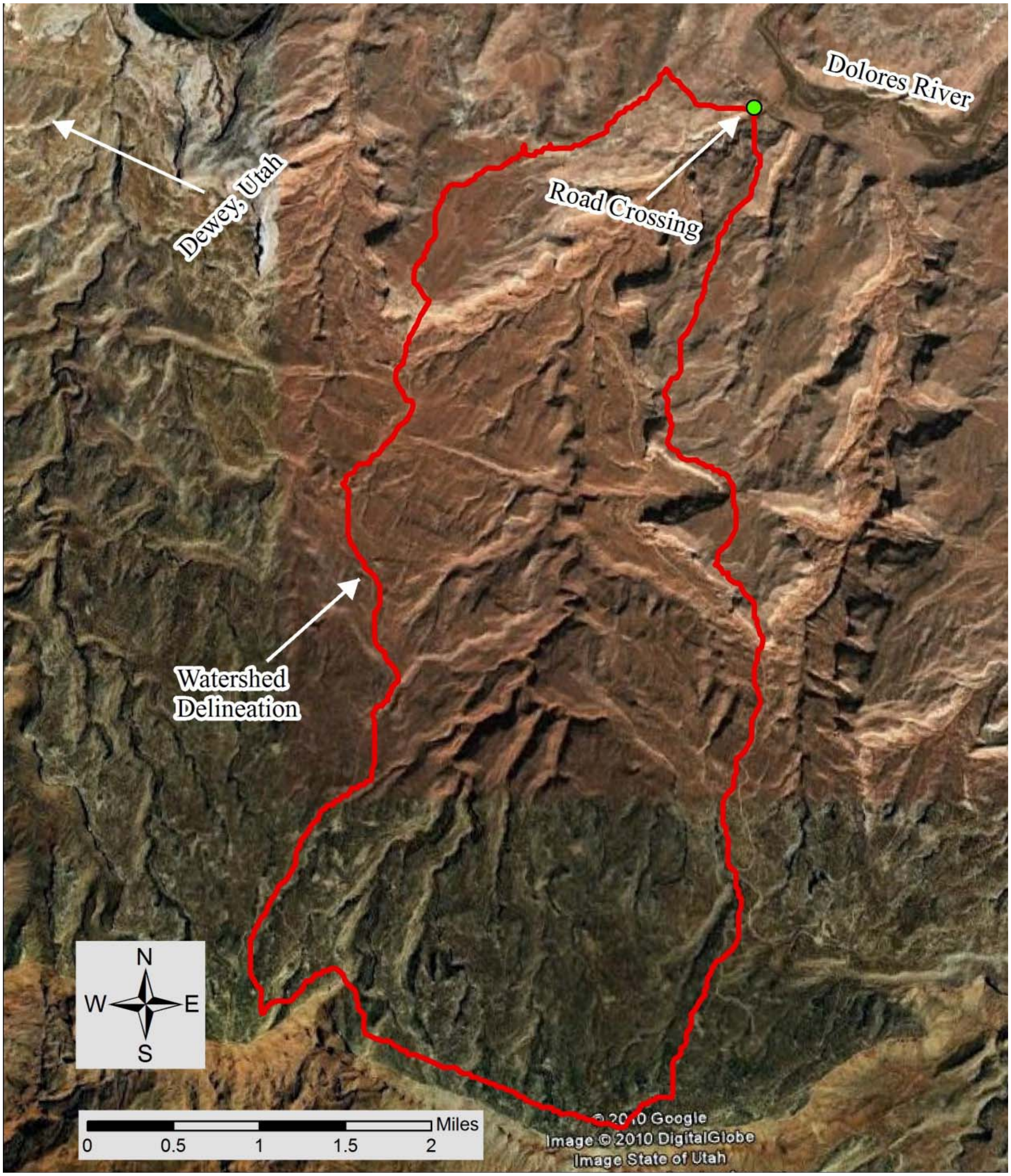

Figure 6.1: Watershed delineation and for example problem located 25-miles north-east of Moab, UT.

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 6.1 (which is also Equation 2.1). 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 6.1, the necessary parameters were provided from the delineation of the watershed, which are presented below:

      (Equation 6.1)

      Where, $A = 11.522$ mi^2
      $L = 7.955$ mi
      $L_{ca} = 4.216$ mi
      $S = 370.1$ft/mi

      Therefore,

   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 6.2.

Table 6.1: 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-hour (in/hr)	2-hour (in/hr)	3-hour (in/hr)	6-hour (in/hr)	12-hour (in/hr)	24-hour (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

Since the time of concentration value was between two and three hours, linear interpolation was used to obtain the rainfall intensity. The values shown in bold print in Table 6.2 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:

–

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:

$$MAP = 12.62 \text{ inches}$$

5. Now that all the needed values were determined, they were implemented into the predictor equation from Table 3.1. This computation is shown below:

–

6. From Table 4.3 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 a software, such as Hec-HMS, as a means for verification or refined design.

6.3 Addendum to Example Problem

The example problem in section 6.2 does not provide an example on 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 Geo-Hydrologic Regions #1 and #7, then it is worthwhile to show the steps to compute this value. For simplicity purposes, the watershed used in section 6.2 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 6.2.

Table 6.2: 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

From the computations in Table 6.2, the weighted average $K_{sat,surf}$ value was calculated using Equation 6.3:

(Eq. 6.3)

Therefore,

6.4 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 authors have not been able to determine if the FS (flow south) parameter can be determined using Arc Hydro. Table 6.3 shows the different methods that can be used to obtain the various basin geometric characteristics used in the equations of Table 3.1.

Table 6.3: 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

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APPENDIX A: COMPUTED AND GATHERED DATA

Table A.1: Peak flows at selected streamflow gaging stations in the geo-hydrologic 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	Gage Station Name	Peak Flow From 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
		Geo-Hydrologic Region #1									
1	10090800	BATTLE CREEK TRIB NR TREASURETON ID	45	96	138	198	247	299	354	431	19
2	10069000	GEORGETOWN CREEK BEL LITTLE RIGHT HAND FORK, UTAH	51	69	82	100	114	129	145	167	17
3	10099000	HIGH CREEK NEAR RICHMOND, UTAH	214	335	418	524	603	682	761	865	22
4	10102300	SUMMIT CREEK ABV DIVERSIONS NR SMITHFIELD, UTAH	147	212	252	300	334	366	397	436	18
5	9208000	LA BARGE CREEK NR LA BARGE MEADOWS RANGER STA, WY	131	164	183	204	218	231	242	257	33
[1]6	9204700	SAND CREEK DRAW TRIBUTARY NEAR BOULDER, WY	10	27	46	77	108	145	190	260	18
[2]7	10019700	WHITNEY CANYON CREEK NEAR EVANSTON, WY	45	84	116	163	202	245	291	358	17
[5]8	9214000	LITTLE SANDY CREEK NEAR ELKHORN, WY	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	10130000	SILVER CREEK NEAR WANSHIP, UT	122	236	326	454	558	668	783	945	14
10	10129350	CRANDALL CREEK NEAR PEOA, UTAH	90	123	143	167	184	201	217	237	10
11	10128200	SOUTH FORK WEBER RIVER NEAR OAKLEY, UTAH	197	226	242	261	273	284	295	308	10
12	9216290	EAST OTTERSON WASH NEAR GREEN RIVER, WY	142	305	477	798	1,140	1,580	2,170	3,230	16
[5]13	10011200	WEST FORK BEAR RIVER AT WHITNEY DAM, NR OAKLEY, UT	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	9221680	MUD SPRING HOLLOW NEAR CHURCH BUTTE, NR LYMAN, WY	55	188	367	763	1,240	1,920	2,890	4,790	20
[5]15	9224600	BLACKS FORK TRIBUTARY NEAR GRANGER, WY	101	191	279	432	583	774	1,010	1,420	9
[1]16	9224800	MEADOW SPRINGS WASH TRIB NEAR GREEN RIVER, WY	23	88	182	404	681	1,100	1,700	2,930	18
[4]17	9216350	SKUNK CANYON CREEK NEAR GREEN RIVER, WY	15	45	93	222	412	745	1,320	2,770	11
[3]18	9224810	BLACKS FORK TRIBUTARY NO 2 NEAR GREEN RIVER, WY	17	64	128	274	451	708	1,080	1,790	17
[1]19	9224820	BLACKS FORK TRIBUTARY NO 3 NEAR GREEN RIVER, WY	18	68	142	320	547	893	1,410	2,470	20
[1]20	9224840	BLACKS FORK TRIBUTARY NO 4 NEAR GREEN RIVER, WY	11	23	36	58	79	106	139	194	17
21	9227500	WEST FORK BEAVER CREEK NEAR LONETREE, WYOMING	163	251	321	422	508	604	710	868	14
22	9226500	MIDDLE FORK BEAVER CREEK NEAR LONETREE, WYO.	308	487	622	810	963	1,130	1,300	1,550	22
23	9225200	SQUAW HOLLOW NEAR BURNTFORK, WY	103	229	351	560	759	1,000	1,300	1,780	20
[4]24	9229450	HENRYS FORK TRIBUTARY NEAR MANILA, UT	22	96	210	491	859	1,430	2,290	4,080	10
[1,2]25	9225300	GREEN RIVER TRIBUTARY NO 2 NEAR BURNTFORK, WY	214	971	2,070	4,530	7,410	11,400	16,900	26,900	21
		Geo-Hydrologic Region #2									
26	10137680	NORTH FORK OGDEN RIVER NEAR EDEN, UTAH	91	120	138	160	176	191	206	226	11
27	10141400	HOWARD SLOUGH AT HOOPER, UTAH	175	231	265	303	329	354	377	406	13
28	10139300	WHEELER CREEK NEAR HUNTSVILLE, UTAH	104	224	330	492	632	789	962	1,220	37
[4]29	10172810	MACK CANYON NR GRANTSVILLE, UTAH	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	10141500	HOLMES CREEK NEAR KAYSVILLE, UTAH	18	31	41	55	67	79	91	109	17
31	10172805	NORTH WILLOW CREEK NR GRANTSVILLE, UTAH	26	54	80	123	163	210	265	353	13
32	10172800	SOUTH WILLOW CREEK NEAR GRANTSVILLE, UT	32	56	75	102	124	147	172	208	48
33	10142000	FARMINGTON CR ABV DIV NR FARMINGTON, UTAH	154	247	315	407	479	553	631	739	34
34	10142500	RICKS C AB DIVERSIONS, NR CENTERVILLE, UTAH	19	40	58	87	114	144	178	230	17

Table A.1: Peak flows at selected streamflow gaging stations in the geo-hydrologic 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	Gage Station Name	Peak Flow From 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
Geo-Hydrologic Region #2 (continued)											
35	10143000	PARRISH C AB DIVERSIONS NR CENTERVILLE, UT	14	23	30	38	44	50	56	63	19
36	10143500	CENTERVILLE CREEK ABV DIV NR CENTERVILLE, UT	14	26	36	50	63	78	94	118	40
37	10145126	STORM DRAIN TO MILL CK,620 SO 200 W,BOUNTIFUL, UT	27	49	68	96	121	148	179	226	36
38	10144000	STONE CREEK ABOVE DIVERSION NEAR BOUNTIFUL, UT	25	72	131	256	402	611	907	1,480	16
39	10135000	HARDSCRABBLE CREEK NEAR PORTERVILLE, UTAH	246	364	436	518	574	626	674	733	29
40	10145000	MILL C AT MUELLER PARK, NR BOUNTIFUL, UTAH	42	77	105	143	175	208	244	294	19
[1]41	10172760	CLOVER CREEK NEAR CLOVER, UTAH	13	40	71	129	189	264	357	513	14
42	10172791	SETTLEMENT CREEK ABOVE RESERVOIR NEAR TOOELE, UT	18	41	62	94	123	155	191	244	10
43	10172765	CLOVER CREEK ABOVE BIG HOLLOW, NEAR CLOVER, UT	16	30	40	55	68	82	96	117	17
44	10172500	CITY CREEK NEAR SALT LAKE CITY, UTAH	64	96	118	146	167	188	209	236	70
[4]45	10172790	SETTLEMENT CANYON NR TOOELE, UTAH	21	63	108	188	265	359	471	648	11
46	10172200	RED BUTTE CREEK AT FORT DOUGLAS, NEAR SLC, UT	15	32	48	72	95	120	150	196	45
47	10172000	EMIGRATION CREEK NEAR SALT LAKE CITY, UTAH	25	46	63	89	111	137	166	210	57
48	10170000	MILL CREEK NEAR SALT LAKE CITY, UTAH	50	75	91	113	129	146	162	184	63
[4]49	10172720	EAST GOVERNMENT CREEK TRIBUTARY NEAR VERNON, UT	ND	ND	ND	ND	ND	ND	ND	ND	ND
50	10166430	WEST CANYON CREEK NEAR CEDAR FORT, UT	31	86	154	295	458	689	1,010	1,640	33
51	10167500	LITTLE COTTONWOOD CREEK NR SALT LAKE CITY, UT	387	512	595	699	776	853	930	1,030	51
52	10133700	THREEMILE CREEK NEAR PARK CITY, UTAH	10	15	18	23	26	30	33	39	13
53	10133600	MCLEOD CREEK NEAR PARK CITY, UT	64	107	138	180	212	245	279	326	12
54	10165500	DRY CREEK NEAR ALPINE, UTAH	201	279	332	401	453	507	561	636	23
55	10172700	VERNON CREEK NEAR VERNON, UT	21	69	136	289	481	770	1,200	2,080	49
56	10160000	DEER CREEK NEAR WILDWOOD, UTAH	61	88	104	123	137	150	162	178	11
57	10160800	NO FK PROVO RIV AT WILDWOOD UTAH	106	148	176	212	240	267	296	334	10
Geo-Hydrologic Region #3											
58	10172909	BURNT CK NR SHORES, NV	1	8	24	86	204	457	980	2,540	21
59	10172920	COTTON CREEK NEAR GROUSE CREEK, UTAH	3	17	42	119	244	475	893	1,970	10
60	13077700	GEORGE CREEK NEAR YOST, UTAH	68	108	142	195	242	298	363	466	30
61	13079000	CLEAR CREEK NEAR NAF, IDAHO	114	180	234	313	381	457	542	671	28
62	10172913	LORAY WASH TRIB NR COBRE, NV	10	92	270	796	1,550	2,740	4,550	8,190	18
63	10172952	DUNN CREEK NEAR PARK VALLEY, UT	45	78	105	144	177	213	253	312	32
[4]64	10172925	GR ST LAKE DESERT TR NO 3 NR PARK VALLEY, UT	8	129	520	2,170	5,260	11,400	22,900	51,700	12
65	10122500	DEVIL CREEK AB CAMPBELL CREEK NR MALAD CITY, ID	64	109	146	202	250	304	365	457	23
[4]66	10172902	DEAD CEDAR WASH NR WENDOVER, UTAH	3	237	1,580	9,290	25,700	59,200	119,000	256,000	18
67	10126180	SULPHUR CREEK NR. CORINNE, UT	175	235	273	320	355	389	423	467	15
68	10172900	BAR CREEK NEAR IBAPAH, UTAH	71	376	837	1,860	3,040	4,640	6,730	10,400	15
[4]69	10172905	GREAT SALT LAKE DESERT TRIB NEAR DELLE, UTAH	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]70	10172835	SKULL VALLEY TRIBUTARY NR DELLE, UTAH	0	1	3	12	29	62	120	265	12

Table A.1: Peak flows at selected streamflow gaging stations in the geo-hydrologic 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	Gage Station Name	Peak Flow From 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
Geo-Hydrologic Region #3 (continued)											
71	10172870	TROUT CREEK NEAR CALLAO, UT	44	83	112	152	183	215	249	294	43
[4]72	10172830	NORTH FORK MUSKRAT CANYON NR TIMPIE, UT	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]73	10172885	GR SALT LAKE DESERT TR NO.2 NR DUGWAY, UT	3	148	992	6,890	22,900	65,500	167,000	499,000	12
74	10243260	LEHMAN CK NR BAKER, NV	24	49	72	111	148	192	245	330	19
75	10243240	BAKER CK AT NARROWS NR BAKER, NV	75	137	187	258	317	381	449	547	28
76	10242460	ESCALANTE VALLEY TRIB NR PANACA, NV	21	121	273	607	979	1,470	2,090	3,120	18
77	10242440	COTTONWOOD CREEK NR ENTERPRISE, UTAH	147	395	668	1,180	1,700	2,380	3,230	4,710	11
Geo-Hydrologic Region #4											
78	9216600	CUTTHROAT DRAW NEAR ROCK SPRINGS, WY	90	185	282	459	641	877	1,180	1,720	22
79	9216900	BITTER CR TRIB NR GREEN RIVER WY	12	24	34	49	62	77	93	116	24
80	9235600	POT CREEK ABOVE DIVERSIONS, NEAR VERNAL, UT	62	126	182	271	351	444	549	712	35
81	9264000	ASHLEY C BELOW TROUT C NR VERNAL, UTAH	433	561	638	726	787	844	898	967	11
82	9264500	SOUTH FORK ASHLEY C NR VERNAL, UTAH	313	414	474	543	592	637	681	735	12
83	9268500	NORTH FORK OF DRY FORK NEAR DRY FORK, UTAH	76	116	143	178	204	231	258	294	44
84	9268900	BROWNIE CANYON ABOVE SINKS, NR DRY FORK, UT	187	281	342	419	475	529	583	654	29
85	9269000	EAST FORK OF DRY FORK NEAR DRY FORK, UTAH	129	191	229	272	302	329	355	386	18
86	9273500	HADES CREEK NEAR HANNA, UTAH	75	108	129	154	172	190	206	227	19
87	9276000	WOLF CREEK ABOVE RHOADES CANYON NEAR HANNA, UT	50	73	88	107	121	134	148	165	38
88	9278000	SOUTH FORK ROCK CREEK NEAR HANNA,UTAH	93	138	167	202	227	252	275	305	38
89	9280400	HOBBLE CREEK AT DANIELS SUMMIT NEAR WALLSBURG, UT	69	102	124	150	169	188	207	231	21
90	9287500	WATER HOLLOW NR FRUITLAND, UTAH	28	60	91	143	194	256	331	454	26
91	9298000	FARM CREEK NEAR WHITEROCKS, UTAH	88	174	239	327	395	463	532	623	31
[7]92	10153500	PROVO RIVER NEAR KAMAS, UTAH	503	632	710	802	866	928	988	1,060	20
93	10153800	NORTH FORK PROVO RIVER NEAR KAMAS, UT	395	546	639	749	826	899	970	1,060	33
94	10154000	SHINGLE CREEK NEAR KAMAS, UTAH	178	203	218	236	248	259	270	284	10
Geo-Hydrologic Region #5											
[1]95	10146900	UTAH LAKE TRIBUTARY NEAR ELBERTA, UTAH	181	712	1,380	2,690	4,060	5,790	7,920	11,400	12
96	10147500	PAYSON CREEK ABV DIVERSIONS, NEAR PAYSON, UTAH	140	259	350	476	577	683	793	946	15
97	10147000	SUMMIT CREEK NEAR SANTAQUIN, UTAH	73	123	157	201	234	267	300	343	19
[1]98	10220300	TINTIC WASH TR NEAR NEPHI, UTAH	64	158	255	425	592	799	1,050	1,470	14
99	10224100	OAK CREEK ABOVE LITTLE CREEK, NEAR OAK CITY, UT	19	42	65	104	142	189	246	339	31
100	10148300	DAIRY FORK NEAR THISTLE, UTAH	151	392	672	1,240	1,870	2,740	3,940	6,190	14
101	10219200	CHICKEN CREEK NEAR LEVAN, UT	46	132	230	419	618	879	1,210	1,790	33
102	10148200	TIE FORK NEAR SOLDIER SUMMIT, UT	23	79	166	388	696	1,210	2,040	3,970	33
103	10208500	OAK CREEK NR. FAIRVIEW, UTAH	145	283	413	632	842	1,100	1,410	1,930	25
104	10233000	MEADOW CREEK NEAR MEADOW UTAH	52	104	150	223	287	360	444	572	11
105	10210000	PLEASANT CREEK NEAR MOUNT PLEASANT, UTAH	159	332	509	830	1,160	1,580	2,130	3,090	21

Table A.1: Peak flows at selected streamflow gaging stations in the geo-hydrologic 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	Gage Station Name	Peak Flow From 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
Geo-Hydrologic Region #5 (continued)											
106	10211000	TWIN CREEK NEAR MOUNT PLEASANT, UTAH	68	132	194	298	399	523	675	929	12
107	10215700	OAK CREEK NEAR SPRING CITY, UT	91	150	195	258	310	366	426	514	25
108	10215900	MANTI CREEK BLW DUGWAY CREEK, NR MANTI, UT	315	456	552	678	773	870	969	1,100	40
109	10237500	INDIAN CREEK NEAR BEAVER, UTAH	33	70	104	160	212	274	347	462	13
[3]110	10204200	MILL CREEK NEAR GLENWOOD, UTAH	2	18	57	181	375	711	1,260	2,500	11
111	10236000	NORTH FORK NORTH CREEK NEAR BEAVER, UTAH	40	77	106	149	185	223	265	324	18
112	10236500	SOUTH FORK NORTH CREEK NEAR BEAVER, UTAH	174	468	771	1,300	1,800	2,410	3,140	4,300	11
113	10205070	COTTONWOOD CREEK NEAR SALINA, UTAH	25	101	220	521	925	1,570	2,570	4,740	10
[5]114	10234000	THREE CREEKS NEAR BEAVER, UTAH		ND	ND	ND	ND	ND	ND	ND	ND
115	10205300	SHEEP CREEK AT MOUTH NEAR SALINA, UTAH	12	23	33	47	59	71	84	104	12
116	10235000	SOUTH CREEK NEAR BEAVER, UTAH	33	80	126	204	277	364	466	628	12
117	10187300	OTTER CREEK NEAR KOOSHAREM, UT	57	79	92	107	117	127	135	146	18
Geo-Hydrologic Region #6											
118	9310000	GOOSEBERRY CREEK NEAR SCOFIELD, UT	217	308	365	434	483	530	575	633	65
119	9310700	MUD CRK BL WINTER QUARTERS CYN @ SCOFIELD, UT	104	196	272	386	483	593	714	894	26
120	9312700	BEAVER CREEK NEAR SOLDIER SUMMIT, UTAH	42	83	119	177	229	288	357	464	29
121	9271800	HALFWAY HOLLOW TRIB. NEAR LAPOINT, UTAH	92	301	529	925	1,300	1,730	2,230	2,990	15
[1]122	9308200	PLEASANT VALLEY WASH TRIB. NEAR MYTON, UTAH	92	1,000	3,010	8,740	16,500	28,000	44,300	74,500	11
123	9309100	GATE CANYON NEAR MYTON, UTAH	177	726	1,410	2,680	3,960	5,500	7,310	10,100	12
124	9327600	FERRON CREEK TRIB. NEAR FERRON, UTAH	106	337	624	1,210	1,880	2,780	4,000	6,230	12
125	9329050	SEVEN MILE CREEK NEAR FISH LAKE, UT	183	268	319	376	414	449	481	520	35
126	9263800	COW WASH NEAR JENSEN, UTAH	302	802	1,310	2,170	2,990	3,950	5,090	6,860	14
127	9314400	COLEMAN WASH NEAR WOODSIDE, UTAH	254	607	948	1,510	2,040	2,670	3,400	4,550	10
[1]128	9328300	SIDS DRAW NEAR CASTLE DALE, UTAH	437	1,190	1,960	3,310	4,610	6,170	8,020	11,000	15
129	9315150	SALERATUS WASH TRIB. NR WOODSIDE, UTAH	816	2,250	3,780	6,520	9,220	12,600	16,600	23,200	15
130	9315200	SALERATUS WASH TRIB NO 2 NR WOODSIDE, UTAH	990	2,530	3,980	6,260	8,250	10,500	12,900	16,500	15
131	9328600	GEORGES DRAW NEAR HANKSVILLE, UTAH	215	592	1,000	1,750	2,500	3,440	4,610	6,570	14
132	9328720	OLD WOMAN WASH NEAR HANKSVILLE, UTAH	263	936	1,730	3,220	4,710	6,550	8,770	12,300	10
133	9315900	BROWNS WASH TRIB. NR. GREEN RIVER, UTAH	206	608	1,070	1,970	2,930	4,180	5,790	8,610	15
134	9338000	EAST FORK BOULDER CREEK NEAR BOULDER, UTAH	203	304	369	447	502	555	606	671	20
135	9330300	NEILSON WASH NEAR CAINEVILLE, UTAH	991	2,390	3,620	5,470	7,020	8,700	10,500	13,000	15
136	9338500	EAST FORK DEER CREEK NEAR BOULDER, UTAH	22	66	117	217	321	457	630	928	20
[1]137	9306235	CORRAL GULCH BELOW WATER GULCH, NR RANGELY, CO.	14	69	160	397	716	1,220	1,990	3,600	14
138	9306240	BOX ELDER GULCH NEAR RANGELY, CO.	14	57	120	268	454	733	1,140	1,960	11
139	9328900	CRESENT WASH NEAR CRESENT JUNCTION, UTAH	418	1,110	1,930	3,590	5,430	7,990	11,500	18,000	10
[1]140	9403800	BITTER SEEPS WASH TRIB NEAR FREDONIA, ARIZ.	135	567	1,150	2,360	3,710	5,490	7,790	11,800	14
141	9182600	SALT WASH NEAR THOMPSON, UTAH	262	713	1,220	2,200	3,240	4,600	6,370	9,500	15

Table A.1: Peak flows at selected streamflow gaging stations in the geo-hydrologic 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	Gage Station Name	Peak Flow From Flood Frequency Analyses, for Recurrence Year								Number of Annual Peak Flows
			2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	
Geo-Hydrologic Region #6 (continued)											
[1]142	9306042	PICEANCE CREEK TRIBUTARY NEAR RIO BLANCO, CO.	7	48	135	416	871	1,700	3,160	6,730	18
[4]143	9306052	SCANDARD GULCH AT MOUTH, NEAR RIO BLANCO, CO.	6	11	16	24	32	41	51	68	11
[1]144	9306039	COTTONWOOD GULCH NEAR RIO BLANCO, CO.	3	23	79	311	772	1,780	3,900	10,300	11
145	9163050	BADGER WASH NEAR MACK, CO.	111	202	279	397	502	622	759	969	10
[1]146	9306036	SORGHUM GULCH AT MOUTH, NEAR RIO BLANCO, CO.	11	59	146	380	709	1,240	2,080	3,890	12
[4]147	9163300	EAST SALT CREEK TRIBUTARY NEAR MACK, CO.	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]148	9403750	SAGEBRUSH DRAW NEAR FREDONIA, ARIZ.	ND	ND	ND	ND	ND	ND	ND	ND	ND
149	9153290	REED WASH NEAR MACK, CO.	156	209	245	292	328	365	403	455	25
150	9333900	BUTLER CANYON NEAR HITE, UTAH	420	758	1,030	1,410	1,730	2,080	2,450	2,980	16
[5]151	9153300	REED WASH NEAR LOMA, CO.	ND	ND	ND	ND	ND	ND	ND	ND	ND
152	9181000	ONION CREEK NEAR MOAB, UTAH	730	1,390	1,920	2,660	3,260	3,910	4,590	5,550	13
[4]153	9153200	LITTLE SALT WASH TRIBUTARY NEAR FRUITA, CO.	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]154	9379820	BUCK TANK DRAW NEAR KANAB, UTAH	10	70	208	692	1,540	3,190	6,310	14,600	10
155	9152900	ADOBE CREEK NEAR FRUITA, CO.	133	181	210	245	270	293	316	344	11
[6]156	9152650	LEACH CREEK AT DURHAM, CO.	238	376	476	610	715	823	936	1,090	10
157	9182000	CASTLE CREEK ABOVE DIVERSIONS, NEAR MOAB, UT	9	19	27	38	46	55	65	77	24
158	9183500	MILL CREEK AT SHELEY TUNNEL, NEAR MOAB, UT	188	404	611	960	1,290	1,700	2,190	2,990	26
159	9185200	KANE SPRINGS CANYON NEAR MOAB, UTAH	529	842	1,070	1,370	1,610	1,850	2,110	2,460	15
160	9106200	LEWIS WASH NEAR GRAND JUNCTION, CO.	60	113	156	219	271	327	387	474	10
161	9177500	TAYLOR CREEK NEAR GATEWAY, CO.	114	265	400	608	787	985	1,200	1,520	23
[4]162	9379980	JACK BENCH WASH TRIBUTARY NEAR PAGE, ARIZ.	ND	ND	ND	ND	ND	ND	ND	ND	ND
163	9104500	MESA CREEK NEAR MESA, CO.	40	59	74	96	113	132	153	183	24
164	9334400	FRY CANYON NEAR HITE, UTAH	412	1,910	4,090	8,890	14,400	22,100	32,300	50,500	15
[4]165	9151700	DEER CREEK TRIBUTARY NEAR DOMINGUEZ, CO.	ND	ND	ND	ND	ND	ND	ND	ND	ND
166	9137800	DIRTY GEORGE CREEK NEAR GRAND MESA, CO.	44	68	84	104	118	133	147	166	12
[5]167	9185800	INDIAN CREEK TUNNEL NEAR MONTICELLO, UTAH	ND	ND	ND	ND	ND	ND	ND	ND	ND
[4]168	9169800	EAST PARADOX CREEK TRIBUTARY NEAR BEDROCK, CO.	ND	ND	ND	ND	ND	ND	ND	ND	ND
169	9378170	SOUTH CREEK ABOVE RESERVOIR NEAR MONTICELLO, UT	39	82	123	193	259	338	434	589	23
170	9378630	RECAPTURE CREEK NEAR BLANDING, UT	12	36	62	111	162	227	308	448	42
171	9378950	COMB WASH NEAR BLANDING, UTAH	732	1,430	2,100	3,250	4,380	5,790	7,540	10,500	10
[4]172	9168700	DISAPPOINTMENT CREEK TRIB NEAR SLICK ROCK, CO.	41	131	233	424	617	858	1,160	1,640	12
173	9175800	DEAD HORSE CREEK NEAR NATURITA, CO.	151	546	1,040	2,020	3,060	4,410	6,130	9,050	11
174	9379560	EL CAPITAN WASH NEAR KAYENTA, ARIZ.	455	939	1,410	2,240	3,060	4,080	5,350	7,500	14
[1]175	9379100	LONG HOUSE WASH NEAR KAYENTA, ARIZ.	170	1,140	3,080	8,810	17,300	31,700	55,100	107,000	15
[4]176	9371300	MCELMO CREEK TRIBUTARY NEAR CORTEZ, CO.	51	353	957	2,750	5,400	9,890	17,200	33,300	11
177	9369500	MIDDLE MANCOS RIVER NEAR MANCOS, CO.	105	196	267	367	449	534	625	752	15
178	9369000	EAST MANCOS RIVER NEAR MANCOS, CO.	107	183	244	335	413	500	596	741	15

Table A.1: Peak flows at selected streamflow gaging stations in the geo-hydrologic 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	Gage Station Name	Peak Flow From Flood Frequency Analyses, for Recurrence Year								Number of Annual Peak Flows
			2 year (cfs)	5 year (cfs)	10 year (cfs)	25 year (cfs)	50 year (cfs)	100 year (cfs)	200 year (cfs)	500 year (cfs)	
Geo-Hydrologic Region #6 (continued)											
[1]179	9379060	LUKACHUKAI CREEK TRIBUTARY NEAR LUKACHUKAI, ARIZ.	13	51	105	225	368	572	857	1,400	14
[1]180	9368020	MALPAIS ARROYO NR SHIPROCK, NM	124	308	502	850	1,200	1,640	2,200	3,130	23
[1]181	9367550	STEVENS ARROYO NR KIRTLAND, NM	136	472	893	1,740	2,670	3,910	5,520	8,350	21
182	9367400	LA PLATA RIVER TRIB NR FARMINGTON, NM	62	179	313	570	840	1,190	1,650	2,440	27
[1]183	9367530	LOCKE ARROYO NR. KIRTLAND, NM	110	249	384	612	830	1,090	1,410	1,920	35
[1]184	9367840	YAZZIE WASH NR. MEXICAN SPRINGS, NM	273	610	912	1,380	1,790	2,250	2,760	3,520	37
[1]185	9367860	CHUSCA WASH NEAR MEXICAN SPRINGS, NM	1,090	2,430	3,680	5,710	7,570	9,760	12,300	16,300	29
[1]186	9367880	CATRON WASH NR MEXICAN SPRINGS, NM	1,710	3,010	4,050	5,570	6,830	8,220	9,730	11,900	18
[1]187	9367900	BLACK SPRINGS WASH NR MEXICAN SPRINGS, NM	429	1,050	1,650	2,640	3,560	4,640	5,890	7,820	53
Geo-Hydrologic Region #7											
188	10241600	SUMMIT CREEK NEAR SUMMIT, UTAH	68	216	412	847	1,370	2,140	3,260	5,480	23
189	10241400	LITTLE CREEK NEAR PARAGONAH, UTAH	36	126	245	509	824	1,280	1,920	3,170	21
190	9408400	SANTA CLARA RIVER NEAR PINE VALLEY, UT	68	152	235	378	518	692	904	1,260	49
191	10241470	CENTER CREEK ABV PAROWAN CREEK, NEAR PAROWAN, UT	57	142	232	399	571	792	1,070	1,560	23
192	9406300	KANARRA CREEK AT KANARRAVILLE, UTAH	140	366	611	1,060	1,530	2,120	2,880	4,170	23
193	10241430	RED CREEK NEAR PARAGONAH, UTAH	14	25	33	45	55	65	76	93	11
194	9406700	SOUTH ASH CREEK BELOW MILL CREEK NEAR PINTURA, UT	199	549	927	1,610	2,300	3,160	4,210	5,960	16
[1]195	9415100	PULSIPHER WASH NR MESQUITE, NV	44	344	968	2,820	5,510	9,970	17,000	31,900	18
196	9406800	SOUTH ASH CREEK NEAR PINTURA, UT	192	468	743	1,220	1,670	2,220	2,880	3,950	14
197	9408000	LEEDS CREEK NEAR LEEDS, UT	155	673	1,460	3,330	5,690	9,220	14,400	24,600	45
[3]198	9415050	BIG BEND WASH TRIB NEAR LITTLEFIELD, ARIZ.	2	32	133	587	1,490	3,410	7,160	17,300	13
199	9405420	N FK VIRGIN R BLW BULLOCH CANYON NR GLENDALE, UT	207	410	598	907	1,200	1,550	1,960	2,630	11
200	9404500	MINERAL GULCH NEAR MT. CARMEL, UTAH	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 square miles. 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.

Map Unit ID	Gage Station Number	*Basin Geometric Characteristics*								
		Basin Area (mi^2)	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)
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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Map Unit ID	Gage Station Number	*Basin Geometric Characteristics*								
		Basin Area (mi^2)	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)
Geo-Hydrologic Region #2 (continued)										
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
Geo-Hydrologic 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
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

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.

Map Unit ID	Gage Station Number	*Basin Geometric Characteristics* Basin Area (mi^2)	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)
Geo-Hydrologic Region #3 (continued)										
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
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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.

Map Unit ID	Gage Station Number	*Basin Geometric Characteristics* Basin Area (mi^2)	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)
Geo-Hydrologic Region #5 (continued)										
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
Geo-Hydrologic 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
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

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.

Map Unit ID	Gage Station Number	*Basin Geometric Characteristics* Basin Area (mi^2)	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)
Geo-Hydrologic Region #6 (continued)										
[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
[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

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.

Map Unit ID	Gage Station Number	Basin Geometric Characteristics: Basin Area (mi^2)	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)
Geo-Hydrologic Region #6 (continued)										
[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
Geo-Hydrologic 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
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

[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 taken out. 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 dropped from analyses.
[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 square miles. 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		Hydrologic Soil Group*			
Code	Land Use Description	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.

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)
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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.

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)
36	10143500	60.5	5.54	22.60	23.60	29.70	39.73	2.69
Geo-Hydrologic Region #2 (continued)								
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
Geo-Hydrologic 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
[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

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.

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)
Geo-Hydrologic Region #3 (continued)								
[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
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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)**
Geo-Hydrologic Region #5 (continued)								
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
Geo-Hydrologic 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
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

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.

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)
Geo-Hydrologic Region #6 (continued)								
[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
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

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)
Geo-Hydrologic Region #6 (continued)								
[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
Geo-Hydrologic 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
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 square miles. 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)
Geo-Hydrologic 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
Geo-Hydrologic 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
35	10143000	0.64	0.85	1.04	1.35	1.63	1.96	2.36	3.00

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)
36	10143500	0.57	0.76	0.93	1.20	1.46	1.75	2.11	2.69
Geo-Hydrologic Region #2 (continued)									
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
Geo-Hydrologic 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
[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

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)
[4]72	10172830	0.66	0.90	1.13	1.49	1.83	2.21	2.63	3.30
Geo-Hydrologic Region #3 (continued)									
[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
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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)
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
Geo-Hydrologic Region #5 (continued)									
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
Geo-Hydrologic 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
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

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)
[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
Geo-Hydrologic Region #6 (continued)									
[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
[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

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)
[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
Geo-Hydrologic Region #6 (continued)									
[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
Geo-Hydrologic 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 square miles. Stations were dropped from analyses.

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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

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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.

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 sq. miles, 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 2. 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 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.

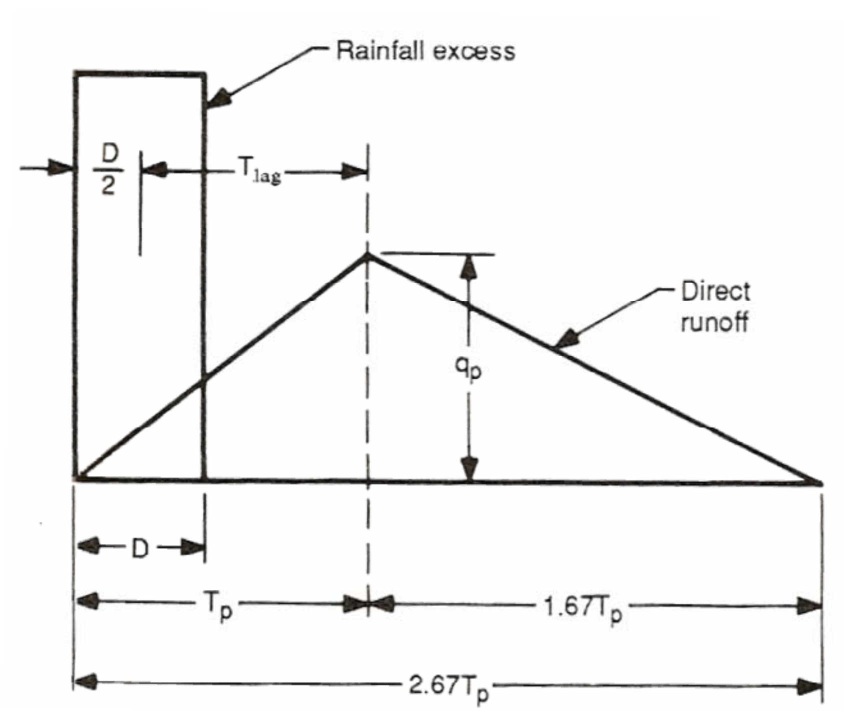

Figure 1: SCS triangular hydrograph detailing lag time

Table 1: List of empirical equations included in WMS*

Empirical equations already programed 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 sq. miles	No
Eagleson	Valid for urban area and < 7 sq. miles	No
Espey	Valid for impervious are from 25 to 40%	No
Putnam	Valid for very shallow slopes (U.S. Great Planes)	No
Riverside County	Valid for mountainous/foothills/valley areas and < 650 sq. miles	Yes
SCS	Valid for areas less than 2000 acres	No
Taylor Schwartz	Developed for N.E. United States	No
Tulsa District	Valid for slopes under 90 ft/mile	No
Time of Concentration Equations		
Fort Bend	Valid for slopes under 33 ft/mile	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

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 square miles, 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 sq. miles) 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.

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 inches/hour.

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 2 summarizes the time of concentration values obtained from each approach. As expected, the results from Table 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.

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

Watershed Geometric Properties	Empirical Equation		Travel Time Summation Method			
Area = 20.11 mi^2 Mean Channel Slope = 217.9 ft/mile Mean Bottom Width = 20 ft	ADOT	Riverside County	Q_2 = 310 (cfs) n = 0.065	Q_2 = 310 (cfs) n = 0.08	Q_{100} = 640 (cfs) n = 0.065	Q_{100} = 640 (cfs) 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
1000-year Rain Intensity (in/hr)	1.34	1.20	1.49	1.32	1.80	1.59

Tables 3 and 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 2, 3, and 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 3: Typical rainfall intensity results for a medium sized watershed

Watershed Geometric Properties	*Empirical Equation*		*Travel Time Summation Method*			
Area = 8.88 mi^2 Mean Channel Slope = 432.5 ft/mile Mean Bottom Width = 10 ft	ADOT	Riverside County	Q_2 = 75 (cfs) n = 0.065	Q_2 = 75 (cfs) n = 0.08	Q_{100} = 230 (cfs) n = 0.065	Q_{100} = 230 (cfs) 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	0.44	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
1000-year Rain Intensity (in/hr)	2.22	2.16	2.41	2.21	3.04	2.75

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

Watershed Geometric Properties	*Empirical Equation*		*Travel Time Summation Method*			
Area = 3.06 mi^2 Mean Channel Slope = 474.1 ft/mile Mean Bottom Width = 10 ft	ADOT	Riverside County	Q_2 = 70 (cfs) n = 0.065	Q_2 = 70 (cfs) n = 0.08	Q_{100} = 190 (cfs) n = 0.065	Q_{100} = 190 (cfs) 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
1000-year Rain Intensity (in/hr)	2.84	2.85	3.46	3.20	4.05	3.76

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.

References

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

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

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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*** in [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
Geo-Hydrologic 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
Geo-Hydrologic 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

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* in [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
35	10143000	10	13	13	13	13	12	11	10
Geo-Hydrologic Region #2 (continued)									
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
Geo-Hydrologic 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
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

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*** in [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
[4]70	10172835	0	1	3	8	15	26	42	73
71	10172870	13	19	21	22	22	22	22	21
Geo-Hydrologic Region #3 (continued)									
[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
Geo-Hydrologic 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
Geo-Hydrologic 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

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* in [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
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
Geo-Hydrologic Region #5 (continued)									
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
Geo-Hydrologic 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
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

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*** in [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
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
Geo-Hydrologic Region #6 (continued)									
[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
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

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*** in [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
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
Geo-Hydrologic Region #6 (continued)									
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
Geo-Hydrologic 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
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 square miles. 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
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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
Log(2yr, 24hr Prec.)	0.264	0.187	0.128	0.053	0.003	-0.039	-0.074	-0.110	0.052
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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
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
Geo-Hydrologic 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
Geo-Hydrologic 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
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

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
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
Geo-Hydrologic 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