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The development of regional regression equations for flood flow estimates of ungauged streams in the state of Arkansas

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THE DEVELOPMENT OF REGIONAL REGRESSION EQUATIONS FOR FLOOD FLOW ESTIMATES OF UNGAUGED STREAMS IN THE STATE OF ARKANSAS

THE DEVELOPMENT OF REGIONAL REGRESSION EQUATIONS FOR FLOOD FLOW ESTIMATES OF UNGAUGED RURAL STREAMS IN THE STATE OF ARKANSAS

A thesis submitted in partial fulfillment of the requirements for Honors Studies in Civil Engineering

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INTRODUCTION

Statement of the Problem

Knowledge of the frequency and magnitude of floods on streams is crucial to the design of bridges and culverts. Estimates of the peak magnitude and frequency of flood events are also used in the design of flood control structures, the management and regulation of flood plains, the establishment of flood insurance rates, and the formulation of emergency evacuation plans for flood-prone areas (Tortorelli and McCabe, 2001). The most reliable estimates of floods of specified probability at gauged sites are based on frequency analyses of stream gauging station records (Becker, 1986). This type of specified and accurate flood stream flow analysis is not possible for every stream due to the lack of gauging stations and the many years of data required for such an analysis. It is therefore necessary to determine a mathematical relationship between peak flows and physiographic and hydrologic characteristics of the gauged watersheds so that peak runoff from an ungauged watershed can be calculated using an equation specific to the region in which that stream flows. The United States Geological Survey (USGS) has developed and published such regression equations for every state.

The Little Rock USGS office last updated these equations for Arkansas in 1995 (Hodge & Tasker, 1995). These equations have average standard errors of prediction from 35% to 45% for 100-year estimations. Although these wide margins of error are acceptable for regression equations, new methods of creating regression equations offer greater accuracy. Now an additional 10 years of data from existing and newly installed gauging stations can be used to develop more accurate equations. This is achieved by using a regionalization approach that incorporates local watershed characteristics using geographic information systems and up-to-date spatial data in addition to gauging station data. Once developed, these more accurate equations will be used for the prediction of peak streamflow frequencies and magnitudes in ungauged streams for the design of bridges, culverts, and flood control structures throughout the state.

Objectives of Study

The objective of this project is to improve the accuracy of the peak streamflow frequency estimates in ungauged streams by using a regionalization approach and the Bulletin 17B method of flood flow analysis. The entire state will be considered one region and the final results will be compared to previous studies done in the state. The data used will be the most up-to-date available from the USGS gauging stations around the state. This includes data from gauging stations that had less than 10 years of data when the last such study was conducted by Hodge & Tasker (1995). The data from a station will be used if that site contains more than 10 years of unregulated data. The resulting data will then be processed using the Bulletin 17B method and then by using least sum of squares regression analysis, the most accurate regression equation for specific frequencies will be calculated. An evaluation of the equations will be included with the final flood flow prediction equations. An evaluation of the HEC-SSP program and how it performs the Bulletin 17B analysis will be included with the final regression equations.

LITERATURE REVIEW

Overview

Performing an accurate flood flow frequency analysis is necessary to create flood flow prediction equations that are used for the sizing of hydrologic structures such as bridges and culverts. Identifying the most accurate distribution and using the best correlating parameters for that distribution for streamflow data is sometimes esoteric and there are several analytical methods that can be used to fit the natural distribution of extreme streamflows. Several federal organizations have worked together to refine a method for determining flood flow frequencies and magnitudes which is known as the Bulletin 17B method (IACWD, 1982). A program recently released by the US Army Corps of Engineers Hydrologic Engineering Center named HEC-SSP performs the Bulletin 17B analysis. HEC-SSP is available at http://www.hec.usace.army.mil/software/hec-ssp/.

Estimated peak streamflows for unregulated streams are developed by using years of accumulated river gauging data. Including the most recent data in a flood flow frequency analysis allows for the most accurate hydrologic estimates. Moreover, it has long been known that annual flood series are too short for reliable estimation for extreme events. Therefore, complete data for many years, including historical events, is crucial in estimation of extreme events (Zhang and Singh, 2005). For this reason, researchers group data from similar stations together to give a better prediction on extreme events. The regionalization method is used to develop a flood frequency curve that is then compared with hydrologic or physiographic characteristics of that watershed or region. Finally, regression equations are developed that express an accurate relationship between the peak streamflows and the statistically important characteristics of that region, as proven through statistic error analysis.

Definition of Flood Frequency Analysis

Flood frequency analysis is a procedure that is completed on floodplain analyses, construction projects, and other projects pertaining to water resources. It is done to calculate the probable magnitude of a flood and relates it to a risk tolerance level. Flood frequency analyses are completed using statistics to find a recurrence interval, in years, that is associated with a specific magnitude flood. Any water resource structure is built to accept a certain level of risk, which is called the probability of exceedance. This is expressed as the reciprocal of the return period and traditionally is classified at intervals of 2, 5, 10, 20, 50, 100, and 500 years.

Regional Flood Frequency Analysis - Regionalization

A regional flood frequency analysis, or regionalization, was the method used in this analysis. A regional flood frequency analysis is used when there is either no or insufficient gauging data from a stream to do a proper flood frequency analysis. To find flood flow magnitudes for that stream or any streams in its region, the gauging data from watersheds with similar physical characteristics are analyzed in a group as a homogeneous population. Homogeneous means that all observations in the data series originate from the same parent population. Even though stream flood flow magnitudes are different among the streams, if they have similar event frequencies, they can be grouped and analyzed together. This is done because analyzing the data samples together gives more accurate conclusions than if only one sample was used (Hosking & Wallis, 1997). A regression analysis then is used to develop equations correlating that region's physical characteristics to the estimated flood flows.

Regional frequency analysis involves five steps: 1) screening of the data 2) identification of homogeneous regions 3) choice of a frequency distribution 4) estimation of the frequency distribution, and 5) evaluation of the results (Hosking & Wallis, 1997).

Data Screening

The first step to using the regionalization method involves screening the data to eliminate unfit data. Data from a single gauging station is seen fit only if it has at least 10 years of data and is on a stream not regulated by any hydrologic structure (IACWD, 1982). Historical data, specifically, high discharge events, are used as they give good bearing to the estimation of extreme flood events. Historical data includes any event that was not recorded by the gauging station because the station was damaged, not built for a flood of that magnitude, or was not built yet, but the flood was still estimated by observation or by historic written records. Abnormally large or small data recordings should be checked with data from surrounding stations to eliminate gross errors. Applying the discordancy measure compares peak flow responses with the peak flows within the entire group. The discordancy measure compares data from one station with the data from surrounding stations to help find erroneous data. If the discordancy measure is large, then the site is said to be discordant and that peak data is not used in the study. Gauging stations that had drainage areas of 2750 square miles or greater were also left out. Almost all sites with drainage areas of 2750 square miles or greater already have gauging stations on them, meaning a more accurate single flood frequency analysis can be completed for that one station. Therefore, these stations do not benefit from a regional flood frequency analysis.

Identification of Homogenous Regions

After establishing which stations have data that can be used, those stations are recorded and data about the physiographic, geographic, and hydrologic characteristics that influence that station are collected. This data includes: latitude, longitude, station elevation, watershed area, mean basin elevation, basin length, basin slope, basin perimeter, shape factor, max stream length, max stream slope, overland flow, north facing, south facing, and average precipitation. This data is collected and the screened stations with the accompanying data are compared to each other using a multivariate analysis. The analysis compares all variables on a one by one basis for all the stations chosen. A graphical representation allows for inspection of the relationship between the variables to see which variables are related.

A region can be determined based on the variables that show correlation among the group of stations. Regions may be delineated by several variables, including physical location or elevation. Certain variables such as longitudinal and latitudinal coordinates, elevation, and watershed perimeter share relationships with other variables. For example, at differing elevations different average annual rainfalls can be expected. Therefore, elevation might only be needed to be considered in the final regression equation since the annual rainfall average is, in a way, expressed through the elevation variable.

Fitting a Theoretical Distribution

Choosing a distribution is sometimes difficult because flood events are a succession of natural events which are not known to fit any one specific known statistical distribution (IACWD, 1982). The Bulletin 17B method is the accepted method of flood flow frequency analysis outlined by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data in 1982 (IACWD, 1982). This is a widely accepted method used by Federal agencies when performing flood flow frequency analyses. Bulletin 17B is used to plot the logarithms of annual peak discharges to a log Pearson Type III (LPIII) distribution using the method of moments to compute mean, standard deviation, and skew of the log-transformed data (Flynn & Kirby, 2006).

Estimation of a Frequency Distribution

The fourth step of estimating the frequency distribution and magnitudes is also included in the Bulletin 17B analysis. The best fitting prediction curve to the flood flow data is calculated using the method of moments within the HEC-SSP program. A relationship is found between the prediction curve and quantifiable watershed characteristics by using the method of least sum of squares. The error of this line and the prediction curve is evaluated by also using the method of least squares.

Bulletin 17B

Concept of Bulletin 17B

Bulletin 17B fits a Log Pearson III distribution to observed annual peaks by computing the base 10 logarithms of the discharge at selected exceedance probabilities (IACWD, 1982). This is expressed in the equations:

$$LogQ = \overline{X} + KS \tag{1}$$

$$K = \frac{2}{G}\left[\left[\left(K_N - \frac{G}{6}\right)\frac{G}{6} + 1\right]^3 - 1\right] \qquad \text{For } -1.0 \le G \le 1.0 \tag{2}$$

where,

Q = discharge,

$\overline{X}$ = mean of annual peak flow,

K = factor that is a function of the selected exceedance probability and the skew, coefficient, available in Appendix 3 of Bulletin 17B,

S = standard deviation of logarithms,

K_N = standard normal deviate,

G = skew coefficient of logarithms.

Bulletin 17B recommends many methods and mechanisms to account for differences between the stations within a region. The skew associated with each station, incomplete records, broken records, historical data, zero flood years, low and high outliers, plotting positions, and confidence limits are all addressed by Bulletin 17B and the HEC-SSP software, which uses Bulletin 17B analysis and are more closely examined in the following pages.

Skew

The Log Pearson Type III method assumes that the flood flow data is a normal distribution, which can be visualized as a bell curve. When graphed, the actual flood data does not fit a normal bell curve distribution but rather contains a skew. Skewness is defined as the asymmetry in the distribution of the sample data values (Easton & McColl, 2007). A normal bell curve is symmetrical. When a skew is introduced, the distribution becomes asymmetrical, such as with the occurrence of a certain magnitude flood. This concept is represented in Figure 1.

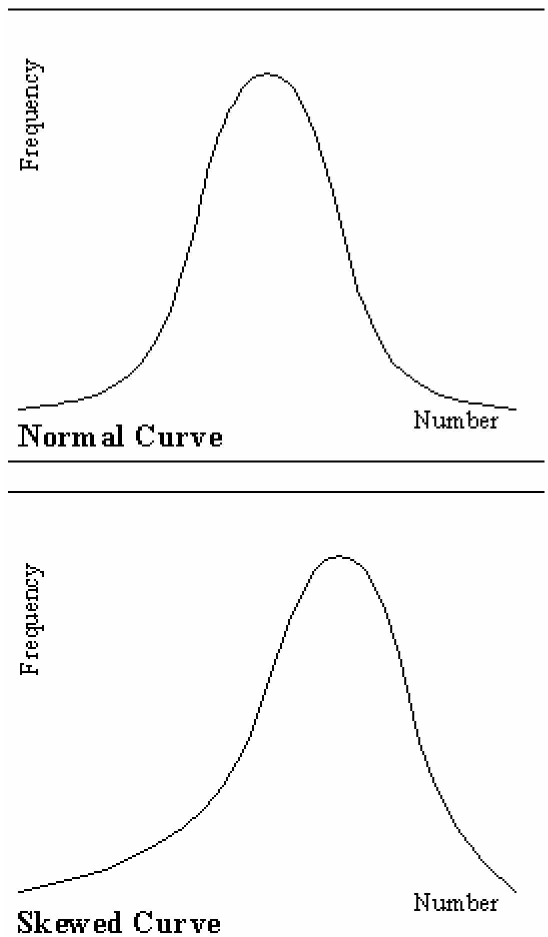

Figure 1 - Normal vs. Skewed Distribution

The skew is accounted for by introducing a coefficient to shift the apex thus making the curve asymmetrical. The station skew used in flood frequency analyses are calculated by using the following equations as outlined in Bulletin 17B:

$$\overline{X} = \frac{\Sigma X}{N} \tag{3}$$

$$S = \left[\frac{\Sigma(X - \overline{X})^2}{(N-1)}\right]^{0.5} \tag{4a}$$

$$S = \left[\frac{(\Sigma X^2) - \frac{(\Sigma X^2)}{N}}{(N-1)}\right]^{0.5} \tag{4b}$$

$$G = \frac{N\Sigma(X - \overline{X})^3}{(N-1)(N-2)S^3} \tag{5a}$$

$$G = \frac{N^2(\Sigma X^3) - 3N(\Sigma X)(\Sigma X^2) + 2(\Sigma X)^3}{N(N-1)(N-2)S^3} \tag{5b}$$

where,

X = logarithm of annual peak flow,

N = number of items in data set,

S = standard deviation of logarithm,

$\overline{X}$ = mean logarithm.

The skew coefficient is sensitive to extreme events; therefore it is difficult to obtain accurate skew estimates from small samples.

Skew coefficients accuracy can be improved by weighting the station skew with generalized skew estimated by pooling information from nearby sites (IACWD, 1982).

The recommended procedure for developing generalized skew coefficients requires the use of at least 40 stations, or all the stations within a 100-mile radius be used when calculating skew coefficients and the stations used should have 25 years or more of recorded data (IACWD, 1982). The actual procedure for calculating generalized skew coefficients also includes using one of three methods: 1) skew isolines drawn on a map 2) skew prediction equations and 3) the mean of the station skew values (IACWD, 1982).

Developing a skew isoline map starts with plotting each station skew value at the centroids of its drainage basin and then evaluating the plotted data to find any geographic or topographic trends. Isolines are drawn between congruent values if a pattern is evident. The average of the differences squared between the observed and the isoline values, otherwise known as the mean-square error (MSE), is computed. MSE values are used in evaluating the accuracy of the isoline map. If no pattern can be found and therefore no lines can be drawn, then this method should not be used (IACWD, 1982).

Skew prediction equations can be developed that relate the station skew coefficient or the differences from the isoline map to the predictor variables that have an effect on the skew coefficient of the station record (IACWD, 1982). These variables include watershed and climatologic variables. The developed prediction equation should preferably be used for estimating the skew coefficient at stations with variables that are within range of predetermined skew and station data that can be used to calibrate the equation. Again, the MSE will be used to evaluate the accuracy of the prediction equation (IACWD, 1982)

The mean of the station skew values requires the mean and variance of the skew coefficients for all stations. In the cases where the variability of the runoff regime is so large as to inhibit finding 40 stations with similar hydrology, the arithmetic mean and variance of only 20 stations may be used to find the generalized skew coefficient. The only requirement of the 20 stations is that the meteorologic, topographic, and geographic characteristics of their drainage basins should be representative of the region around the station of interest (IACWD, 1982)

Station skews for the USGS stations used in this study have already been calculated using one of the three methods and that station skew value is already stored in the metadata for each individual station, along with the flood data from the gauging stations. The HEC-SSP program, which is used to run the Bulletin 17B analysis, contains three options for skew. One is to use the station skew, which has already been found from the generalized skew map which was developed when Bulletin 17B was compiled and is attached to the data that is provided by USGS. The second option is to use a weighted skew by weighing the station and generalized skew coefficient form a better estimate for skew in a given watershed (IACWD, 1982). The third option is to use a regionalized skew which can be entered manually along with a regional mean standard error.

To weigh the skew, the generalized skew coefficient is first assumed to be unbiased and independent of station skew. Then by weighing the station and generalized skew in inverse proportion to their individual MSE, the MSE of the weighed estimate is minimized (IACWD, 1982). This is expressed in the equation:

$$G_W = \frac{MSE_{\overline{G}}(G) + MSE_G(\overline{G})}{MSE_{\overline{G}} + MSE_G} \tag{6}$$

where,

G_W = weighted skew coefficient,

$MSE_{\overline{G}}$ = mean-square error of generalized skew,

G = station skew,

MSE_G = mean-square error of station skew,

$\overline{G}$ = generalized skew.

If the MSE of the generalized skew can be estimated, then equation 6 can be used regardless of the source of generalized skew (IACWD, 1982).

When using the weighted skew option within HEC-SSP, the following equation is used instead of equation 6 because it requires only the station skew and the record length in years and the results are sufficiently accurate:

$$MSE_G \cong 10^{[A-B[\log_{10}(N/10)]]} \tag{7}$$

where,

MSE_G = mean-square error of station skew,

N = record length (years),

A = -0.33 + 0.08|G| if $|G| \leq 0.90$,

= -0.52 + 0.30|G| if $|G| > 0.90$,

B = 0.94 – 0.26|G| if $|G| \leq 1.50$,

= 0.55 if $|G| > 1.50$,

$|G|$ = absolute value of the station skew.

Using equation 7 with stations having absolute skew values (logs) greater than 2 and long periods of record gives little weight to the station skew value (IACWD, 1982). Using equation 6 may also improperly weigh the generalized skew if the generalized and station skews differ by more than 0.5. If this situation occurs, an examination of the data and the flood-producing characteristics of the watershed should be made and possibly greater weight given to the station skews (IACWD, 1982).

The regional skew can be found off of Plate 1 in Bulletin 17B and the MSE can be entered manually. The default MSE for the entire country is 0.302.

Outliers

Outliers are extreme values in a frequency distribution that depart significantly from the trend of the remaining data and can have a disproportionate influence on the mean (NEDARC, 2007). Simply ignoring or deleting these outliers can significantly affect the statistical parameters calculated from the data, especially for small data sets (IACWD, 1982). HEC-SSP allows for the manual identification of high and low outlier thresholds, and also for the default detection and treatment of outliers as outlined in Bulletin 17B (Brunner, 2006).

If the station skew is greater than 0.4, tests for high outliers are considered first. If the station skew is less than -0.4, then tests for low outliers are considered first. If the station skew is between 0.4 and -0.4, then tests for both high and low outliers should be applied removing outliers from the data set (IACWD, 1982).

If the logarithms of peaks in a sample are greater than X_H in equation 8, then they are considered high outliers. Flood peaks that are considered high outliers should be compared with historical data and flood information at nearby sites. If the information available indicates that the high outlier is a maximum over an extended period of time, then that data should be treated as historic flood data. If information is not available to indicate that the high outlier should be addressed as historic flood data, then the data should be retained as part of the systematic record (IACWD, 1982). The equation to calculate the high outlier threshold is:

$$X_H = \overline{X} + K_N S \tag{8}$$

where,

X_H = high outlier threshold in log units,

$\overline{X}$ = mean logarithm of systematic peaks (X's) excluding zero flood events, peaks below gauge base, and outliers previously detected,

K_N = K value from Appendix 4 of Bulletin 17B for sample size N,

S = standard deviation of X's.

Equation 9 calculates the low outlier threshold. Equation 10 is used to calculate the low outlier threshold for data in which an adjustment for historical flood data has previously been made. If the logarithm of any annual peaks in a sample is less than X_L in equation 9 or 10, then they are considered low outliers and are deleted from the data set and the conditional probability adjustment in Appendix 5 of Bulletin 17B is applied (IACWD, 1982). The low outlier threshold is:

$$X_{:L} = \overline{X} - K_N S \tag{9}$$

where,

X_L = low outlier threshold in log units.

The equation for data that has adjustments made for historical data:

$$X_L = \tilde{M} - K_H \tilde{S} \tag{10}$$

where,

$\tilde{M}$ = historically adjusted mean logarithm,

K_H = K value from Appendix 4 for period used to compute $\tilde{M}$ and $\tilde{S}$,

$\tilde{S}$ = historically adjusted standard deviation.

Bulletin 17B analysis and HEC-SSP computations require that all outliers, historical data, personal analyses, and results of data from nearby gauging stations to be well documented. Outliers that lie close to the threshold should be tested for sensitivity of the results to being treated as outliers (IACWD, 1982).

Broken Record

Certain gauging stations may be missing data due to the gauge being removed, damaged or any other reason that would cause it to not record data certain years and therefore put a break in the continuous systematic data. Bulletin 17B recommends analyzing the different record segments as a continuous record with a length equal to both the records combined. The only reason this action would not be taken is if there is a physical change in the watershed that would make the entire record not homogeneous

(IACWD, 1982). It is up to the analyst to investigate the watershed data before assuming both segments.

Incomplete Record

Incomplete records are records in which only some peak flows are missing because they were too low or too high to record or the gauge was out of operation for a short time because of flood damage. Systematic records with incomplete data require different treatment than broken records do (IACWD, 1982). For stations missing data because the flooding was too high, there is usually information available from which a discharge estimate can be made (IACWD, 1982). USGS routinely enters estimates for some gauging stations throughout the state of Arkansas. For crest gauge sites where the bottom of the gauge is not reached in some years, conditional probability adjustment is recommended as outlined in Appendix 5 of Bulletin 17B (IACWD, 1982). HEC-SSP treats incomplete records as outlined by Bulletin 17B.

Zero Flood Years

Some stations are located in arid regions that have no flow for the entire year. The Log Pearson III distribution prohibits the inclusion of zero flood values because the logarithm of zero is negative infinity. Bulletin 17B recommends the conditional probability adjustment for zero flood years as outlined in Appendix 5 of Bulletin 17B.

Historical Data

Historical data is an estimated flood event that occurred before gauging devices began the systematic record. Bulletin 17B outlines a statistical adjustment for this historic data. The underlying assumption to this adjustment is that the data from the systematic record is representative of the interval between the historic record and the systematic record. Before historical data is used, it is important to evaluate the reliability of the data, the peak discharge magnitude, changes in the watershed conditions over an extended period of time, and the effects of these on the computed frequency curve (IACWD, 1982). HEC-SSP treats historical data in the method outlined by Bulletin 17B (Brunner, 2006).

In a historical data adjustment, the historic data is used to define the historically longer period of years, “H”. The number of events, “Z”, that are known to be the largest in the historically longer period “H” are given a weight of 1.0. The remaining events, “N”, from the systematic record are given a weight calculated by equation 11 (IACWD, 1982). Computations for the weights of the individual year’s data can be calculated directly using the equations:

$$W = \frac{(H - Z)}{(N + L)} \tag{11}$$

$$\tilde{M} = \frac{W\Sigma X + \Sigma X_Z}{H - WL} \tag{12}$$

$$\tilde{S}^2 = \frac{W\Sigma(X - \tilde{M})^2 + \Sigma(X_Z - \tilde{M})^2}{(H - WL - 1)} \tag{13}$$

$$\tilde{G} = \frac{H - WL}{(H - WL - 1)(H - WL - 2)}\left[\frac{W\Sigma(X - \tilde{M})^3 + \Sigma(X_Z - \tilde{M})^3}{\tilde{S}^3}\right] \tag{14}$$

where,

W = systematic record weight,

H = number of years in historic period,

Z = number of historic peaks including high outliers that have historic information,

N = record length (years),

L = number of low values to be excluded, such as: number of zeros, number of incomplete record years (below measurable base), and low outliers which have been identified,

$\tilde{M}$ = historically adjusted mean,

X = logarithmic magnitude of systematic peaks excluding zero flood events, peaks below base and high or low outliers,

X_Z = logarithmic magnitude of a historic peak including a high outlier that has historic information,

$\tilde{S}$ = historically adjusted standard deviation,

$\tilde{G}$ = historically adjusted skew coefficient.

After adjusting the data, the historically adjusted frequency curve is plotted logarithmically through points established by equation 15.

The historically adjusted plotting positions for the individual flood events are found by using equation 18, in which the historically adjusted order number of each event, "$\tilde{m}$" is computed from equations 16 and 17 (IACWD, 1982). These equations are:

$$LogQ = \tilde{M} + K\tilde{S} \tag{15}$$

$$\tilde{m} = E \text{ when } 1 \le E \le Z \tag{16}$$

$$\tilde{m} = WE - (W-1)(Z+0.5) \qquad \text{when } (Z+1) \le E \le (Z+N+L) \tag{17}$$

$$P\tilde{P} = \frac{\tilde{m} - a}{H + 1 - 2a}(100) \qquad (18)$$

where,

$\tilde{m}$ = historically adjusted order number of each event for use in formulas to compute the plotting position on a probability graph,

E = event number when events are ranked in order from greatest magnitude to smallest magnitude, ranging from 1 to (Z + N),

$P\tilde{P}$ = plotting position in percent,

a = constant that is characteristic of a given plotting position formula; for Weibull formula, a = 0; for Median formula, a = 0.3; and for Hazen formula, a = 0.5.

Calculating the historically adjusted skew is then calculated using the method previously outlined in this paper and then weighed with the generalized skew (IACWD, 1982). This process is the same as explained in the skew section of this paper.

HEC-SSP follows this method for data years labeled as historic data in the data downloadable through the USGS website. Some stations report systematic record data that contains both usable historical and unusable regulated data. These sites require all of the usable data to be entered manually. The historical data is isolated by entering beginning and end dates between which the historical data is contained (Brunner, 2006). Bulletin 17B analysis is executed thereafter.

Confidence Limits

How well a sample will predict the total flood population depends on the sample size, its accuracy, and if the underlying distribution is known (IACWD, 1982). Confidence limits provide a measure of the uncertainty of the estimated exceedance probability of a selected discharge or a measure of the uncertainty of the discharge at a selected exceedance probability (IACWD, 1982). It is recommended to evaluate the data for data points close to the confidence limits after the analysis is completed. Peak flows for the low probability storms sometimes contain a very high difference between the confidence limits, which needs to be evaluated by the analyst. HEC-SSP defaults to 5% and 95% confidence limits. The confidence limits can also be changed to any value and the program will run the 17B analysis with the adjustment included (Brunner, 2006).

Expected Probability

The expected probability is the average of the true probabilities of all magnitude estimates for any specified flood frequency that might be made from successive samples of a specified size (IACWD, 1982). It essentially represents a measure of the central tendency of the spread between confidence limits. Expected probability curves depart from the normal distribution in an attempt to account for uncertainty in application of the curve (IACWD, 1982). Computing the expected probability helps account for the errors in the flood flow collection, which are usually random and greatest during maximum flood flows (IACWD, 1982). Measurement errors are usually random and the variance added is therefore relatively small in comparison to the year-to-year variance in flood flows. Peak flood flows errors for historic events can be very high due to uncertainty of the stage and stage-discharge relationships (IACWD, 1982). The expected probability of a normal distribution can be calculated using the equation:

$$P_N = prob\left[t_{N-1} > K_N\left(\frac{N}{N+1}\right)^{1/2}\right] \tag{19}$$

where,

T_{N-1} = the Student's t-statistic with N-1 degrees of freedom,

K_N = standard normal variate of the desired probability of exceedance,

N = sample size.

HEC-SSP calculates both the normal distribution and the expected distribution and labels both respectively on the final graphical and tabular output (Brunner, 2006).

Evaluation of Results

After completing a regional flood flow analysis, the results must be observed and understood. In many cases, the results are compared to previous flood flow studies. Direct comparison of the difference in flood flowrates is a common way to compare equations. Results from this study can be compared to two recently completed studies which are explained more in depth in the following section.

Previous Studies in Arkansas

Flood frequency analyses have been conducted periodically for each state by the USGS using available stream flood flow data. The last such study for Arkansas was conducted by Hodge & Tasker (1995) using the Bulletin 17B method and regression analysis was used to correlate the streams physical and flood characteristics. Their analysis resulted in four sets of regression equations for four different regions of

Arkansas, based on the physiography and drainage boundaries (Hodge & Tasker, 1995). Their analysis included the use of 204 rural stations that had 10 years or more of unregulated records and with drainage areas of less than 7,770 square kilometers and slopes less than 70.3 m/km (Hodge & Tasker, 1995). Of the 204 stations used, 189 were in Arkansas and the other 15 were stations located in Missouri, Oklahoma, and Louisiana. Large rivers such as the Red, Arkansas, White, Black, St. Francis, Mississippi, and Ouachita Rivers were all treated individually as their flood flow characteristics differ from smaller tributary streams (Hodge & Tasker, 1995).

Regions were defined by an analysis of covariance tests using dummy variables that represented subregions (Hodge & Tasker, 1995). The analysis indicated that there were significant differences in the models for the four subregions. The regions defined by Hodge & Tasker (1995) are bounded by major river basin divides. This is helpful because the drainage basin of a smaller stream will not overlap two regions (Hodge & Tasker, 1995).

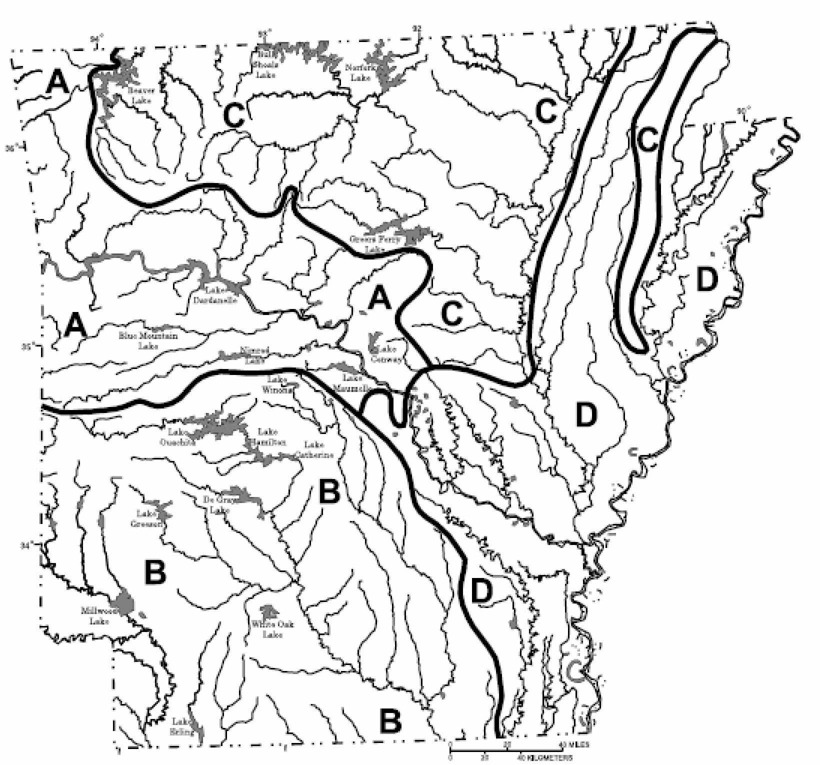

Figure 2 - Regions of Arkansas Defined by Hodge & Tasker (1995)

According to the analysis by Hodge & Tasker (1995), the variables that appeared to be the most significant were drainage area, main channel slope, mean basin elevation, and basin shape factor. The variables and range of values used in each region are reported in Table 1.

Table 1 - Range of Explanatory Variables for Regression Equations in Arkansas

Hydrologic study region	Drainage area (sq. km)	Main channel slope (m/km)	Mean basin elevation (m)	Basin shape factor
Region A	0.23-1,980	0.56-70.3	--	--
Region B	0.13-6,890	--	43.3-381	0.058-0.642
Region C	0.21-5,280	--	--	--
Region D	0.52-4,530	0.086-7.73	--	0.015-0.533

Source: Hodge & Tasker, 1995

A region of influence method of analysis was also performed by Hodge & Tasker (1995) as an alternative to the regional flood frequency analysis. This was only used as an alternative because the region of influence method was still being improved.

A second study was performed by Chhibber (2006), who also used four regions within the state. His approach used L-Moments to compute flood flows (Chhibber, 2006).

Flood Frequency Analyses in Surrounding States

Individually conducted flood frequency analyses are available for the surrounding states of Oklahoma, Texas, Tennessee, and Missouri. A range of approaches were taken to find equations that use the physiography as a predictor of flood flows.

Oklahoma

Oklahoma used gauging data from 352 sites with at least 8 years of data in Oklahoma and 25 kilometers into the neighboring states of Arkansas, Kansas, Missouri, New Mexico, and Texas. 162 additional miscellaneous measurement sites or streamflow gauging stations with short records were also used, making a total of 671 measurements. These included gauging stations that were in unregulated basins and basins affected by regulation, urbanization, and irrigation (Tortorelli & McCabe, 2001).

The state of Oklahoma was divided into two regions; east and west. Extreme peak discharges were plotted and a major difference was apparent at roughly the 28-inch mean annual precipitation line, which divides the state into two halves at 98 degrees 15 minutes longitude (Tortorelli & McCabe, 2001). The regions were decided upon by visual inspection.

Drainage area was noted as the most influential basin characteristic. A study was done by Asquith & Slade (1995) which determined that channel length and channel slope were not as important as drainage area. A multi-linear regression analysis was conducted on the data to find regression equations for the two regions. The Bulletin 17B method was used for calculation and distribution of the data and used its guidelines for skew and outliers.

Tennessee

Tennessee used the region of influence method. Data was used from a total of 297 gauging stations within the state and 156 gauging stations in the neighboring states of Georgia, North Carolina, Virginia, Alabama, Kentucky, and Mississippi. All stations were taken from drainage basins with 1 to 30 percent total impervious cover. The drainage basins containing 30 percent total impervious cover were shown to have similar streamflow characteristics to rural drainage basins. The state was divided into four hydrologic regions as outlined by major geographical and hydrologic boundaries (Law & Tasker, 2000).

A computer program was developed for the state that compared the basin characteristics of the different gauging stations in order to find similarities among sites. The program found the most important variables were the contributing drainage area, channel slope, climate slope, and a physiographic-region factor that allows the region of influence method to capture the uniqueness in flood magnitude potential found in the four hydrologic areas (Law & Tasker, 2000).

Aside from using the region of influence method to find a relationship among gauging stations, the rest of the analysis was complted using the Bulletin 17B method.

Multivariable regression equations were used to find a best fit line that matched the distribution among site data.

Missouri

Missouri used a standard regional flood frequency analysis to analyze gauge data from a total of 278 gauging stations having at least 10 years of unregulated data. 230 stations were located in Missouri and the remaining 48 were from the neighboring states of Iowa, Kansas, and Arkansas. No stations in Illinois were used (Alexander and Wilson, 1995). The state was separated into three regions delineated by major physiographic characteristics.

The Bulletin 17B method was used to complete the flood flow frequency analysis for each region. An ordinary least squares regression analysis was used to indicate that drainage area and main channel slope were the significant factors in predicting flood flows. Generalized least square regressions were used to find a best fit curve for the discharge data. The regression was computed by using a computer program called GLSNET that was developed in conjunction with USGS (Alexander and Wilson, 1995).

Texas

Texas used data from 559 stream gauging stations in Texas and 105 stream gauging stations in the neighboring states of Arkansas, Louisiana, New Mexico, and Oklahoma to execute a regional flood flow analysis. The state was separated into 11 different regions delineated on basis of physiography and climate conditions. For 5 of the 11 regions, the relation between the peak discharge frequency and the contributing drainage area were non-linear, which required that one set of equations be made for drainage areas less than 32 square miles and another set of equations for drainage areas greater than 32 square miles (Sumioka & Kernell, 2001).

The analysis was run using the Bulletin 17B method of analysis. The weighted standard error of prediction ranged greatly among regions.

Flood flow prediction equations were developed for the different regions of Texas using multivariate regression analysis. A computer program was also developed by Asquith and Slade (1999) that constructs a unique set of regression equations for each gauging site. Variables that were found to be significant were contributing drainage area, basin shape factor, and stream slope.

Louisiana

Louisiana used both the regionalization method and the region of influence method. In the final regression equations, the region of influence method was found to produce lower root-mean-square errors than the regionalization model. They used 227 gauging stations within Louisiana and 133 gauging stations 50 miles into the neighboring states of Texas, Arkansas, and Mississippi for a total of 360 gauging stations (Ensminger, 1998). Stations with only 10 years of annual maximum discharge data, and with drainage areas of less than 3,000 square miles were used, bringing the final number of gauging stations used to 303.

The regionalization approach used the Bulletin 17B method to complete the flood flow frequency analysis. The final regression analysis for the regionalization model showed drainage area, channel slope, and mean annual precipitation to be the best variables for prediction equations. Even though the state has four distinct regions; pine hills, alluvial plains, prairies, and coastal marshes, significant differences were delineated between the pine hills region and the non-pine hill regions.

A summary of the the most recent flood flow frequency studies for the states surrounding Arkansas is included in Table 2.

Table 2 - Summary of Flood Flow Analysis in Surrounding States

State	Type of Analysis Used	Parameters Used in Flood Prediction Equations	Stations Used	Hydrologic Regions
Arkansas	Multivariable Regression (Bulletin 17B) Region of Influence Used as alternate	DA - Drainage Area S - Main Channel Slope E - Mean Basin Elevation SH - Basin Shape Factor	189 In-State 15 Out-of-State	4
Oklahoma	Multiple Linear Regression with Adjustments (Bulletin 17B)	DA - Drainage Area	352 In-State 162 Out-of-State	2
Texas	Regression Analysis within NFF Program (Bulletin 17B)	DA - Drainage Area SH - Basin Shape Factor S - Main-Channel Slope	559 In-State 105 Out-of-State	11
Tennessee	Single-Variable and Multi-Variable Regression Analysis (Bulletin 17B) Region of Influence Used as alternative	DA - Drainage Area S - Main-Channel Slope CF - Climate Factor PF - Physiographic Region Factor	297 In-State 156 Out-of-State	4
Missouri	Generalized Least Squares Regression (Bulletin 17B)	DA - Drainage Area S - Main-Channel Slope	230 In-State 48 Out-of-State	3
Louisiana	Regionalization (Bulletin 17B) Region of Influence Used as alternative	DA - Drainage Area S - Main Channel Slope AP - Mean Annual Precipitation	227 In-State 133 Out-of-State	2

RESEARCH METHODS

Overview

Performing a regional flood frequency analysis for the state of Arkansas involves many steps. These steps include procuring and screening the data from the gauging stations within the state to eliminate data that has been affected by diversion or regulation and also to eliminate stations that have less than 10 years of recorded data. A Bulletin 17B analysis must then be completed on data from each site to find predicted flood flows and their frequencies using the beta version of HEC-SSP. Finally, a multiple regression analysis must be performed to find prediction equations for the estimated flood flows by relating them to the physiographic characteristics of the gauging station. The following pages summarize the procedures used to complete the estimation of flood flow magnitudes of ungauged streams.

Flood Flow Data

Stream gauging stations solely from Arkansas were used in this study, unlike other states that used data from gauging stations a certain distance into the surrounding states. This decision was made to simplify the study. USGS maintains gauging stations throughout the state which either measure peak flood flows or measure data continuously. Data was taken from the USGS Office of Surface Water website (http://nwis.waterdata.usgs.gov/usa/nwis/peak). Flood flow data recorded through the 2006 water year were used. A water year is 12-month period that spans from October 1 to September 30, which is chosen because it is a relatively dry time of year. The total number of USGS stations that were considered in this study was 372. Stations were screened and those that did not have at least 10 years of data unaffected by regulation or diversion were left out, which brought the actual number of stations down to 258. Furthermore, after discordant sites and sites with watersheds greater than 2750 square miles were taken out, the total number was brought down to 184.

Special attention was given to the side notes posted about each data point from each station on the USGS website. Notes for years that indicated the flood flow was affected by a dam failure, regulation, or an unknown degree of diversion or regulation were noted and deleted from that systematic data set. Discordant sites or peak data were deleted. Discordant sites and data were taken from the recent study completed by Chhibber (2006). The remaining segmented data was then treated as incomplete data as outlined in Bulletin 17B earlier in this paper.

Bulletin 17B Analysis

Data may be entered into HEC-SSP software four different ways: import from another HEC-DSS file, import data from the USGS website, import from a Microsoft Excel™ spreadsheet, or manually enter the data into a table. Data from stations that were completely unregulated or not affected by dam failure were entered into HEC-SSP by downloading the entire data set from the USGS website through the HEC-SSP. Data from stations that were affected by regulation or diversion but still had at least of 10 years of data were entered into HEC-SSP by way of a Microsoft Excel™ spreadsheet or by using the manual data entry option. Any historical data included in the data set was also entered manually using the historic data option in HEC-SSP so that the program could treat it as historical peaks as outlined in Bulletin 17B.

HEC-SSP offers three options for generalized skew, as discussed in the literature review section: station skew, generalized skew, and regional skew. The station skew was used in this study.

HEC-SSP also offers several different plotting positions. The user may specify among the Weibull, Median or Hazen plotting positions. HEC-SSP also allows the user to manually enter the A & B constants. For the purpose of this study, the default Weibull position was used.

HEC-SSP by default calculates the confidence limits at 5 and 95 percent. The user may define their own confidence limits, though for this study, the default values were used.

The result of the Bulletin 17B analysis was a log Pearson III plot, from which the values from the expected probability curve, not the calculated curve, were used for the prediction of the 2, 5, 10, 20, 50, 100, and 500 year storms. A discussion of the expected probability curve is included in the expected probability section of the literature review section. The expected values were used because they are higher and therefore more conservative. These values were recorded in a spreadsheet along side the physiographic data for the same site. This study used the expected probability curve, which is higher and more conservative than the computed probability curve, therefore the default option of computing the expected probability curve was not changed.

HEC-SSP also offers an option to use a manual low outlier threshold. The default is zero, and this default was used in this study. Low and high outliers were left to be calculated using the methods outlined in Bulletin 17B.

The historic data option was used whenever there was data available that was marked as historical data. If the data were to be imported and evaluated using the USGS website data import option, HEC-SSP would not recognize this earmark. Hence, this option was utilized whenever there was historic data in the data record.

Manual recurrence intervals can be specified, though for this study, the defaults were used because they contained the recurrence intervals that were being studied.

Log Pearson III plots were calculated for all available and fit data by using the HEC-SSP software. The program output includes four flood flows for each common recurrence interval (2 year, 5 year, etc.): the lower confidence limit, computed flow, expected flow, and upper confidence limit. The flood flows for the expected flood flow were used in this study because they are a more conservative, or higher, estimate. The flood flows were recorded in a Microsoft Excel™ spreadsheet.

Watershed Data

Physical data was calculated using the Watershed Modeling System (WMS) software, which was previously performed by Chhibber (2006). This data was compared to data provided by USGS and in most cases, the WMS value was used. Precipitation data for each watershed was obtained from Dr. Steve J. Burian, Assistant Professor of Civil and Environmental Engineering, University of Utah, Salt Lake City, Utah (Burian et al. 2007).

Regression Analysis

Before performing a regression analysis on the data, a statistical method known as multivariate analysis was used to find correlations among physiographic data so that redundant variables could be left out of the final regression analysis. JMP statistical software package was then used to compute a multiple regression analysis for each recurrence interval flow to find an equation relating the peak flow to the physiographic characteristics of the watershed. JMP software can be found at http://www.jmp.com/.

The underlying principle of a linear regression is to find a straight line that best fits the data set for which you wish to find a prediction equation. Both stepwise regression and the least sum of squares method were used in this study. In the stepwise regression, all of the physiographic variables were considered for the final equations. A forward stepwise regression was used, which means that the regressor that most improved the fit was brought into the equation based on a specified level of significance. After each step in the stepwise regression, a least squares regression is computed with the given variables.

In a least squares regression, the distance between each data point and the prediction line is squared and the sum of all of the distances from each point to the prediction line is minimized, thus producing a best fit line. Every regression of course also contains a residual. Linear regression analysis assumes that all the prediction variables are independent and the residuals follow a normal distribution (Draper & Smith, 1998). In an effort to compute an equation that properly depicts the mathematics of the flood flow distribution, the logarithm of all data was taken, a least squares regression was computed, and a graph of the residual was analyzed to see if the underlying mathematics were properly modeled.

Preliminary equations were calculated to study how well a regression equation fit the data when using the raw data. The raw data produced regression equations that did not fit well. A plot of the residuals versus the prediction variable should show a random distribution. The log of the data was taken in an effort to find the correct underlying mathematics.

The residual of the final equations can be measured by several methods. The adjusted coefficient of determination, also known as the R squared statistic, was noted in the analysis. A higher adjusted R squared value indicates a better fit.

The computed error in the final equations was noted and the usability of the aforementioned methods and programs were noted and are included in the results and discussion section.

RESULTS AND DISCUSSION

Overview

Peak streamflow data provided by USGS from 372 stream gauging stations in Arkansas were considered for this study with a final 184 being used in the analysis after screening the data. All watersheds, watershed boundaries, and watershed physiographic data were found using Watershed Modeling Software (WMS). The flood flow frequency analysis for each gauging station was completed using the Bulletin 17B method within the HEC-SSP program. The regression analysis to correlate physiographic watershed characteristics to flood flow quantiles was computed using a stepwise multiple variable regression analysis within JMP statistical software package.

Watershed Modeling

Available watershed data was first obtained from USGS. Many stations did not have associated physiographic data provided by USGS and therefore the WMS values were used for all of the stations. All watershed modeling was completed using WMS by Chhibber (2006). Differences explored in Chhibber's analysis showed that the WMS values in most cases were not significantly different than those provided by USGS. Large differences between the WMS and USGS values were proven to be the error of the USGS data.

Cluster Analysis

Previous flood flow frequency studies for ungauged streams in the state of Arkansas separated the state into several regions and unique prediction equations were found for each region, often using different variables for different regions. Chhibber

(2006) explored different clusters in Arkansas and found no region to be more accurate than when using the state as a whole.

Screening the Data

Data was obtained for all 372 stations and after omitting those stations that did not have at least 10 years of unregulated data only 184 stations remained. A map of the stations used in this study is shown in Figure 3.

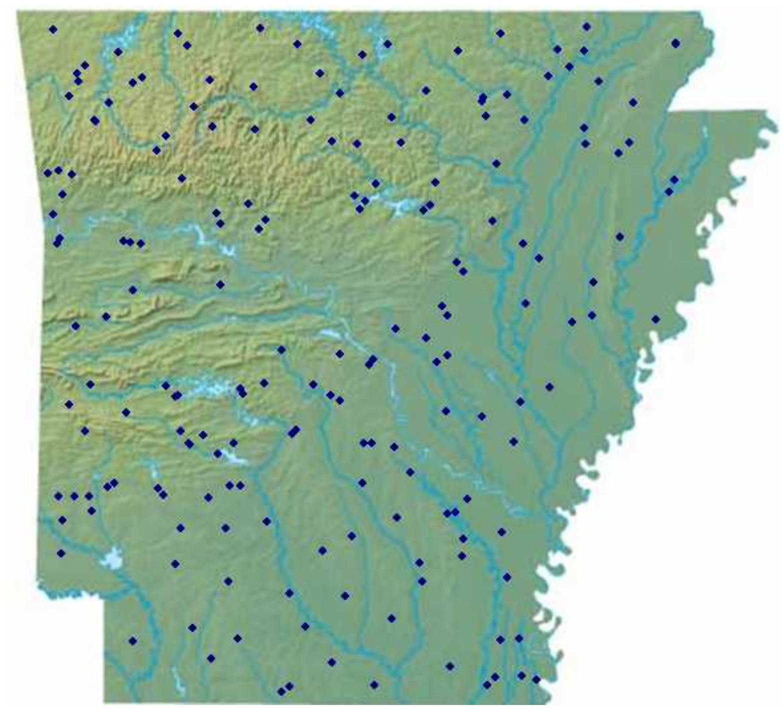

Figure 3 - Location of USGS Stations Used in Study

A previous similar study performed by Chhibber (2006) revealed the presence of several sites that were shown to be grossly discordant from the rest of the state. The extremely different values were evaluated one by one with surrounding sites. If the value did not correlate with similar high or low events in surrounding stations, or if there was no record of localized extreme events from the National Climatic Data Center (NCDC), that data was deleted from the station and the station was tested again for discordance. Discordancy calculations were ran using a method outlined by Hosking and Wallis (1997). A table of the discordant data is provided in Table 3.

Table 3 - Discordant Sites

Station Number	Action Taken	Comments
7047860	Station Retained	1200 cfs for August 13, 2002 for a watershed size of 0.95 sq. mi seemed odd. But NCDC website says there was a flash flood in Jonesboro on that date at 6 a.m. Twenty homes and some businesses were flooded. Many roads throughout the city were flooded.
7077680	Station Retained	Nothing was obvious from the station dataset
7078170	92 cfs and 30 cfs deleted	No extreme events (including draught) were reported by NCDC for Arkansas County, AR for December 1970 and July 1972
7078210	645 cfs deleted	No extreme events (including draught) were reported by NCDC for Arkansas County, AR for April 1973. Data point might be erroneous; it appears it could be 64.5 cfs.
7249457	Station Retained	Nothing was obvious from the station dataset
7257200	Station Retained	Nothing was obvious from the station dataset. Neighboring stations (7257100 and 7256500) have similar low flows for May 1981. NCDC does not report any extreme event for this period.
7263860	Station Retained	Neighboring stations (7264100) has similar low flow for May 1971. NCDC does not report any extreme event for this period.
7360150	1220 cfs deleted	NCDC does not report any extreme event for this period. 1220 cfs for a watershed area of 0.42 sq. mi. seems erroneous.
7364128	750 cfs deleted	No extreme events (including draught) were reported by NCDC for Lincoln County, AR for March 1996

Source: Chhibber (2006)

Bulletin 17B Analysis

After screening and importing the data into HEC-SSP, the program ran the process of fitting the flood flow data to a predictive curve on a log Pearson III plot as outlined by Bulletin 17B. An example of a log Pearson III plot is shown in Figure 4.

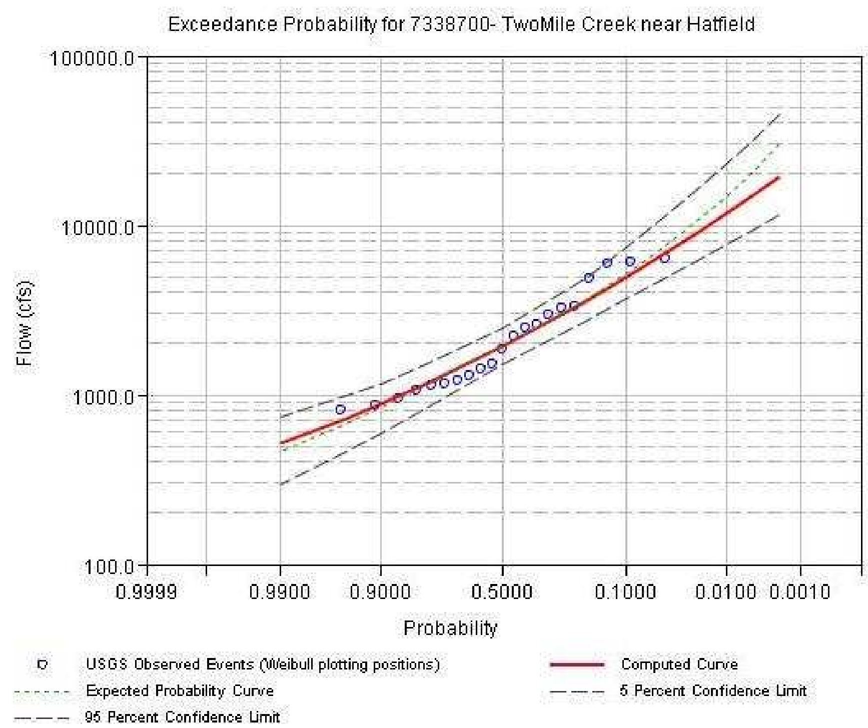

Figure 4 - Pearson Log III plot for station 7338700 from HEC-SSP

Data for stations with no historical data was imported from the USGS Surface Water Website through the HEC-SSP program. The program performed wonderfully in this aspect, although speed performance dropped significantly when 25 or more stations and their data were all stored in the same study file. This problem was avoided by splitting the entire data group into 11 study files.

Data that had regulation or historical data that needed to be analyzed differently or eliminated, respectively, had to be either entered through a Microsoft Excel™ spreadsheet or entered into the program using the manual option. Theoretically the program should have been able to import the data via Microsoft Excel™ spreadsheet, which is simplest, although when the number of data years reached around 15 or 20, the program usually froze upon import. For these larger fragmented data sets, data was entered using the manual option, which creates a metadata file. Format must be in either the dd/mm/yyyy or the ddmmmyyyy format in Microsoft Excel™ and it must be in the ddmmmyyyy format to be entered into HEC-SSP manually. For example, the 21st of March 1968 must be in the format 21MAR1968 for the program to read the data properly.

A significant downfall in the program was its lack of ability to use data before the year 1900. Every method and combination possible for data entry was attempted and the program read every piece of data from the 1800s as from the year 1900. The US Army Corps of Engineers was notified of the problem in May 2007.

Older data, especially from high flood magnitude events is very useful for the accurate prediction of higher flood flow storm events, so it is unfortunate that this data could not be used. At the same time, however, many of the stations that had data from the 1800s available were on large rivers such as the Mississippi and Arkansas Rivers, both of which were not used in the final analysis because their drainage areas are over 2750 square miles. Ultimately, this problem did not affect the analysis too much, though it is a problem that needs to be fixed if the program is going to be an effective tool for single site analysis.

Physiographic Data

Data for each station used were collected by Chhibber (2006) and used in this study. Table 4 lists each variable and its description. In the regression analysis, these values were regressed with the flood flows for each standard recurrence interval.

Table 4 - List of Variables

Physical/Hydrologic watershed characteristics	Description
Latitude	The global latitude of the gauging station
Longitude	The global longitude of the gauging station
Station Elevation	The elevation of the gauging station
Watershed Area	A topographic area within a line drawn connecting the highest points uphill of a stream gauging station through which overland flow drains.
Mean Basin Elevation	Arithmetic average of elevations of all the points inside the watershed area.
Basin Length	Length of the basin from the outlet point to the farthest point inside the watershed
Basin Slope	Bed slope of the basin order channel, within two points at 10% and 85% of the channel run.
Basin Perimeter	Perimeter of the watershed along its boundary.
Shape Factor	The ratio of the square of the basin length to the basin area.
Max. stream length	The maximum channel flow length along the main channel.
Max. stream slope	Bed slope along the max. stream length
Overland flow	Sum of sheet flow and shallow concentrated flow (TR-55).
North and South facing	Percentage of basin whose aspect is directed towards the north (and south).
Average Precipitation	Average measured precipitation as measured at the gauging station

Regression Analysis

A preliminary regression analysis was completed using the raw physiographic data. The residual versus predicted plot using the raw data shown in Figure 5 appears to be a cone shape that diverges from zero, meaning the underlying mathematics have not been properly identified. The best equation using the raw data computed an adjusted R squared of 0.5731.

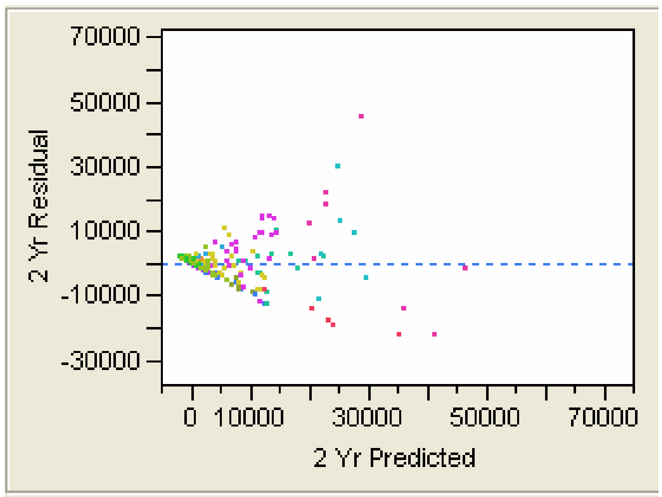

Figure 5 - Residual vs. Preliminary 2 Year Equation Using Raw Data

Figure 6 shows a random distribution of residuals after the logarithm of the data was taken. The random distribution means the equation decently represents the line created from the data computed using the Bulletin 17B method.

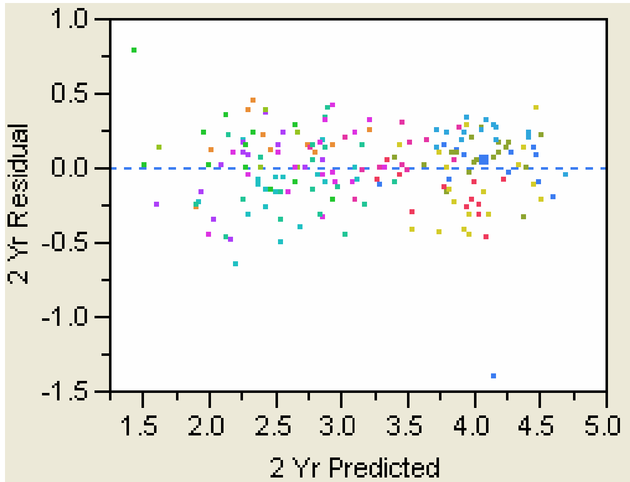

Figure 6 - Residual vs. Preliminary 2 year Equation Using Logged Data

After verifying that a linear regression equation fits well to the logarithm of the data, all of the original data was evaluated using a multivariate analysis. A multivariate analysis compares every data point of one variable with the data point of every other data point in an effort to make any one-to-one relationships among the variables apparent so redundant variables can be eliminated. Figure 7 illustrates the first multivariate analysis completed after taking the log of all of the physiographic data in an effort to identify redundant variables. A close one-to-one relationship appears as a clustering of data in a 45 degree line between the x and y axes.

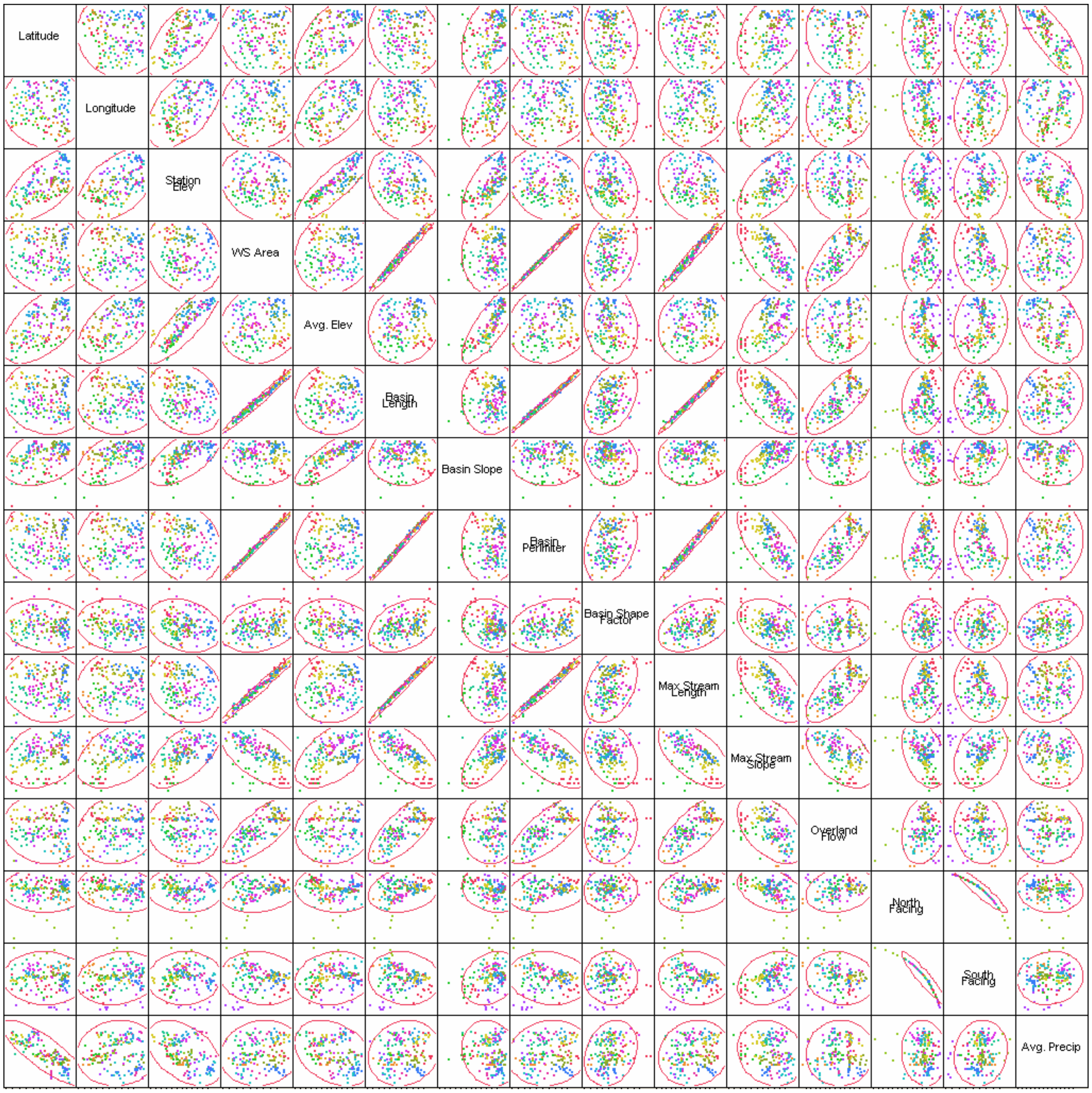

Figure 7 - Complete Multivariate Analysis

Illustrated in Figure 8 is the multivariant analysis of the variables that were determined to be redundant.

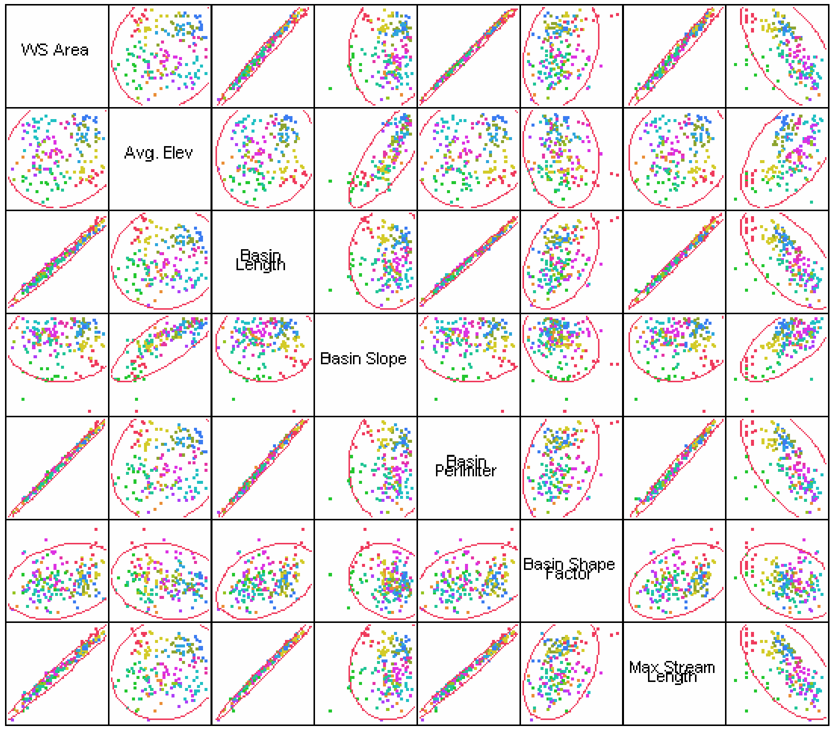

Figure 8 - Multivariate Analysis of Redundant Variables

A strong correlation between watershed area, basin length, basin perimeter, and max stream length is evident. To avoid redundancy in the final regression equation, only watershed area was taken into consideration in the final equations.

The purpose of this study was to create simple prediction equations; therefore several equations were considered comparing accuracy with number of variables to find a good median. All possible regression equations using every combination and number of variables were computed and the best equations using six or less variables are presented in Table 5.

Table 5 - Best Fitting Variables and Associated Errors for the 2 Year Regression

Num. of variables	Adjusted R squared	Cp	Intercept	Water Shed Area	Basin Slope	Basin Shape Factor	North Facing	Avg. Elev.	Avg. Precip.
6	0.9140	7.00	0.782	0.660	0.179	-0.397	-0.450	0.229	1.233
5	0.9127	5.52	3.169	0.665	0.201	-0.364	-0.489	0.153	
4	0.9141	5.65	3.614	0.668	0.270	-0.373	-0.450		
3	0.9105	8.21	2.892	0.658	0.290	-0.352			
2	0.9062	16.13	2.785	0.643	0.310				
1	0.8652	100.33	2.366	0.651					

A graph of the effect of the number of variables versus the adjusted R squared is illustrated in Figure 9.

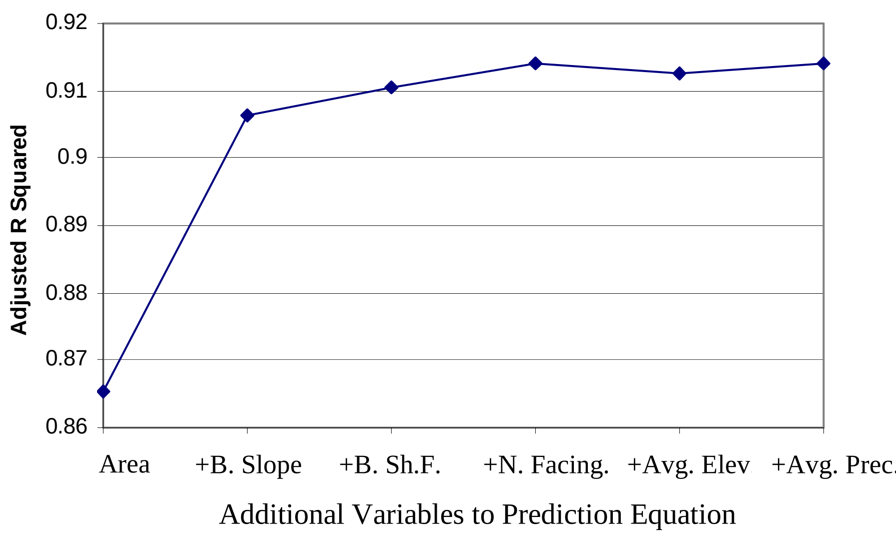

Figure 9 - Adjusted R Squared vs. Variables Used in Prediction Equation

Mallow's Cp is also a good measure of redundancy among the variables in a regression equation. Mallow's Cp value basically is a value that converges to the number of variables in the equation when an accurate regression equation for the given variables has been reached. A Mallow's Cp value that is close to the number of variables used in the equation indicates a good fit. The final Cp of 8.21 when using three variables is not as good as a Cp of 5.52 when 5 variables, however it does indicate the equation has a fair measure of predictability and the variables share a low level of redundancy. Using five variables would create an equation that is cumbersome to use while not improving the predictive capability of the equation a significant amount. The final prediction equations had no more than three variables because the fourth variable that would have been added, north facing, is not a user-friendly variable to calculate.

Another multivariate analysis was completed using the final three variables to ensure that they were independent of each other and had little redundancy. Figure 10 illustrates that their final analysis showed no strong correlation patterns among them.

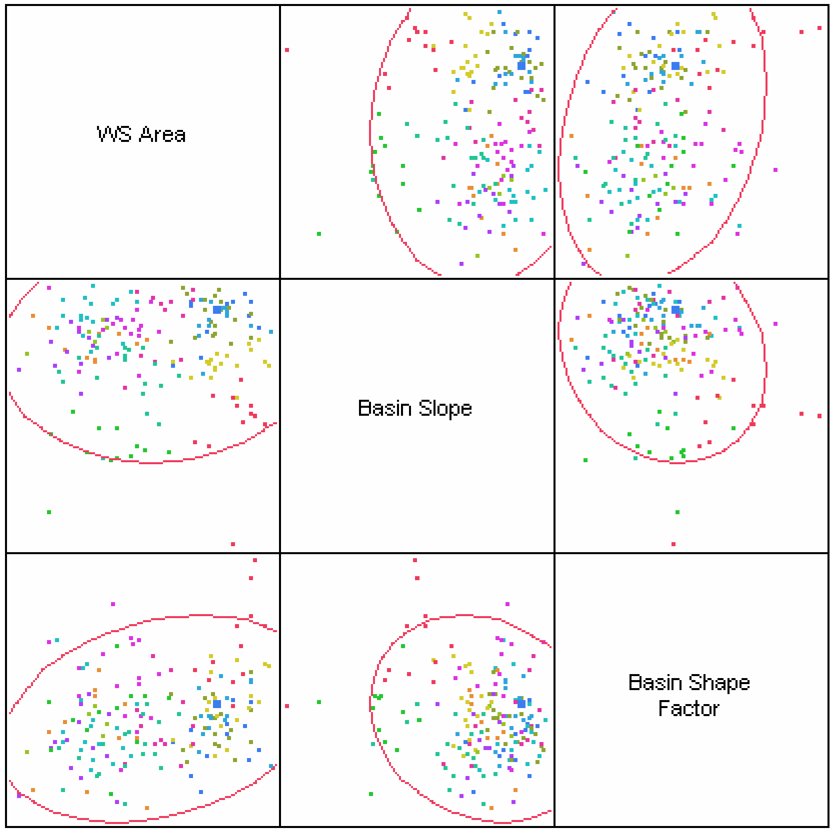

Figure 10 - Multivariate Analysis for Regression Equation Variables

The final regression equations for each of the recurrence intervals for the entire state of Arkansas are shown below. The root mean square error (RMSE) of these regression equations to the LPIII projections are reported in brackets after the equations. It is important to keep in mind that additional error was included from the estimation of the LPIII projections from the actual data, so the overall error of prediction of these equations are even more than shown below.

$$Q_2 = 779A^{0.658}BS^{0.290}SH^{-0.352} \qquad [\text{RMSE} = 25.4\%] \qquad (20)$$

$$Q_5 = 1676A^{0.649}BS^{0.336}SH^{-0.364} \qquad [\text{RMSE} = 23.9\%] \qquad (21)$$

$$Q_{10} = 2504A^{0.644}BS^{0.359}SH^{-0.370} \qquad \text{[RMSE = 23.9\%]} \qquad (22)$$

$$Q_{20} = 3513A^{0.640}BS^{0.378}SH^{-0.375} \qquad \text{[RMSE = 24.6\%]} \qquad (23)$$

$$Q_{50} = 5204A^{0.634}BS^{0.399}SH^{-0.381} \qquad \text{[RMSE = 26.4\%]} \qquad (24)$$

$$Q_{100} = 6834A^{0.629}BS^{0.413}SH^{-0.386} \qquad \text{[RMSE = 28.6\%]} \qquad (25)$$

$$Q_{500} = 12108A^{0.619}BS^{0.440}SH^{-0.394} \qquad \text{[RMSE = 35.7\%]} \qquad (26)$$

where,

Q = predicted flood flows for the subscripted frequency (cfs),

A = watershed area (sq. mi.),

BS = basin slope (ft/ft),

SH = shape factor (mi^2/mi^2).

Flood Flow Prediction Equation Comparison

A matter of interest in this study was to observe how grouping the entire state into one region affected the prediction equations. To compare the differrent equations, 20 stations comprising 11% of the stations used in this study, were chosen and flood flow predictions were made using the equations developed by Hodge & Tasker (1995), Chhibber (2006), and the state-wide equations developed in this study. The LPIII projections originally computed using Bulletin 17B analysis were also compared to the results from this study. Stations were chosen at random until five stations were found for each region. When these five stations had been reached, any successive stations chosen from that region were rejected and another station was chosen until all regions had five stations. This was done in an attempt to give an even cross-section of values produced by the set of four equations developed by Hodge & Tasker and Chhibber.

In order to create the comparison plots, the relative error between the two methods was evaluated. That is, difference of the two flows for the methods being compared was divided by the method being subtracted. For example, the caculated flood flow for a specific station using Chhibber's method had the same calculation using the statewide method (labeled "Q McCall") subtracted from it and then the difference was divided by Q McCall in order to "normalize" the data. A variability chart was chosen to display the data. The box plots shown at every recurrence interval show a middle box composed of three horizontal lines showing from bottom to top: 25th percentile, 50th percentile, otherwise known as the median, and 75th percentile. The "whiskers" at the top and bottom show any outliers and are no longer than 1.5 times the length of the box. The short horizontal dash indicates the cell mean. Figures 11 through 14 show the three different comparisons that were calculated using JMP software. Figure 11 and 12 are graphs of the difference of flows from the statewide equations developed in this study and the methods used by Chhibber and Hodge & Tasker versus the different recurrence intervals. Figure 13 is a graph of the difference of the results from this study and the calculated LPIII values versus the recurrence intervals. Figure 14 is the same as the Figure 13 but the Hodge & Tasker values were used instead of the statewide equations.

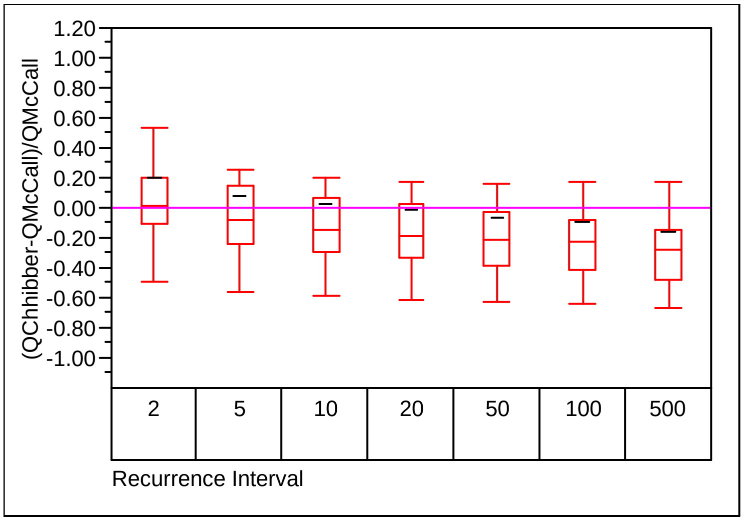

Figure 11 - (QChhibber-QMcCall)/QMcCall vs. Recurrence Interval

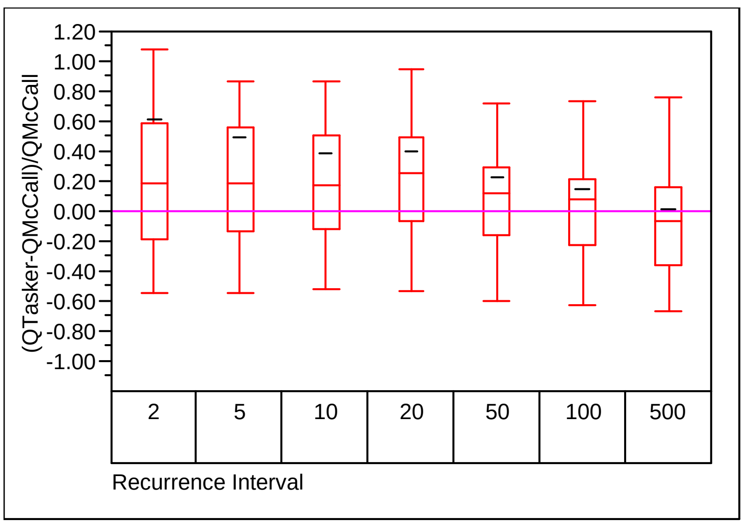

Figure 12 - (QHodge&Tasker-QMcCall)/QMcCall vs. Recurrence Interval

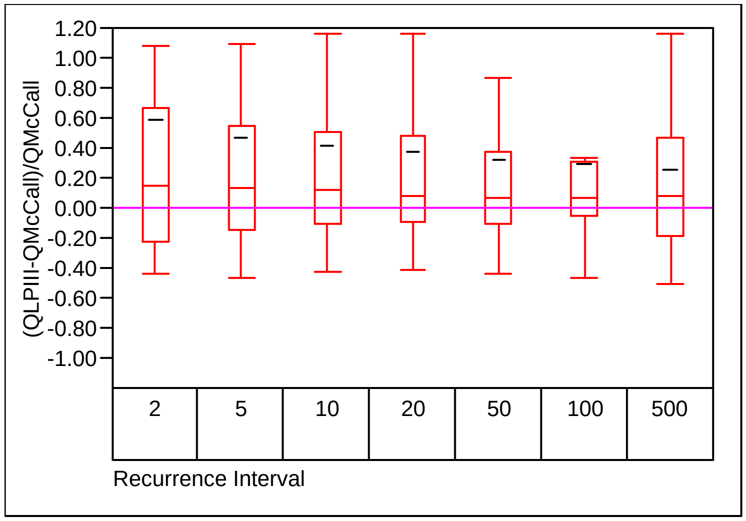

Figure 13 - (QLPIII-QMcCall)/QMcCall vs. Recurrence Interval

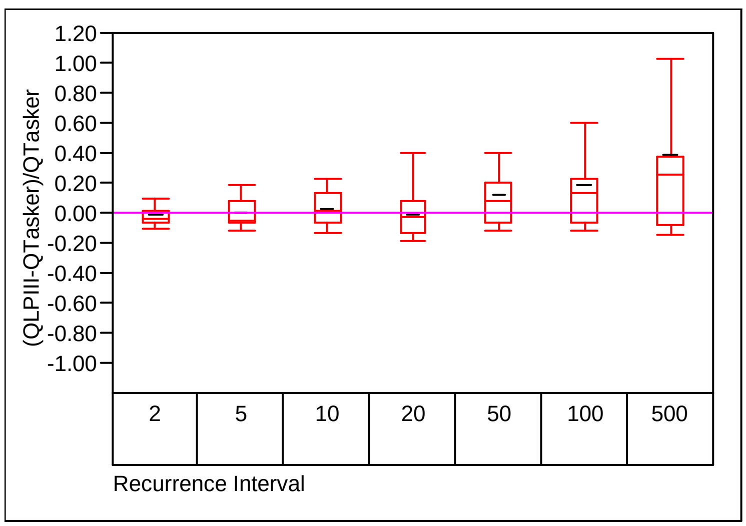

Figure 14 - (QLPIII-QHodge&Tasker)/QHodge&Tasker vs. Recurrence Interval

The most notable trend visible in the Figure 11 is the slow and linear decrease below zero of the mean. This indicates that, on average, Chhibber's method resulted in larger values than the statewide equations for the first three recurrence intervals and smaller values for the last four values. The first recurrence interval has an especially large spread of differences. Although the median is zero, meaning that the statewide values are equally split – half more than Chhibber and half less than Chhibber; the mean is positive, meaning that on average Chhibber's method yielded more conservative values. The median grew more negative and the 25th to 75th percentile range decreased as the recurrence interval grew, meaning that the statewide method calculated more conservative flows for the higher interval flows.

A comparison with the Hodge & Tasker method shows a much more evenly spaced distribution across the graph. The two methods differed most in the first recurrence interval, though there was a much wider spread of values for Hodge & Tasker and the statewide flows for the all of the recurrence intervals. This indicates that the behavior of the statewide equations is similar to Hodge & Tasker's equations, regardless of the wide distribution of differences. This is probably because Hodge & Tasker used the same Bulletin 17B method. The large differences are probably due to the fact that they grouped streams that looked alike and responded alike, while the statewide equations averaged all different behaving streams within the state. As far as flow values go, Hodge & Tasker's method yielded a higher average of results since the mean is above zero for every interval.

Comparison of the statewide equations to the LPIII values, flow values as close to actual flood flows as possible, shows a mean that is always positive – between about 25% and 60% more positive as compared to the statewide equations. While the mean is close to zero, the results show variability with the distribution lieing more on the high side. This means that whenever the difference between the two methods diverges from zero, the state-wide equations more often that not underestimate the LPIII values. This is favorable because the LPIII values sometimes underestimate the higher recurrence intervals. This is because the LPIII projection has to give equal importance to the error for the lower recurrence interval storms as to the high ones, which can pull down the projection and greatly decrease the higher projected storm flood flows, but at the very least makes them slightly less than actual.

The comparison shown in Figure 14 of the LPIII values and Hodge & Tasker's values is shown because Hodge & Tasker used similar methods as were used in this method and the effect of regionalization is the largest difference between the two methods. Comparing Figure 13 to Figure 14, the statewide method yielded a mean that, aside from the 500 year storm, was consistently higher than Hodge & Tasker's method, meaning that Hodge & Tasker's regionalization of the state into four regions resulted in more conservative answers than the statewide equations. The smaller boxes and "whiskers" for the smaller floods indicate that Hodge & Tasker also resulted in values with less variability of differences. For the 2 to 20 year storms, the mean was nearly zero and the variability low for the 2 to 10 year storms, meaning both give similar answers for those intervals. For the higher recurrence intervals, Hodge & Tasker resulted in results that were often less than the LPIII projections.

Conclusion

One of the objectives of this study was to evaluate the performance of the new program HEC-SSP released by the U.S. Corps of Engineers which uses the Bulletin 17B method on compute flood flow data. The program ran well, completing the Bulletin 17B computation on many stations without problems. The program lacks the ability to process data from before the year 1900. It also has problems with reopening a study when it already has saved several stations stations and their associated computed data.

Lastly, performance dropped off dramatically when more than 25 or so stations were in the study. Once these problems have been addressed, HEC-SSP will be a valuable tool for the hydrologic community.

Even though the more conservative values were taken from the Bulletin 17B analysis and were used for the final regression analysis, it appears that the equations built from this analysis are generally less conservative than those developed from Hodge & Tasker's study and for the first year or two of Chhibber's method. The resulting equations calculate values that will always underestimate the true behavior of the more extreme behaving streams in the state. This is because the state-wide equations averages in milder behaving streams with the extreme behaving streams since no regions were used to separate watersheds into regions of similar behaving streams. Taken as a whole, the statewide equations developed in this study more often than not underestimate the LPIII values.

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APPENDIX A: DATA

Station Identificat-ion Number	Station Elev. (ft)	Area (sq. mi.)	Basin Avg. elevation (ft)	Basin Slope (ft/ft)	Basin shape factor (mi^2/mi^2)	Discharge for Recurrence Interval (years) *Second row are calculated values using equations developed in this study						
						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7046600	213.15	2121.92	287.63	0.0058	6.44	13,675	21,889	27,615	33,266	40,765	46,545	60,463
						14,041	21,742	27,467	33,572	42,158	49,119	69,108
7047200	219.52	0.18	220.07	0.0005	3.13	168	200	215	227	240	248	262
						19	28	36	43	55	65	94
7047820	270.27	1.36	327.59	0.0361	3.33	497	772	977	1,192	1,503	1,763	2,474
						238	433	594	776	1,063	1,322	2,114
7047823	270.34	0.36	313.15	0.0474	2.61	139	221	281	342	429	500	690
						117	219	304	403	560	704	1,152
7047860	289.63	0.9	325.94	0.0368	1.34	420	644	862	1,150	1,714	2,367	5,493
						252	464	642	844	1,166	1,461	2,364
7047880	329.06	0.09	388.22	0.1222	1.35	44	83	129	197	346	528	1,453
						78	155	223	304	436	562	961
7047924	192.78	0.5	202.03	0.0082	2.66	107	209	304	424	635	851	1,651
						87	149	199	254	340	417	648
7047942	192.52	531.86	253.24	0.012	3.76	5,786	10,617	14,989	20,283	29,212	37,840	66,954
						8,430	13,755	17,850	22,303	28,768	34,188	49,953
7047950	166.68	780.45	242.3	0.0063	4.07	8,228	12,933	16,254	19,574	24,057	27,572	36,259
						8,753	13,804	17,608	21,691	27,526	32,343	46,235

Station Identific-ation Number	Station Elev. (ft)	Area (sq. mi.)	Basin Avg. elevation (ft)	Basin Slope (ft/ft)	Basin shape factor (mi^2/mi^2)	Discharge for Recurrence Interval (years) *Second row are calculated values using equations developed in this study						
						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7047975	461.83	1.18	1941.34	0.2835	2.66	204	406	574	762	1,047	1,295	2,002
						427	856	1,234	1,680	2,408	3,089	5,240
7047990	390.04	0.69	1499.41	0.1193	3.2	177	405	606	837	1,189	1,495	2,346
						219	422	598	802	1,130	1,435	2,388
7048000	1232	82.84	1702.89	0.1567	2.41	8,679	16,783	23,659	31,475	43,552	54,262	85,605
						6,110	11,471	15,983	21,173	29,225	36,420	58,315
7048600	1138.25	398.44	1687	0.1713	2.52	24,249	45,490	64,022	85,673	120,427	152,397	251,674
						17,350	32,229	44,633	58,843	80,589	99,746	157,544
7048900	1279.92	1.11	1375.02	0.0445	1.63	144	278	419	612	988	1,405	3,150
						285	527	731	964	1,333	1,671	2,709
7048940	1477.16	22.41	1913.75	0.1737	2.17	2,986	6,155	9,018	12,451	18,097	23,437	40,676
						2,763	5,281	7,428	9,917	13,835	17,388	28,310
7049000	1168.06	264.68	1610.16	0.1458	3.08	13,193	22,093	28,341	34,507	42,634	48,856	63,630
						11,788	21,763	30,052	39,524	54,016	66,775	105,270
7049500	1006.47	1026.76	1571.5	0.121	1.82	24,758	47,280	64,419	82,457	107,569	127,752	177,644
						32,792	59,673	81,752	106,840	144,720	177,699	276,142
7050200	1336.31	2.81	1647.55	0.1721	1.74	609	1,350	2,036	2,868	4,241	5,539	9,684
						760	1,483	2,110	2,843	4,020	5,110	8,507
7050285	1294.68	82.02	1883.9	0.1819	1.55	9,853	17,637	23,707	30,277	39,947	48,167	71,027
						7,404	14,072	19,726	26,265	36,466	45,642	73,642

Station Identificat-ion Number	Station Elev. (ft)	Area (sq. mi.)	Basin Avg. elevation (ft)	Basin Slope (ft/ft)	Basin shape factor (mi^2/mi^2)	Discharge for Recurrence Interval (years) *Second row are calculated values using equations developed in this study						
						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7050400	1012.11	0.74	1347.68	0.106	2	192	331	443	566	754	920	1,411
						261	504	713	956	1,348	1,713	2,849
7050500	963.1	527.34	1583.19	0.1768	3.22	16,513	29,435	39,944	51,549	68,980	84,020	126,407
						19,315	35,737	49,384	64,993	88,791	109,658	172,523
7054400	717.34	3.42	1035.93	0.1919	2.44	1,109	2,011	2,897	4,054	6,233	8,587	18,376
						792	1,545	2,197	2,959	4,181	5,308	8,822
7054450	455.71	0.85	1031.8	0.1982	2.13	269	434	541	639	759	844	1,028
						336	665	954	1,293	1,845	2,362	3,988
7055000	419.66	6057.68	1272.08	0.1046	1.59	72,177	123,815	165,653	212,479	284,775	349,439	544,526
						105,995	188,867	255,810	331,255	442,950	538,351	819,535
7055550	1158.66	4.23	1280.6	0.0552	2.03	582	1,109	1,641	2,348	3,698	5,169	11,292
						677	1,248	1,724	2,268	3,121	3,894	6,253
7055608	1088.54	409.11	1104.63	0.1232	2.3	582	1,109	1,641	2,348	3,698	5,169	11,292
						16,569	30,342	41,719	54,677	74,397	91,688	143,600
7055650	1132.67	8.32	1880.3	0.2382	2.88	1,446	3,451	5,348	7,662	11,457	15,012	26,058
						1,428	2,785	3,958	5,330	7,517	9,523	15,757
7055800	832.74	6.1	1466.59	0.2419	1.86	1,078	2,331	3,538	5,062	7,731	10,406	19,908
						1,364	2,683	3,832	5,178	7,338	9,334	15,553
7056000	560.35	828.62	1466.92	0.2271	2.49	38,247	68,992	92,283	116,441	150,013	176,883	244,528
						30,611	57,236	79,493	105,063	144,121	178,442	281,949

Station Identificat-ion Number	Station Elev. (ft)	Area (sq. mi.)	Basin Avg. elevation (ft)	Basin Slope (ft/ft)	Basin shape factor (mi^2/mi^2)	Discharge for Recurrence Interval (years) *Second row are calculated values using equations developed in this study						
						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7057000	451.98	1096	1356.34	0.1763	3.12	36,772	69,371	97,208	129,116	179,077	223,954	358,172
						31,581	58,062	79,951	104,926	142,736	175,658	274,393
7057300	721.57	0.76	846.67	0.071	4.32	279	470	610	755	956	1,119	1,538
						181	338	472	626	872	1,096	1,793
7059000	432.67	1612.53	1001.56	0.0883	1.98	25,445	43,172	54,885	65,944	79,629	89,342	109,893
						39,102	69,777	94,642	122,675	164,543	200,613	307,511
7060500	316.38	9963.82	1192.07	0.0947	1.39	119,402	194,814	252,835	314,981	406,031	483,228	697,458
						149,803	264,947	357,435	461,370	614,312	744,229	1,125,506
7060600	569.94	1.24	707.49	0.0998	1.82	224	429	667	1,024	1,818	2,820	4,433
						373	714	1,007	1,348	1,893	2,397	3,963
7060670	621.12	3.25	840.32	0.1143	1.21	835	1,323	1,734	2,214	3,004	3,758	6,315
						844	1,621	2,288	3,063	4,300	5,441	8,971
7060710	434.99	58.43	950.17	0.2653	1.99	4,313	9,445	13,671	18,234	24,705	29,960	43,197
						6,052	11,704	16,553	22,201	31,086	39,132	63,873
7060830	988.74	0.24	1054.55	0.0298	2.14	59	127	184	246	336	412	608
						84	155	214	281	388	487	790
7061000	237.72	11056.4	1139.92	0.0595	2.02	136,013	216,862	277,985	342,675	436,300	514,807	729,413
						122,908	211,631	281,692	359,583	472,776	567,688	844,405
7061100	339.33	3.76	462.03	0.0715	2.24	787	1,475	2,069	2,762	3,878	4,912	8,190
						653	1,216	1,691	2,235	3,093	3,873	6,266

Station Identificat-ion Number	Station Elev. (ft)	Area (sq. mi.)	Basin Avg. elevation (ft)	Basin Slope (ft/ft)	Basin shape factor (mi^2/mi^2)	Discharge for Recurrence Interval (years) *Second row are calculated values using equations developed in this study						
						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7068870	404.59	0.18	460.64	0.0874	2.34	136	202	257	319	420	515	830
						92	178	253	339	480	612	1,025
7068890	258.66	229.23	497.65	0.0741	2.69	15,673	29,931	41,298	53,729	72,100	87,638	130,414
						9,243	16,589	22,589	29,365	39,632	48,599	75,419
7069250	560.66	0.48	666.28	0.1028	1.66	239	418	583	783	1,127	1,465	2,632
						208	403	572	768	1,087	1,384	2,314
7069290	609.26	2.28	767.48	0.1058	1.86	533	999	1,415	1,915	2,753	3,564	6,322
						562	1,073	1,511	2,018	2,827	3,572	5,878
7069500	254.07	1161.47	743.98	0.0643	2.93	24,994	45,370	62,156	80,846	109,142	133,724	203,595
						25,037	43,954	59,141	76,148	101,421	123,066	187,061
7072000	291.98	1117.18	854.86	0.0647	4.15	10,921	21,285	31,426	44,379	67,390	90,631	173,428
						21,629	37,836	50,821	65,340	86,875	105,263	159,644
7072200	390.55	1.26	467.51	0.0339	3.52	601	836	993	1,149	1,358	1,524	1,944
						218	395	541	707	967	1,202	1,919
7072500	229.56	7461.54	752.35	0.0713	1.74	39,906	66,359	86,937	109,097	141,684	169,367	246,207
						105,390	183,962	246,590	316,592	419,197	506,000	760,221
7073000	406.56	215.31	730.44	0.071	3.38	9,045	14,943	19,515	24,431	31,656	37,795	54,854
						8,083	14,449	19,634	25,481	34,325	42,031	65,073
7073500	420.62	99.61	678.03	0.0645	2.67	4,522	8,438	11,989	16,264	23,373	30,126	52,097
						5,144	9,244	12,599	16,391	22,169	27,247	42,480

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7074000	298.07	471.9	666.57	0.0547	2.42	14,092	25,422	35,181	46,471	64,387	80,669	130,240
						14,127	24,875	33,535	43,243	57,777	70,332	107,567
7074200	560.7	1.19	639.83	0.0511	2.03	618	1,027	1,254	1,438	1,622	1,732	1,901
						288	534	741	978	1,354	1,699	2,757
7074250	270.47	35.61	432.81	0.0582	3.36	2,885	5,895	8,906	12,867	20,260	28,169	59,927
						2,340	4,213	5,750	7,489	10,155	12,513	19,619
7074500	194.09	19957.9	949.74	0.0665	1.44	106,423	178,117	238,350	307,344	416,742	516,470	824,602
						210,915	364,572	486,060	621,358	817,625	982,059	1,460,475
7074550	265.78	5.96	274.03	0.0024	3.31	211	512	846	1,315	2,252	3,313	7,926
						288	455	582	719	921	1,096	1,605
7074855	204.13	1.6	212.7	0.0051	2.85	310	492	640	806	1,069	1,311	2,080
						159	264	346	436	572	693	1,051
7074865	388.05	8.37	553.57	0.0565	2.21	1,192	2,794	4,318	6,202	9,379	12,421	22,398
						1,037	1,898	2,615	3,430	4,701	5,844	9,321
7074900	1083.2	0.32	1294.69	0.1925	2.35	94	167	218	267	331	379	485
						169	337	485	660	946	1,215	2,069
7074950	1352.49	1.55	1511.98	0.0752	2.11	308	671	983	1,335	1,865	2,324	3,590
						378	711	995	1,321	1,841	2,318	3,790
7075000	483.12	302.07	1274.87	0.1448	2.78	21,659	40,202	56,539	75,748	106,774	135,433	224,754
						13,304	24,556	33,902	44,581	60,907	75,275	118,590

Station Identificat-ion Number	Station Elev. (ft)	Area (sq. mi.)	Basin Avg. elevation (ft)	Basin Slope (ft/ft)	Basin shape factor (mi^2/mi^2)	Discharge for Recurrence Interval (years) *Second row are calculated values using equations developed in this study						
						2 yr	**5 yr**	**10 yr**	**20 yr**	**50 yr**	**100 yr**	**500 yr**
7075300	481.11	148.28	1138.89	0.14	3.28	9,337	17,403	24,224	31,987	44,051	54,809	86,652
						7,782	14,406	19,924	26,236	35,936	44,515	70,472
7075500	430.02	316.32	1171.73	0.1801	2.48	22,314	35,406	44,388	53,237	64,918	73,974	95,759
						15,209	28,382	39,399	52,044	71,459	88,617	140,497
7075600	483.12	1.32	681.53	0.06	2.99	252	485	708	991	1,492	1,999	3,828
						281	523	727	961	1,330	1,668	2,708
7075800	725.13	0.2	824.93	0.0589	2.03	50	102	147	201	285	362	593
						93	176	247	330	463	587	973
7076000	261.78	1148.74	1061.19	0.1293	2.16	54,711	74,816	87,088	98,267	111,957	121,846	143,752
						33,886	61,663	84,473	110,391	149,484	183,459	284,893
7076630	281.85	0.69	333.51	0.0322	1.53	230	372	455	526	603	653	743
						194	356	491	644	888	1,111	1,795
7076820	224.4	4.96	305.21	0.0345	3.06	790	1,155	1,413	1,675	2,040	2,340	3,136
						568	1,017	1,386	1,803	2,448	3,025	4,774
7076850	194.54	164.89	294.79	0.0333	2.9	6,340	11,281	14,910	18,647	23,802	27,873	38,029
						5,747	9,963	13,334	17,089	22,714	27,578	41,996
7076870	209.97	23.05	257.26	0.0165	1.67	2,021	3,997	5,511	7,073	9,199	10,864	14,886
						1,560	2,683	3,580	4,575	6,084	7,407	11,337
7077100	329.39	12.82	409.08	0.0633	1.15	2,898	4,218	4,989	5,659	6,426	6,945	7,974
						1,786	3,299	4,564	6,010	8,267	10,306	16,503

Station Identification Number	Station Elev. (ft)	Area (sq. mi.)	Basin Avg. elevation (ft)	Basin Slope (ft/ft)	Basin shape factor (mi^2/mi^2)	Discharge for Recurrence Interval (years) *Second row are calculated values using equations developed in this study						
						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7077200	340.09	1.61	417.82	0.0741	4.24	388	574	690	797	927	1,020	1,224
						301	563	783	1,036	1,437	1,802	2,928
7077340	374.25	0.67	460.06	0.0773	2.57	276	456	587	721	907	1,057	1,442
						204	388	544	725	1,014	1,282	2,112
7077380	222.99	697	301.59	0.0205	5.31	4,317	5,633	6,584	7,563	8,953	10,097	13,167
						10,418	17,308	22,662	28,525	37,072	44,252	65,241
7077430	255.23	0.19	259.35	0.0043	1.97	34	61	88	123	187	253	507
						42	71	95	120	159	195	302
7077500	182.96	1141.4	274.96	0.0079	10.24	6,060	8,870	10,984	13,220	16,462	19,183	26,636
						8,674	13,624	17,340	21,322	26,975	31,589	44,929
7077555	164.17	1280.55	266.42	0.0074	12.07	5,473	8,147	9,643	10,901	12,258	13,115	14,628
						8,664	13,527	17,163	21,052	26,552	31,022	43,936
7077860	168.19	11.45	178.21	0.0028	3.35	351	473	532	576	619	643	679
						461	729	933	1,152	1,476	1,753	2,561
7077920	194.65	30.95	207.66	0.0027	3.24	524	748	864	955	1,047	1,102	1,195
						887	1,389	1,768	2,174	2,767	3,269	4,725
7078000	175.14	177.92	213.11	0.0031	3.89	2,449	4,081	5,179	6,233	7,573	8,562	10,762
						2,737	4,236	5,356	6,551	8,265	9,689	13,795
7078170	188.87	3.46	197.03	0.0052	5.34	186	216	236	256	284	306	366
						213	348	454	568	741	890	1,334

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7188900	1000.42	1.14	1159.3	0.1731	2.5	109	306	486	692	990	1,234	1,828
						370	725	1,034	1,396	1,981	2,525	4,230
7194800	1030.84	167.35	1301.78	0.0756	1.86	10,501	24,311	37,032	52,374	77,392	100,611	172,638
						8,606	15,574	21,296	27,782	37,665	46,358	72,421
7194890	1119.37	38.56	1292.54	0.0299	2.15	1,536	3,517	5,399	7,723	11,632	15,393	27,721
						2,379	4,173	5,622	7,243	9,706	11,871	18,332
7195000	1052	128.99	1277.9	0.0379	1.34	5,481	10,515	14,527	18,849	25,088	30,272	44,005
						6,661	11,751	15,868	20,485	27,470	33,583	51,765
7195200	1076.87	0.38	1279.01	0.0449	2.2	50	124	200	297	470	643	1,253
						127	237	329	435	605	761	1,245
7247000	569.53	202.72	871.68	0.1035	2.76	11,055	19,238	25,370	31,759	40,714	48,008	66,875
						9,307	16,978	23,307	30,503	41,482	51,131	80,149
7249447	430.28	9.99	518.29	0.0405	2.49	1,679	2,397	2,814	3,179	3,598	3,883	4,447
						1,014	1,823	2,488	3,239	4,400	5,437	8,570
7249457	479.88	1.01	563.98	0.0643	3.37	465	550	592	626	661	683	723
						231	431	600	794	1,103	1,385	2,257
7249490	759.01	92.32	1509.31	0.1889	2.51	8,213	17,587	25,634	34,817	48,897	61,202	96,218
						6,829	12,912	18,053	23,986	33,209	41,462	66,629
7249500	850.07	34.91	1395.66	0.1783	4.28	N/A	N/A	N/A	N/A	N/A	N/A	N/A
						2,935	5,548	7,759	10,310	14,295	17,872	28,832

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7249650	864.99	8.35	1405.29	0.1767	3.06	1,305	2,539	3,523	4,590	6,138	7,436	10,892
						1,285	2,470	3,485	4,665	6,535	8,242	13,521
7249950	843.52	0.33	992.89	0.1194	2.13	37	101	169	257	412	564	1,069
						155	303	432	583	827	1,056	1,776
7250000	408.04	437.8	1119.63	0.1498	2.22	24,184	41,509	53,869	66,174	82,524	95,114	125,192
						18,565	34,298	47,365	62,302	85,104	105,154	165,496
7251790	456.23	72.2	1654.47	0.2306	1.78	8,528	16,487	23,825	32,923	48,774	64,764	123,111
						6,946	13,340	18,799	25,139	35,075	44,044	71,532
7255100	400	4.92	460.6	0.0158	1.75	828	1,577	2,077	2,539	3,084	3,442	4,114
						548	954	1,281	1,646	2,206	2,705	4,198
7255500	379.87	17.56	533.76	0.0339	2.09	760	1,495	2,072	2,690	3,573	4,291	6,144
						1,485	2,639	3,581	4,640	6,265	7,707	12,039
7256000	352.6	53.08	500.8	0.0352	1.72	3,143	5,151	6,625	8,163	10,351	12,154	16,995
						3,329	5,883	7,953	10,277	13,812	16,922	26,211
7257000	487.66	273.22	1441.97	0.2583	2.06	19,438	36,917	51,908	69,136	96,175	120,506	193,419
						16,369	31,168	43,707	58,221	80,708	100,760	161,789
7257100	446.24	0.25	553.59	0.0868	5.62	49	93	129	170	233	287	444
						84	160	225	301	422	535	887
7257200	348	155.26	1081.23	0.1887	2.45	8,516	11,547	13,125	14,394	15,711	16,530	17,958
						9,693	18,247	25,449	33,745	46,581	58,012	92,758

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7257500	447.54	241.54	1260.19	0.2109	2.31	16,755	29,575	40,209	52,173	70,588	86,867	134,536
						13,670	25,780	35,981	47,740	65,902	82,046	131,062
7257700	467.38	7.02	859.18	0.1079	5.47	793	2,049	2,931	3,717	4,541	5,041	5,806
						810	1,513	2,106	2,786	3,854	4,817	7,775
7258200	698.42	0.92	825.35	0.117	4.47	192	348	480	631	870	1,086	1,742
						234	448	631	844	1,185	1,500	2,480
7258500	423.39	240.63	745.93	0.0909	2.12	12,087	19,445	24,301	28,871	34,592	38,758	47,988
						11,010	19,997	27,390	35,781	48,554	59,767	93,395
7260630	381.55	1.84	536.78	0.1093	2.26	457	872	1,199	1,549	2,051	2,469	3,566
						460	879	1,239	1,655	2,321	2,934	4,836
7263400	357.77	15.01	563.52	0.1849	2.7	2,064	4,081	5,823	7,828	10,965	13,781	22,158
						2,002	3,840	5,413	7,239	10,123	12,745	20,833
7263580	270.52	20.51	471.6	0.076	4.08	3,394	5,532	7,196	9,009	11,727	14,095	20,974
						1,643	3,001	4,128	5,410	7,394	9,161	14,526
7263590	351.84	0.97	480.6	0.0793	2.78	641	879	1,042	1,208	1,439	1,630	2,150
						256	483	677	901	1,258	1,586	2,604
7263860	205.49	2.69	213.77	0.0021	1.31	378	504	562	605	644	664	691
						227	364	468	581	751	899	1,332
7263910	257.25	2.4	322.05	0.0382	2.81	619	866	1,037	1,208	1,446	1,638	2,142
						374	678	930	1,215	1,662	2,065	3,294

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7264000	199.11	199.14	315.72	0.0353	4.21	2,064	4,081	5,823	7,828	10,965	13,781	22,158
						5,804	10,027	13,395	17,141	22,735	27,548	41,813
7264050	239	85.89	290.9	0.0218	2.07	1,320	2,257	3,153	4,319	6,515	8,952	19,559
						3,726	6,398	8,525	10,884	14,424	17,496	26,584
7264100	217.67	8.38	234.14	0.0031	2.14	890	1,266	1,461	1,616	1,772	1,867	2,022
						452	725	934	1,160	1,496	1,786	2,634
7265001	256.33	635.68	255.62	0.012	4.68	3,330	4,779	5,715	6,599	7,725	8,565	10,513
						8,777	14,260	18,465	23,030	29,634	35,147	51,173
7338700	937.49	16.02	1294.23	0.2	4.85	1,933	3,606	5,207	7,252	10,970	14,858	30,042
						1,739	3,323	4,675	6,241	8,708	10,940	17,825
7339500	318.24	187.74	838.04	0.1084	2.47	14,766	27,752	39,265	52,993	75,714	97,339	168,827
						9,326	17,082	23,500	30,809	41,986	51,835	81,489
7339800	396.03	6.24	561.28	0.0726	5.79							
						655	1,202	1,658	2,178	2,988	3,715	5,938
7340000	272.89	2679.39	828.7	0.077	1.7	45,197	69,847	88,507	108,334	137,272	161,740	229,655
						55,382	97,939	132,208	170,705	227,822	276,739	421,007
7340200	306.67	10.66	416.1	0.0135	1.9	1,618	2,718	3,458	4,169	5,069	5,736	7,211
						847	1,451	1,933	2,467	3,279	3,994	6,120
7340300	771.88	89.28	1318.02	0.2552	2.09	14,308	23,839	30,331	36,594	44,607	50,587	64,232
						7,774	14,942	21,063	28,174	39,306	49,335	80,072

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7340500	335.48	361.93	924.04	0.1505	2.63	27,840	47,690	64,343	83,394	113,545	141,005	225,845
						15,452	28,544	39,421	51,853	70,846	87,551	137,885
7340530	336.34	0.67	393.96	0.0258	4.37	191	354	480	612	798	949	1,339
						123	221	302	392	535	664	1,057
7341000	353.09	120.24	787.33	0.0925	3.56	9,712	19,298	28,067	38,681	56,407	73,337	128,992
						5,841	10,618	14,554	19,022	25,849	31,855	49,941
7341100	389.54	9.31	598.02	0.0914	2.73	2,146	4,648	6,650	8,778	11,714	14,059	19,707
						1,187	2,214	3,078	4,068	5,622	7,025	11,319
7341700	289.09	11.74	352.66	0.0175	2.11	2,026	3,635	5,168	7,130	10,723	14,518	29,664
						937	1,622	2,171	2,783	3,715	4,536	6,988
7344320	259.02	1.4	294.56	0.021	1.55	283	499	634	754	889	979	1,144
						272	485	661	858	1,167	1,446	2,293
7348615	214.57	226.76	309.85	0.026	3.26	4,142	9,347	14,709	21,986	36,056	51,806	120,214
						6,330	10,804	14,345	18,264	24,087	29,080	43,808
7348630	308.31	0.05	324.62	0.0271	1.29	23	45	66	94	144	196	396
						35	65	91	120	168	212	350
7349430	234.36	233.37	322.78	0.0284	1.89	3,256	6,715	9,742	13,265	18,828	23,881	39,121
						8,018	13,827	18,454	23,597	31,275	37,903	57,469
7355800	704.15	0.66	1198.29	0.0862	3.29	182	290	377	474	623	756	1,154
						192	364	512	682	955	1,208	1,992

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7355900	678.46	0.18	1223.95	0.2645	5.51	35	64	98	151	271	429	1,381
						94	189	274	374	539	694	1,191
7356000	655.14	413.55	1137.21	0.1367	3.28	22,679	36,287	46,264	56,521	70,820	82,362	112,084
						15,178	27,807	38,241	50,127	68,205	84,025	131,580
7356500	612.05	60.95	871.67	0.1249	3.11	6,799	11,771	15,484	19,344	24,742	29,131	40,456
						4,274	7,938	11,002	14,512	19,942	24,779	39,474
7356700	602.86	1.85	747.97	0.0827	4.93	422	886	1,322	1,863	2,792	3,707	6,864
						323	605	843	1,116	1,548	1,942	3,156
7357000	404.16	1095.56	950.16	0.0917	3.82	45,038	75,336	99,401	126,280	168,004	205,756	323,022
						24,324	43,291	58,650	75,945	101,780	123,988	189,986
7357501	421.1	1100.63	949	0.0921	3.9	41,420	69,670	93,226	120,519	164,864	206,911	347,312
						24,251	43,157	58,467	75,704	101,451	123,580	189,342
7357700	656.55	3.87	804.94	0.111	1.63	645	1,348	1,985	2,748	3,996	5,166	8,882
						845	1,613	2,269	3,029	4,238	5,348	8,774
7359500	228.05	1581.4	810.36	0.061	3.12	74,684	140,116	211,055	314,859	545,151	846,858	2,690,061
						29,548	51,566	69,167	88,830	117,917	142,713	215,840
7359520	249.97	2.85	502.46	0.0994	7.92	272	707	1,213	1,954	3,497	5,321	13,780
						384	717	998	1,320	1,829	2,290	3,710
7359610	577.81	132.05	963.1	0.1912	2.72	19,168	36,244	52,536	73,415	111,522	151,939	312,941
						8,431	15,883	22,163	29,399	40,607	50,597	80,993

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7359700	514.41	201.96	935.43	0.1817	2.67	20,952	38,555	52,598	67,858	90,269	109,253	161,245
						11,059	20,711	28,808	38,115	52,460	65,187	103,778
7359710	565.92	8.64	750.75	0.084	5.68	2,240	3,952	5,238	6,590	8,509	10,076	14,194
						852	1,570	2,170	2,854	3,921	4,878	7,803
7359750	607.24	2.26	749.55	0.0848	2.54	813	1,702	2,445	3,273	4,502	5,556	8,423
						469	884	1,236	1,642	2,286	2,875	4,691
7359800	394.85	301.53	843.25	0.1489	4.02	26,034	40,884	51,514	62,343	77,316	89,397	120,563
						11,765	21,648	29,841	39,189	53,454	65,969	103,703
7359805	448.77	7.72	715.97	0.1476	2.35	967	2,704	4,894	8,354	16,315	26,832	86,721
						1,271	2,432	3,425	4,576	6,400	8,065	13,204
7360800	337.29	119.65	581.88	0.0678	1.96	10,792	18,902	25,632	33,235	45,034	55,569	87,004
						6,565	11,848	16,183	21,091	28,577	35,169	54,941
7361000	324.28	381.89	784.03	0.1238	2.73	26,873	52,673	76,145	104,906	154,164	202,957	375,617
						14,929	27,306	37,523	49,154	66,846	82,346	128,898
7361200	281.07	142.45	410.35	0.0237	2.31	7,241	12,813	17,356	22,407	30,081	36,796	56,196
						5,123	8,780	11,684	14,903	19,712	23,864	36,126
7361500	229.33	178.83	540.4	0.0922	2.76	12,335	18,332	22,191	25,798	30,318	33,631	41,089
						8,288	15,055	20,625	26,947	36,585	45,050	70,486
7361600	182.13	1071.17	553.64	0.0559	2.98	32,729	61,934	86,324	114,432	159,027	200,186	329,777
						22,658	39,544	53,053	68,144	90,528	109,669	166,180

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7361680	290.81	1.46	359.4	0.0499	1.55	231	494	687	877	1,114	1,286	1,643
						359	667	926	1,223	1,693	2,123	3,443
7361760	238.22	9.08	396.9	0.0687	3.7	713	1,069	1,355	1,679	2,197	2,683	4,296
						966	1,772	2,443	3,207	4,397	5,466	8,720
7361780	249.46	3.46	319.55	0.0422	3.65	462	740	973	1,241	1,677	2,089	3,463
						447	808	1,107	1,446	1,974	2,449	3,894
7361800	149.96	265.15	290.49	0.041	2.72	16,821	24,127	29,352	34,693	42,185	48,296	64,449
						8,534	14,885	19,978	25,664	34,177	41,532	63,332
7361894	184.5	9.12	248.61	0.0224	3.92	329	572	760	962	1,259	1,512	2,220
						686	1,194	1,604	2,060	2,758	3,374	5,220
7362050	129.93	10.4	205.99	0.0487	2.8	379	935	1,507	2,258	3,612	5,002	10,035
						1,054	1,908	2,612	3,410	4,646	5,751	9,098
7362100	97.56	384.36	228.62	0.0402	1.98	6,398	13,835	21,160	30,456	46,679	62,722	117,575
						12,115	21,121	28,336	36,392	48,428	58,817	89,537
7362330	142.4	12.71	189.25	0.0076	3.09	884	1,896	2,793	3,833	5,458	6,906	11,126
						678	1,123	1,471	1,851	2,422	2,916	4,376
7362450	240.22	4.83	316.49	0.0405	1.69	676	1,331	1,841	2,381	3,139	3,753	5,295
						721	1,310	1,798	2,352	3,217	3,997	6,367
7362587	781.35	26.97	1148.98	0.1465	2.1	5,634	8,946	11,658	14,769	19,792	24,544	40,415
						3,006	5,692	7,969	10,599	14,720	18,442	29,840

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7362715	388.07	4.69	516.78	0.0875	2.77	1,531	2,673	3,470	4,255	5,278	6,043	7,793
						743	1,391	1,938	2,566	3,557	4,457	7,222
7363000	260.91	549.43	639.75	0.1105	1.82	27,866	45,558	57,710	69,498	84,783	96,283	122,964
						21,166	38,574	52,901	69,189	93,892	115,503	180,174
7363050	233.82	1.49	335.39	0.0678	1.58	159	387	699	1,234	2,624	4,659	18,806
						395	744	1,040	1,381	1,923	2,422	3,960
7363200	152.86	1125.26	461.96	0.0466	3.31	22,505	38,791	49,728	60,029	72,821	82,027	101,946
						21,396	36,966	49,344	63,117	83,452	100,762	151,733
7363300	200	204.01	337.47	0.0217	4.84	6,962	14,736	21,204	28,319	38,707	47,410	70,453
						4,875	8,221	10,850	13,746	18,028	21,679	32,431
7363330	186.22	4.8	293.8	0.0345	2.3	445	990	1,479	2,055	2,967	3,797	6,269
						615	1,105	1,509	1,965	2,673	3,309	5,235
7363430	309.87	0.67	355.38	0.0371	1.85	114	268	433	662	1,110	1,610	3,723
						186	341	472	621	858	1,075	1,741
7363450	212.55	0.27	245.33	0.0254	2.01	45	110	171	243	357	461	762
						89	162	223	292	402	503	812
7363500	97.06	2095.32	359.25	0.0326	4.49	21,892	38,705	51,259	64,164	81,944	96,071	131,316
						26,084	43,924	57,865	73,220	95,555	114,268	168,951
7364000	86.02	2438.28	337.95	0.0301	4.38	19,167	35,491	49,071	64,437	88,213	109,462	172,797
						28,408	47,611	62,569	79,014	102,865	122,795	180,930

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7364030	143.33	0.33	169.16	0.0191	1.36	46	102	144	185	237	274	353
						107	193	264	345	472	589	946
7364070	149.24	5.65	170.4	0.0476	2.35	339	552	701	850	1,051	1,208	1,593
						746	1,358	1,866	2,443	3,343	4,153	6,615
7364110	229.19	0.74	268.19	0.0137	3.05	132	252	361	492	711	920	1,604
						124	217	293	377	508	625	981
7364120	153.25	218.83	228.84	0.0131	4.6	1,734	2,446	2,866	3,237	3,671	3,971	4,590
						4,490	7,397	9,650	12,108	15,712	18,759	27,674
7364125	217.47	4.89	306.66	0.0493	1.18	1,048	1,560	1,866	2,138	2,455	2,673	3,110
						873	1,608	2,222	2,922	4,022	5,019	8,059
7364128	167.94	101.6	191.27	0.0036	4.24	1,535	1,748	1,851	1,933	2,019	2,072	2,166
						1,918	3,001	3,816	4,689	5,951	7,008	10,068
7364140	191.17	37.27	289.84	0.0331	2.19	3,944	6,804	9,771	13,967	22,928	34,239	99,099
						2,380	4,195	5,665	7,314	9,823	12,032	18,635
7364150	120.48	588.48	208.25	0.0095	6.45	4,460	11,786	21,969	39,227	81,828	140,428	481,153
						6,963	11,158	14,348	17,793	22,751	26,862	38,795
7364165	209.11	18.2	284.41	0.0322	1.9	849	1,605	2,408	3,527	5,803	8,456	21,026
						1,549	2,749	3,726	4,825	6,511	8,006	12,494
7364190	85.17	1157.77	190.91	0.0097	7.11	4,762	5,985	6,720	7,386	8,206	8,800	10,135
						10,566	16,825	21,560	26,662	33,948	39,939	57,280

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7364260	139.81	20.05	169.94	0.0058	2.6	704	1,290	1,709	2,126	2,669	3,083	4,023
						899	1,468	1,909	2,387	3,100	3,714	5,514
7364550	202.65	0.07	232.26	0.0422	1.95	57	100	155	243	450	727	2,334
						43	81	113	151	211	268	446
7365800	149.74	180.21	248.26	0.0319	3.11	4,779	11,154	17,840	26,744	43,164	60,272	123,681
						5,871	10,141	13,548	17,337	23,001	27,888	42,357
7365900	155.63	50.49	239.6	0.0225	2.82	2,010	4,883	8,220	13,125	23,491	35,892	95,170
						2,377	4,093	5,462	6,982	9,271	11,263	17,176
7367658	158.17	0.93	162.93	0.0027	2.4	155	209	247	285	338	381	494
						98	159	207	258	336	405	608
7367661	92.1	313.55	413.2	0.0315	2.48	4,526	6,996	8,726	10,450	12,776	14,601	19,132
						9,120	15,709	20,950	26,774	35,441	42,893	64,883
7367670	179.19	3.34	126.46	0.0022	2.95	261	389	480	573	703	810	1,093
						200	316	406	501	644	768	1,129
7367680	83.24	618.57	404.11	0.0304	2.66	8,006	11,819	14,261	16,538	19,383	21,464	26,136
						13,771	23,517	31,219	39,748	52,341	63,077	94,625
7367740	164.83	1.83	114.89	0.0023	2.11	232	297	335	370	411	441	507
						153	245	317	393	509	609	906

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						2 yr	5 yr	10 yr	20 yr	50 yr	100 yr	500 yr
7369680	80.92	508.33	222.43	0.0002	3.03	2,459	3,949	5,869	8,892	15,969	25,313	78,608
						2,693	3,651	4,318	4,998	5,925	6,658	8,729