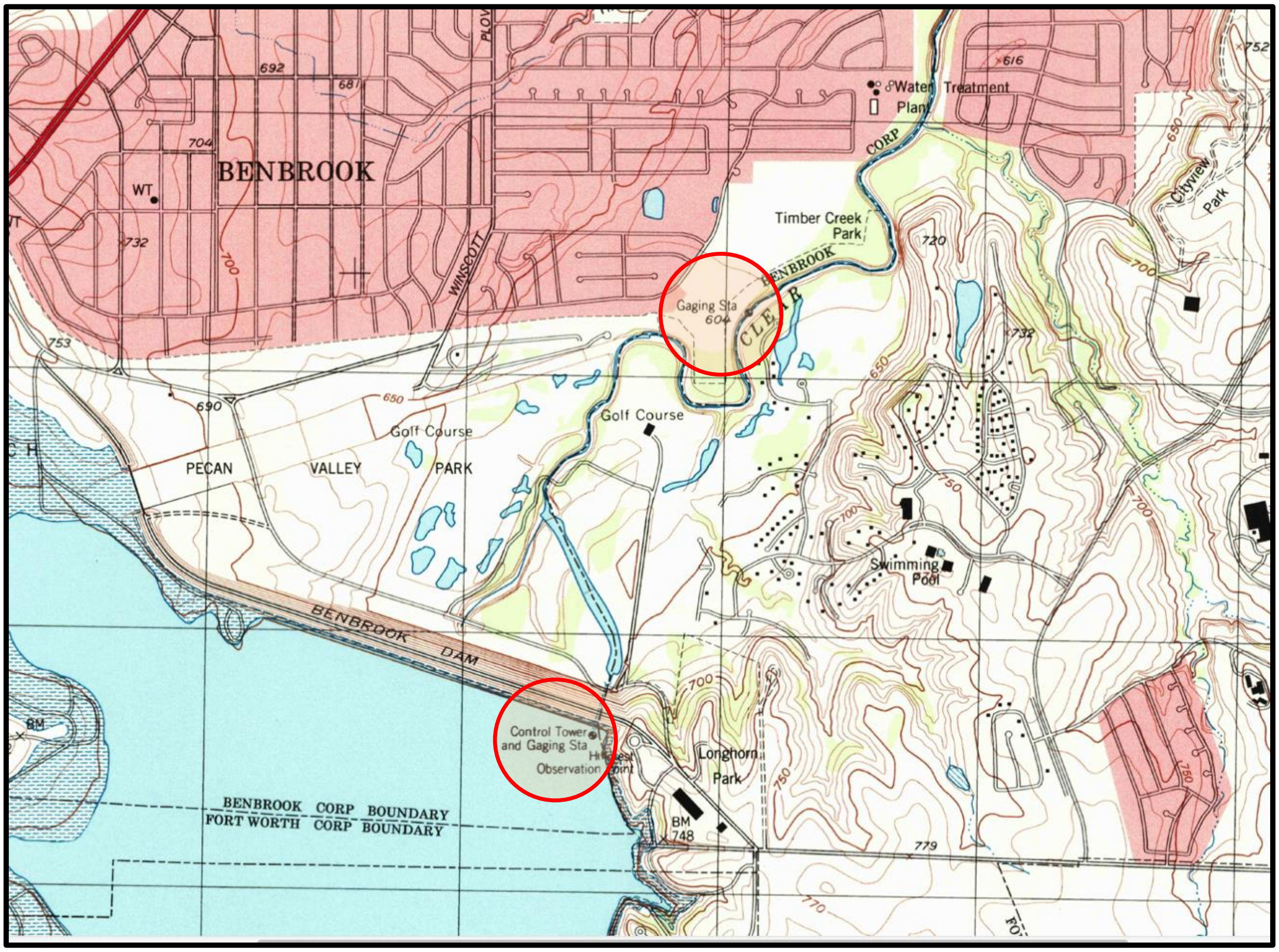
Magnitude and Frequency of Peak Streamflow and *N*-day Streamflow Volumes for Selected Surface Water Monitoring Locations, West and Clear Forks of the Trinity River, Fort Worth, Texas, through Water Year 2016



U.S. Department of the Interior
U.S. Geological Survey

Background

The Fort Worth Floodway is a federal project developed by the U.S. Army Corps of Engineers (USACE) in cooperation with Tarrant Regional Water District (TRWD). The Floodway protects Fort Worth and surrounding communities from floods on the Clear Fork and West Fork Trinity Rivers. The hydrologic analyses used for the project was initially performed in the 1930s and updated in the 1950s. The hydrology for the design was largely governed by two large flood events in 1922 and 1949 in conjunction with data from U.S. Geological Survey (USGS) streamgages observed records.

The study area, shown in figure 1, includes 4 major reservoirs: Lake Bridgeport, Eagle Mountain Lake, Lake Benbrook, and Lake Worth. These four reservoirs, used for both flood control and water supply, regulate a high percentage of watershed drainage areas within the study area. Combined, these reservoirs regulate about 82 percent of the drainage area of the 08047500 Clear Fork Trinity River at Fort Worth streamgage and about 92 percent at the 08048000 West Fork Trinity River at Fort Worth streamgage. Additional smaller reservoirs exist throughout the study area.

Regulation complicates statistical assessments of peak streamflow frequency from observational datasets. Enhanced understanding of observed and potential magnitudes of large flood events, their frequency, and potential relations to covariates could aid decision makers at TRWD and USACE.

Large floods can be defined through analysis of observed instantaneous annual peak streamflow values, and this is commonly done for design of transportation and flood-protection infrastructure (*e.g.* Asquith and Roussel [2009]). Another phenomena are *N*-day (number of consecutive days) annual maxima streamflow volumes. Volumetric flood frequency can be informative when flood regulation is present in a watershed because annual peak streamflow might be more sensitive to the effects of regulation than are flood volumes. Regulation of flood peaks is not directly a consumptive use of water, thus *N*-day annual maxima are expected to be less affected by flood regulation. More secure inferences of large flood magnitude and frequency might be obtained using streamflow volumes than peaks.

Flood-risk assessments commonly are based on statistics of annual peak streamflow time series (USGS, 2014). The USGS readily provides such time series from the USGS peak values file. Those data almost exclusively are composed only of the date and peak streamflow and rudimentary watershed qualification codes, such as urban or regulated. The statewide regionalization of flood peaks for unregulated basins using rural and unregulated observation data is available in Asquith and Roussel (2009).

Of interest for this study are the code 5 and 6 annual peaks and their relation to non-code 5 or 6 record. The code 5 indicates that there is regulation but the effect is unknown, while 6 is intended by the USGS to communicate that a given annual peak is affected by regulation (Asquith, 2001). Temporal integration of storage capacities into storage-time dependent risk modeling for this study might help quantify the effects of regulation.

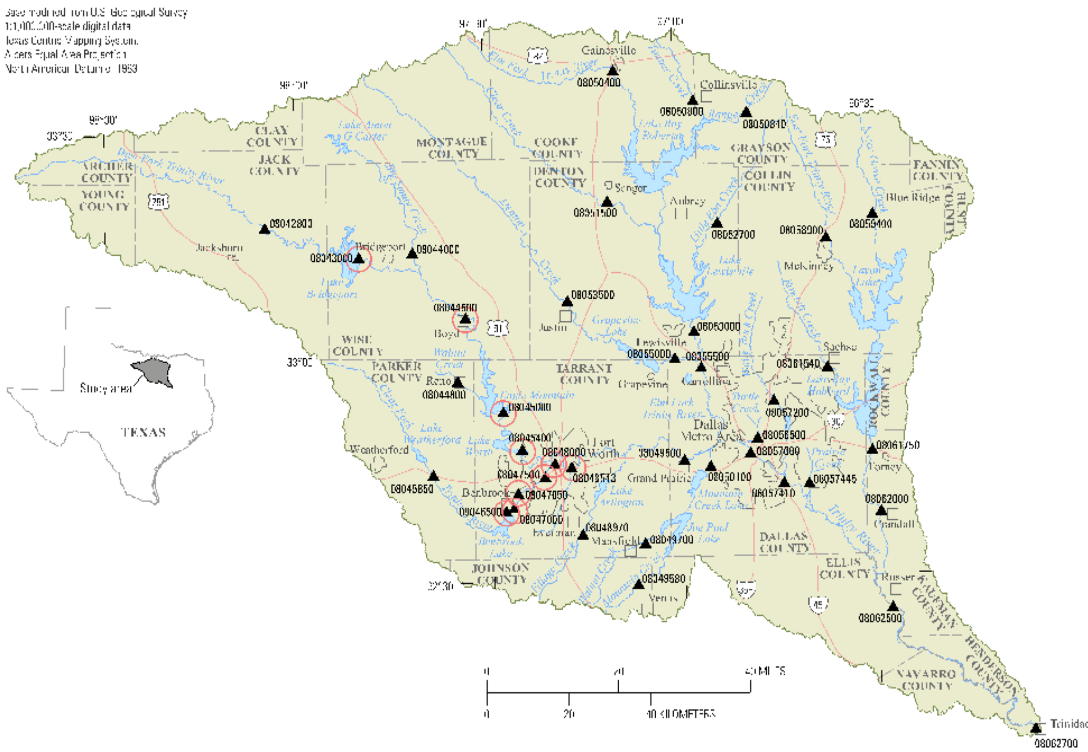


Figure 1. U.S. Geological Survey (USGS) streamgages (six) and reservoir (four) stations of principal interest to this study are circled in red.

Problem

The TRWD seeks innovative statistical analyses to define estimates of the magnitude and frequency of both peak streamflow and *N*-day annual maxima streamflow that can provide complementary perspective to watershed modeling results.

Peak streamflows from regulated watersheds can commonly exhibit temporal trends in magnitude and variability attributable to reservoir storage increases and changes in flood-wave timings amongst tributaries. Further changes can also occur over time as the result of infrastructure development. Regulated peak streamflow records are thus expected to show nonstationarity or trends. In other words, the statistical properties of annual peak and *N*-day maxima change in time.

It is hypothesized for this study that analysis of *N*-day annual maxima streamflow volumes could provide for more reliable frequency analysis because flood volumes are less affected by reservoir routing, which first manifests itself as an expected reduction in the peak streamflow.

The statistical approaches for annual maxima *N*-day volumes are not materially divergent from those for annual peaks. Some subtleties, however, are the following two problems:

(1) An authoritative fixed-interval recording to true bias correction for annual maximum *N*-day data is lacking (*e.g.* the bias that say the mean annual maximum 1-day value is statistically less than the true because the event could have spanned through midnight) is lacking, and

(2) A rigorous means for transformation of *N*-day flood-volume frequency into the peak frequency domain—this not necessarily a trivial regression problem. It is possible that a rigorous

and defendable means of converting magnitude and frequency based on *N*-day annual maxima to representable peak streamflow frequency is problematic given available information.

Objective

The objective of this study is to develop statistical models of hydrologic risk associated with magnitude and frequency of annual peak streamflow and *N*-day annual maxima.

Scope

Frequency levels (hydrologic risk) as expressed in terms of annual return period include 2, 5, 10, 25, 50, 100, 200, and 500 years. The *N*-days for this study will at least be 1, 2, 3, 4, 5, 6, and 7 days; it is understood from communication with TRWD (David Marshall) that durations longer than a week are not of particular interest.

The streamgages of principal interest for this study are 08044500 West Fork Trinity River near Boyd, 08048000 West Fork Trinity River at Fort Worth, and 08048543 West Fork Trinity at Beach Street, Fort Worth, 08047000 Clear Fork Trinity River near Benbrook, 08047050 Mary's Creek at Benbrook, 08047500 Clear Fork Trinity River at Fort Worth.

The reservoirs of principal interest are 08043000 Bridgeport Reservoir above Bridgeport, 08045000 Eagle Mountain Reservoir above Fort Worth, 08045400 Lake Worth above Fort Worth, and 08046500 Benbrook Lake near Benbrook.

Magnitude and frequency curves are relations between a hydrologic magnitude (such as peak streamflow on the vertical axis) and probability or return period (horizontal axis). Frequency curves are a depiction thus of hydrologic risk. Many such curves will result from this proposed study for annual peak and *N*-day annual maxima streamflow. Explicitly identified as primary motivation of the proposed study is the development of frequency curves with confidence limits representative of a comprehensive use of observational data that will be used to augment practical inquiries of hydrologic risk of the Fort Worth Floodway. The two sites therefore requiring special attention in final deliverables of the study are (1) 08048000 West Fork Trinity River at Fort Worth and (2) 08047500 Clear Fork Trinity River at Fort Worth.

Approach

The general ideas involving the statistical approach are well understood by the hydrologic discipline. The basic theme is estimation of parameters of a selected probability distribution for a given hydrologic phenomena represented by a time series of annual maxima (such as the 3-day annual maxima). After a probability distribution is fit, extrapolation to return periods not represented by number of years of data is possible. Extensive details germane to this project can be found in Asquith (1998, 2001, 2011, 2016), Asquith and Roussel (2009), Hosking (2015), Hosking and Wallis (1997), Salvadori and others (2007), USGS (2014), and Veilleux and others (2014). The *R* statistical programming language (R Core Team, 2016) will be used.

Task 1: Data Acquisition and Preprocessing

A semi-independent sequence of steps for data preparation for this study is readily identified:

1. Acquire annual peak and daily mean streamflow data for streamgages through the USGS National Water Information System (NWIS);

2. Acquire daily storage for the reservoirs of principal interest. These data are not comprehensively available through USGS-NWIS and data acquisition will be made in conjunction with anticipated support from TWRD and USACE collaborative partners;
3. Acquire annual cumulative reservoir conservation (normal pool) storage and flood-capacity storage for each of the streamgages and reservoirs by temporal integration of the National Inventory of Dams (NID);
4. Recast daily storage data and outflow information for each reservoir into a net daily inflows and treat these inflows as daily mean streamflows for a pseudo-streamgage coincident with the reservoir; and
5. Compute *N*-day annual maxima for the streamgages and pseudo-streamgages (the reservoir locations of this study).

Task 2: Fixed-Interval Bias Correction

A fixed-interval bias correction requires specific attention for this project and is needed because daily mean streamflow values are recorded on fixed intervals but the true streamflow of *N*-day length on average is larger. Technical details of experimental computations for streamgage 08042800 are available upon request. The results of that indicate that the 1-day annual maxima, fixed-interval bias correction is about 7-percent correction (Asquith, 1998).

Task 3: Statistical Analyses

Statistical analyses will be conducted using algorithms such those by Asquith (2011, 2015, 2016), Hosking (2016), Rigby and Stasinopoulos (2005), USGS (2014), Veilleux and others (2014), Venables and Ripley (2002). Technical details of generalized additive models for location, scale, and shape (GAMLSS) referenced below are available upon request, but experimental results for 08047500 Clear Fork Trinity River at Fort Worth, Tex. as shown in figure 2.

1. Compute and interpret frequency curves for the principal streamgages and pseudo-streamgages:
   a. Fit a common probability distribution to whole periods of record of peak streamflow and *N*-day annual maxima using a common parameter estimation scheme. A common distribution is preferred, if justifiable, and likely will be either the log-Pearson Type III (PE3), log-GEV, or log-normal. L-moments will be used for fitting, and these fits will serve as a baseline to potential trends in the first three moments by GAMLSS (see 1.b.); and
   b. Fit Generalized Additive Models (GAMs) for Location, Scale, and Shape (GAMLSS, *http://www.gamlss.org/*) using combinations of predictor variables including time (water year) or more preferably changes in flood-regulation capacity with time. The generalized gamma, $GG(\mu, \sigma, \nu; f)$, distribution (the PE3 is thus included) having parameters μ (mean), σ (standard deviation), and ν (function of skewness) for probability f should suffice as appropriate for GAMLSS (fig. 2).
2. Investigate potential transform functions of peak and *N*-day frequency for frequency analysis, and reiterate previous step as required;
3. Investigate a means to convert *N*-day frequency to pseudo-peak frequency and document conversion suitability and limitations thereof;
4. Confidence limits, where rigorously possible, will be estimated by large sample Monte Carlo simulation based on variance-covariance structures of the sample L-moments; and

5. Investigate joint probability relations between peak streamflow as well as N-day annual maxima for select pairs or combinations of surface water monitoring locations such as, the tributary pairing between the Clear Fork and West Fork Trinity Rivers for streamgages 08047500 and 08048000 as well as the streamgage triad in the West Fork Trinity River of 08047000, 08047050, and 08047500. This particular step is highly experimental.

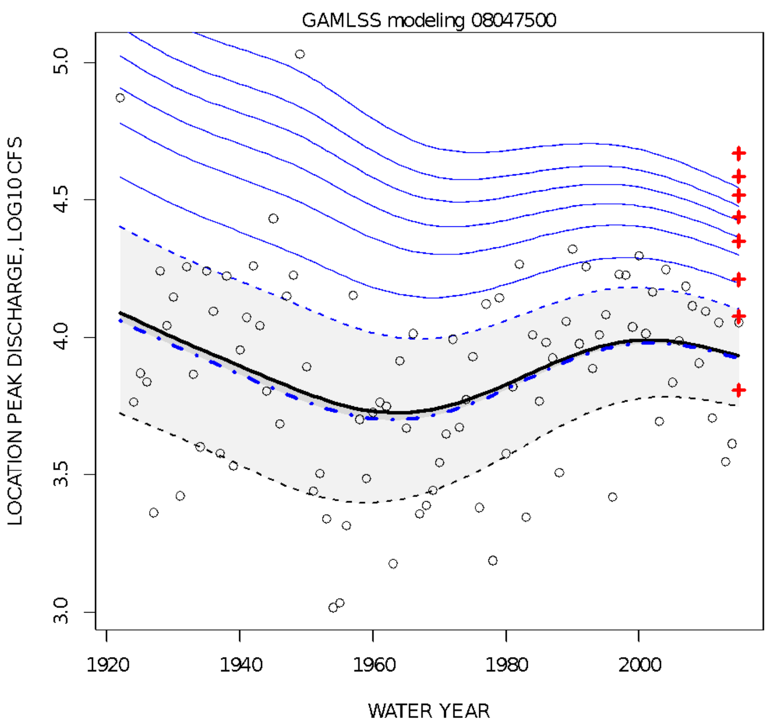


Figure 2. Experimental GAMLSS analysis using a generalized gamma (log10(Q) [streamflow distributed as *GG*) distribution model for base-10 logarithms of annual peak streamflow data for U.S. Geological Survey streamflow-gaging station 08047500 Clear Fork Trinity River at Fort Worth, Tex. showing salient annual return periods (blue lines [dashed and solid] ramp through the 2, 5, 10, 25, 50, 100, 200, and 500-year event) and additional statistical descriptors (black lines) of data having clear temporal dependence.

Figure 2 also highlights a different perspective. Instead of basing the GAMLSS regression fit on time (water year, black and blue lines), the regression can be made using cumulative flood storage by year. Yearly integration of flood storage in the watershed was acquired from USACE (Jerry Cotter, written commun., 2014) and a GAMLSS model fit. Then the fitted GAMLSS model was used to estimate the three parameters of the *GG* distribution for the total flood storage in the watershed for year 2015. The peak-streamflow frequency curve is depicted by the red + signs in figure 2.

Task 4: Communication and Reporting

Towards the end of Task 3 and as experimental and preliminary results become available, presentation to TWRD and others is expected. Subsequent cooperator discussions will inform decision making on the most suitable publication outlets. A manuscript presenting background, statistical methods, and magnitude and frequency of investigated streamflow phenomena will be developed for Journal publication and submitted for peer review. Lastly, Task 1.2 requires daily storage in reservoirs represented by the USGS site ids:

08043000 Bridgeport Reservoir above Bridgeport,
08045000 Eagle Mountain Reservoir above Fort Worth,
08045400 Lake Worth above Fort Worth, and
08046500 Benbrook Lake near Benbrook.

The USGS periods of record for these reservoirs are not expected to encompass the period of all available data; additional data can be acquired from TRWD and USACE. Most importantly, however, is the fact that USGS-NWIS databases are not the official repository for daily storage in these reservoirs. Assistance from reservoir owner/operators will be required to fulfill the objectives of this project

Task 5: Data Management and Archival

Though no original data are collected for this study, intermediate tables for semi-automated statistical processing will be generated. Archival of plain-text tables housing information such as USGS site ids, annual peak and *N*-day maxima streamflow, and select other attributes, such as flood-storage capacity upstream of each site by year require tabulation. Computer scripts will be used for the bulk of statistical processing and visualization of results. These scripts, though not directly intended for public release, will operate on the plain-text tables archived with this project as well as archival of these scripts. An appropriate `README.txt` file and other metadata required to satisfy USGS requirements will be written.

Deliverables

Deliverables from this study would be publication of results directed to the hydrologic engineering community. Appropriate publication outlets include American Society of Civil Engineers (ASCE) Texas Section Proceedings and (or) ASCE Journal of Hydrologic Engineering or similar journals.

Timeline

The timeline for the proposed study is summarized below. A six-month period of projected latency in publication process between effective completion of reporting and final journal publication availability for Task 4 is expected. It is anticipated the draft manuscripts and communication of the results of the project would be provided in the fifth quarter of the project.

	Quarters from beginning of project							
Tasks	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
Task 1: Data Acquisition and Preprocessing	X	X						
Task 2: Fixed-Interval Bias Correction		X						
Task 3: Statistical Analyses			X	X				
Task 4: Communication and Reporting	X			X	X	X	X	X
Task 5: Data Management and Archival								X

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