Updating a Flow Frequency Analysis with Nonstationarity in Period of Record Data

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Abstract

In an urbanized watershed, changes in land use and regulation of the system result in a non-homogenous period of record. Therefore, the period of record data needs to be adjusted to provide a homogenous dataset to compute flow frequency analysis. The evaluation of historical imagery, land use data, and reservoir operation are incorporated into calibrated rainfall-runoff and reservoir models to create a homogeneous dataset representing current conditions. Then, the flow frequency analysis is conducted using USGS Bulletin 17c methodology and hydrologic modeling.

Introduction

Changes in a watershed that occur during the streamflow period of record can result in flood frequency results that reflect nonstationary conditions. The Los Angeles River watershed is a highly urbanized and developed watershed; however, the period of record for many of the streamgages dates back to the 1930s, a time when the watershed was far less developed or undeveloped in some portions. To address the heterogeneity of the period of record due to urbanization and regulation, a homogenous dataset needs to be developed for a flow frequency analysis. Previous efforts in the 1990's to account for the heterogeneity of the record were addressed by considering a shortened period of record of approximately 19 years. The evaluation of historical imagery, land use data and reservoir information are incorporated into calibrated rainfall-runoff and reservoir models to develop a homogenous dataset equivalent to current conditions which incorporates over 90 years of data in the period of record in accordance with U.S. Army Corps of Engineers (USACE) Engineer Manual 1110-2-1417 Flood Runoff Analysis (1994).

Background

The Los Angeles River watershed has a drainage area of 834 square miles. The upper watershed is marked by mountainous regions with steep streams and channels draining to the river valley and urbanized regions in the central and southern watershed. The upper watershed delineated in black and labeled as the Ecosystem Restoration Study Area in Figure 1 is approximately 560 square miles. There are six reservoirs in operation in the upper watershed.

Seven streamgages within the upper watershed were evaluated for the effects of urbanization and regulation. Four of the seven gages were upstream of regulation; thus, they were only impacted by the urbanization. The other three gages were located downstream of regulation; therefore, these three gages would be impacted by both urbanization and regulation.

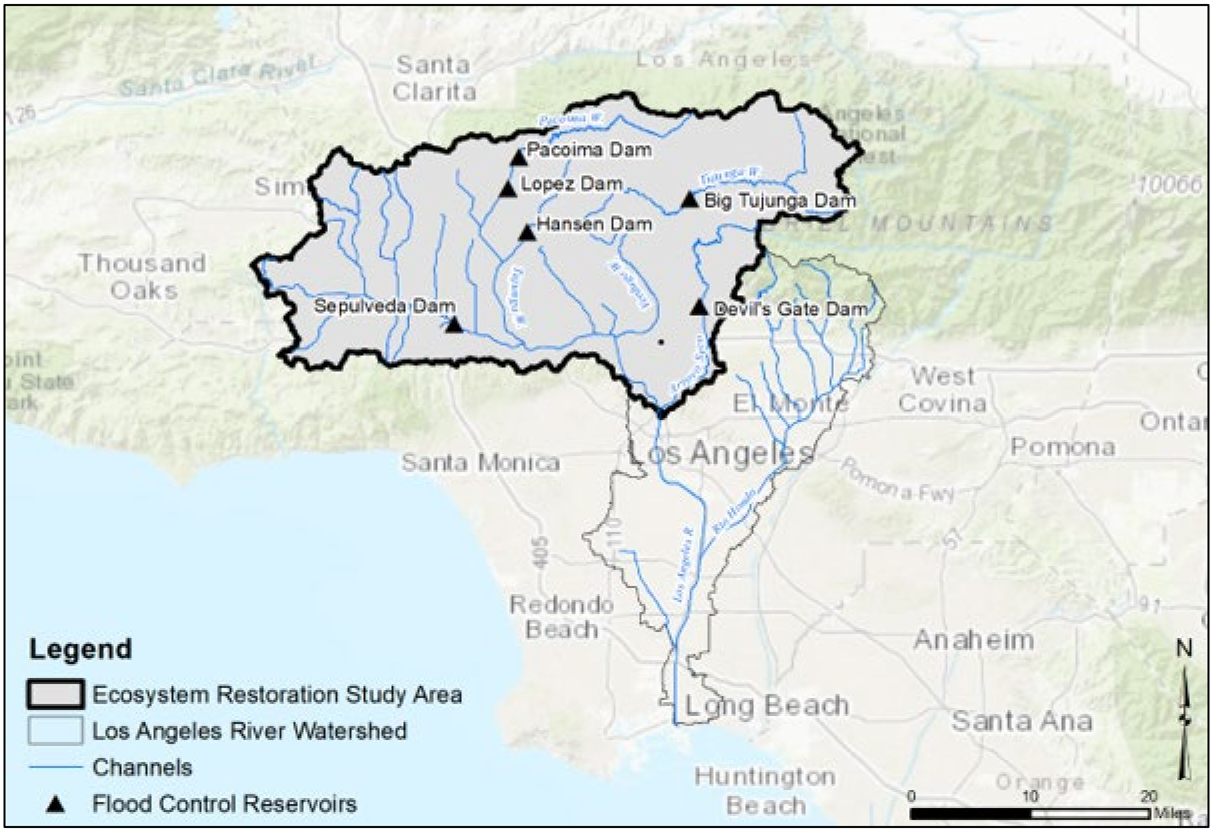

Figure 1. Los Angeles River Watershed

A previous effort recognized the heterogeneity of the period of record because of urbanization and regulation. In an effort to address this issue at an unregulated gage, the previous effort truncated the period of record to establish the homogenous dataset. The systematic record was shortened to 18 years from 1967 to 1984 which eliminated data from 1931 to 1966. This resulted in a flow frequency curve with wide confidence limits. Figure 2 shows the flow frequency curve.

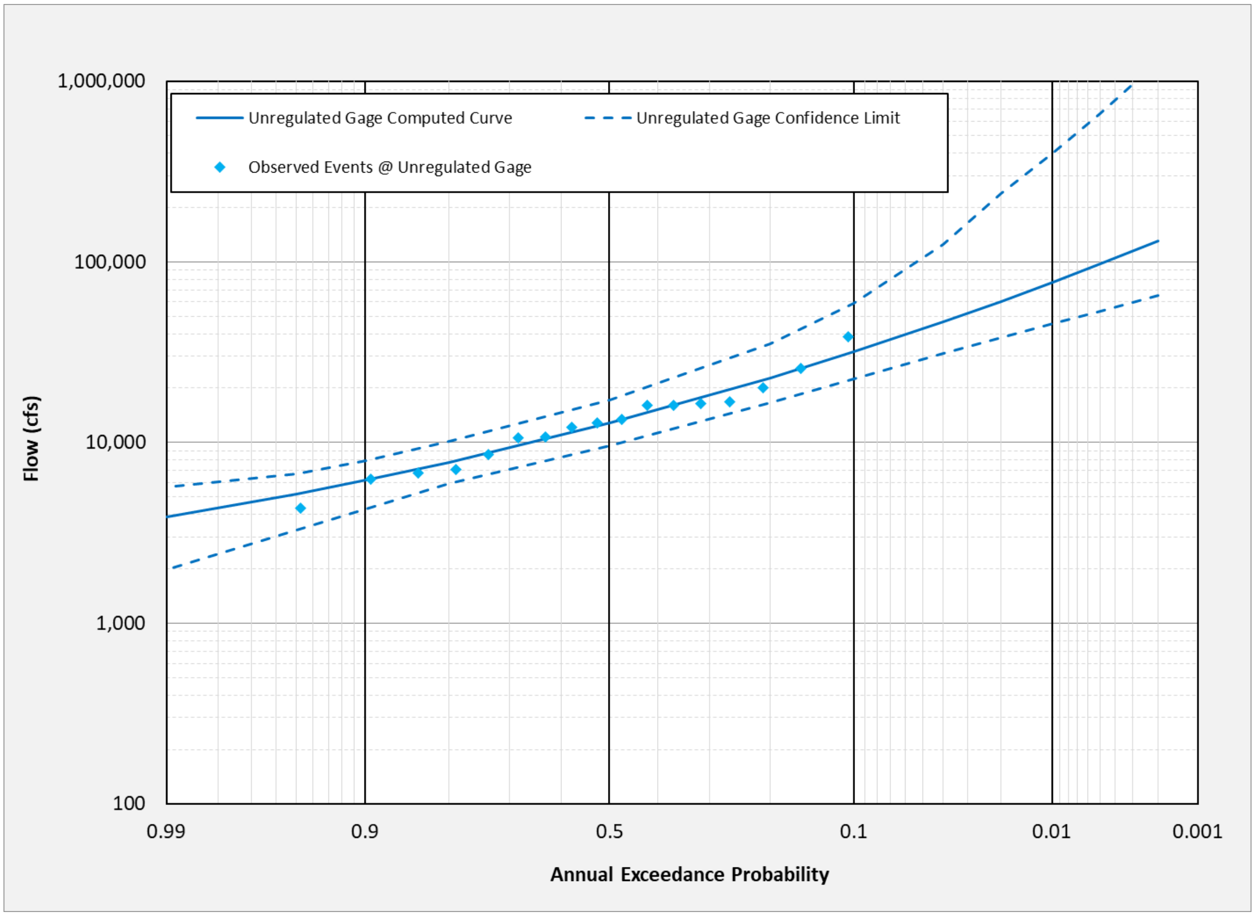

Figure 2. Previous effort flow frequency at unregulated gage

Analysis

To establish stationary time periods within the period of record dataset, population trends, changes in regulations, and time periods considered in a previous study were considered. Population data from the Los Angeles Almanac was examined for population trends to help establish break points in the period of record. The goal was to identify large increases in population which might serve as break points. Four break points were identified with population increases greater than 60,000 people. From 1920 to 1930, the population increased by approximately 85,000. From 1940 to 1950, the population increased by 62,000. From 1950 to 1960, the population increased 71,000. From 1980 to 1990, the population increased by 78,000.

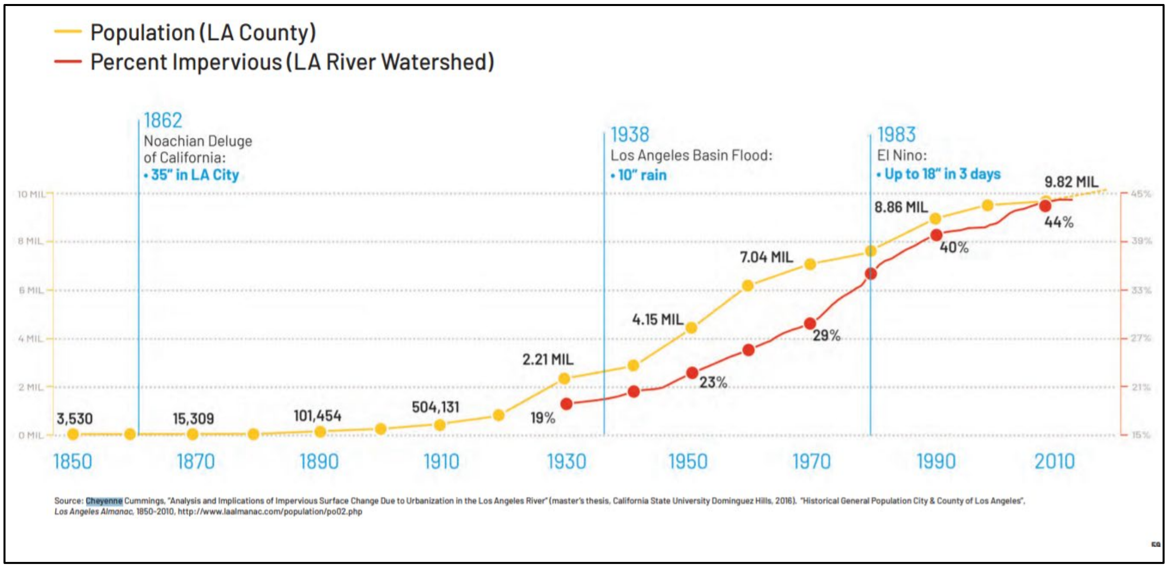

Figure 3. Los Angeles County population and Los Angeles River Watershed impervious trends

Next, changes in regulation were examined. There are six reservoirs within the upper watershed. Five of the six dams were constructed by 1941. Lopez Dam, constructed in 1954, is the smallest in storage capacity of the six listed reservoirs.

Table 1. Reservoirs in the Los Angeles River Watershed

Reservoir	Year Built
Devils Gate	1920
Pacoima Dam	1929
Big Tujunga Dam	1931
Hansen Dam	1940
Sepulveda Dam	1941
Lopez Dam	1954

In a previously study from the early 1990s, three time periods were considered when identifying nonstationarity within the watershed: 1930 to 1948; 1948 to 1966; 1966 to 1984. From the population trend information, regulation, and previous study efforts, it was determined that four time periods would be used: 1930 to 1950; 1950 to 1966; 1966 to 1990; 1990 to present. The breaks in the period of record could be discretized into smaller periods, but the breaks identified in the current analysis allowed for comparison to previous study efforts. Figure 4 shows the period of record data at one unregulated location within the watershed. Urbanization has affected the flows, leading to a non-homogenous dataset. From 1930 to 1966, there was significant urbanization occurring upstream of the gage. From 1966 to present, the watershed above the gage was mostly urbanized. Therefore, the time period of 1966 to 1990 and period of 1990 to present yield similar flows and corresponding plotting positions.

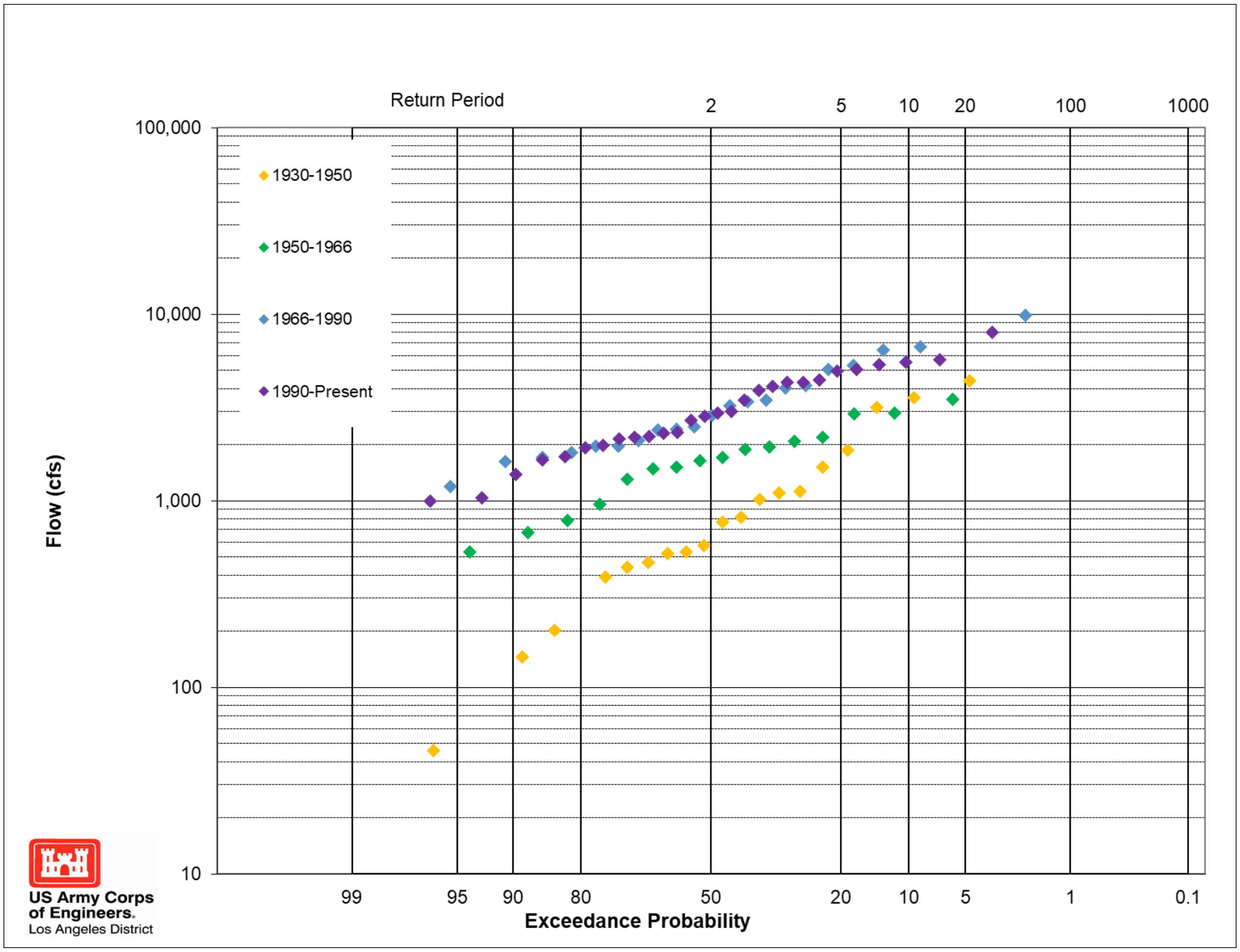

Figure 4. Period of record data divided into 4 time periods

Percent impervious estimates needed to be developed for the different time periods. For the current time period, land use designations were based on Southern California Association of Governments' (SCAG) 2016 Land Use Information for Los Angeles County GIS dataset. To estimate percent impervious for historic time periods, historic aerial imagery was used to determine land use within the watershed. Six aerial imagery datasets from the University of California Santa Barbara's Geospatial Collection from the years of 1938, 1944, 1947, 1956, 1960, 1976 were used. Then, the effective impervious area was calculated using the Sutherland Equation. Figure 5 shows the changes of imperviousness within the watershed over time.

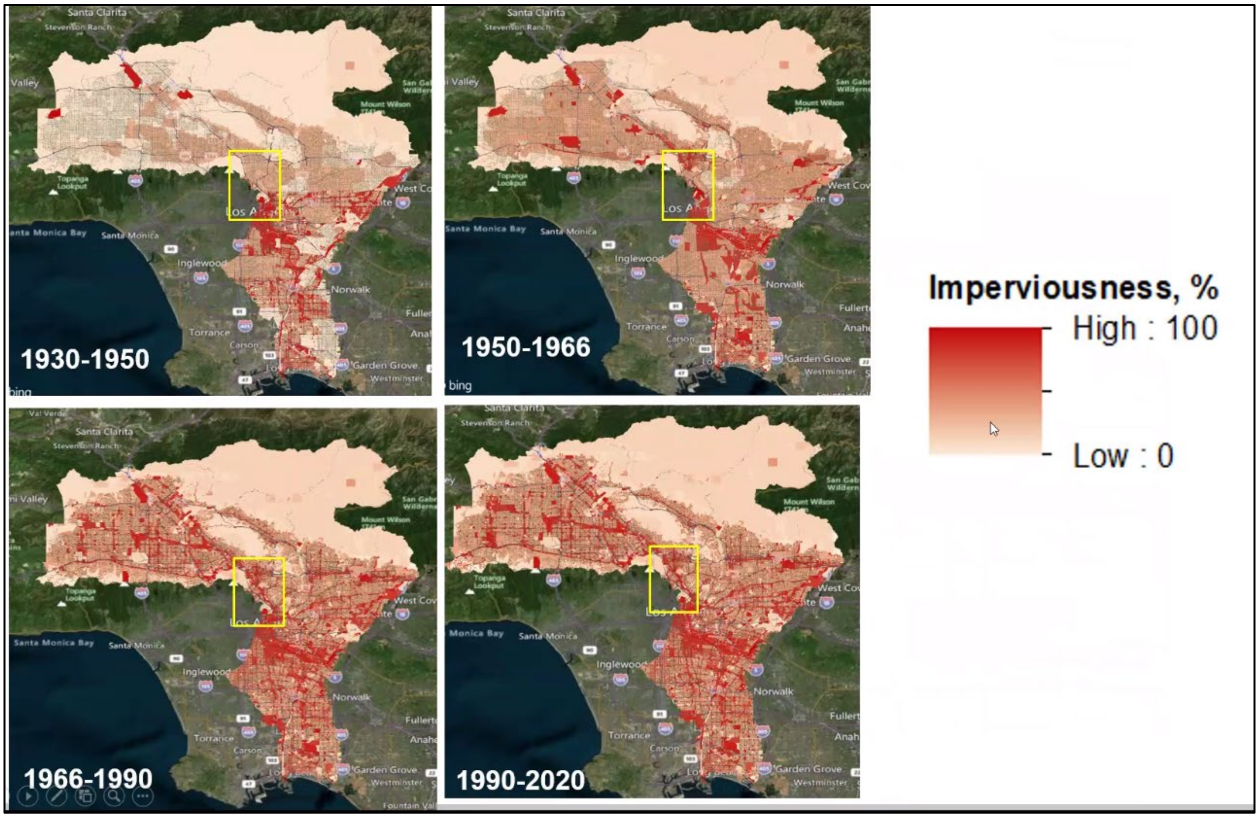

Figure 5. Watershed imperviousness over different time periods

To evaluate the impacts of the changes in the watershed on the flows, a calibrated and validated Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model and a Hydrologic Engineering Center Reservoir Simulation Model (HEC-ResSim) were used. Four separate basin models were developed corresponding to the four different time periods. Within each basin model, the imperviousness was adjusted to reflect the estimated imperviousness of each time period. Identical National Oceanic and Atmospheric Administration (NOAA) precipitation depths using a design storm temporal pattern was applied to the HEC-HMS models to determine the resulting flowrate and the non-stationary adjustment factors.

$$NSF = \frac{P_x}{H_x} \tag{1}$$

$$Q_{present} = Q_{historic} \times NSF \tag{2}$$

Where:

P_x = Peak flow resulting from precipitation depth x on present conditions watershed
H_x = Peak flow resulting from precipitation depth x on historic conditions watershed
NSF = Non-stationary Factor
$Q_{present}$ = Adjusted peak flow
$Q_{historic}$ = Observed peak flow

Non-stationary adjustment factors were plotted against the corresponding flow rates to create a curve by which the observed peak flows could be adjusted. The Non-stationarity Factor (NFS) were applied to the observed flow data to account for the impacts of urbanization and regulation. Figure 6 shows the NSF plotted against flow for an unregulated gage. The watershed upstream of the gage was fairly undeveloped during the 1930s to 1950s; therefore, there is a higher NSF. As development increased in the watershed, the NSF adjustment becomes less. Also, as the flows increase on the y-axis, the effects of urbanization have less of an impact on the flows.

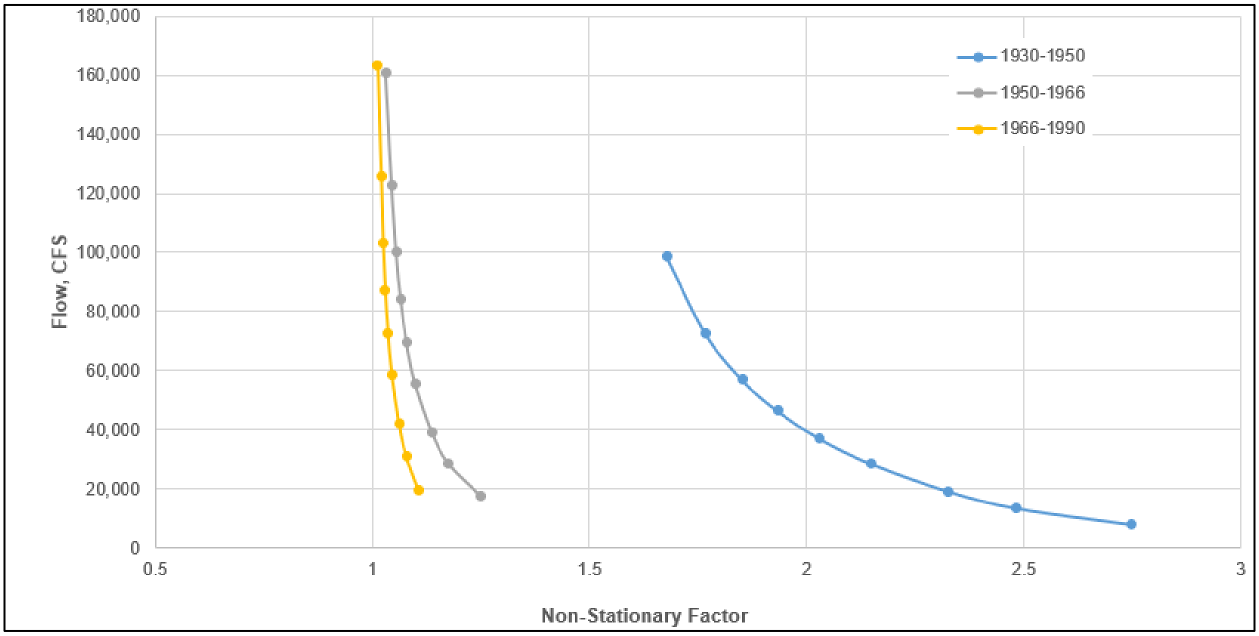

Figure 6. Non-stationary factor at unregulated gage

Figure 7 shows the NSF plotted against flow for a gage location downstream of regulation. The NSF were applied to the observed flow data to account for the impacts of urbanization and regulation. With urbanization and regulation, there are two competing factors. When the NSF is less than 1 as shown in a portion of the blue curve, the adjusted observed flows would be less if brought to the present conditions. Even though urbanization would increase flows, the addition of regulation would decrease the flows. The regulation is holding back flows and limiting the amount of discharge downstream. The effects of limiting of downstream discharge is greater than the effects of urbanization; thus, resulting in the NSF less than 1.

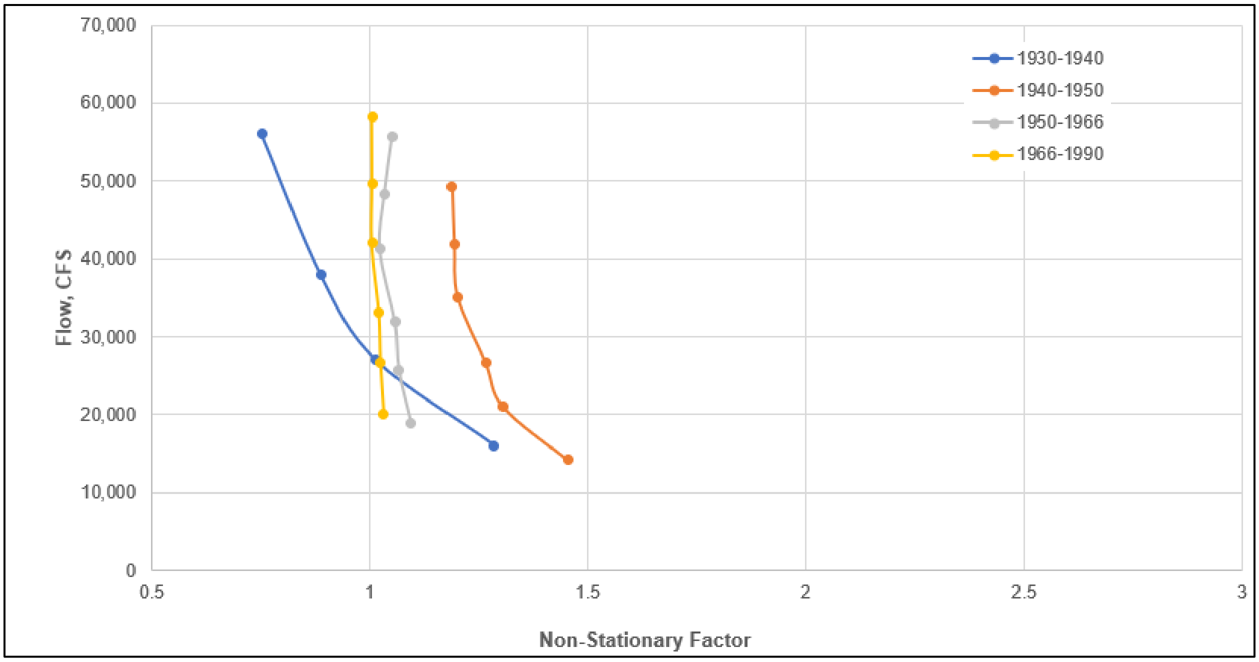

Figure 7. Non-stationary factor at gage downstream of regulation

To evaluate the affects of the NSF, the USACE Time Series Toolbox (TST) was used to examine the Non-stationary adjustment. The TST is an online analytic tool for preliminary analysis for flow data. This web tool applies various statistical tests to facilitate a better understanding of any trend(s) in the data. Trends are calculated with two methods – traditional slope (least squares regression) and Sen's slope – that fit regression curves to the data. Traditional slope method fits a simple linear regression to the data and takes the slope of the resulting line. Sen's slope is a robust, nonparametric method to determine the presence of a trend by taking the average of all the slopes between every two points in two-dimensional series. Trend analyses were conducted for the observed peak flows and the adjusted peak flows with NSF. A decreased slope indicates improving the nonstationary trend while an increased slope is worsening the trend. Therefore, a decreased slope in the NSF adjusted peak flows compared to the observed peak flows indicates an improved fit. Table 2 compares the trends for observed peak flow and the adjusted peak flow. The gage upstream of regulation and the gage downstream of regulation show a decreased slope for the adjusted peak flow compared to the observed peak flow for both trend methods. This indicates that the NSF adjustments are improving the homogeneity of the period of record flow dataset.

Table 2. Slope comparison for observed peak flow vs adjusted peak flow

Gage	Trend Method	Observed Peak Flow	Adjusted Peak Flow
Gage Upstream of Regulation	Traditional	211	142
	Sen's Slope	154	110
Gage Downstream of Regulation	Traditional	92	75
	Sen's Slope	133	91

Results

After the NSF was applied to the observed events, a flow frequency analysis was conducted on the adjusted data. The entire period of record dataset, now adjusted, reflects the current conditions of the watershed. Figure 8 shows a flow frequency analysis for an unregulated gage. Bulletin17c analyses on the observed events and the adjusted events were conducted. With the increase of urbanization, the adjusted event curve has higher flow values than the observed event curve because it necessarily increased historic observed flows to represent the higher peaks expected under increased imperviousness. For example, at 0.01 Annual Exceedance Probability, the adjusted event curve shows a flow of 62,000 cfs, while the observed event curve shows a flow of 57,000 cfs. At the frequent end of the curve with a 0.5 AEP, the adjusted curve shows a flow of 11,000 cfs, while the observed event curve shows a flow of 9,200 cfs.

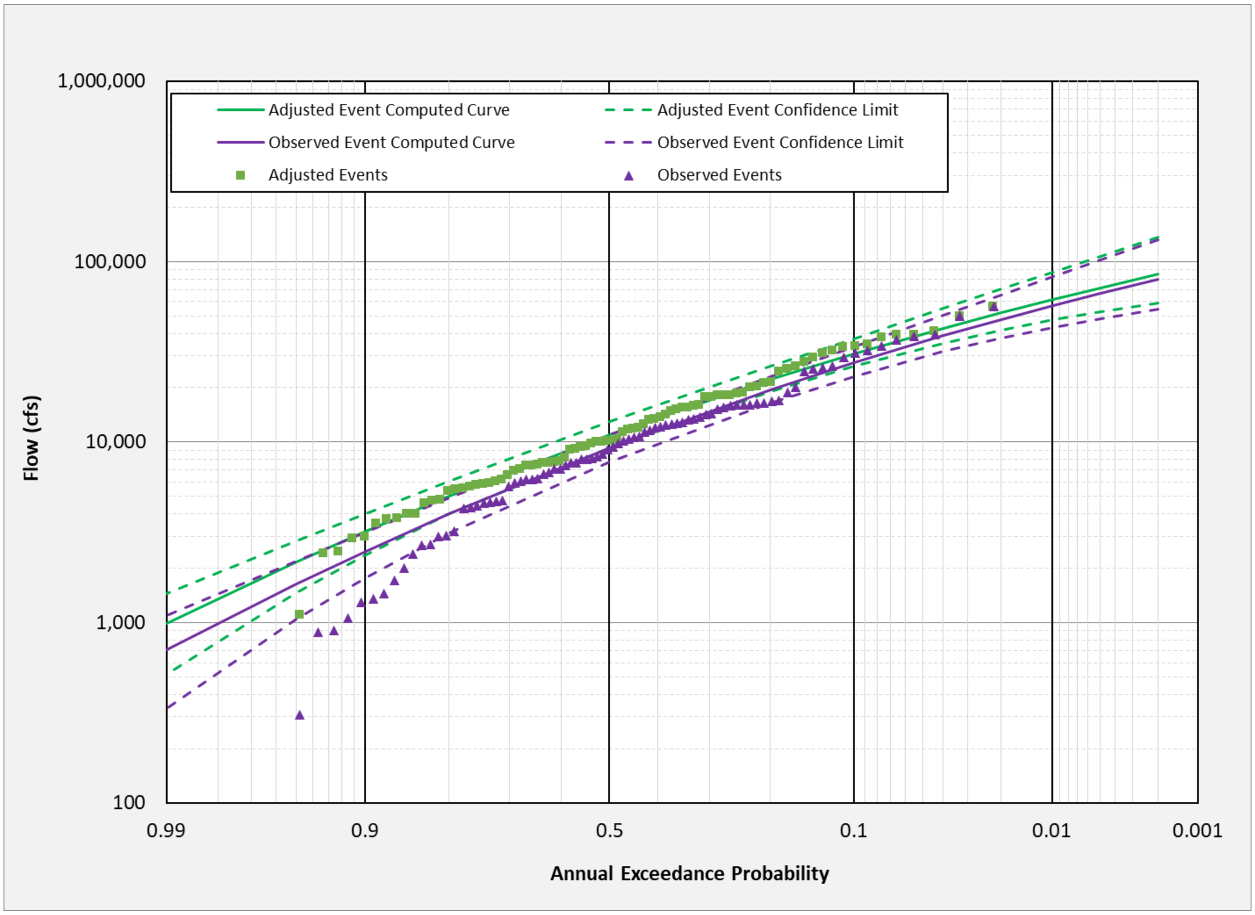

Figure 8. Flow frequency analysis for an unregulated gage

Figure 9 compares the adjusted events and observed events at a regulated gage. The events increased in flows because of the urbanization, but regulation may have limited the increase in these flows compared with those of the unregulated gage..

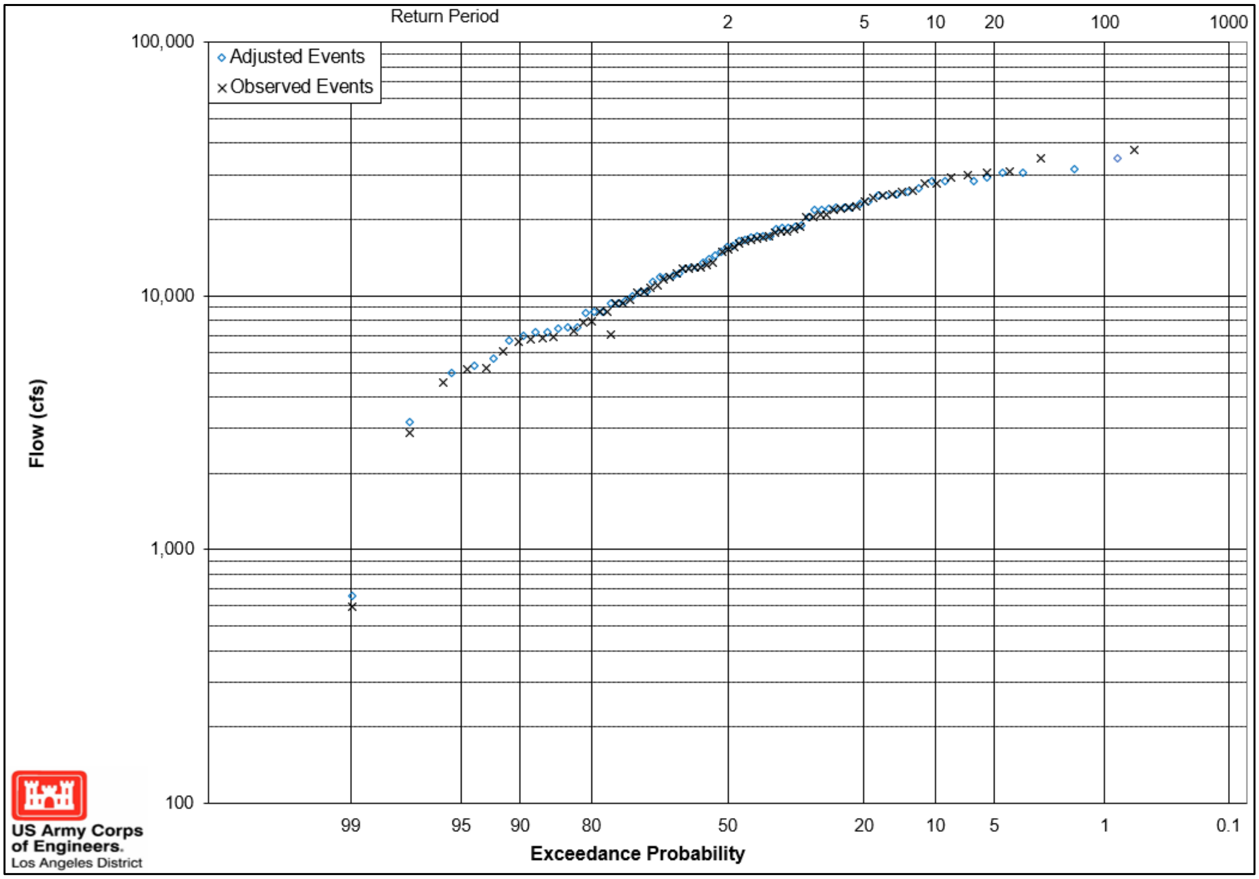

Figure 9. Adjusted and observed events for a regulated gage

Figure 10 compares the flow frequency analysis from the NSF adjusted events for an unregulated gage to the previous effort flow frequency analysis for an unregulated gage. By adjusting the observed events to current conditions using a NSF, the systematic record of 90 years can be used for the Bulletin 17C analysis. The confidence limits are not as wide compared to the previous effort due to the increase in the number of observations as a result of adding the NSF adjusted full period of record.

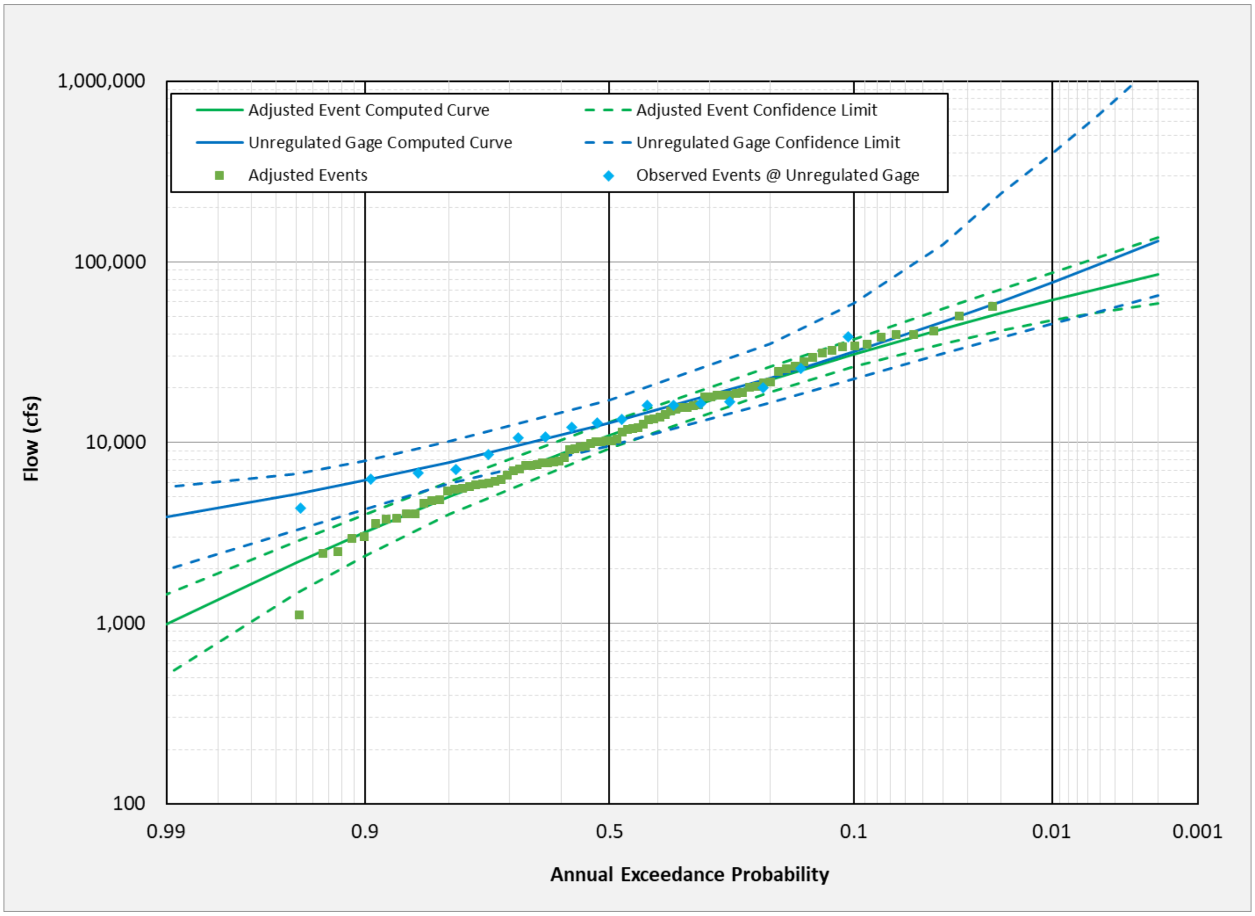

Figure 10. Comparison of Flow Frequency Analysis for an Unregulated Gage

Limitations

The following are limitations of this effort.

The period of record data was discretized into four separate static time periods. Additional discretization of the period of record data could provide a more homogenous dataset which could change the adjusted events. .

The NSF was based on a design storm temporal pattern over the upper watershed. Different temporal patterns from observed events and additional hypothetical storms could be used to determine the NSF. The NSF maybe different when using more or different temporal patterns.

Post-wildfire and debris flows were not considered in non-stationarity analysis.

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