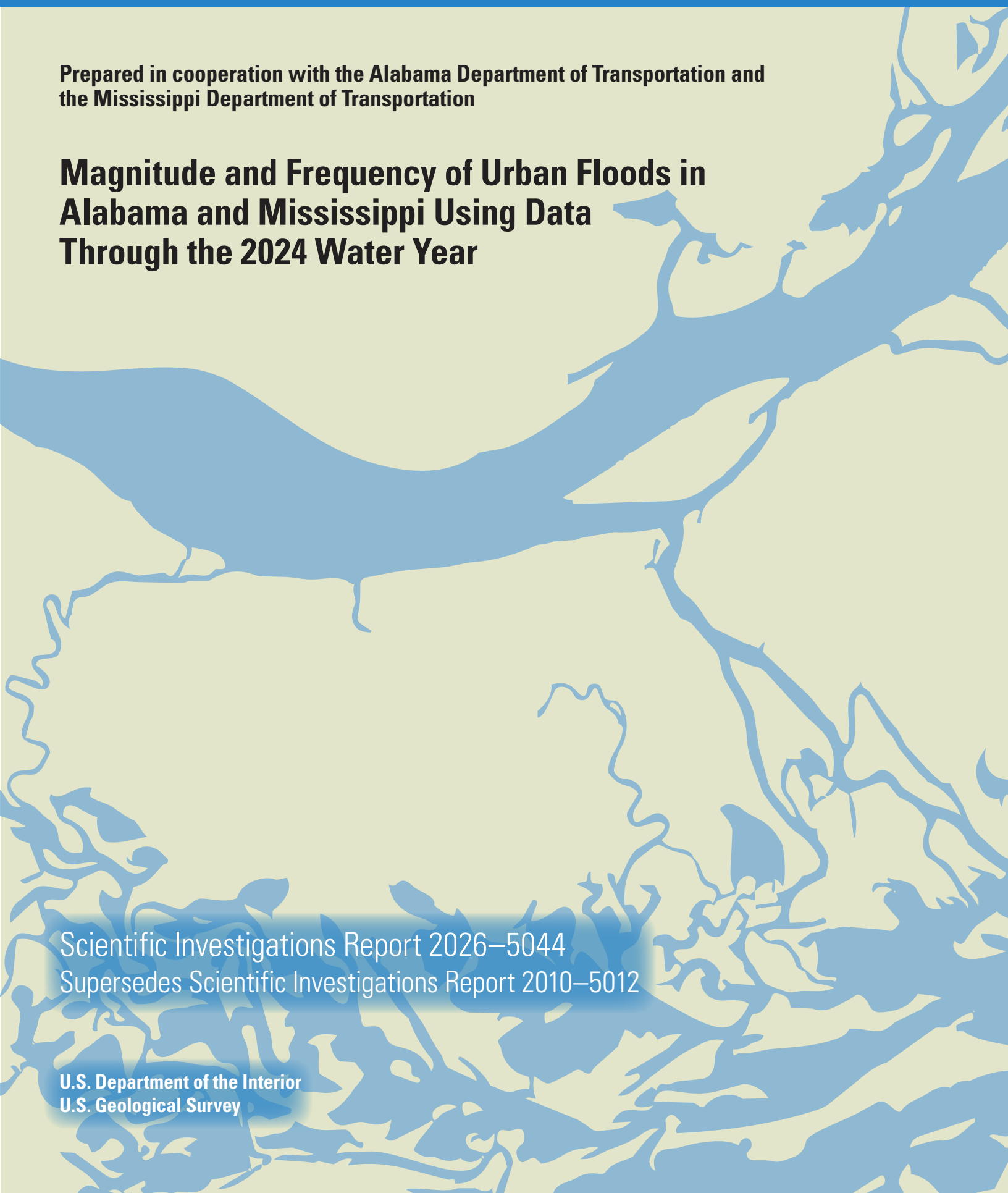
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Magnitude and Frequency of Urban Floods in Alabama and Mississippi Using Data Through the 2024 Water Year



Scientific Investigations Report 2026–5044
Supersedes Scientific Investigations Report 2010–5012

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

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By Daniel M. Wagner and Brandon T. Anderson

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C = (°F – 32) / 1.8.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

AEP	annual exceedance probability
AVP	average variance of prediction
EMA	Expected Moments Algorithm
GLS	generalized least squares
LP3	log-Pearson type III
MEV	model error variance
MGBT	multiple Grubbs-Beck test
MSE	mean squared error
NWIS	National Water Information System
PILF	potentially influential low flood
Sp	standard error of prediction
USGS	U.S. Geological Survey
WLS	weighted least-squares
WREG	weighted-multiple-linear regression (software)

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By Daniel M. Wagner and Brandon T. Anderson

Abstract

To improve flood-frequency estimates for urban streams in Alabama and Mississippi, the U.S Geological Survey, in cooperation with the Alabama and Mississippi Departments of Transportation, estimated streamflows corresponding to selected annual exceedance probabilities (AEPs) for 64 streamgages on urban streams in the two States—48 in Alabama and 16 in Mississippi. Using estimates from 42 of the 64 streamgages, regression equations were developed that can be used to predict streamflows corresponding to the selected AEPs at ungaged locations on urban streams. Annual peak-flow data through September 2024 were used in the at-site flood-frequency analyses. Drainage area and the percentage of developed land use in the drainage basins of the streamgages (from the 2011 National Land Cover Database) were identified as statistically significant explanatory variables. Pseudo coefficient of determination (pseudo-R^2) values ranged from 81 percent for the 0.2-percent AEP (500-year flood) to 91 percent for the 4- and 2-percent AEPs (25- and 50-year floods, respectively). Standard errors of prediction ranged from 23.1 percent for the 4-percent AEP (25-year flood) to 36.1 percent for the 2-percent AEP (500-year flood).

Introduction

Knowledge of the magnitude and frequency of flooding is important for the effective management of floodplains, including the safe and economic design of bridges, culverts, dams, levees, and other structures in and near streams (Hedgecock and Lee, 2010). In urban areas, the magnitude and frequency of flooding is used to inform the design of culverts, detention basins, and stream restoration projects. Impervious surfaces such as rooftops and concrete decrease infiltration of rainfall, and storm sewers concentrate runoff from roads and parking lots. Streamgages located on urban streams are typically not used in the development of regression equations for estimating flood frequency at ungaged locations on rural streams (Feaster and others, 2014). Prediction of peak streamflows at ungaged locations on streams in urban areas requires unique regression equations that account for urban development and impervious surfaces in the drainage basins of streamgages used to develop the equations. The last urban flood-frequency study for Alabama was published more than 15 years ago (Hedgecock and Lee, 2010), and the last urban flood-frequency study for Mississippi was previously published more than 30 years ago in 1991 as equations in the rural flood-frequency report (Landers and Wilson, 1991). Since that time, improvements in statistical techniques, specifically the Expected Moments Algorithm (EMA) and multiple Grubbs-Beck test (MGBT) for low outliers, have increased the accuracy of flood-frequency estimates (Cohn and others, 1997, 2013) and have been incorporated in the U.S. Geological Survey (USGS) flood-frequency software, PeakFQ (Siefken and others, 2024). The EMA allows for the incorporation of censored observations, historical flood data, low outliers, and uncertain data points in the flood-frequency analysis, whereas the MGBT increases the accuracy of flood-frequency estimates by statistically detecting and removing low annual peak flows that have a large effect on the frequency analysis and is incorporated in PeakFQ.

In 2022, the USGS, in cooperation with the Alabama and Mississippi Departments of Transportation, began a study to update streamflows corresponding to selected annual exceedance probabilities (AEPs) for urban streams in Alabama and Mississippi and develop urban flood-frequency equations using annual peak-flow data through the 2024 water year. (A water year is defined as the period October 1–September 30, named for the year in which it ends.) The results are published in associated USGS data releases (Wagner, 2025a, b) and will be available in the USGS StreamStats application (USGS, 2025c), an online tool that, in addition to providing basin characteristics and flow characteristics for streamgages used in the study, can be used to delineate a drainage basin at an ungaged location on a stream, compute selected basin characteristics, and generate estimates of flow statistics.

Purpose and Scope

The purpose of this report is to present the methods used for at-site flood-frequency analysis and development of the regression equations, performance metrics for the regression

equations, and applications of the regression equations. The scope of the study included streamgages in urban areas of Alabama and Mississippi (fig. 1) that had 10 or more years of annual peak streamflows through the 2024 water year with qualification code C (annual peak streamflow affected by urbanization; refer also to https://api.waterdata.usgs.gov/docs/ogcapi/migration#migrating-from-%2Fpeak-to-%2Fpeaks), 20 percent or more developed land use in their drainage basins (the sum of classes 21–24 in the 2011 National Land Cover Database; USGS, 2014), and drainage areas less than approximately 50 square miles (mi^2). Outside the scope of the report is the presentation of tabular results from the at-site flood-frequency analyses or regression models; these data are available in associated USGS data releases (Wagner, 2025a, b).

Description of Study Area

The study area (fig. 1) includes urban areas in the States of Alabama and Mississippi. Rainfall in Alabama and Mississippi generally is associated with the movement of warm and cold fronts across these States from November through April and with isolated thunderstorms that occur from May through October. From June through September, tropical storms or hurricanes occasionally enter the States along the gulf coast and produce unusually large amounts of rainfall. The average annual precipitation for Alabama is 53.07 inches, and the average annual high and low temperatures for the State are 76 and 54 degrees Fahrenheit, respectively. The average annual precipitation for Mississippi is 54.14 inches, and the average annual high and low temperatures for the State are 76 and 54 degrees Fahrenheit, respectively (U.S. Climate Data, 2023).

Previous Investigations

The magnitude and frequency of floods in Alabama were described by Peirce (1954), Speer and Gamble (1964), Gamble (1965), Barnes and Golden (1966), Hains (1973), Olin (1984), Atkins (1996), Hedgecock and Feaster (2007), and Anderson (2020). The magnitude and frequency of floods for rural streams with small drainage areas were described by Olin and Bingham (1977), Hedgecock (2004), and Anderson (2020) and for urban streams by Olin and Bingham (1982) and Hedgecock and Lee (2010).

The magnitude and frequency of floods in Mississippi were described by Wilson and Trotter (1961). Colson and Hudson (1976) updated the flood frequency for the entire State of Mississippi, including the Mississippi Alluvial Plain. Landers (1985) used linear regression to estimate the magnitude and frequency of floods for streams in the alluvial plain of the lower part of the Mississippi River. Landers and Wilson (1991) updated the rural flood frequency for Mississippi, including national urban equations, but did not update the alluvial plain and republished the results from Landers (1985) because not enough new record was available. Anderson (2018) updated flood-frequency and regression equations for rural streamgages in the State, excluding the alluvial plain, for which at-site flood-frequency and regression equations were later updated (Anderson, 2021).

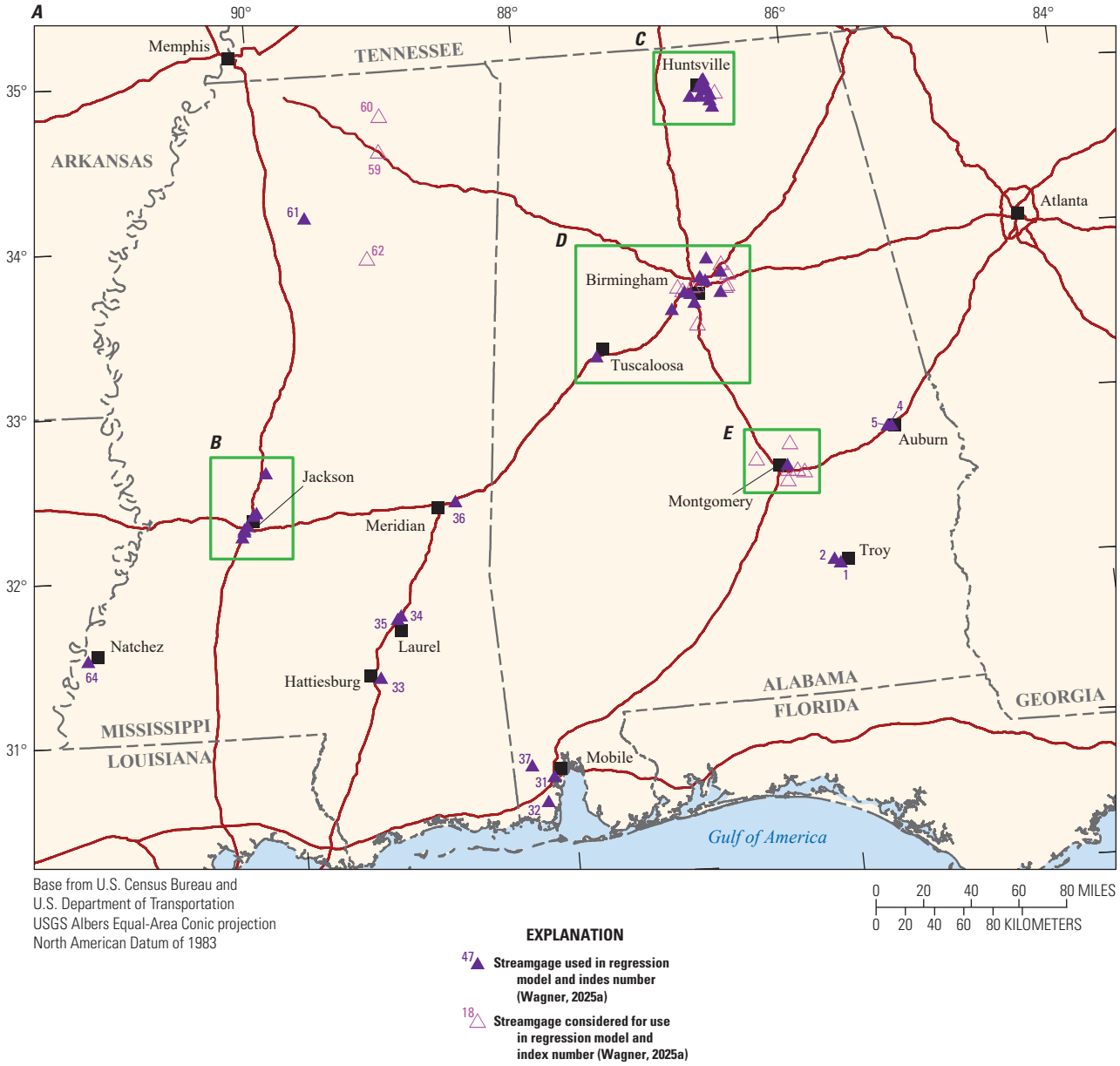
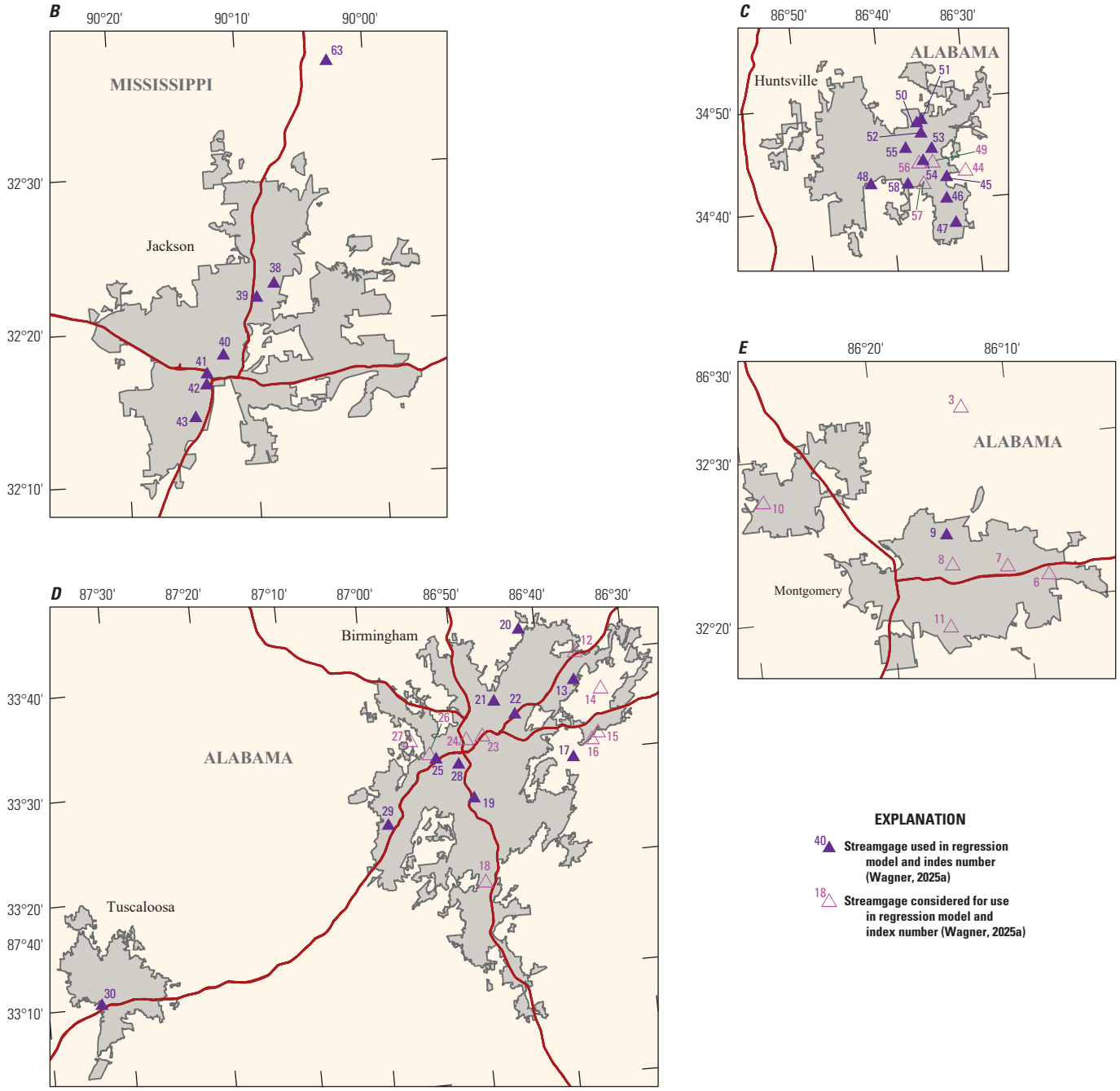


Figure 1. Maps showing (*A*) locations of 64 urban streamgages in Alabama and Mississippi considered in the study, including streamgage locations near (*B*) Jackson, Mississippi; (*C*) Huntsville, Alabama; (*D*) Birmingham, Ala.; and (*E*) Montgomery, Ala.



Base from U.S. Census Bureau and
U.S. Department of Transportation
USGS Albers Equal-Area Conic projection
North American Datum of 1983

Figure 1.—Continued

Streamgage Selection

In the R environment (R Core Team, 2021), the "whatNWISsites," "readNWISdata," "readNWISsite," and "readNWISpeak" functions in version 2.7.14 of the "dataRetrieval" package (DeCicco and others, 2023) were used to retrieve site information and annual peak flow data from the USGS National Water Information System (NWIS) database for all streamgages in Alabama and Mississippi that had 10 or more years of annual peak-flow data through the 2024 water year and peak-flow qualification code C on all or part of the annual peak-flow record (all or part of the annual peak-flow record affected by urbanization, mining, agricultural changes, channelization, or other) (USGS, 2025a). A total of 83 candidate streamgages were identified that met these criteria. The 83 candidate streamgages were further screened and 17 were removed from the dataset, leaving 66 candidate streamgages for flood-frequency analysis. The streamgages removed from analysis consisted of 9 streamgages having drainage areas greater than 100 mi^2, 2 streamgages whose annual peak-flow records were affected by regulation, 3 streamgages having less than 10 annual peaks assigned qualification code C, and 3 streamgages for which qualification code C indicated channelization.

The candidate streamgages were either continuous-record or crest-stage gages. Continuous-record gages are equipped with instrumentation to record the height of the water surface above the gage datum, or stage, at fixed time intervals. The stage data are transmitted by satellite to USGS offices, and a stage-streamflow rating is used to determine streamflow corresponding to the measured stage value. Crest-stage gages record only the peak stage of a flood; the peak stage is then applied to a stage-streamflow rating to determine the associated streamflow.

Flood-Frequency Analysis

For the 66 candidate streamgages, annual peak-flow data were retrieved from the USGS NWIS database using the "multiple site numbers" functionality (USGS, 2025b). Annual peak flow data through the 2024 water year available at the time of download were used for flood-frequency analysis. The period of record analyzed for each streamgage was determined using the presence of qualification code C assigned to annual peak-flows.

In flood-frequency analysis, a log-Pearson type III (LP3) mathematical probability distribution is fit to the logarithms of annual peak flow data from streamgages and then used to estimate streamflow values corresponding to selected annual exceedance probabilities (AEPs), as described in Federal guidelines for flood-frequency analysis, Bulletin 17C (England and others, 2018). The LP3 distribution is a three-parameter distribution that requires estimates of the mean, standard deviation, and skew coefficient. The EMA (Cohn and others, 1997) uses the LP3 distribution but allows for the incorporation of historical data, censored observations (annual peaks known to be greater or less than a specified magnitude), and uncertain data points by using perception thresholds and flow intervals. If no historical, censored, or interval data are incorporated, the EMA method produces estimates of the mean, standard deviation, and skew identical to those produced by the standard LP3 method described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982).

In previous USGS reports about floods, the term "recurrence interval" (in years) was used to characterize flood frequency (for example, the 100-year flood). The USGS and other Federal agencies now refer to the *P*-percent chance of occurrence, or annual exceedance probability (AEP). For example, the 0.01, or 1-percent, AEP has a 1-percent chance of occurring in any given year and corresponds to a recurrence interval of 100 years (the reciprocal of the AEP) (Griffis and Stedinger, 2007).

The MGBT for low outliers, referred to as "potentially influential low floods" (PILFs), is incorporated in the EMA (Cohn and others, 2013). PILFs are annual peaks that meet three criteria: (1) their magnitude is much smaller than the flood quantile of interest; (2) they occur below a statistically significant break in the time series of annual peaks; and (3) they have excessive influence on the estimated frequency of larger floods. USGS PeakFQ software, version 8.0.0 (Siefken and others, 2024), was used to conduct flood-frequency analyses. For 61 of the 66 streamgages, the MGBT was used to statistically identify and remove PILFs; however, for 5 streamgages, a manually determined low-outlier threshold improved the fit of the upper tail of the frequency curve to the annual peak-flow data (see values of "FIXED" in column "PILF_Method" in file "AL_MS_UrbanFFreq_lp3.csv" in Wagner, 2025a). One or more PILFs were identified at 24 of 66 streamgages. After censoring for PILFs, 2 streamgages, USGS sites 02372755 and 03575272 (USGS, 2025a), had less than 10 noncensored annual peaks for flood-frequency analysis and were removed, leaving 64 streamgages in the final dataset (fig. 1). Censored and historical data were not present in the annual peak-flow records of all streamgages; therefore, the user is encouraged to examine the peak-flow ("AL_MS_UrbanFFreq_nwis_peak.txt") and specification ("AL_MS_UrbanFFreq.psf") files in Wagner (2025a) carefully for streamgages of interest.

Basin Characteristics

Basin characteristics for the streamgages in this study were obtained from the USGS map-based web application StreamStats (USGS, 2025c). The drainage basins of the 64 candidate streamgages considered for use in regression modeling were delineated by first manually snapping the streamgage locations to the stream grids for Alabama and Mississippi using version 3.4.2 of Esri ArcGIS Pro software

(Esri, 2024) and then submitting the snapped locations to the USGS StreamStats batch processor by State (refer to https://streamstats.usgs.gov/ss/?BP=submitBatch).

The drainage areas of the delineated basins of the 64 candidate streamgages were compared to the published drainage areas in the USGS NWIS database. Streamgages for which the delineated drainage area differed from NWIS by greater than 5 percent were investigated. The locations of several streamgages were adjusted and the batch jobs resubmitted to StreamStats. The delineated drainage basins of streamgages 02420495, 02471065, 02480002 and 0357568980 still differed from the NWIS areas by greater than 10 percent; however, the snapped locations of the streamgages were determined to be correct, and the delineated drainage areas were also considered to be correct. The final basin polygons were used within StreamStats to compute candidate basin characteristics for use as explanatory variables in regression modeling.

The basin characteristics that were common for Alabama and Mississippi were drainage area (DRNAREA) and the percentages of the streamgage basins in developed land use (LC11DEV, the sum of classes 21–24 from the 2011 National Land Cover Database; USGS, 2014). For the 64 candidate streamgages, DRNAREA ranged from 0.73 to 53.6 mi^2 and LC11DEV ranged from 20.2 to 99.1 percent. Five streamgages, 02423110, 0357526200, 07267000, 07269000 and 07281965, had less than 20 percent LC11DEV and were removed from the dataset of candidate streamgages for regression modeling, leaving 59 candidate streamgages for consideration in the regression model.

Regression Analysis

Because of the relatively small number of urban streamgages available for use in a regression model, a formal screening of redundant, nested streamgage basins was not conducted. However, 7 streamgages—02423160, 02423397, 02423398, 02458200, 02458300, 02458502, and 02458600—were considered redundant with other streamgages on those streams and removed from the dataset, leaving 52 streamgages for use in the regression modeling.

Estimates of streamflow corresponding to selected AEPs, obtained from flood-frequency analysis of the 52 streamgages, were related to basin characteristics DRNAREA and LC11DEV using ordinary least-squares multiple-linear regression analysis in the R environment (R Core Team, 2021) to evaluate the statistical significance of each basin characteristic (Wagner and others, 2016). During this process, one streamgage, 03575950, exhibited unusual relations of streamflow estimates to DRNAREA. The streamgage was determined to be located on a spring in an area of karst topography—hence the unusual relation between DRNAREA and streamflow—and was removed from the dataset, leaving 51 streamgages for use in regression modeling. Multicollinearity of the basin characteristics was assessed using the variance inflation factor, which was a low value of 1.09 for both characteristics, indicating little, if any, multicollinearity.

The USGS weighted-multiple-linear regression (WREG) software, version 3.0, was used in the R environment to complete the final multiple-linear regression analysis (Eng and others, 2009; Farmer, 2021). Weighted least-squares (WLS) and generalized least-squares (GLS) regression models were tested. In WLS regression, streamgages are weighted according to differences in the lengths of their annual peak streamflow records; in GLS regression, streamgages are weighted according to differences in record lengths and the spatial cross-correlation of concurrent annual peak flows between pairs of streamgages. For GLS regression, a correlation smoothing function was developed to relate the distance between pairs of streamgages to the correlation of their annual peak flows, using streamgage pairs with 25 or more years of concurrent annual peak flows, an alpha (α) value of 0.15 and a theta (θ) value of 0.78 (refer to "Model Selection" in Eng and others, 2009, p. 15). However, the correlation smoothing function indicated no clear relation between distance and degree of correlation, and on the basis of the pseudo coefficient of determination (pseudo R^2) and average variance of prediction (AVP), WLS performed as well as or better than GLS regression for all but the 0.5- and 0.2-percent AEPs (the 200- and 500-year floods, respectively; Wagner, 2025b). Therefore, the simpler WLS model was selected as the final model.

Regression diagnostics were reviewed to identify streamgages that exhibited high leverage or high influence on the regression model (refer to "Leverage and Influence Statistics" in Eng and others, 2009, p. 6–7). The leverage metric was used to measure how far away the values of a streamgage's basin characteristics were from the centroid of values of the same characteristics of other streamgages, whereas the influence metric was used to determine if a streamgage had a large influence on the estimated regression parameters. The records of streamgages that exhibited high influence (influence values greater than 0.0784; eq. 44 in Eng and others, 2009, p. 7) on the regression model were investigated. Nine streamgages with high influence—02411602, 02419845, 02419875, 02419974, 02420495, 02420980, 0242354750, 0357586650, and 03575933—were found to have poor data quality and were removed, leaving 42 streamgages in the final WLS regression model (Wagner, 2025b).

In the final WLS regression model, the distribution of residuals was relatively normal (fig. 2). The relations between the estimates of streamflows corresponding to the selected AEPs from flood-frequency analysis in PeakFQ software ("observed streamflows") and predictions of streamflows corresponding to the selected AEPs from WLS regression in WREG software ("predicted streamflows") were good, with points evenly dispersed about equal value lines across the range of streamflows and Nash-Sutcliffe Efficiencies (NSEs; Nash and Sutcliffe, 1970) of 0.74 or greater (fig. 3).

Streamgages with high leverage and influence on the final regression model were investigated. Depending on AEP, streamgages 02458450, 02461500, 02471078, 02476500, and 0357587090 exhibited high influence, but no reasons were found to remove them.

The 13 streamgages in Mississippi used to develop the urban regression equations (file "WLSresults.csv" in Wagner, 2025b) were also used to develop the rural regression equations for Mississippi (Anderson, 2018). The predicted streamflows from the urban regression equations were compared to the predicted streamflows from the rural regression equations (USGS, 2025c). For 6 of 13 streamgages, the urban equations predicted more streamflow for all AEPs. For 3 of 13 streamgages, the urban equations predicted less streamflow for all AEPs. For 4 of 13 streamgages, the urban equations predicted more streamflow for some AEPs and less streamflow for others. For streamgage 02485950, the urban equations predicted more streamflow for all but the 1-percent AEP (the 100-year flood). For streamgage 02485700, the urban equations predicted more streamflow for all but the 50- and 20-percent AEPs (the 2- and 5-year floods, respectively). For streamgage 02473047, the urban equations predicted less streamflow for all but the 0.2-percent AEP (the 500-year flood). For streamgage 07289610, the urban equations predicted more streamflow for the 50-, 20-, and 10-percent AEPs (the 2-, 5-, and 10-year floods, respectively) but predicted less streamflow for the 4-, 2-, 1-, 0.5-, and 0.2-percent AEPs (the 25-, 50-, 100-, 200-, and 500-year floods, respectively).

The regression equations use the same variables as the previous urban flood equations for Alabama (table 3 in Hedgecock and Lee, 2010). The regression coefficient of LC11DEV decreases in magnitude as AEP decreases and flood magnitude increases, consistent with the previous equations. This is expected to occur as soil becomes saturated and runoff becomes more similar to that occurring in rural basins (Hedgecock and Lee, 2010). Using DRNAREA and LC11DEV, predictions from the WLS regression equations were compared to predictions using the previous equations. For the selected AEPs, the WLS equations generally predicted less streamflow than the previous GLS equations. Differences of the WLS predictions relative to the previous GLS

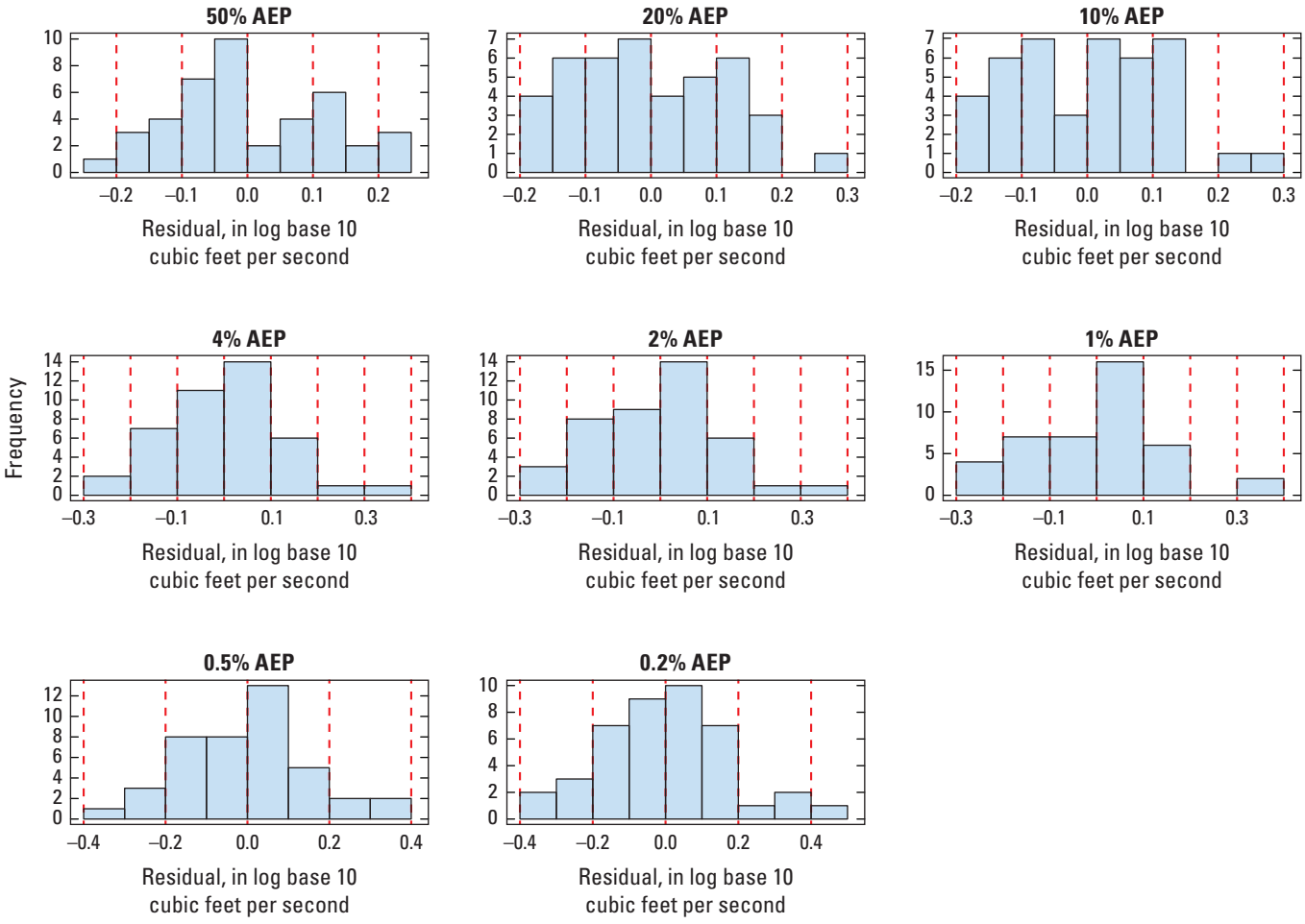


Figure 2. Histograms of residuals from weighted least-squares regression for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent (%) annual exceedance probabilities (AEPs). (Data available in Wagner, 2025b.)

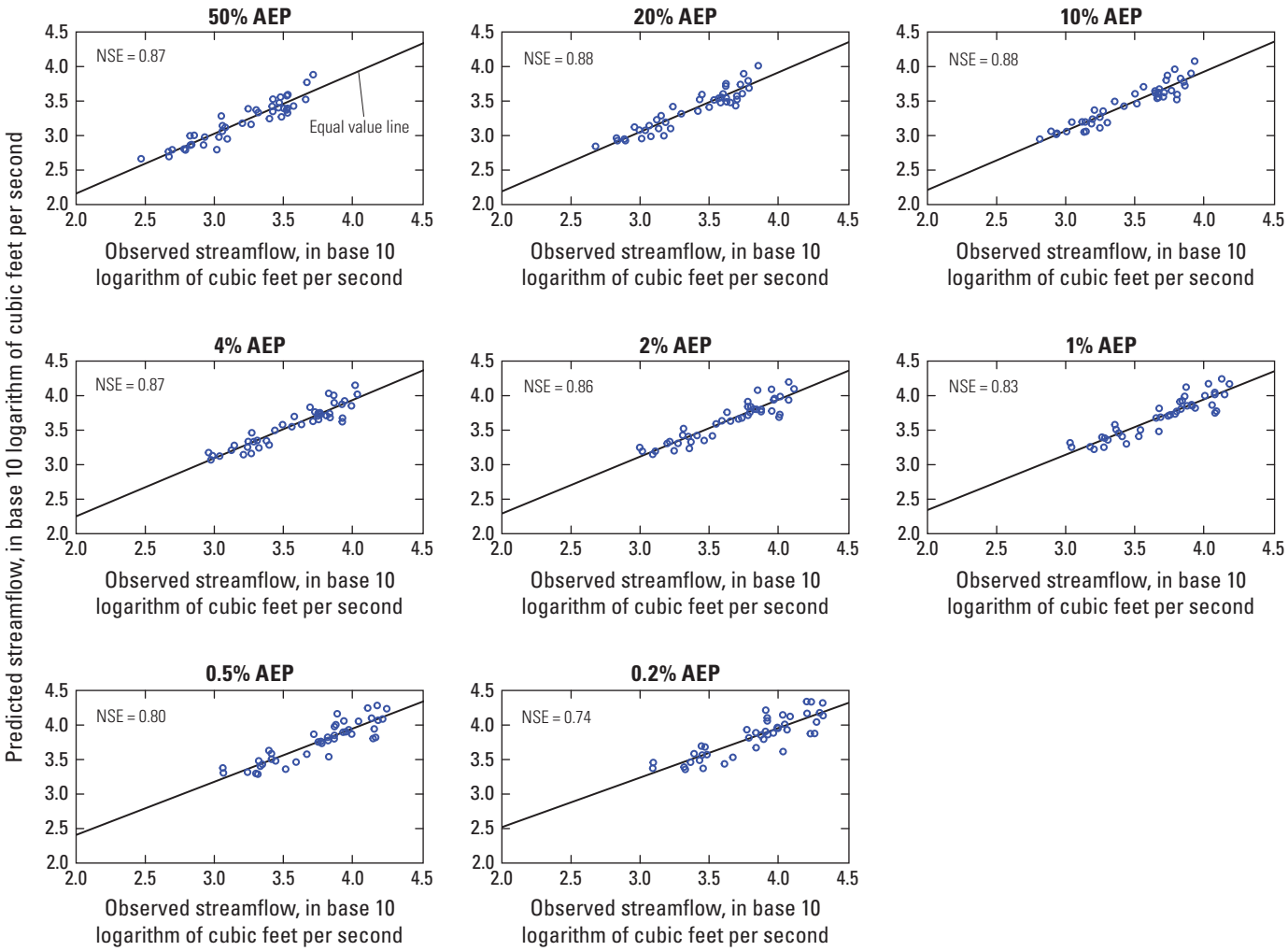


Figure 3. Graphs showing predicted streamflows from weighted least-squares regression plotted against observed streamflows from flood-frequency analysis for the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent (%) annual exceedance probabilities (AEPs). (Data available in Wagner, 2025b.) NSE, Nash-Sutcliffe Efficiency.

predictions ranged from −21 to +18 percent for the 50-percent AEP (median −5 percent), −27 to +7 percent for the 20-percent AEP (median −13 percent), −26 to +2 percent for the 10-percent AEP (median −15 percent), −22 to +0.3 percent for the 4-percent AEP (median −11 percent), −23 to +7 percent for the 2-percent AEP (median −10 percent), −22 to +14 percent for the 1-percent AEP (median −7 percent), −22 to 22 percent for the 0.5-percent AEP (median −3 percent) and −20 to 33 percent for the 0.2-percent AEP (median −1 percent).

Accuracy and Limitations of Regression Equations

The regression equations are applicable at locations on urban streams in Alabama and Mississippi that have basin characteristics within the ranges of those used to develop the equations: DRNAREA from 1.06 to 53.6 mi^2 and LC11DEV from 20 to 100 percent (Wagner, 2025b). The accuracy of the regression equations is not known for locations that have basin characteristics outside these ranges. The regression equations described in this report also do not apply to locations on streams that are substantially affected by regulation from upstream impoundments or other man-made structures. The regression equations are intended to supersede the previous urban flood-frequency equations in Mississippi (Landers and Wilson, 1991) and Alabama (Hedgecock and Lee, 2010).

The accuracy of the WLS regression model is expressed as (1) the residual mean squared error (MSE; eq. 31 in Eng and others, 2009), which is the sum of the model and time-sampling errors, and (2) the model error variance (MEV), which is the same as the MSE only if the time-sampling error variance is zero. MSE ranged from 0.0138 for the 10-percent AEP (10-year flood) to 0.0334 for the 0.2-percent AEP (500-year flood; column “MSE” in file “RegressionEquations.

csv" in Wagner, 2025b). The time-sampling error variance was not zero in this study, and the MEV ranged from 0.0088 for the 4-percent AEP (25-year flood) to 0.0209 for the 0.2-percent AEP (500-year flood; column "MEV" in file "RegressionEquations.csv" in Wagner, 2025b).

The accuracy of predictions from the regression equations is expressed in terms of the coefficient of determination, or R^2 value, the AVP, and standard error of prediction (Sp). The R^2 value represents the proportion of the variation in the dependent variable (streamflow estimates for the selected AEPs) explained by the basin characteristics in the regression model. For GLS regression, the pseudo-R^2 value is reported (column "R2pseudo" in file "RegressionEquations.csv" in Wagner, 2025b), which is based on the variability in streamflow explained by the regression after removing the effect of the time-sampling error (eq. 39 in Eng and others, 2009, p. 6). Pseudo- R^2 values ranged from 0.81, or 81 percent, for the 0.2-percent AEP (500-year flood) to 0.91, or 91 percent, for the 2- and 4-percent AEPs (the 50- and 25-year floods, respectively). The AVP (in base-10 logarithmic units; eq. 32 in Eng and others, 2009, p. 5) ranged from 0.0098 for the 4-percent AEP (25-year flood) to 0.0231 for the 0.2-percent AEP (500-year flood; column "AVP" in file "RegressionEquations.csv" in Wagner, 2025b). Because the base-10 logarithms of the streamflow estimates were used to develop the regression equations, the AVP can be reported as Sp, which represents a percentage of the predicted value (eq. 33 in Eng and others, 2009, p. 5). The Sp ranged from 23.1 percent for the 4-percent AEP (25-year flood) to 36.1 percent for the 0.2-percent AEP (500-year flood; column "Sp" in file "RegressionEquations.csv" in Wagner, 2025b). Sp values were similar to those for the rural regression equations for Alabama, which ranged from 9 to 51 percent, depending on flood region (table 3 in Anderson, 2020), and Mississippi, which ranged from 28 to 46 percent, depending on flood region (table 4 in Anderson, 2018).

Applications of Regression Equations

When applying the regression equations, users are advised not to interpret the empirical results as exact. Regression equations are statistical models that must be interpreted and applied within the limits of the data and with the understanding that the results are best-fit estimates with an associated variance. Methods for estimating streamflows corresponding to selected AEPs for urban streams in the study area differ between gaged locations, ungaged locations on gaged streams, and locations on ungaged streams.

Gaged Locations

For streamgages having short record lengths, the uncertainty of at-site estimates of streamflows corresponding to various AEPs can be reduced by weighting those estimates with predictions from the regression equations (refer to appendix 9, "Weighting of Independent Estimates," in England and others, 2018). If the two are assumed to be independent and unbiased and are weighted in inverse proportion to their associated variances, the variance of the weighted estimate will be less than the variance of either of the independent estimates. A weighted estimate of streamflow corresponding to a selected AEP can be computed using equation 9–2 in England and others (2018):

$$X_{weighted,i} = \frac{X_{site,i} * V_{reg,i} + X_{reg,i} * V_{site,i}}{V_{site,i} + V_{reg,i}}, \quad (1)$$

where

$X_{weighted,i}$ is the base-10 logarithm of the weighted estimate of streamflow corresponding to the selected AEP;

$X_{site,i}$ is the base-10 logarithm of the at-site estimate of streamflow at the streamgage corresponding to the selected AEP;

$V_{reg,i}$ is the variance of prediction for the regression equation corresponding to the selected AEP, in base-10 logarithmic units;

$X_{reg,i}$ is the base-10 logarithm of the regression estimate of streamflow at the streamgage corresponding to the selected AEP; and

$V_{site,i}$ is the variance of prediction of the at-site estimate of streamflow at the streamgage corresponding to the selected AEP, in base-10 logarithmic units.

If the streamgage of interest was used in the development of the regression equations, this weighting method is inappropriate because the estimates are not independent (England and others, 2018). For such streamgages, the at-site estimate should be used.

A 95-percent confidence interval for the weighted estimate (in cubic feet per second; eq. 9–4 in England and others, 2018) can be calculated as

$$95\%_{CIupper,i} = 10^{(Xweighted,i+1.96\sqrt{Vweighted,i})}, \text{ and} \quad (2)$$

$$95\%_{CIlower,i} = 10^{(Xweighted,i-1.96\sqrt{Vweighted,i})}, \quad (3)$$

where

$95\%_{CIupper,I}$ is the upper 95-percent confidence interval for the weighted estimate of the selected AEP for streamgage *i*;

$X_{weighted,i}$ is the weighted estimate of the selected AEP for streamgage *i*, in base-10 logarithmic units;

$V_{weighted,i}$ is the variance of the weighted estimate of the selected AEP for streamgage *i*, in base-10 logarithmic units; and

$95\%_{CIlower,i}$ is the lower 95-percent confidence interval for the weighted estimate of the selected AEP for streamgage *i*.

The variance of the weighted estimate for streamgage *i* (in base-10 logarithmic units) can be calculated as

$$V_{weighted,i} = \frac{V_{site,i} * V_{reg,i}}{V_{site,i} + V_{reg,i}}. \quad (4)$$

Ungaged Locations on Gaged Streams

If the drainage area at an ungaged location on a stream is within 50 percent of the drainage area at a streamgage (drainage area ratio is more than 0.5 or less than 1.5) on the same stream, streamflows corresponding to selected AEPs at the ungaged location can be computed from the streamgage data using a drainage-area ratio method (eq. 13 in Wagner and others, 2016). The drainage area ratio can be calculated by using the following equation:

$$Q_u = \left(\frac{A_u}{A_g}\right)^b Q_g, \quad (5)$$

where

Q_u is the estimate of streamflow corresponding to the selected AEP for the ungaged location, *u*, in cubic feet per second;

A_u is the drainage area of the ungaged location, in square miles;

A_g is the drainage area of the upstream or downstream streamgage, in square miles;

Q_g is the at-site estimate of streamflow (weighted with regression equations using eq. 1, if appropriate) corresponding to the selected AEP for the upstream or downstream streamgage, in cubic feet per second; and

b is the exponent of drainage area from the regression equation corresponding to the selected AEP (column "a" in file "RegressionEquations.csv" in Wagner, 2025b).

The drainage-area ratio method, however, does not weight the resulting streamflow estimate with the predictions from the regression equations for the ungaged location. The estimate can be weighted using the following equation (refer to eq. 23 in Ries and Dillow, 2006):

$$Q_{u(w)} = \left(\frac{2|\Delta A|}{A_g}\right) Q_{u(r)} + \left(1 - \frac{2|\Delta A|}{A_g}\right) Q_u, \quad (6)$$

where

$Q_{u(w)}$ is the weighted estimate of streamflow corresponding to the selected AEP at the ungaged location, in cubic feet per second;

$Q_{u(r)}$ is the prediction of streamflow from the regression equation for the ungaged location for the selected AEP, in cubic feet per second; and

$|\Delta A|$ is the absolute difference in drainage area between the ungaged location and the streamgage, in square miles.

If the drainage area at the ungaged location differs by more than 50 percent from the drainage area of the streamgage, the predicted streamflow from the regression equations for the ungaged location should be used. If an ungaged location is between two streamgages on the same stream, the streamgage either having the longest period of record or that yields the smallest drainage area ratio should be used.

Locations on Ungaged Streams

For locations on ungaged streams or ungaged locations on gaged streams where the drainage area at the ungaged location is not within 50 percent of the drainage area at a streamgage, streamflows corresponding to selected AEPs should be determined using the regression equations. The USGS StreamStats application (USGS, 2025c; https://streamstats.usgs.gov/ss/) provides a platform for delineating drainage basins, computing basin characteristics, and estimating streamflows corresponding to selected AEPs at ungaged locations using the regression equations.

Summary

Flood-frequency estimates for urban streams in Alabama and Mississippi were last updated in 2010 and 1991, respectively; since that time, improvements in estimation techniques have been made, and additional streamflow data are available to increase the accuracy of such estimates. In 2024, the U.S. Geological Survey, in cooperation with the Alabama and Mississippi Departments of Transportation, updated estimates of streamflows corresponding to selected annual exceedance probabilities (AEPs) for 64 urban streamgages in Alabama and Mississippi. Streamgages considered for the study had at least 10 years of annual peak streamflow data that were affected by urbanization and at least 20 percent of their drainage basins in developed land use based on the 2011 National Land Cover Database.

Using streamflow estimates from 42 of the 64 streamgages, weighted least-squares regression equations were developed to predict streamflows corresponding to the selected AEPs at ungaged locations on urban streams in the

two States. Drainage area and the percentages of developed land use in the drainage basins of the streamgages were statistically significant in explaining the variability in annual peak streamflows. Drainage areas of streamgages used to develop the equations ranged from 1.06 to 53.6 square miles, and percentages of the drainage basins of the streamgages in developed land use, based on the 2011 National Land Cover Database (LC11DEV), ranged from 20 to 100 percent. The regression equations are intended to supersede the previous urban flood-frequency equations in Mississippi and Alabama.

The accuracy of the weighted least-squares regression model is expressed as the mean squared error and the model error variance, which is the same as the mean squared error if the time-sampling error variance is zero. Mean squared error ranged from 0.0138 for the 10-percent AEP (10-year flood) to 0.0334 for the 0.2-percent AEP (500-year flood). The time-sampling error variance was not zero in this study, and the model error variance ranged from 0.0088 for the 4-percent AEP (25-year flood) to 0.0209 for the 0.2-percent AEP (500-year flood).

The accuracy of predictions from the regression equations is expressed in terms of the pseudo coefficient of determination, or pseudo-R^2 value; the average variance of prediction; and the standard error of prediction (Sp). The pseudo-R^2 value represents the proportion of the variation in the streamflow estimates that is explained by the basin characteristics in the regression model after removing the effect of the time-sampling error. Pseudo-R^2 values ranged from 0.81, or 81 percent, for the 0.2-percent AEP (500-year flood) to 0.91, or 91 percent, for the 2- and 4-percent AEPs (the 50- and 25-year floods, respectively). The average variance of prediction (in base-10 logarithmic units) ranged from 0.0098 for the 4-percent AEP (25-year flood) to 0.0231 for the 0.2-percent AEP (500-year flood). The average variance of prediction can be reported as a percentage of the predicted value, known as the Sp. The Sp ranged from 23.1 percent for the 4-percent AEP (25-year flood) to 36.1 percent for the 0.2-percent AEP (500-year flood). The Sp values were similar to those for the rural regression equations for Alabama, which ranged from 9 to 51 percent, depending on flood region, and Mississippi, which ranged from 28 to 46 percent, depending on flood region.

Methods for estimating streamflows corresponding to selected AEPs for urban streams in the study area are presented for gaged locations, ungaged locations on gaged streams, and locations on ungaged streams. For gaged locations used to develop the regression equations, the at-site estimates should be used, whereas for gaged locations not used to develop the regression equations, particularly those with short peak-flow records (typically less than 20 years), the at-site estimates can be weighted with the regression equations. For ungaged locations on gaged streams, if the drainage area at the ungaged location is within 50 percent of the drainage area at a streamgage (drainage area ratio is more than 0.5 or less than 1.5), the accuracies of the predictions from the regression equations can be increased with estimates from the gaged location using a drainage area ratio weighting method; otherwise, the regression equations should be used. For ungaged locations on ungaged streams or ungaged locations on gaged streams for which the drainage area is not within 50 percent of the drainage area at a streamgage, the regression equations should be used. The U.S. Geological Survey StreamStats application (https://streamstats.usgs.gov/ss/) provides a platform for delineating drainage basins, computing basin characteristics, and estimating streamflows corresponding to selected AEPs at ungaged locations using the regression equations.

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