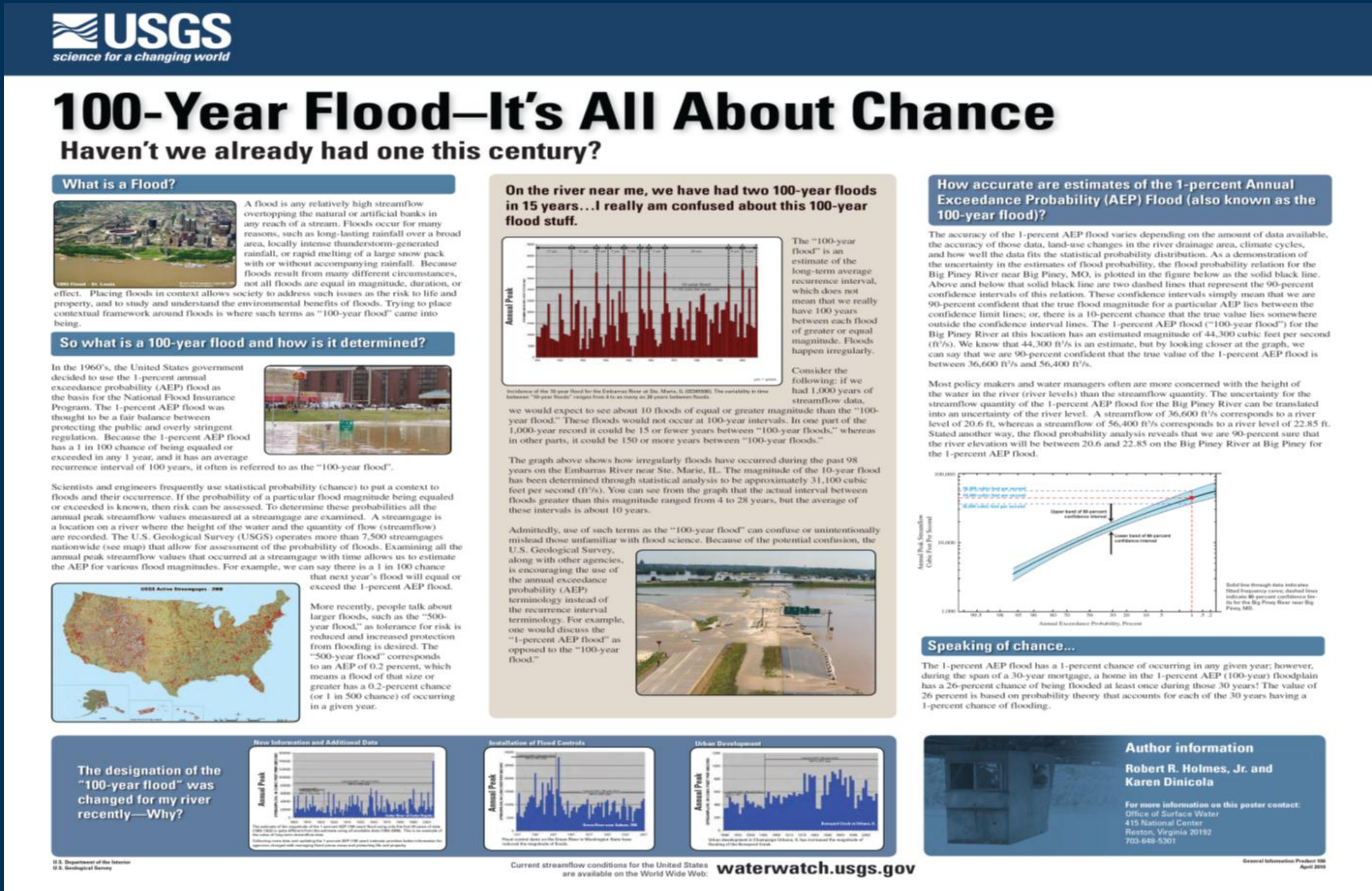
Status on the Development of Methods for Determining Magnitude and Frequency of Floods in California

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

Annual Exceedance Probability (AEP)

- AEP is probability that the discharge will exceed a given discharge in any year.
- AEP in percent is the reciprocal of the recurrence interval times 100.
- Example: For the 100-year flood, the AEP is (1/100)*100 or 1% for any given year. There is a 1 in 100 chance each year that this discharge will occur.



USGS
science for a changing world

100-Year Flood—It's All About Chance

Haven't we already had one this century?

What is a Flood?

A flood is any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream. Floods occur for many reasons, such as long-lasting rainfall over a broad area, locally intense thunderstorm-generated rainfall, or rapid melting of a large snow pack with or without accompanying rainfall. Because floods result from many different circumstances, not all floods are equal in magnitude, duration, or effect. Placing floods in context allows society to address such issues as the risk to life and property, and to study and understand the environmental benefits of floods. Trying to place contextual framework around floods is where such terms as "100-year flood" came into being.

So what is a 100-year flood and how is it determined?

In the 1960's, the United States government decided to use the 1-percent annual exceedance probability (AEP) flood as the basis for the National Flood Insurance Program. The 1-percent AEP flood was thought to be a fair balance between protecting the public and overly stringent regulation. Because the 1-percent AEP flood has a 1 in 100 chance of being equaled or exceeded in any 1 year, and it has an average recurrence interval of 100 years, it often is referred to as the "100-year flood".

Scientists and engineers frequently use statistical probability (chance) to put a context to floods and their occurrence. If the probability of a particular flood magnitude being equaled or exceeded is known, then risk can be assessed. To determine these probabilities all the annual peak streamflow values measured at a streamgage are examined. A streamgage is a location on a river where the height of the water and the quantity of flow (streamflow) are recorded. The U.S. Geological Survey (USGS) operates more than 7,500 streamgages nationwide (see map) that allow for assessment of the probability of floods. Examining all the annual peak streamflow values that occurred at a streamgage with time allows us to estimate the AEP for various flood magnitudes. For example, we can say there is a 1 in 100 chance that next year's flood will equal or exceed the 1-percent AEP flood.

More recently, people talk about larger floods, such as the "500-year flood," as tolerance for risk is reduced and increased protection from flooding is desired. The "500-year flood" corresponds to an AEP of 0.2 percent, which means a flood of that size or greater has a 0.2-percent chance (or 1 in 500 chance) of occurring in a given year.

On the river near me, we have had two 100-year floods in 15 years...I really am confused about this 100-year flood stuff.

Annual Peak

The "100-year flood" is an estimate of the long-term average recurrence interval, which does not mean that we really have 100 years between each flood of greater or equal magnitude. Floods happen irregularly.

Consider the following: if we had 1,000 years of streamflow data, we would expect to see about 10 floods of equal or greater magnitude than the "100-year flood." These floods would not occur at 100-year intervals. In one part of the 1,000-year record it could be 15 or fewer years between "100-year floods," whereas in other parts, it could be 150 or more years between "100-year floods."

The graph above shows how irregularly floods have occurred during the past 98 years on the Embarras River near Ste. Marie, IL. The magnitude of the 10-year flood has been determined through statistical analysis to be approximately 31,100 cubic feet per second (ft^3/s). You can see from the graph that the actual interval between floods greater than this magnitude ranged from 4 to 28 years, but the average of these intervals is about 10 years.

Admittedly, use of such terms as the "100-year flood" can confuse or unintentionally mislead those unfamiliar with flood science. Because of the potential confusion, the U.S. Geological Survey, along with other agencies, is encouraging the use of the annual exceedance probability (AEP) terminology instead of the recurrence interval terminology. For example, one would discuss the "1-percent AEP flood" as opposed to the "100-year flood."

How accurate are estimates of the 1-percent Annual Exceedance Probability (AEP) Flood (also known as the 100-year flood)?

The accuracy of the 1-percent AEP flood varies depending on the amount of data available, the accuracy of those data, land-use changes in the river drainage area, climate cycles, and how well the data fits the statistical probability distribution. As a demonstration of the uncertainty in the estimates of flood probability, the flood probability relation for the Big Piney River near Big Piney, MO, is plotted in the figure below as the solid black line. Above and below that solid black line are two dashed lines that represent the 90-percent confidence intervals of this relation. These confidence intervals simply mean that we are 90-percent confident that the true flood magnitude for a particular AEP lies between the confidence limit lines; or, there is a 10-percent chance that the true value lies somewhere outside the confidence interval lines. The 1-percent AEP flood ("100-year flood") for the Big Piney River at this location has an estimated magnitude of 44,300 cubic feet per second (ft^3/s). We know that 44,300 ft^3/s is an estimate, but by looking closer at the graph, we can say that we are 90-percent confident that the true value of the 1-percent AEP flood is between 36,600 ft^3/s and 56,400 ft^3/s.

Most policy makers and water managers often are more concerned with the height of the water in the river (river levels) than the streamflow quantity. The uncertainty for the streamflow quantity of the 1-percent AEP flood for the Big Piney River can be translated into an uncertainty of the river level. A streamflow of 36,600 ft^3/s corresponds to a river level of 20.6 ft, whereas a streamflow of 56,400 ft^3/s corresponds to a river level of 22.85 ft. Stated another way, the flood probability analysis reveals that we are 90-percent sure that the river elevation will be between 20.6 and 22.85 on the Big Piney River at Big Piney for the 1-percent AEP flood.

Speaking of chance...

The 1-percent AEP flood has a 1-percent chance of occurring in any given year; however, during the span of a 30-year mortgage, a home in the 1-percent AEP (100-year) floodplain has a 26-percent chance of being flooded at least once during those 30 years! The value of 26 percent is based on probability theory that accounts for each of the 30 years having a 1-percent chance of flooding.

The designation of the "100-year flood" was changed for my river recently—Why?

New Information and Additional Data

Installation of Flood Controls

Urban Development

Annual Peak

Author information

Robert R. Holmes, Jr. and Karen Dinicola

For more information on this poster contact:
Office of Surface Water
415 National Center
Reston, Virginia 20192
703-648-5301

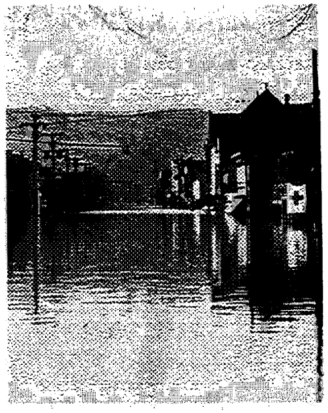
U.S. Department of the Interior
U.S. Geological Survey

Current streamflow conditions for the United States are available on the World Wide Web: **waterwatch.usgs.gov**

General Information Product 106
April 2010

USGS

http://pubs.usgs.gov/gip/106/



Guidelines For Determining

Flood Flow Frequency

Bulletin # 17B
of the
Hydrology Subcommittee

Revised September 1981
Editorial Corrections March 1982

INTERAGENCY ADVISORY COMMITTEE
ON WATER DATA

U.S. Department of the Interior
Geological Survey
Office of Water Data Coordination
Reston, Virginia 22092

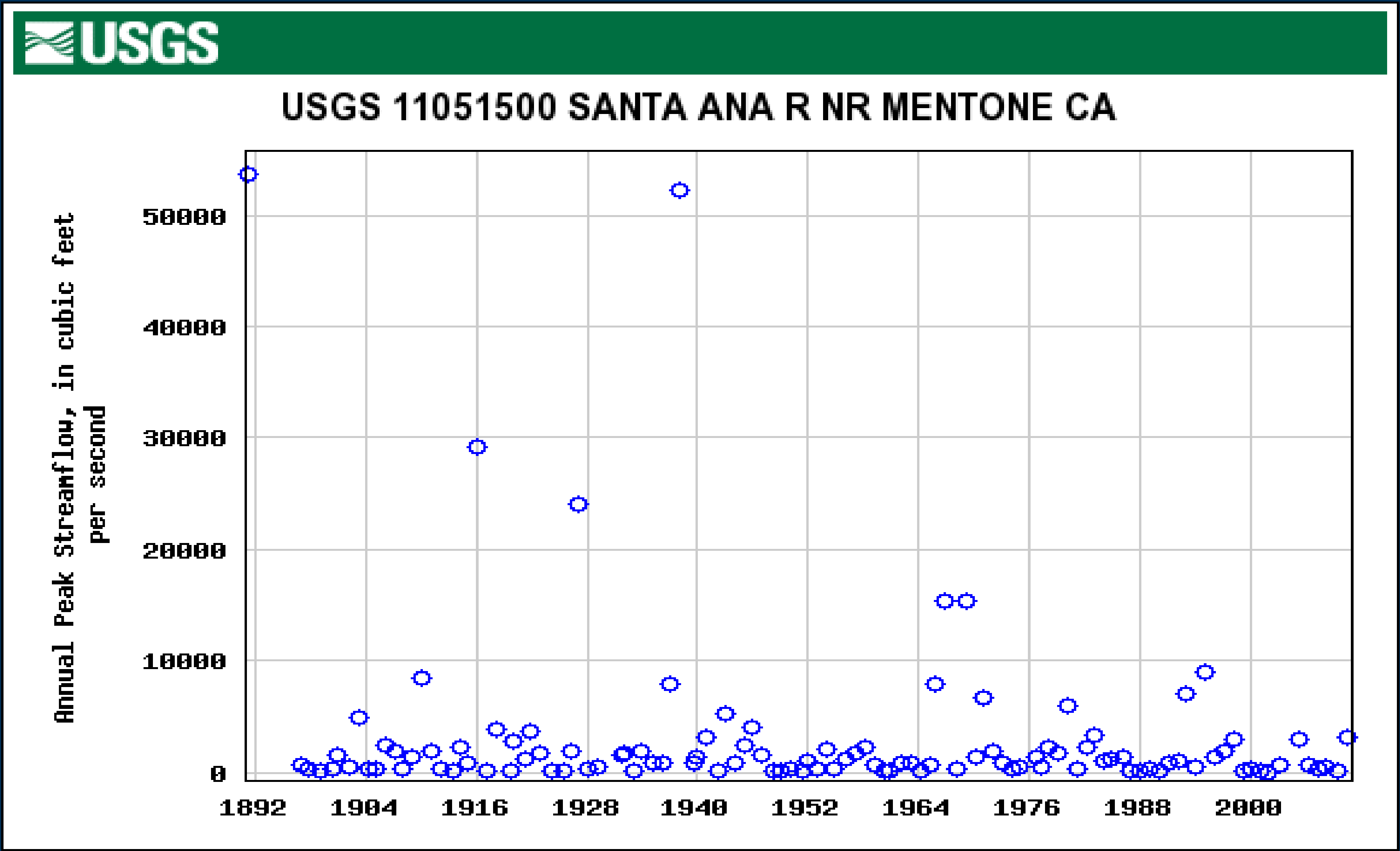
History:

- 1967 Bulletin 15
- 1976 Bulletin 17
- 1977 Bulletin 17A
- 1982 Bulletin 17B
- 20?? Bulletin 17C

USGS

http://water.usgs.gov/osw/bulletin17b/bulletin_17B.html

Annual peak-flow data for a gaged station



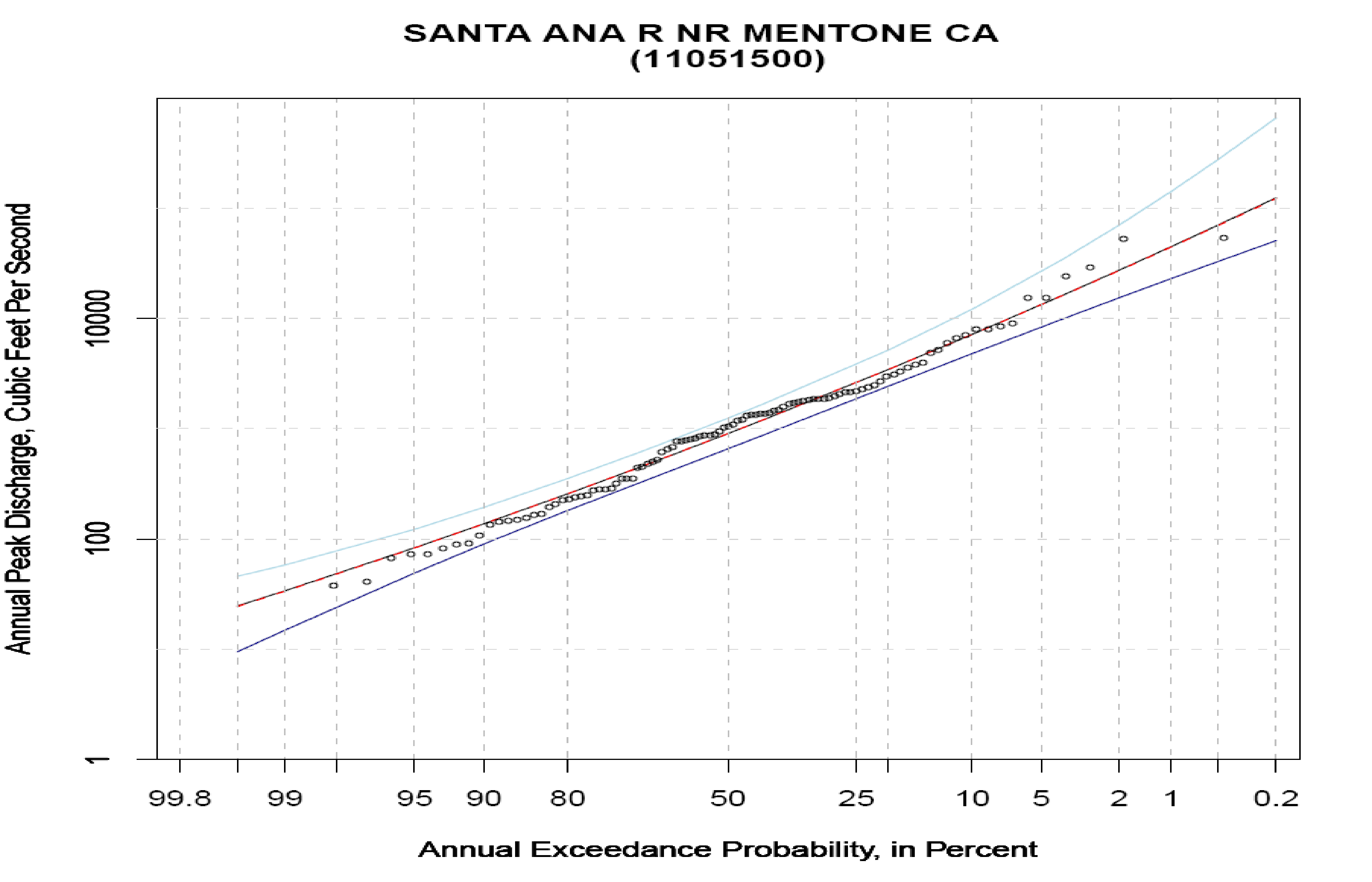
USGS

$$\log Q_p = X + KS ,$$

where

Q_p	is the P-percent chance exceedance flow, in cubic feet per second (ft^3/s);
X	is the mean of the logarithms of the annual peak flows;
K	is a factor based on the skew coefficient and the given percent chance exceedance, which can be obtained from appendix 3 in Bulletin 17B; and
S	is the standard deviation of the logarithms of the annual peak flows, which is a measure of the degree of variation of the annual values about the mean value.

USGS



SANTA ANA R NR MENTONE CA
(11051500)
Annual Peak Discharge, Cubic Feet Per Second
1
100
10000
99.8
99
95
90
80
50
25
10
5
2
1
0.2
Annual Exceedance Probability, in Percent

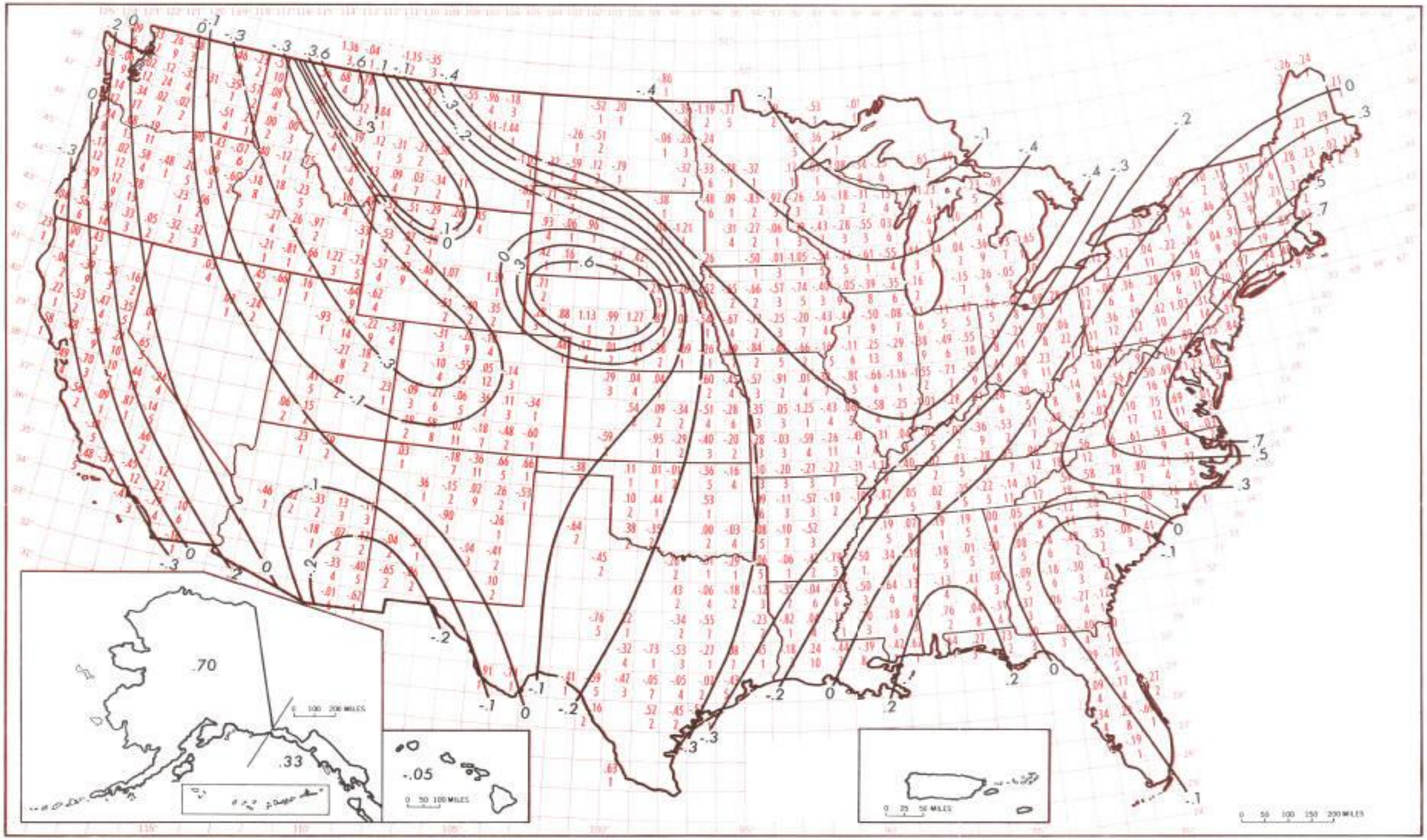
USGS

$$Gw = \frac{MSE_{\overline{G}}(G) + MSE_{G}(\overline{G})}{MSE_{\overline{G}} + MSE_{G}},$$

where

G_w	is the weighted skew coefficient;
G	is the station skew coefficient;
$\overline{G}$	is the regionalized skew coefficient;
$MSE_{\overline{G}}$	is the mean square error of regionalized skew coefficient; and
MSE_G	is the mean square error of station skew coefficient.

USGS



GENERALIZED SKEW COEFFICIENTS OF LOGARITHMS OF ANNUAL MAXIMUM STREAMFLOW

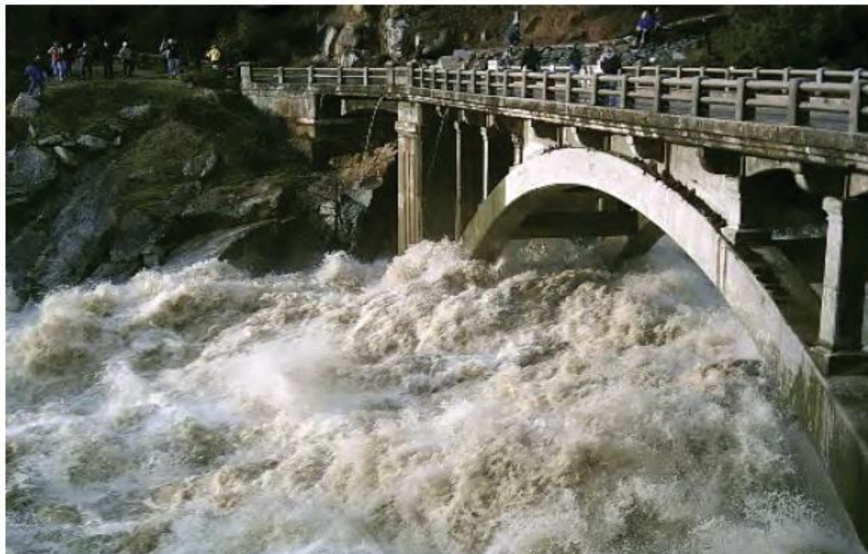
AVERAGE SKEW COEFFICIENT BY ONE DEGREE QUADRANGLES

Lower number in each quadrangle is number of stream gaging stations for which the average shown above it was computed

USGS
science for a changing world

Prepared in cooperation with the Federal Emergency Management Agency, the U.S. Army Corps of Engineers, and the U.S. Forest Service

Regional Skew for California, and Flood Frequency for Selected Sites in the Sacramento-San Joaquin River Basin, Based on Data through Water Year 2006



Scientific Investigations Report 2010–5260

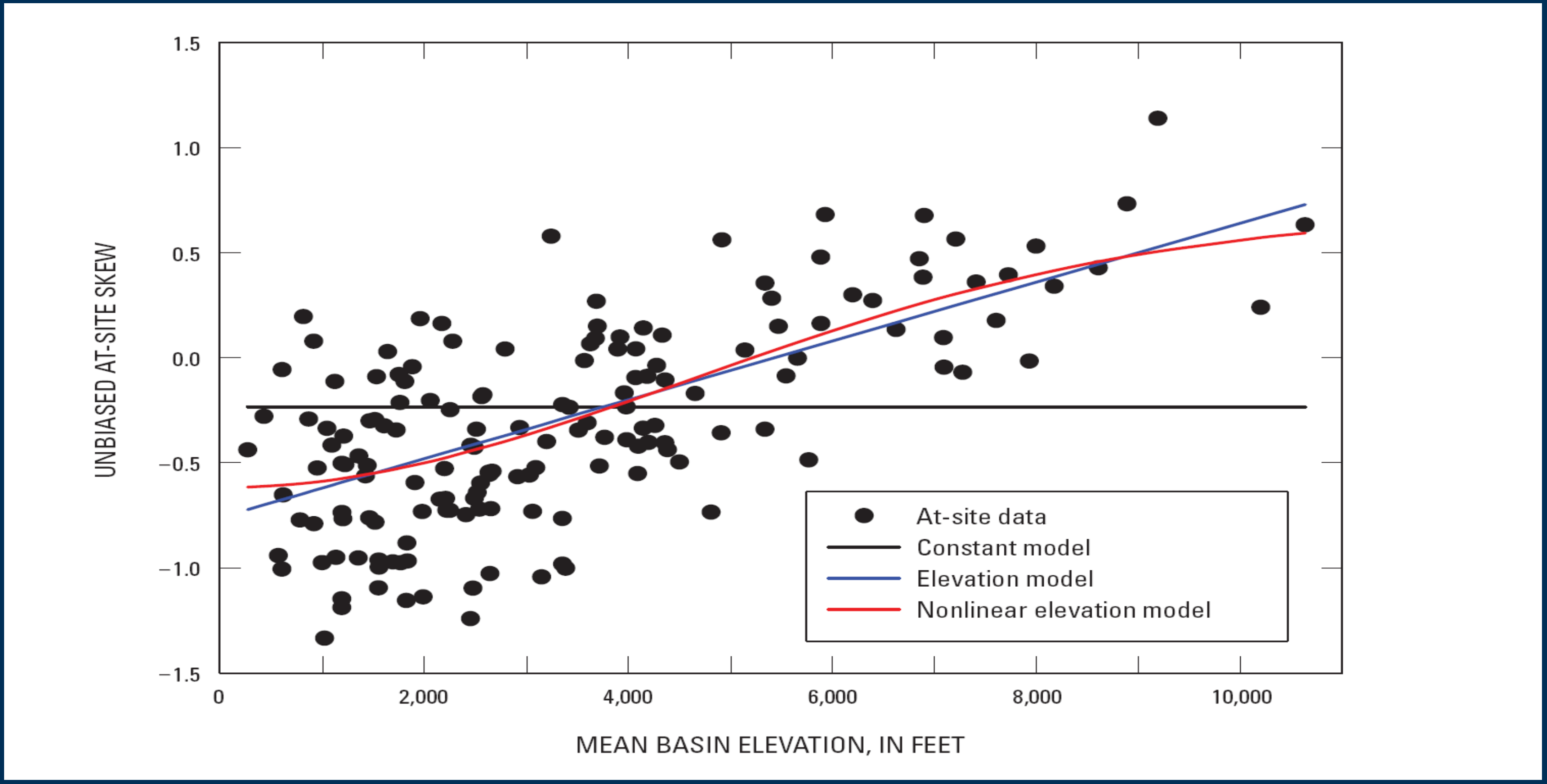
U.S. Department of the Interior
U.S. Geological Survey

USGS

http://pubs.usgs.gov/sir/2010/5260/

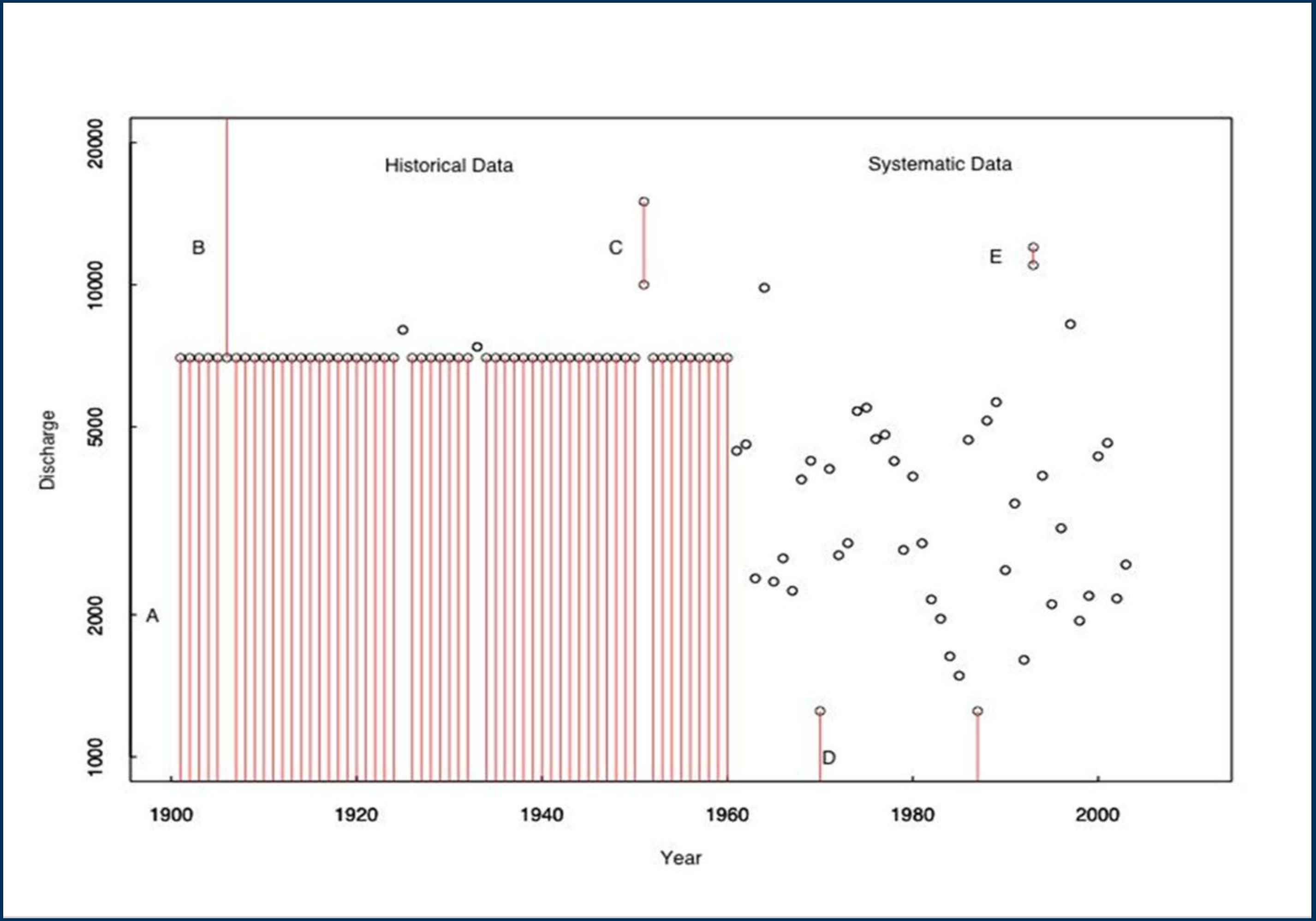
Regional Skew for California

$$G = 0.68 - 1.3e^{-(ELEV/6500)^2}$$



USGS

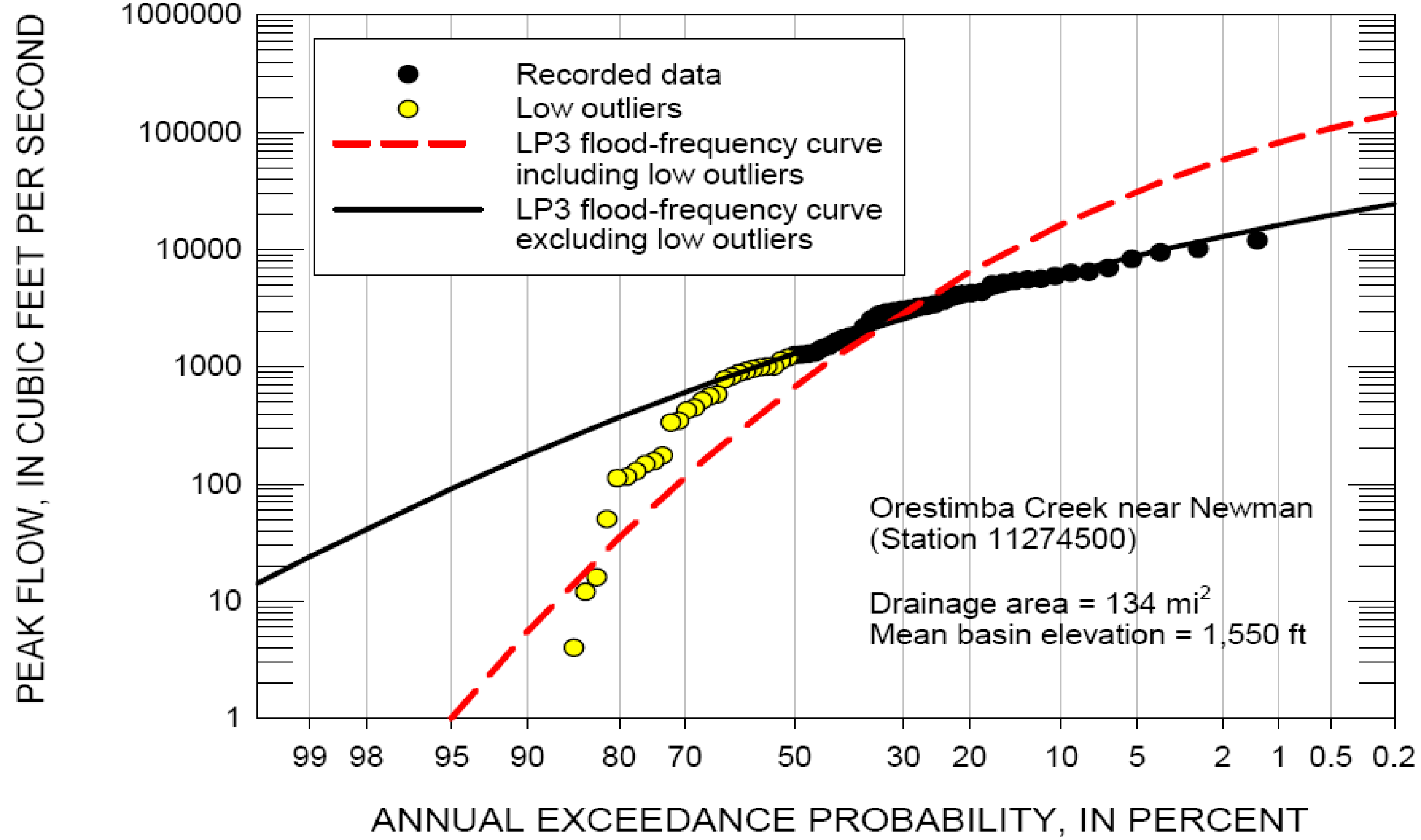
Expected Moments Algorithm (EMA)



USGS

Multiple Grubbs-Beck Test

Figure 2. Flood-frequency curves for Orestimba Creek near Newman, California (station 11274500) showing the effects of including or excluding low outliers identified from the multiple Grubbs-Beck test.



USGS

Regional Regression Analysis

USGS

Regression equations for ungaged sites outside of the desert

$$Q_{AEP} = aA^bB^cC^d\ldots ,$$

where

Q_{AEP} = flood discharge for specified AEP level

A,B,C = are the basin and climatological characteristics

a, b, c, d = the regression coefficients

USGS

Basin Characteristics

- Drainage Area
- Basin Perimeter
- Relief
- Mean Elevation
- Maximum Elevation
- Minimum Elevation
- Percent Lake Area
- High Elevation Index
- Elevation of Outlet
- Relative Relief
- Distance to Coast
- Average Basin Slope
- Percent Impervious Area
- Percent Forested Area
- Mean Annual Precipitation
- Average Maximum January Temperature
- Average Minimum January Temperature
- Longitude of the Basin Centroid
- Latitude of the Basin Centroid

USGS

- Regression equations for regions outside the desert take the form:

$$Q_{AEP} = a(DRNAREA)^b \, (PRECIP)^c$$

- where:

Q_{AEP}	is the annual exceedance probability flow, in cubic feet per second
DRNAREA	is drainage area, in square miles
ELEV	is mean basin elevation, in feet
PRECIP	is mean annual precipitation, in inches
a, b, and c	are the regression coefficients

USGS

- For the Sierra-Nevada Region, the regression equations take the form:

$$Q_{AEP} = a(DRNAREA)^{b}(ELEV)^{c}(PRECIP)^{d}$$

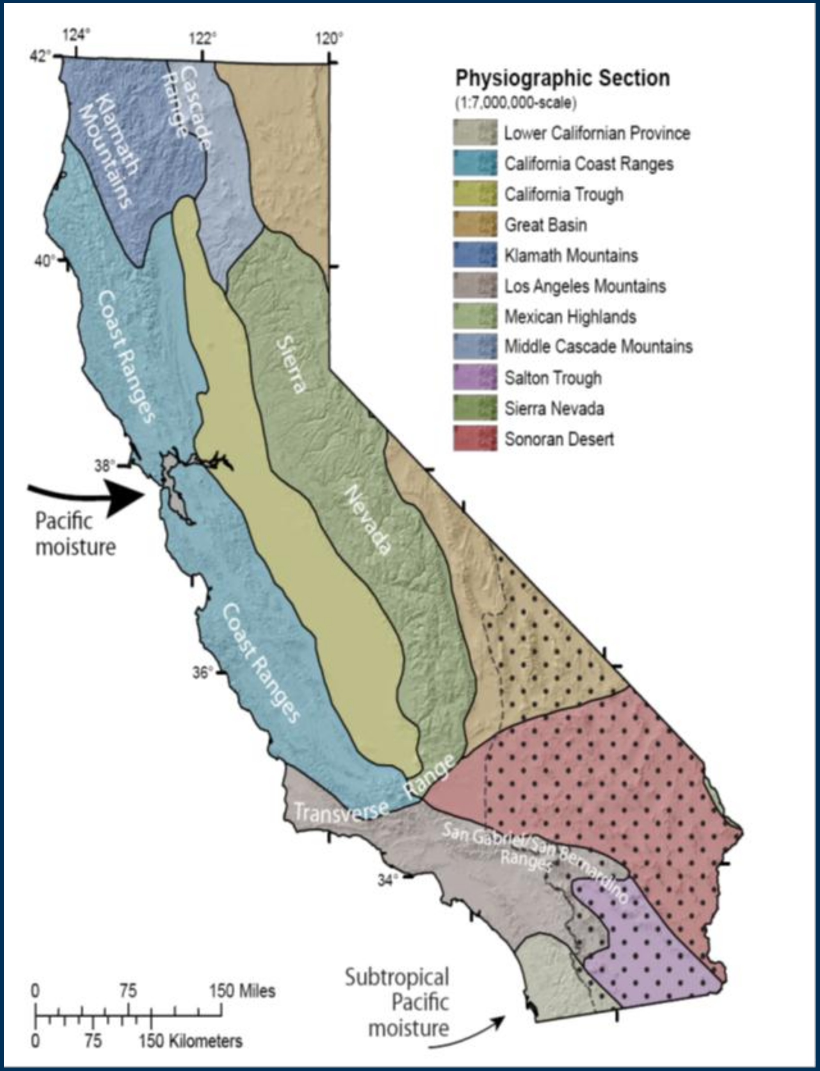
- where:

Q_{AEP}	is the annual exceedance probability flow, in cubic feet per second
DRNAREA	is drainage area, in square miles
ELEV	is mean basin elevation, in feet
PRECIP	is mean annual precipitation, in inches
a, b, c, and d	are the regression coefficients

USGS

Updating Flood Frequency Estimates in the Desert Region of California

- Unique to the western United States:
  - numerous zero flows/ low outliers
  - short annual peak-flow records
  - highly variable peak-flow data
- Standard LP3 fitting method doesn't work with the desert peak-flow data
- As recommended in B17B, flood-frequency estimates are improved by weighting at-site skew with a more robust regional skew estimate

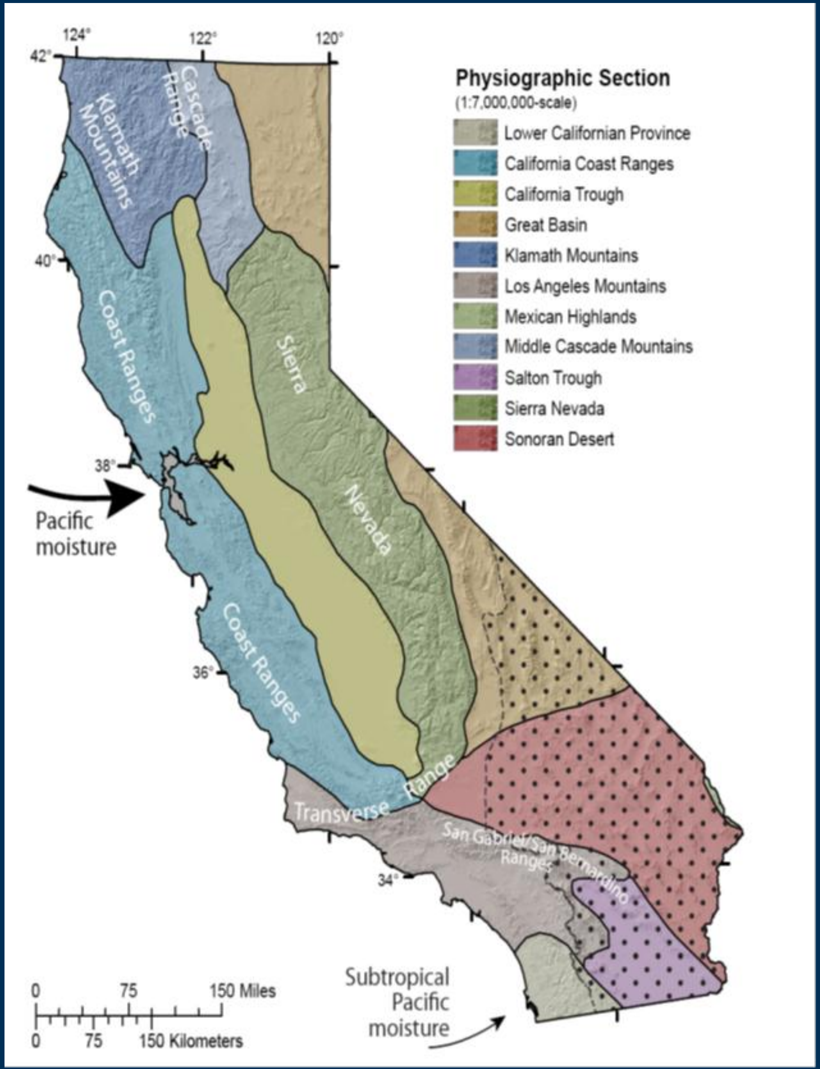


USGS

Updating Flood Frequency Estimates in the Desert Region of California

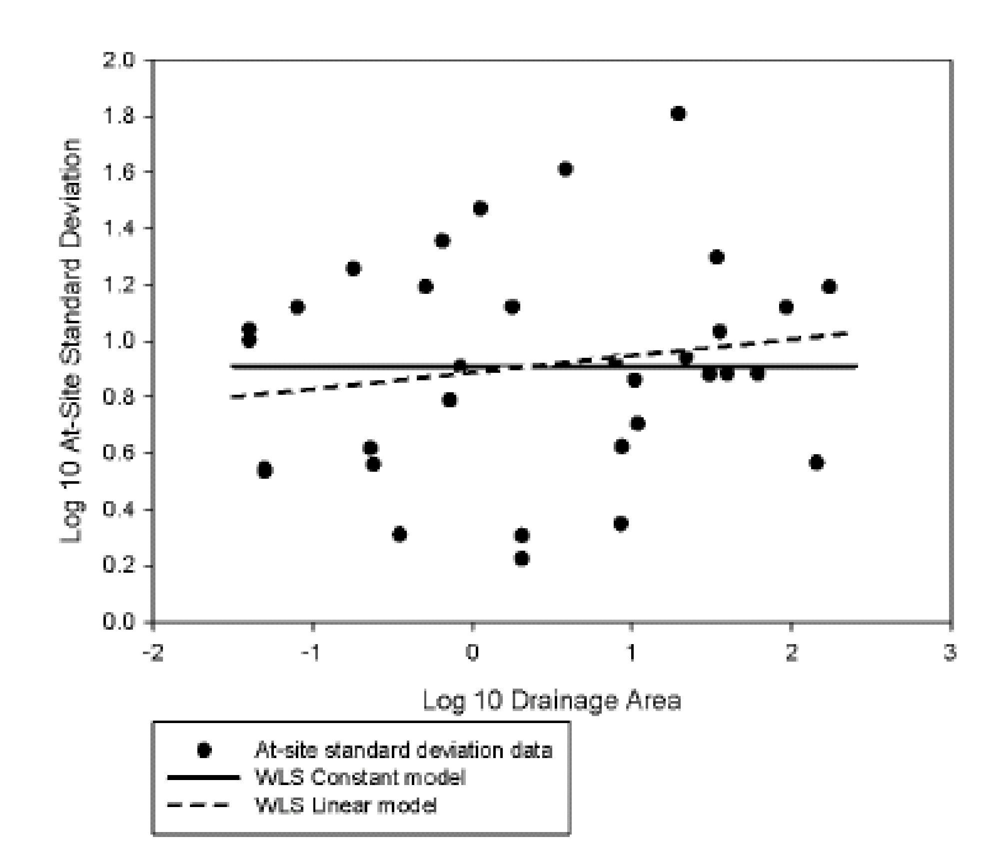
- Because of the problems of the at-site peak flow data, the at-site standard deviation and mean were also weighted with regional estimates of those parameters in the desert region

- In Gotvald and others (2012), in review, regional standard deviation and mean were developed for the desert region of California



USGS

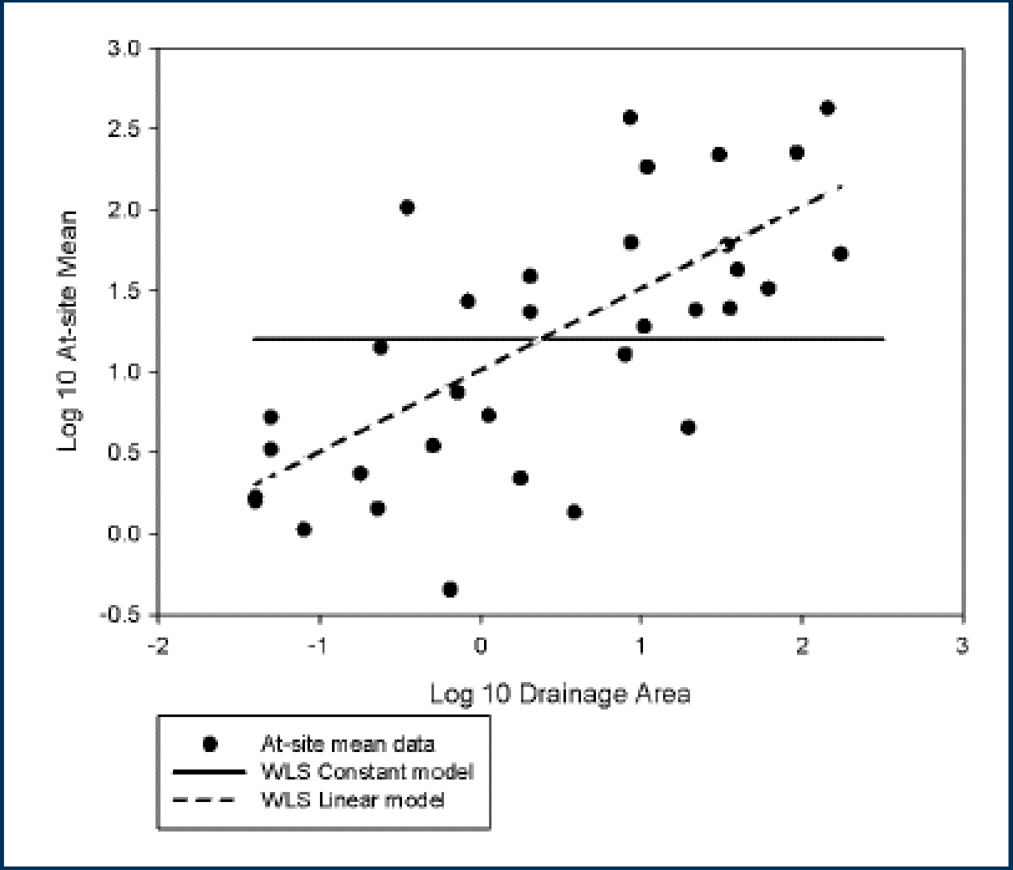
Updating Flood Frequency Estimates in the Desert Region of California



Regional standard deviation: 0.91

USGS

Updating Flood Frequency Estimates in the Desert Region of California

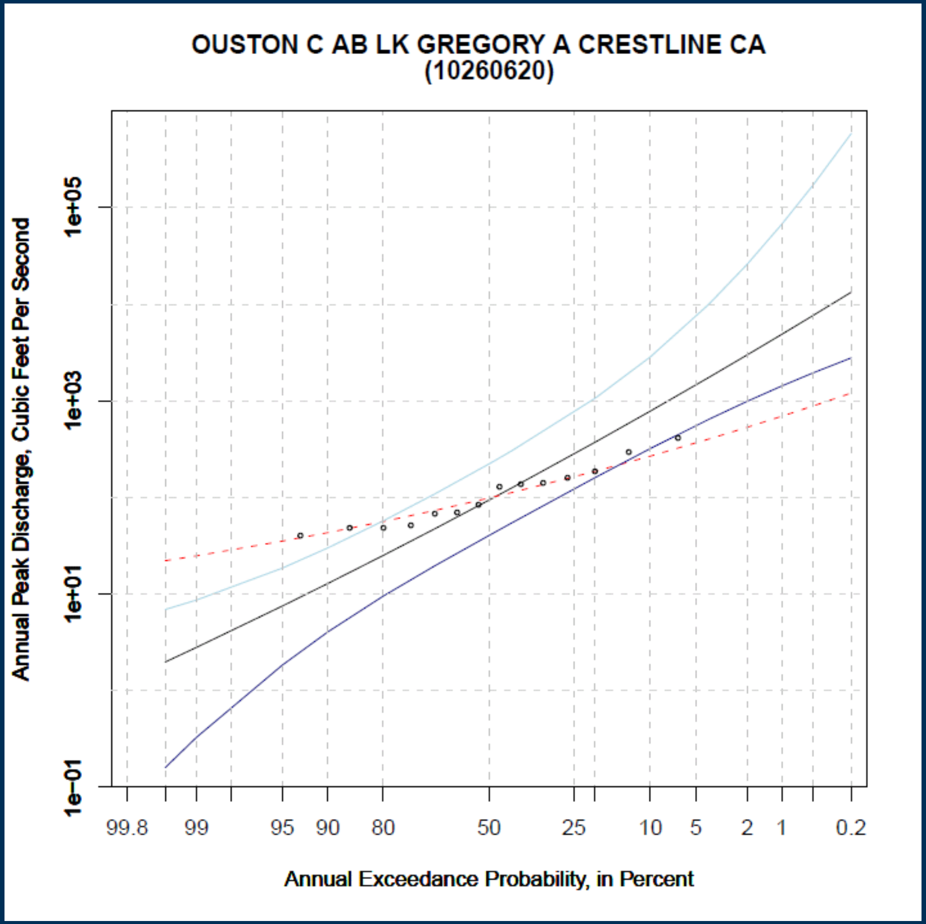


Regional mean:

$$\tilde{\mu}_i = \beta_0 + \beta_1 \log(DRNAREA_i)$$

USGS

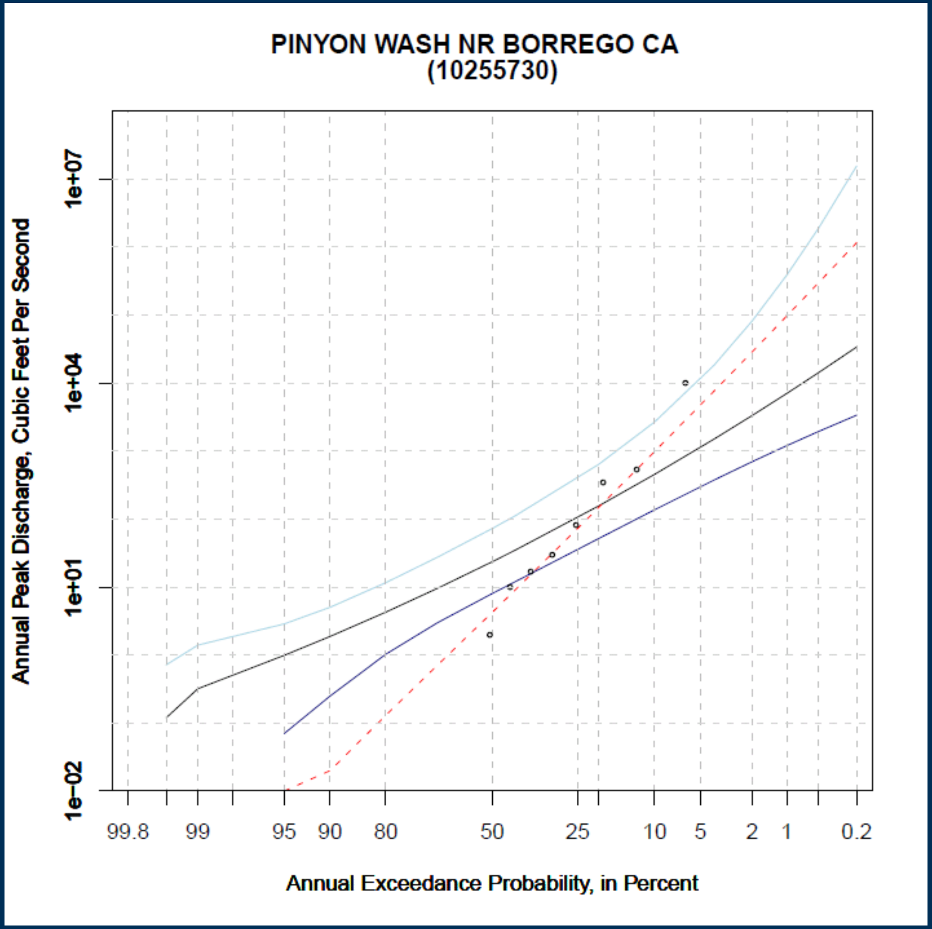
Updating Flood Frequency Estimates in the Desert Region of California



Length of historical period: 14
# of peaks: 14
# of zero flows: 0
# of low outliers using MGBT: 0
At-site standard deviation: 0.31

USGS

Updating Flood Frequency Estimates in the Desert Region of California



Length of historical period: 14
# of peaks: 14
# of zero flows: 6
# of low outliers using MGBT: 6
At-site standard deviation: 1.81

Updating Flood Frequency Estimates in the Desert Region of California

Regional Prediction Equations: $$\log(Q_P)_i = \tilde{\mu}_i + K(\gamma_{W,i}, P) * \tilde{\sigma}_i ,$$

- The average standard errors of prediction for these regression equations range from 214.2 percent for the $Q_{50\%}$ to 856.2 percent for the $Q_{0.2\%}$ annual exceedance probabilities
- The large standard errors indicate the difficulty in accurately predicting flood flows in this region of extreme flow variability
- These standard errors of prediction are smaller than comparable errors reported for the prediction equations for the southwestern United States by Thomas and others, 1997

USGS

Questions ?

Anthony (Tony) Gotvald
Hydrologist
USGS
Atlanta, GA
(770) 903-9310
agotvald@usgs.gov

Nancy Barth
Hydrologist
USGS
Sacramento, CA
(916) 278-3171
nabarth@usgs.gov

USGS