Floods and Flood Frequencies Introduction

- Flood frequencies were updated for USGS gaging stations using data through 2011.
- Long-term gages were investigated for trends and stationarity.
- Regression equations were developed for estimating flood frequencies at ungaged sites.
- At-site flood frequencies were adjusted using weighting methods with regression equations or using record extension methods.

Swiftcurrent Creek at Many Glacier, Nov. 11, 2006
Don Bischoff
Q_{peak}=4,270 cfs

Floods and Flood Frequencies

some definitions

- A flood is any relatively high streamflow that overtops the natural or artificial banks of a river. This definition varies by agency.
- Annual peak flows are the instantaneous peak flow for a given year which are used to determine flood frequencies. Individual peak flows may not necessarily be a flood.
- Discharge is another term for streamflow (or magnitude of flood); it is the measured volume of water that moves past a point in the river in a given amount of time. Discharge is usually expressed in cubic feet per second.

Floods and Flood Frequencies Introduction

- **<u>Flood frequency</u> is the concept of determining the probability of a given flood occurring in any given year.**
- **Flood frequencies are expressed in <u>Annual Exceedance Probabilities (AEP)</u>. A 1-percent AEP has a 1 percent probability of occurring in any given year. The 1-percent AEP is commonly referred to as the 100-year flood.**

Swiftcurrent Creek at Many Glacier, Nov. 11, 2006
Don Bischoff
Q_{peak}=4,270 cfs

Floods and Flood Frequencies Introduction

"I only need the 100-year flood for…"

- **Purpose of this presentation is to provide basic information and methods necessary for deriving the *range* of peak-flows for your design criteria.**

Swiftcurrent Creek at Many Glacier, Nov. 11, 2006
Don Bischoff
Q_{peak}=4,270 cfs

Floods and Flood Frequencies Introduction

"I only need the 100-year flood for…"

- Methods for obtaining flood frequency
  - Gaged sites
    - At-site flood frequency analysis
    - At-site flood frequency analysis weighted with regression equations
    - At-site flood frequency analysis after performing record extension methods
  - Ungaged sites
    - Regional regression equations
    - Drainage-area adjustment

Floods and Flood Frequencies Introduction

"I only need the 100-year flood for…"

- **Understanding uncertainty**
  - **Flood mechanisms**
  - **Extreme flood events**
  - **Confidence intervals**
  - **Period of record**

Flood Frequencies
How are they computed?

- **USGS stream gages record streamflow at various streams**
- **The largest <u>instantaneous streamflow</u> for each water year is recorded and stored in NWIS**

Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1909	5/25/1909	1,410	--
1910	4/29/1910	680	--
1911	6/3/1911	2,590	--
1912	5/22/1912	1,410	--
1913	5/29/1913	1,250	--
1914	6/6/1914	1,490	--
1915	6/13/1915	1,000	--
1916	6/22/1916	1,240	--
1917	5/27/1917	4,020	--
1918	7/15/1918	2,500	--
1919	3/31/1919	748	--
1920	5/13/1920	1,570	--
1921	6/9/1921	564	--
1922	6/11/1922	1,690	--
1923	6/21/1923	2,140	--
1924	5/18/1924	1,160	--
1925	7/24/1925	1,960	--
1926	5/22/1926	873	--
1927	6/12/1927	2,420	--

http://nwis.waterdata.usgs.gov/mt/nwis/peak

Flood Frequencies
How are they computed?

- **PEAKFQ software which uses approved methods to compute flood frequencies from annual peak flow data.**

  http://water.usgs.gov/software/PeakFQ/

- **Bulletin 17B of the Hydrology Subcommittee provides guidelines for determining flood frequency.**

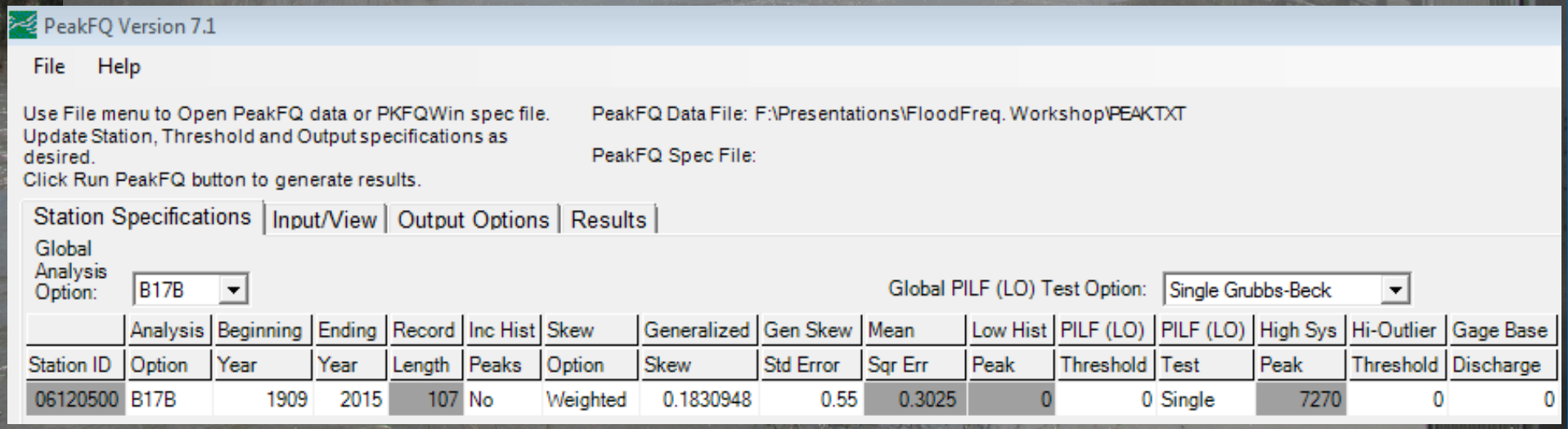
  http://water.usgs.gov/osw/bulletin17b/dl_flow.pdf

- **Bulletin 17C will replace Bulletin 17B and is currently out for public comment**

  http://acwi.gov/hydrology/Frequency/b17c/bulletin17c_draft_for_public_review.pdf

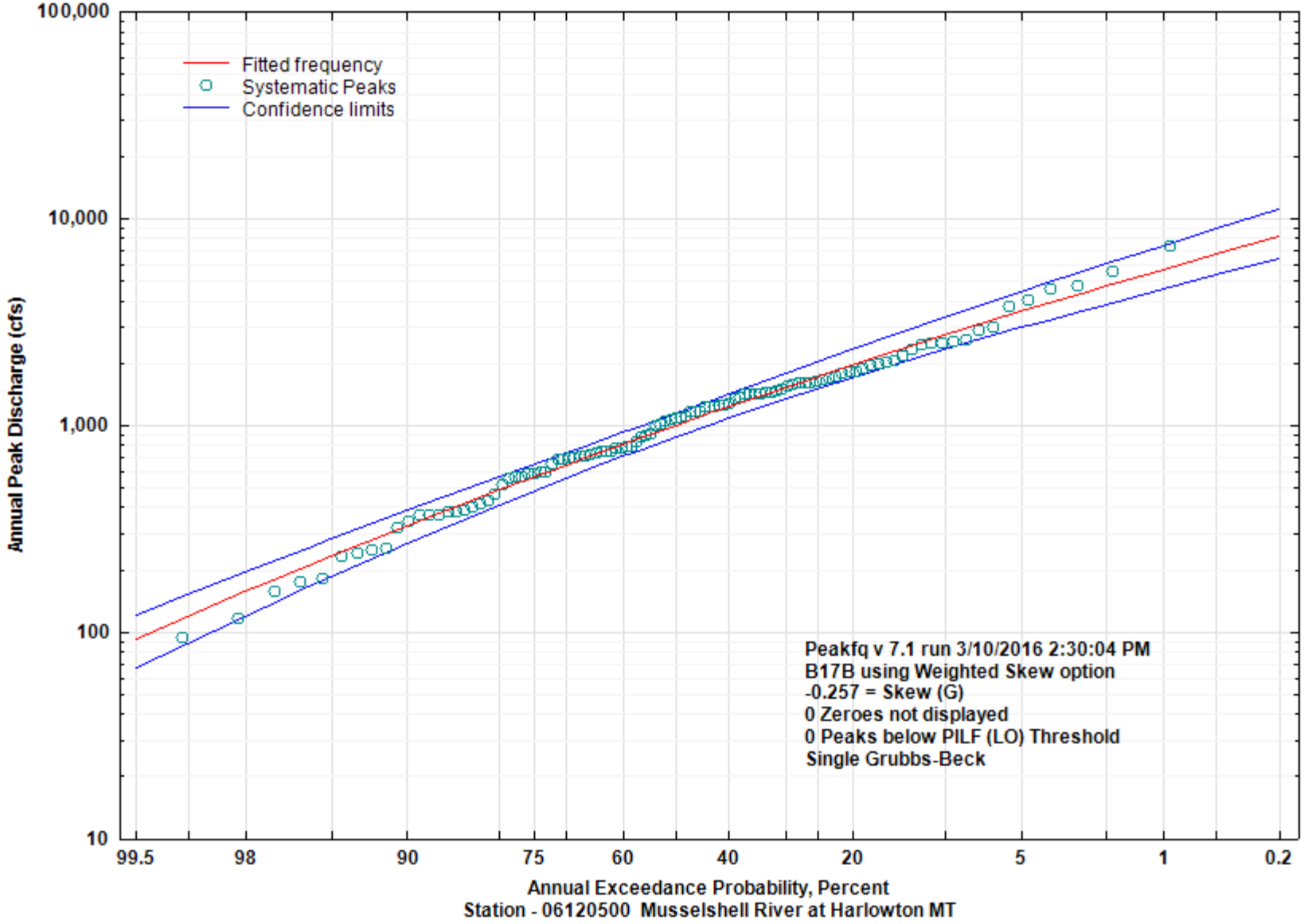
Flood Frequencies
PEAKFQ

- Download <u>peakfq (watstore) format</u> data from NWIS for desired USGS gage
- Open data in PEAKFQ
- Follow guidelines for B17B or B17C for computations (B17C training at 2017 AMFM?)

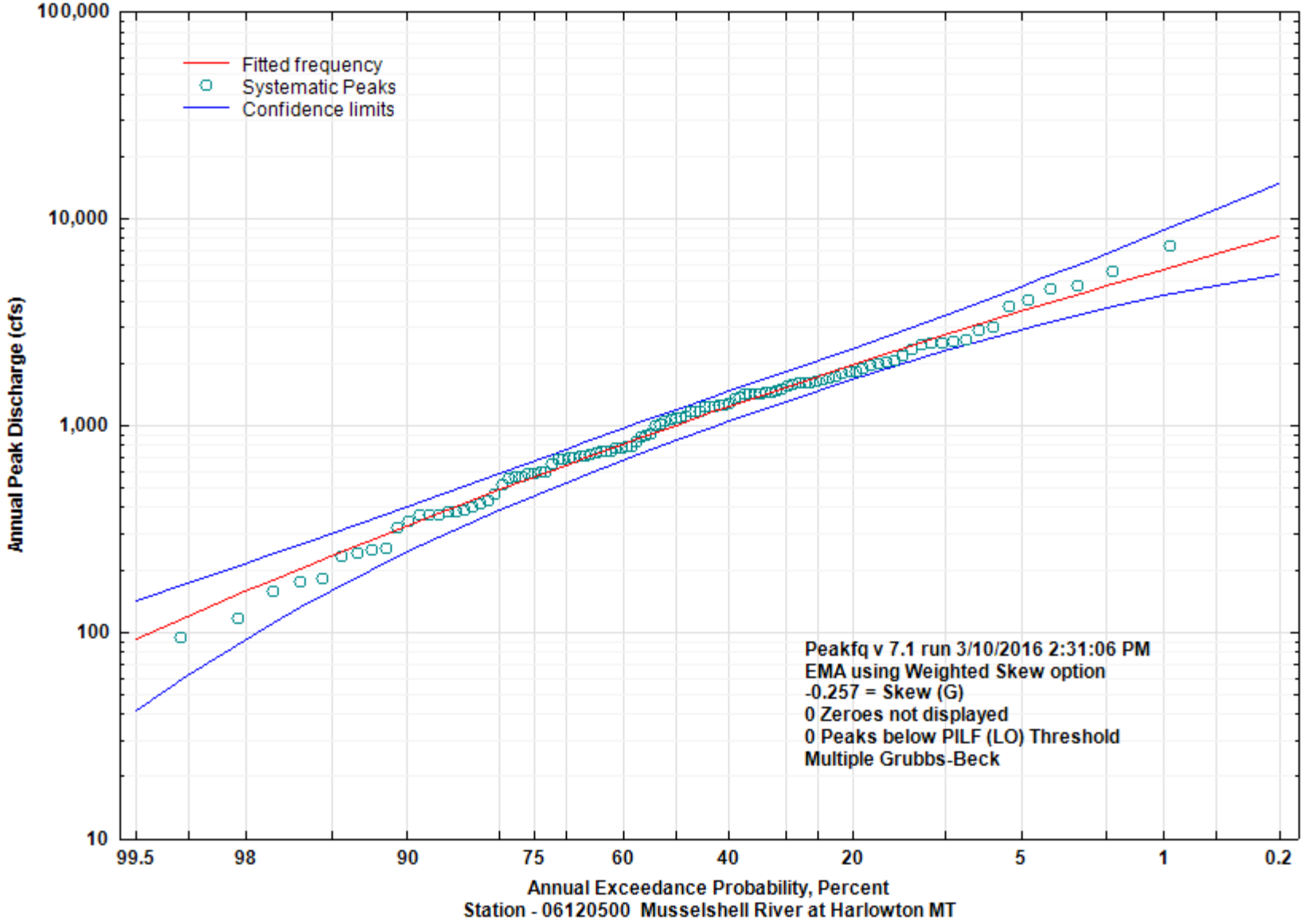


Station ID	Analysis Option	Beginning Year	Ending Year	Record Length	Inc Hist Peaks	Skew Option	Generalized Skew	Gen Skew Std Error	Mean Sqr Err	Low Hist Peak	PILF (LO) Threshold	PILF (LO) Test	High Sys Peak	Hi-Outlier Threshold	Gage Base Discharge
06120500	B17B	1909	2015	107	No	Weighted	0.1830948	0.55	0.3025	0	0	Single	7270	0	0

Flood Frequencies
PEAKFQ-Bulletin 17B



Flood Frequencies
PEAKFQ-Bulletin 17C



Flood Frequencies
PEAKFQ

- **Bulletin 17B**
  - Single Grubbs-Beck low-outlier method
  - Single historic peak
  - Log-Pearson type III for computations and confidence intervals
- **Bulletin 17C**
  - Multiple Grubbs-Beck low-outlier method
  - Multiple historic peaks
  - Uses the basics of Log-Pearson distribution
  - Expected Moments Algorithm for computations and confidence intervals

Flood Frequencies

more definitions

- Peak flow data recorded as part of the normal streamflow gaging operations are considered the systematic record.
- A peak flow data from a single year (separate from the systematic record) and considered largest in some period of time is a historic peak.
- B17B and B17C use different methods for handling historic peaks.

Flood Frequencies

more definitions

- Analysis assumes that the recorded peak flow data is a sample of the TRUE population of peak flow data, and this population remains constant or stationary through time. Thus, the population of peak flows is not changing due to climate or anthropogenic changes.
- Statistical methods test for stationarity and trends in peak flow data.
- Are peak flow data ever stationary?

Flood Frequencies

more definitions

- Flood frequency analyses assume that all floods for a given site have a similar cause of flooding; thus, they are considered a <u>single population</u>.
- Sites with multiple causes (2 or more) of flooding are considered a <u>mixed population</u>. A classic mixed population is rain caused floods and hurricane caused floods which is common on the east coast.
- In a classic mixed population, the peaks can be separated by cause of flooding and a <u>mixed-population flood frequency analysis</u> performed.

Flooding Mechanisms in Montana

- Snowmelt
  - Low elevation
    - Late winter through early spring, generally before May
  - High elevation
    - Typically May through mid-July

USGS

Flooding Mechanisms in Montana

- Rainfall
  - Large convective storms-somewhat widespread and usually more significant for larger drainages
    - Gulf storms, commonly spring storms
    - Pacific storms, commonly fall storms
  - Thunderstorm events-usually local events and usually more significant for smaller drainages

USGS

Flooding Mechanisms in Montana

- Ice/debris jams
  - Can cause significant flooding without a large streamflow
  - Not currently well understood in Montana from a frequency/magnitude perspective
- Others
  - Rain on snow
  - Flash flooding
    - Chinooks
    - Burn areas
  - Dam failure (not included in flood freq. analysis)

USGS

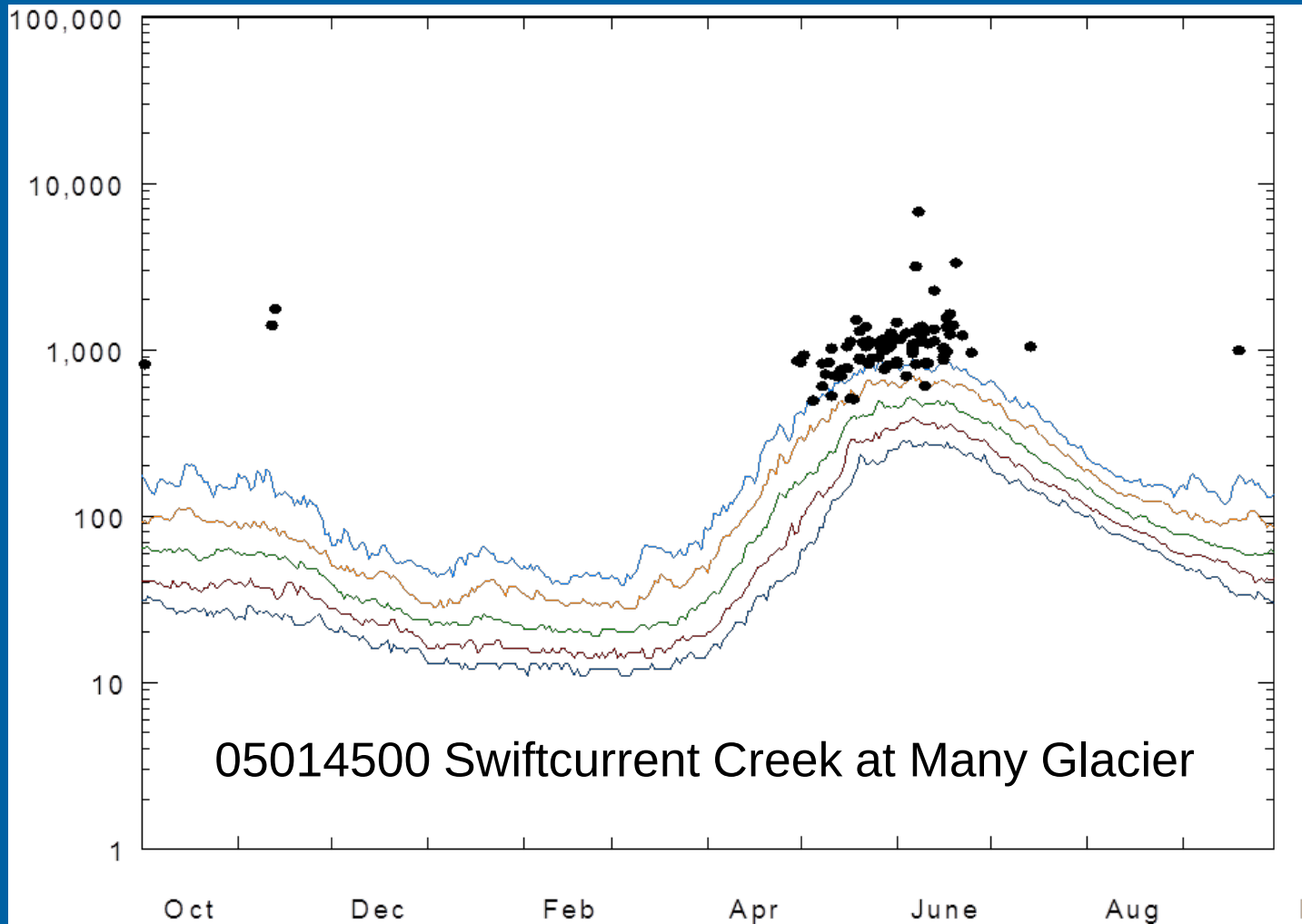
Mixed population of floods

- 2 or more causes of flooding
- Classic example is hurricanes vs. rainfall on east coast.
- Does Montana have mixed-population floods and can we separate the populations?

USGS

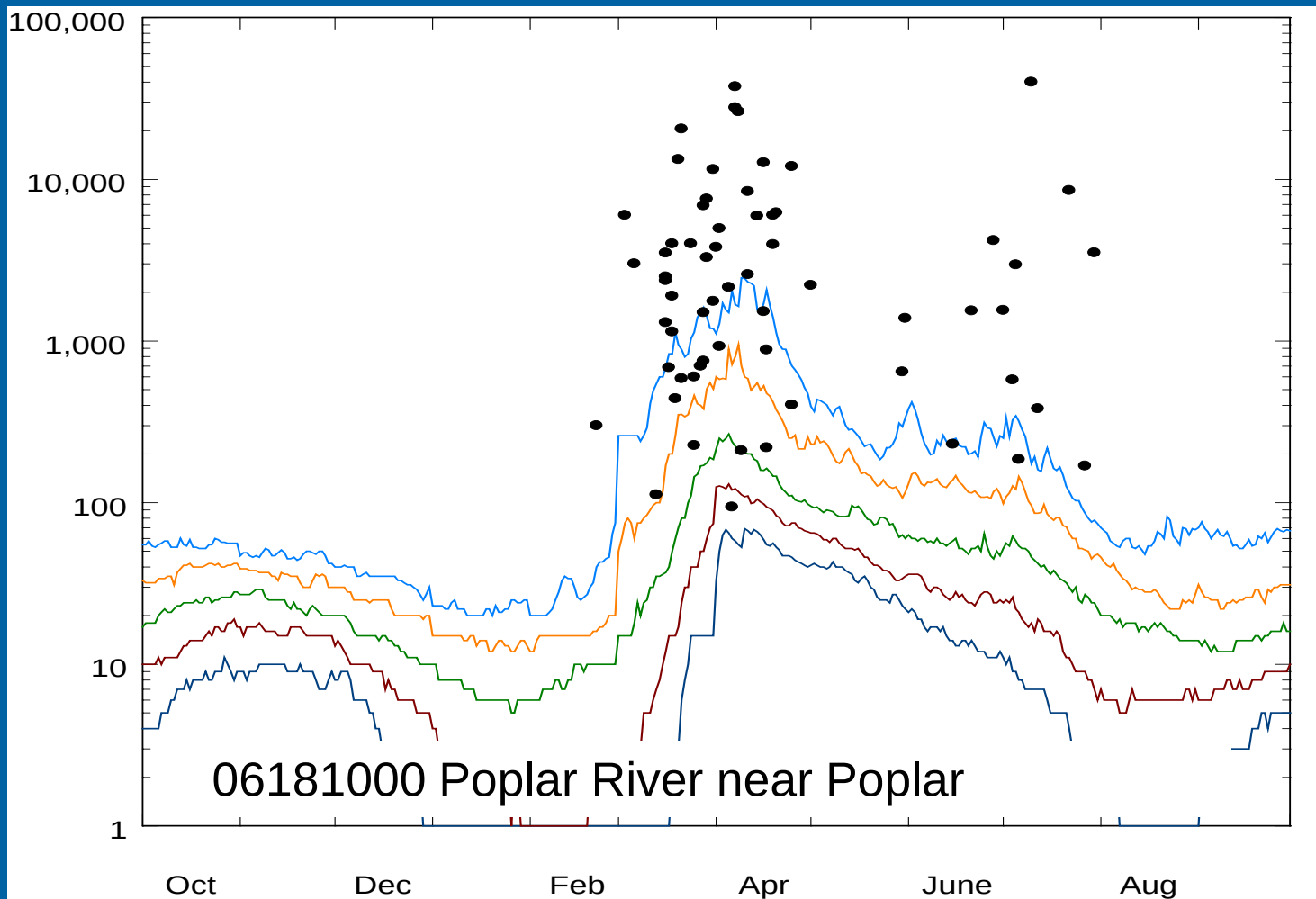
Timing of peak flows

- Timing of peak flows may help identify flooding mechanism

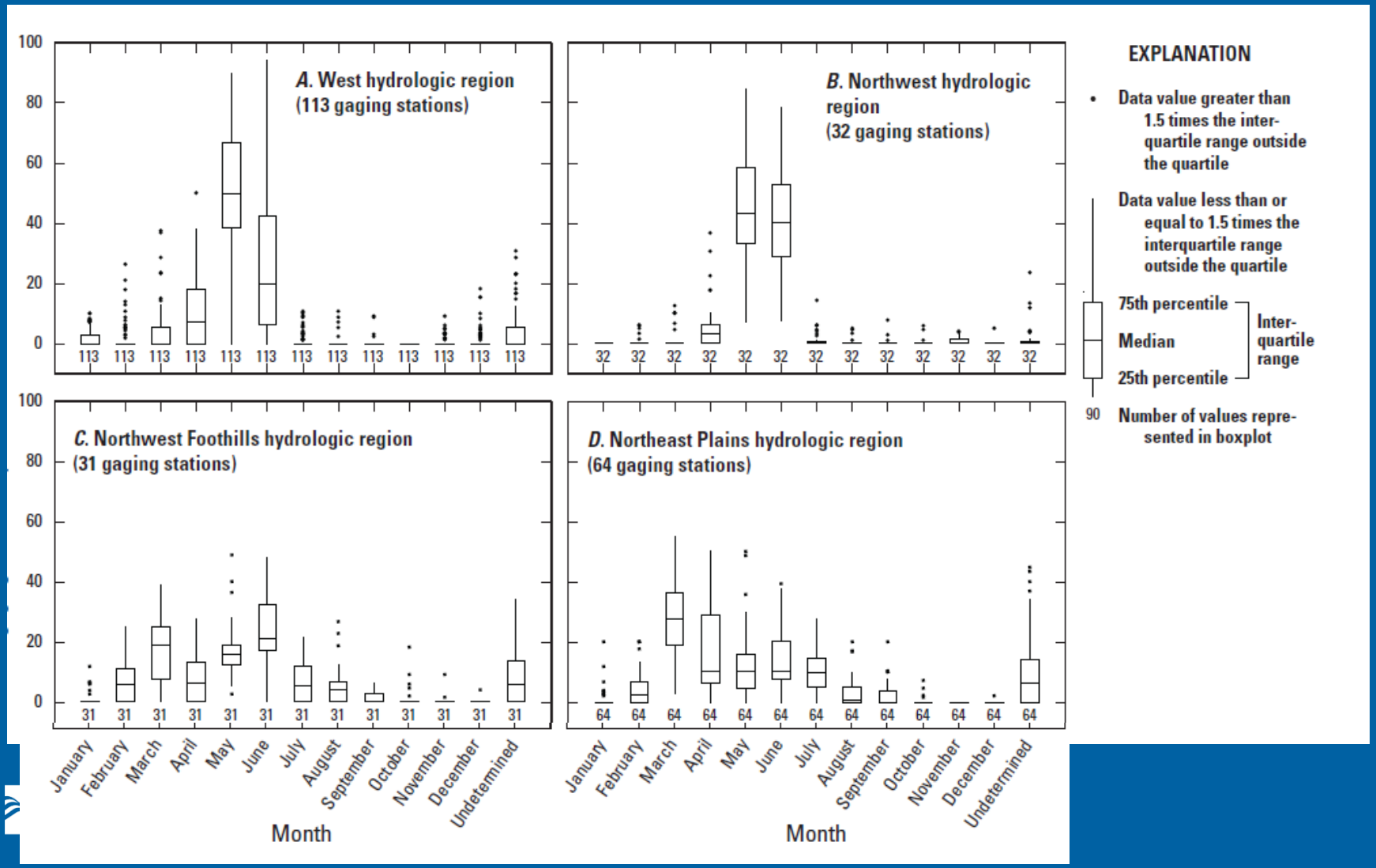


Timing of peak flows

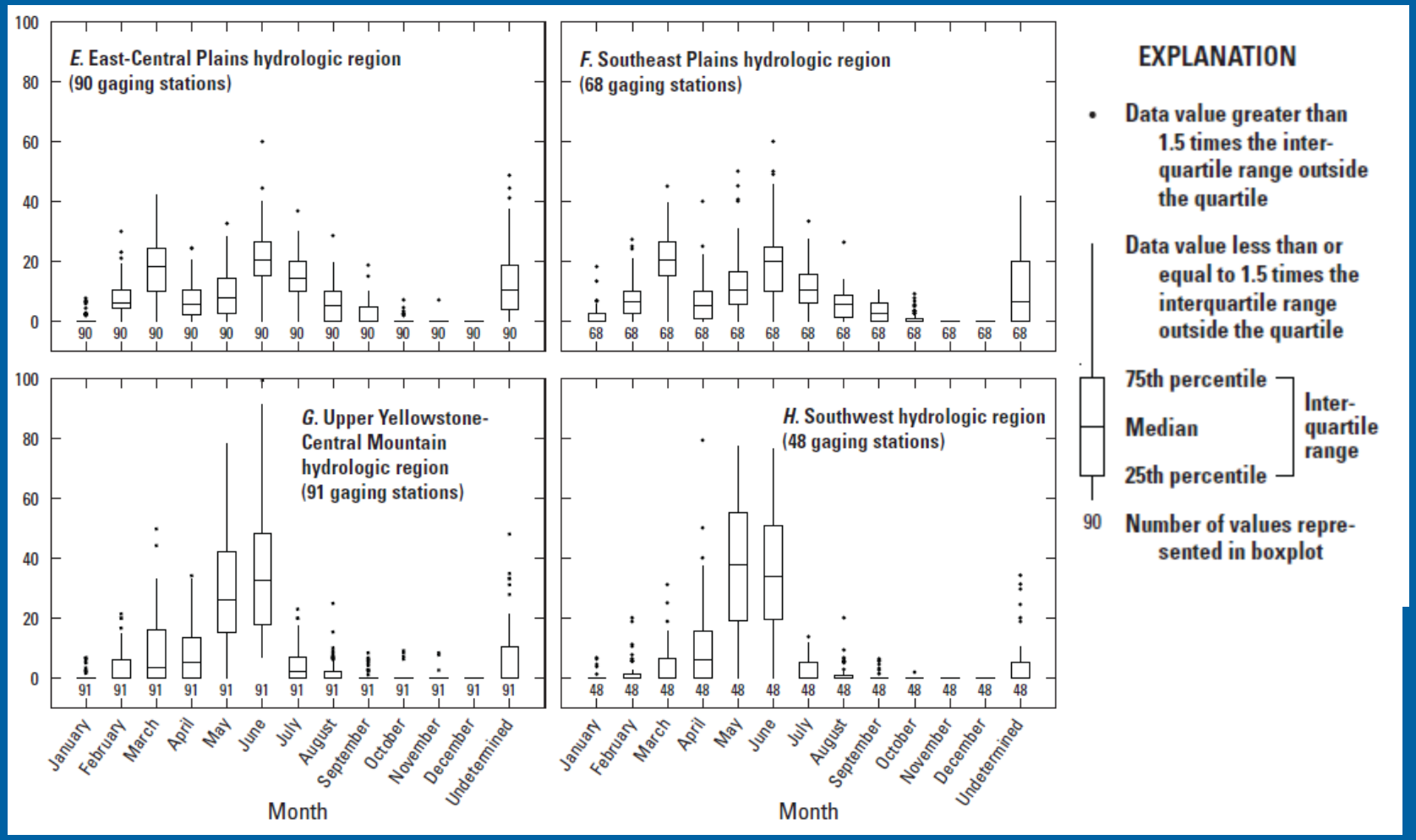
- Timing of peak flows may help identify flooding mechanism



Timing of peak flows



Timing of peak flows



USGS

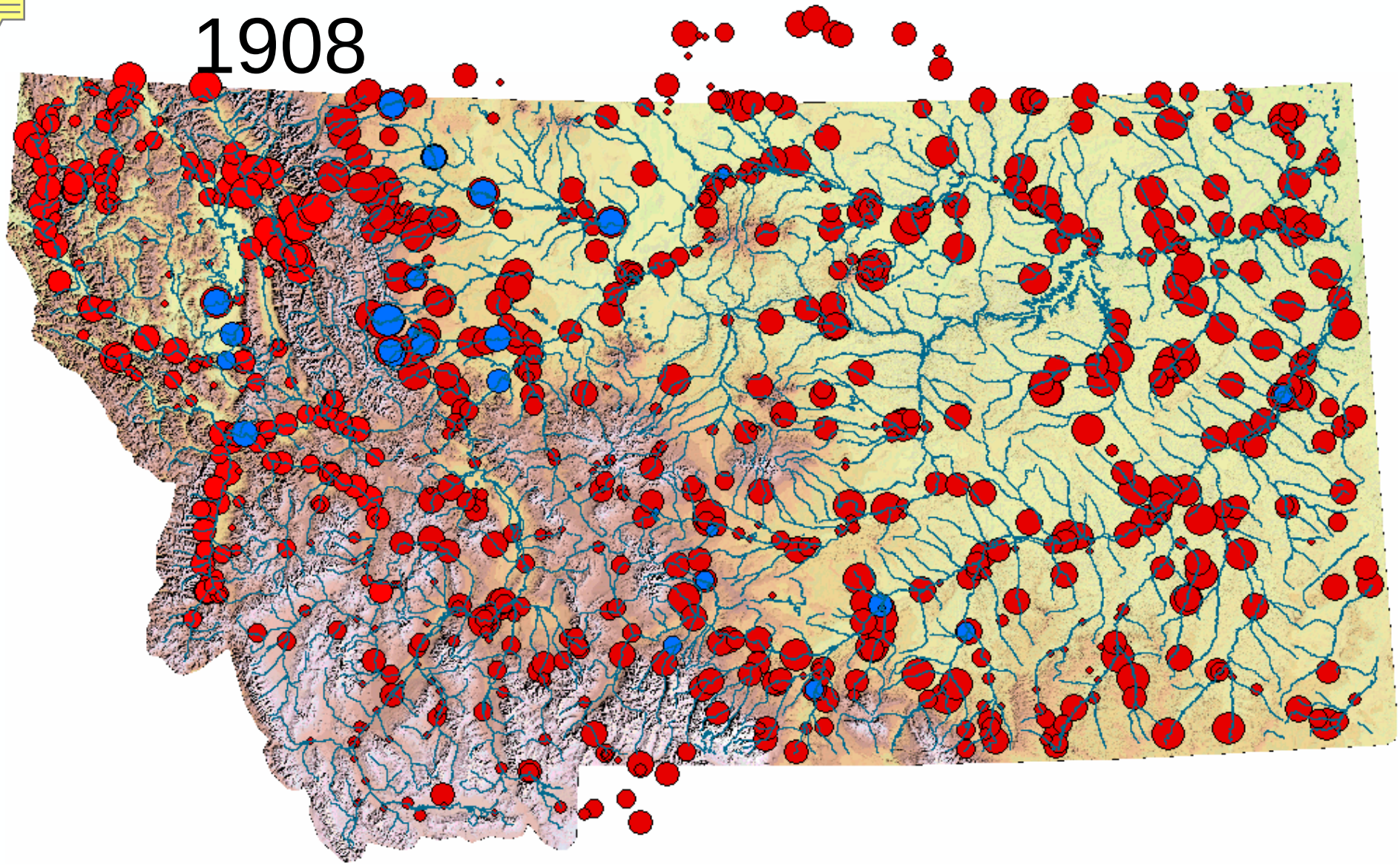
Significant Montana Floods

- According to National Weather Service[1]
  - 1908
  - 1948
  - 1964
  - 1978
  - 2011
- Others
  - 1952-North-central MT
  - 1953-Central MT
  - 1975-Statewide
  - 1981-Central MT

USGS

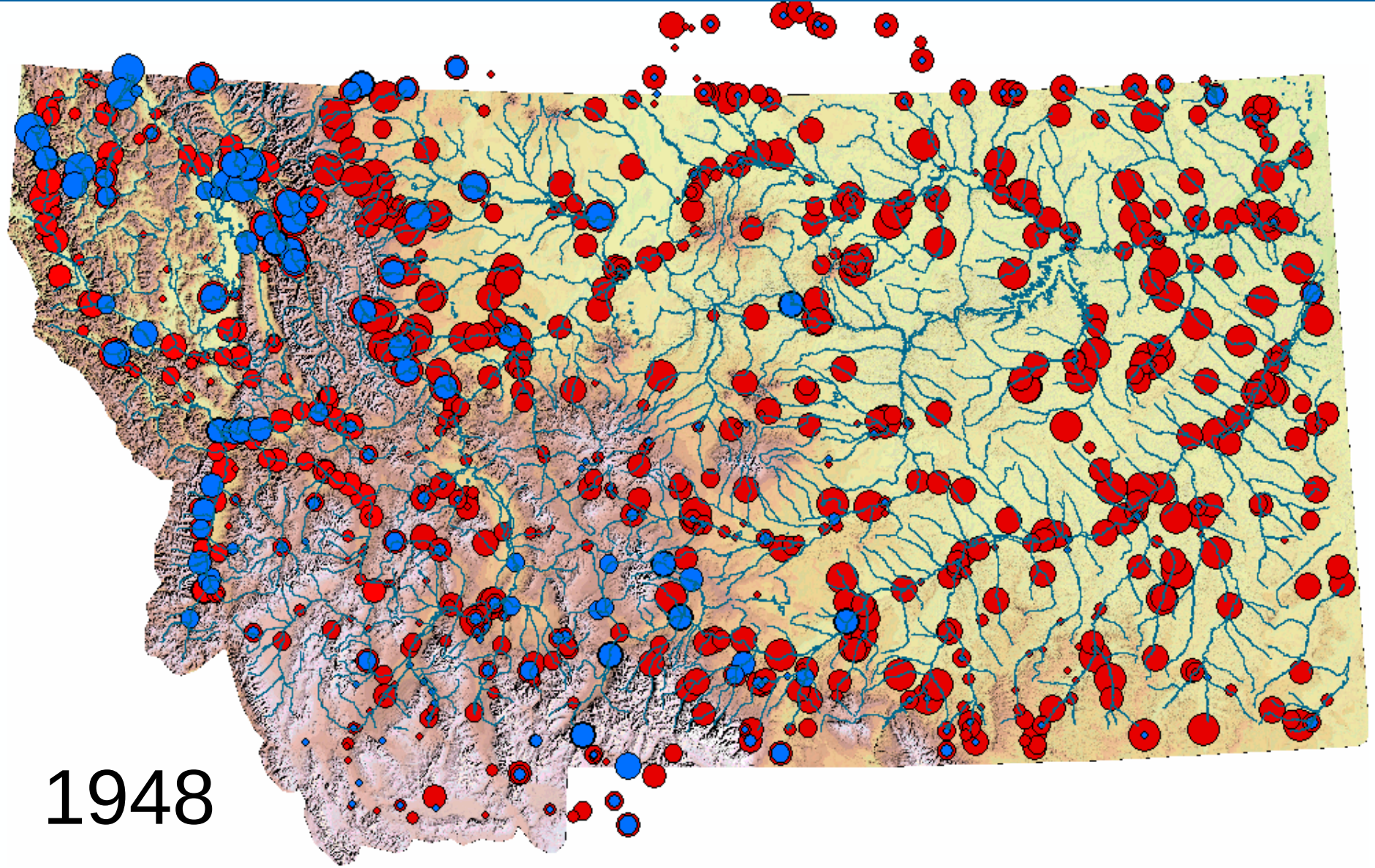
[1]http://www.floodsafety.noaa.gov/states/mt-flood.shtml

1908



Maximum peak of record, normalized by drainage area

Peak for year (if gaged), normalized by drainage area

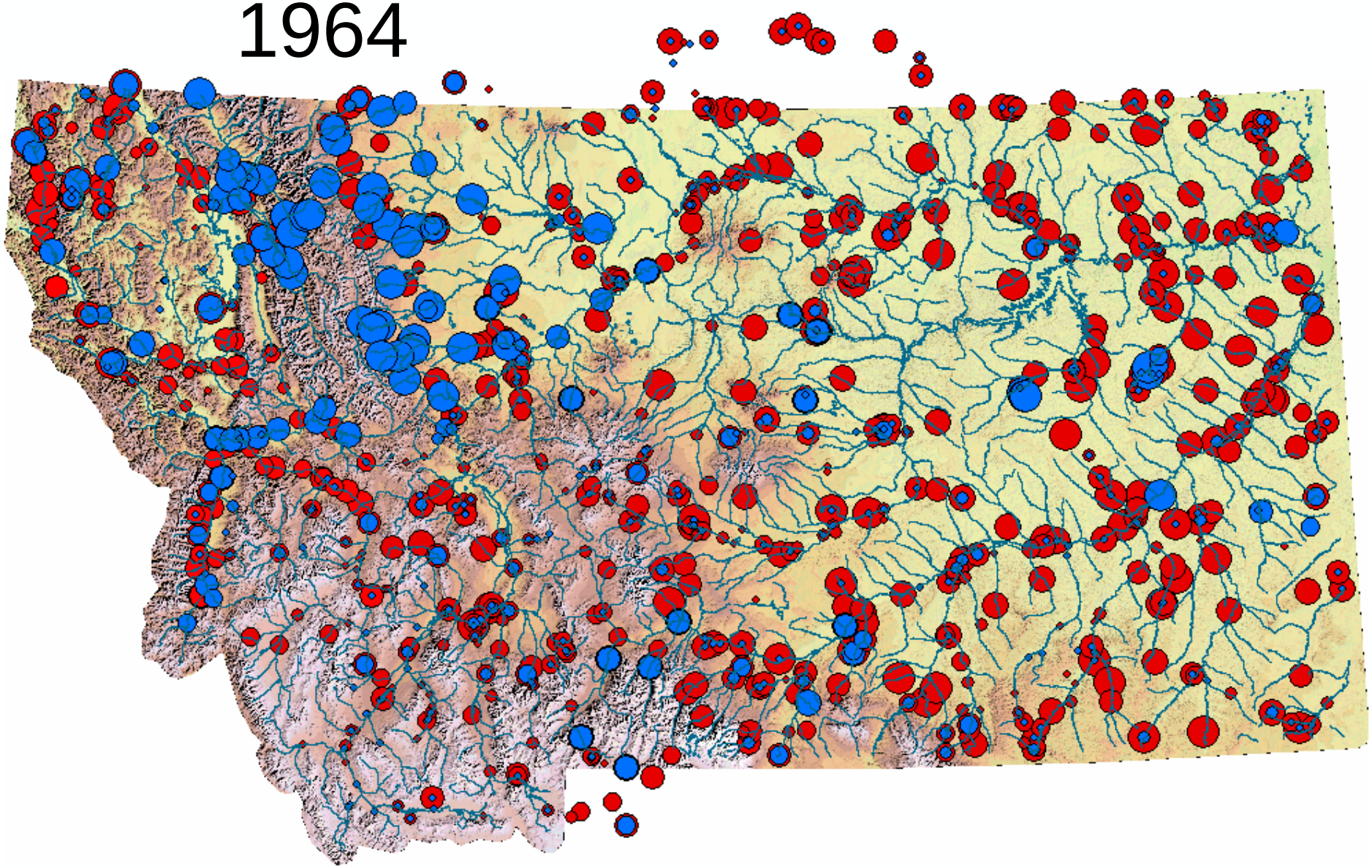


USGS

Maximum peak of record, normalized by drainage area

Peak for year (if gaged), normalized by drainage area

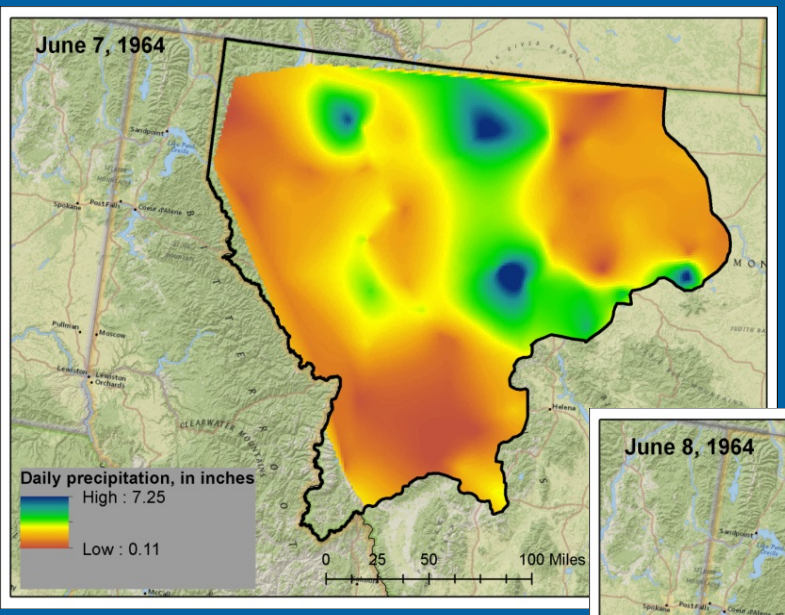
1964

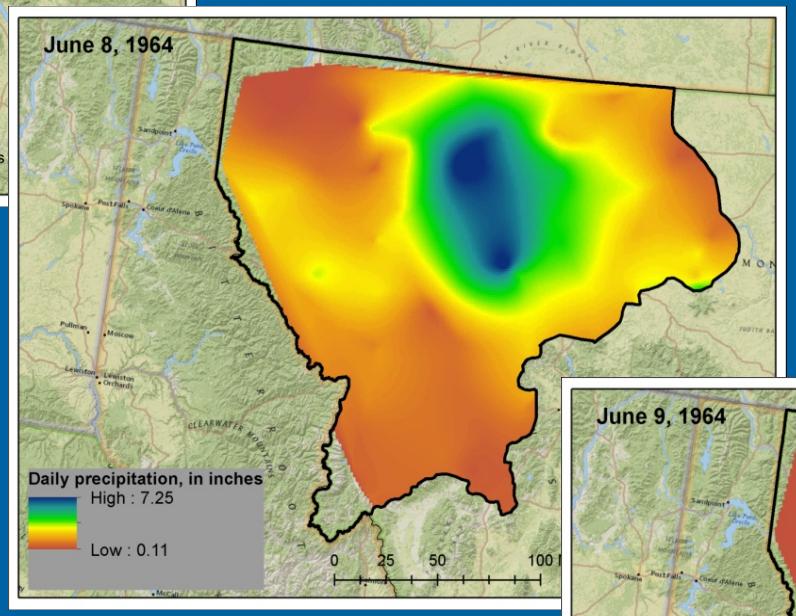


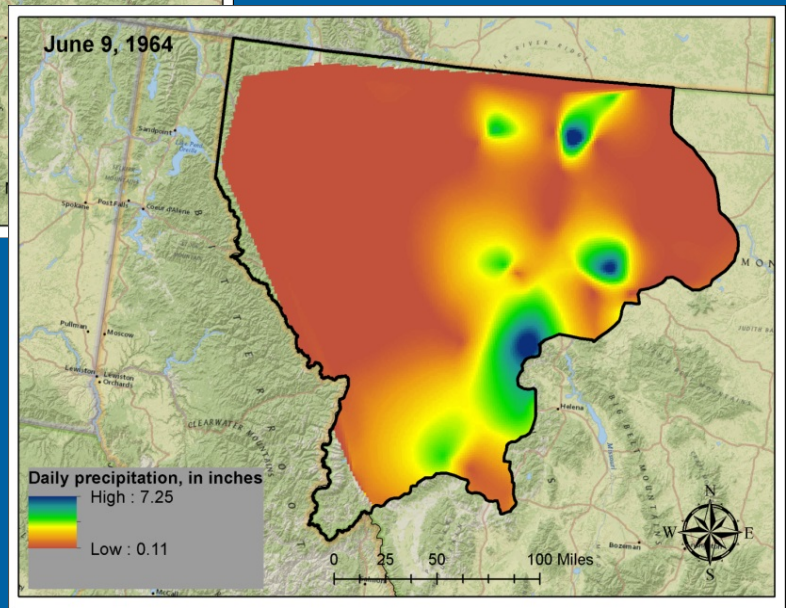
Maximum peak of record, normalized by drainage area

Peak for year (if gaged), normalized by drainage area

Precip. for 1964

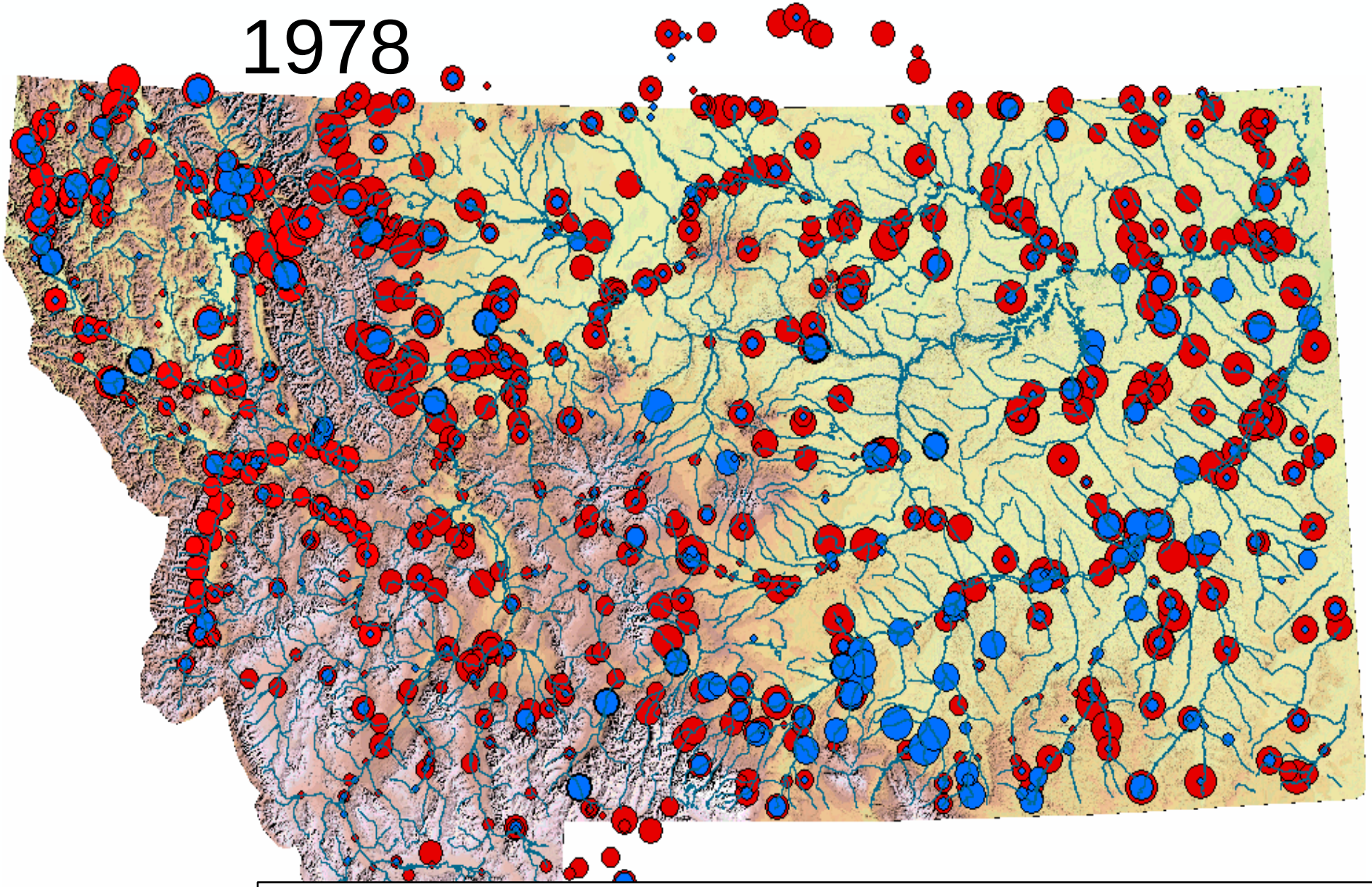






USGS

1978



Maximum peak of record, normalized by drainage area

Peak for year (if gaged), normalized by drainage area

Trends and stationarity

- Chapter B studied trends and stationarity in Montana
- Trends of long-term gaging stations
  - 75+ years of record
  - 5+ years of data in the 1930s (particularly dry period)
  - Small urbanization or reservoir effect
- 24 selected gages
  - Magnitude
  - Timing

USGS

Trends and stationarity

- General Conclusions
  - 1930s-1940s: Lower peak flows
  - 1950s-1970s, even 1980s: Larger peak flows
  - Late 1980s-present: Lower peak flows

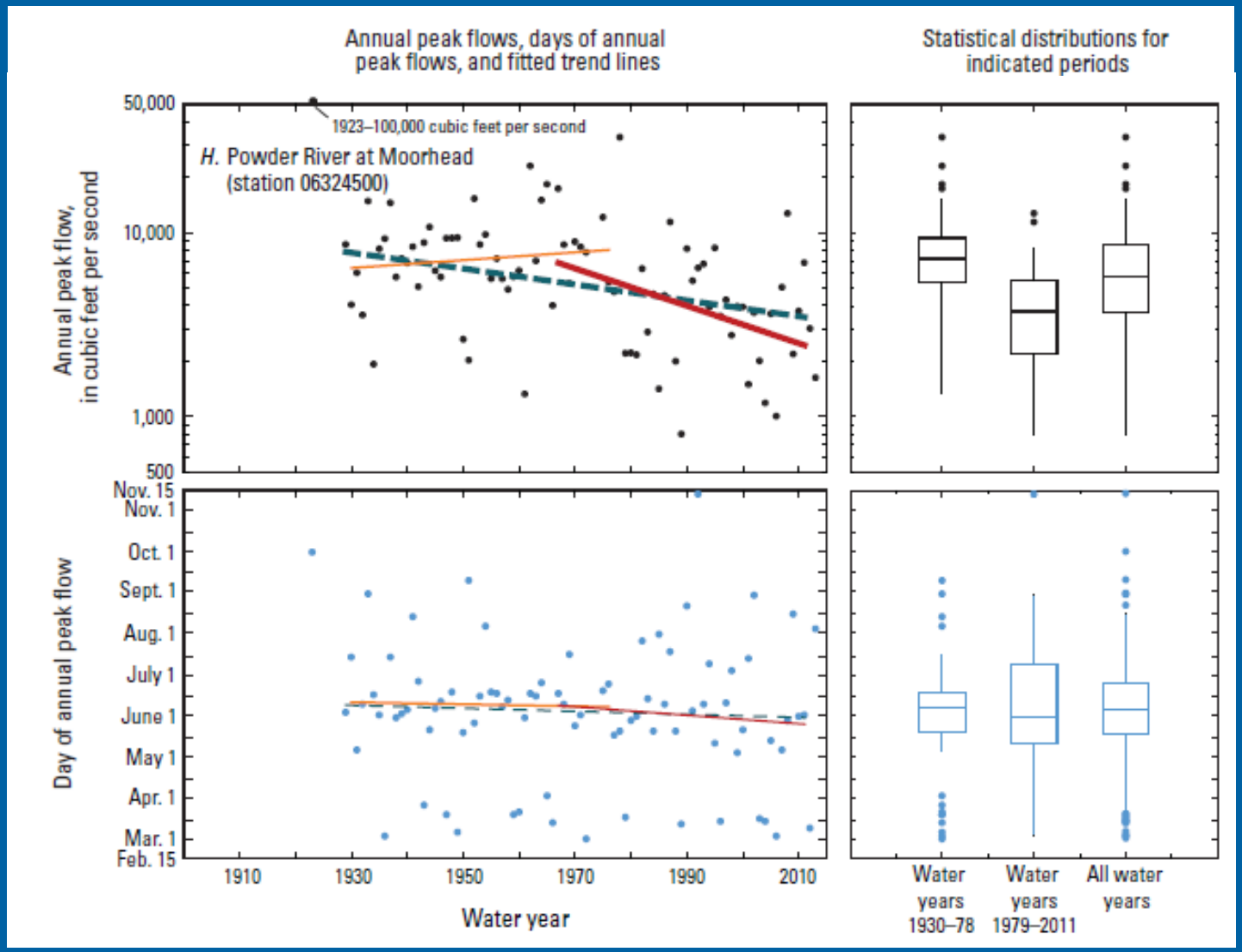
USGS

Trends and stationarity

- General Conclusions
  - Magnitude of peak flows
    - Upwards trends during 1930-1976 generally stronger than downward trends during 1967-2011
    - Annual peak flow for most long-term gaging stations can be considered stationary for peak-flow frequency analyses
  - Timing of peak flows
    - Earlier peak trends (1967-2011) were generally stronger than later peak trends (1930-1976)
    - Differences in timing are variable and not particularly strong; however 5 of 7 high-elevation gages showing trends of earlier peaks

USGS

Trends and stationarity



EXPLANATION

[Water year is defined as the 12-month period from October 1 through September 30 and is designated by the year in which it ends]

Annual peak flows and days of annual peak flows

- Annual peak flow
- Day of annual peak flow

Fitted trend lines

- Start of systematic data collection through 1940
- 1930 through 1976
- 1967 through 2011
- Start of systematic data collection through 2011

Bold lines indicate statistical significance (*p*-value less than 0.05)

Boxplots

- Data value greater than 1.5 times the interquartile range outside the quartile

Data value less than or equal to 1.5 times the interquartile range outside the quartile

75th percentile

median

25th percentile

Inter-quartile range

Trends and stationarity

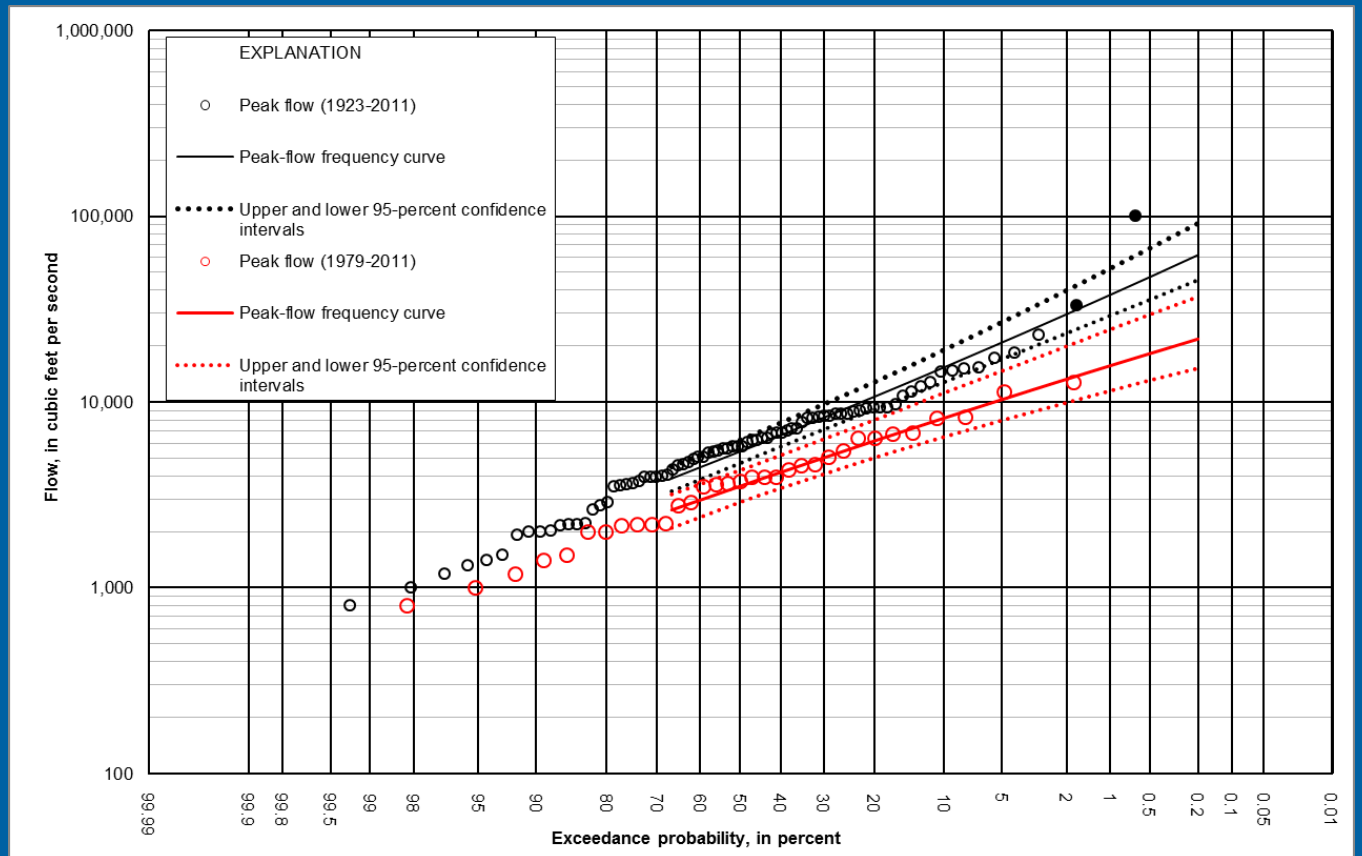


Figure 1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hlrsch, 2002) and peak-flow frequency curve

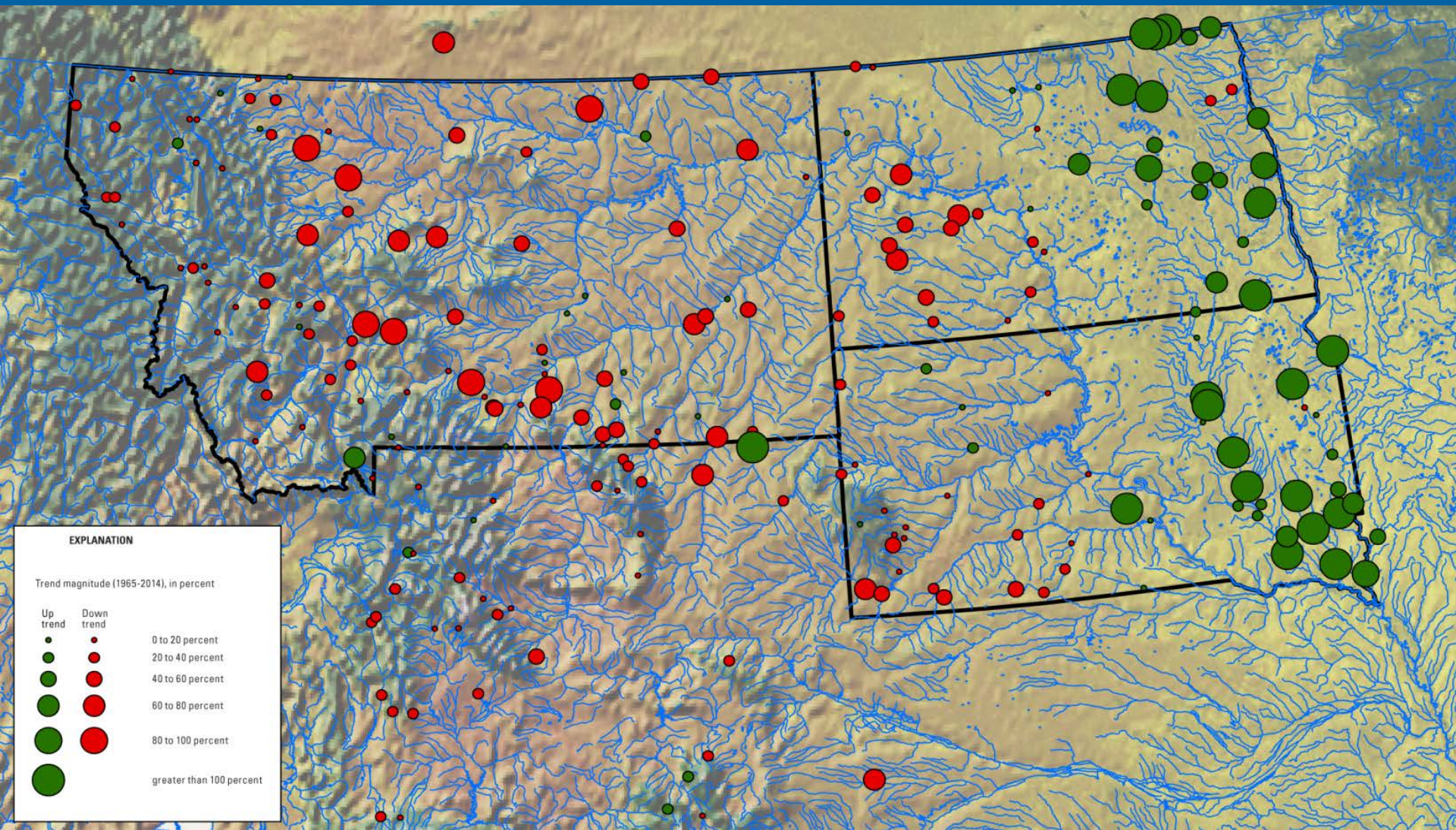
	Peak flow, in cubic feet per second, for indicated annual exceedance probability, in percent									
Period	**66.7**	**50**	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
1923-2011	3,879	5,424	6,238	10,680	15,390	22,920	29,780	37,820	47,190	61,930
1979-2011	2,625	3,526	3,981	6,172	8,198	11,020	13,300	15,710	18,250	21,850
Percent difference in flood frequency estimates for 1923-2011 versus 1979-2011										
	-32	-35	-36	-42	-47	-52	-55	-58	-61	-65

Trends and stationarity

- More research and analyses are needed to better understand downward trends of peak flow magnitudes and timing in Eastern Montana
  - Effects of smaller dams and land use practices
  - Effects of climate changes
- How do I proceed? Be conservative!
  - Consider your period of record for analysis
  - Use record extension or regression equations to adjust your analyses

USGS

Regional trends study



Peak flow analyses (Chapter C)

- Performed analyses using Bulletin 17B however USGS formally adopted 17C
- 725 streamflow gaging stations in and near Montana
  - 579 unregulated streamflow stations
  - 146 regulated streamflow stations
    - 100 analyzed for post-regulation period only
    - 17 analyzed for pre-regulation period only
    - 29 analyzed for both pre- and post-regulation
  - Pre-regulation analyses used for regression equations

USGS

Peak flow analyses

- **Peak flow data**
  - **Largest instantaneous peak flow for each year of record**
  - **1 peak recorded per water year**
  - **Available in NWIS**

  http://nwis.waterdata.usgs.gov/mt/nwis/peak
  - **Data qualification codes**
    - **Codes 1-9 for discharge**
    - **Codes A-E for gage height**

USGS

Peak flow analyses (show fig. of data retrieval from NWIS)

- Data qualification codes for discharge
  - 1 Q is equal to the maximum daily discharge
  - 2 Q is an estimate
  - 3 Q affected by dam failure
  - 4 Q is less than indicated value
  - 5 Q affected to unknown degree by regulation or diversion
  - 6 Q affected by regulation or diversion
  - 7 Q is a historic peak
  - 8 Q is greater than indicated value
  - 9 Q is due to snowmelt, hurricane, ice/debris dam

USGS

Peak flow analyses

- Data qualification codes for gage height
  - A Year of occurrence is unknown or not exact
  - B Month or day of occurrence is unknown (common with CSGs)
  - C All or part of record affected by basin development or changes (urbanization, ag., wildfire, land cover)
  - D Gage base discharge changed
  - E Only the peak exceeded the flood base

USGS

Peak flow analyses

- What is skew?
  - Station skew is the 3rd moment measure of the peak-flow data around the mean
  - Skew affects the shape of the flood frequency curve
  - Strong positive vs. Strong negative

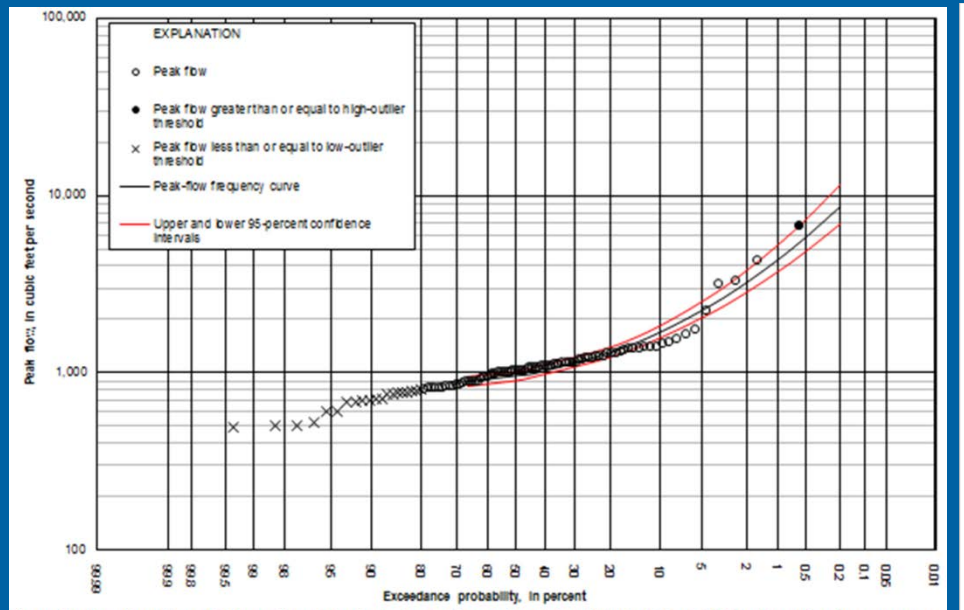


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

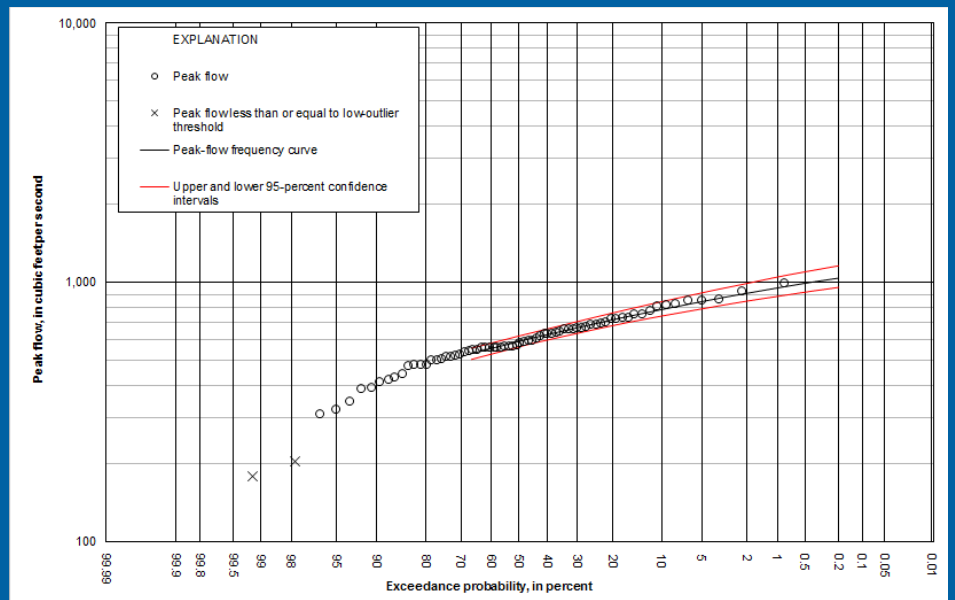
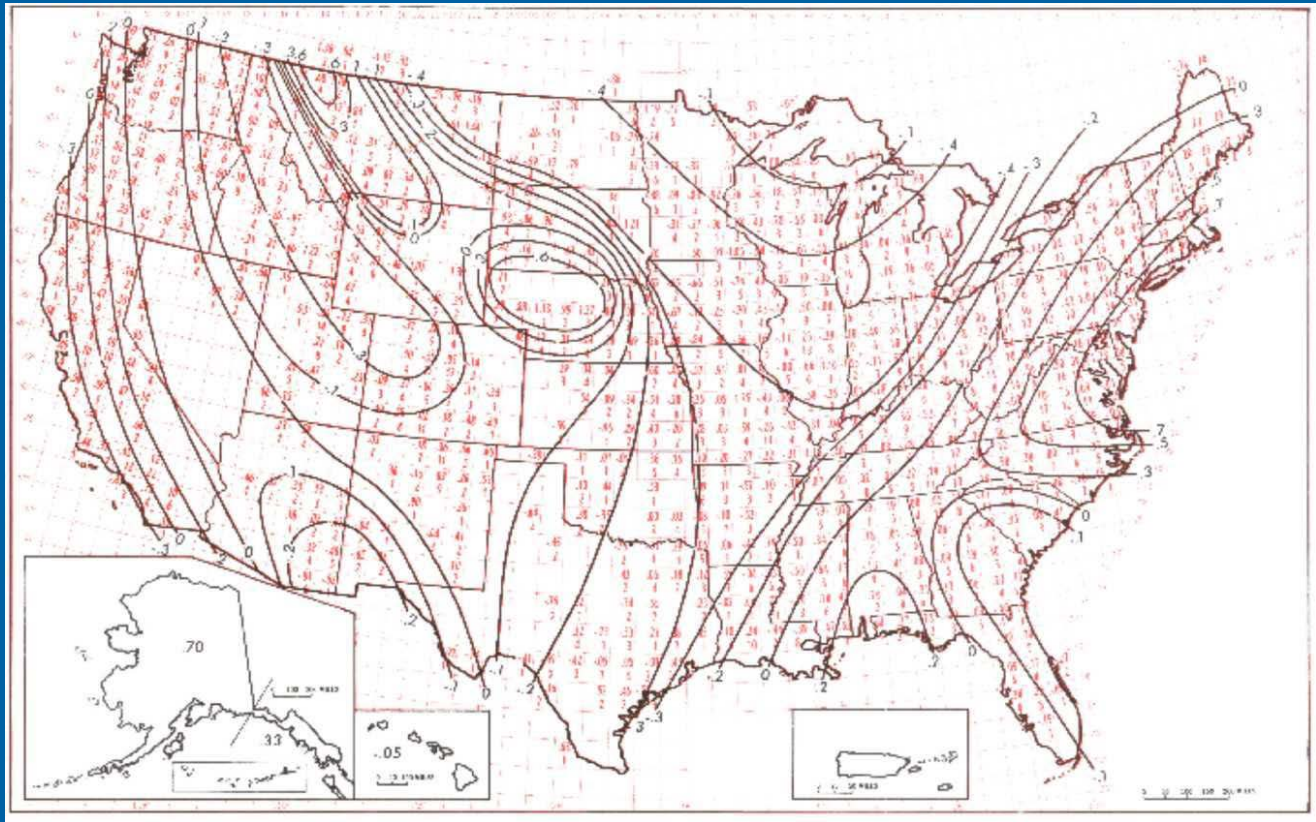


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Peak flow analyses

- Regional (generalized) skew map
  - Developed in 1974
  - Long-term unregulated gages
  - Variance equal to about 17 years of data



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

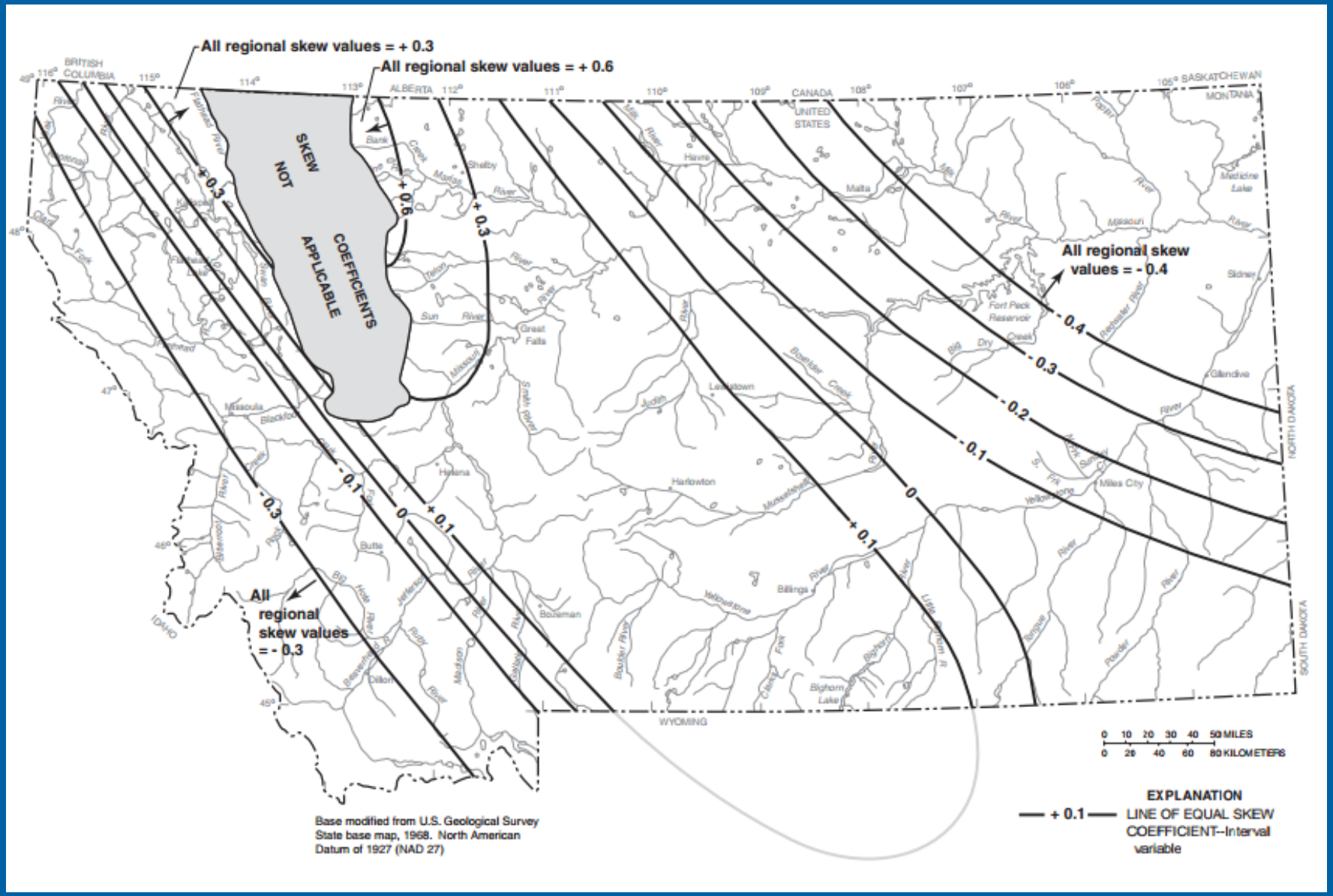
USGS

Peak flow analyses

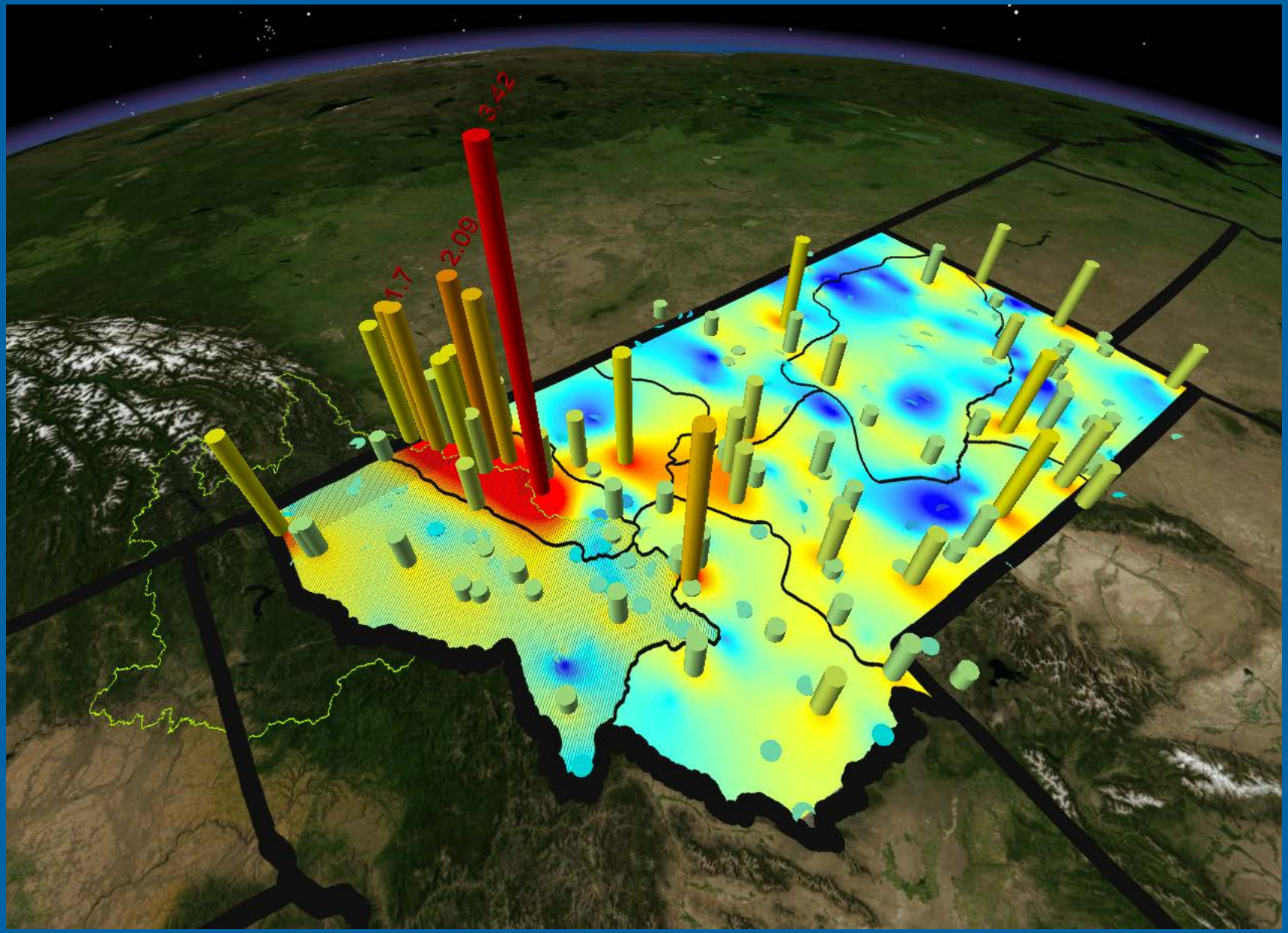
- Weighted skew
  - Computed using the station skew, the generalized skew, and the mean square error of the generalized skew (default is 0.55)
  - Mean square error = 0.64 (WRIR 03-4308)
  - Similar to using an equivalent years of record weighting.
  - Gages with short records have less weight than those with long records.

USGS

Montana skew map (WRIR 03-4308)



Station skew values



Weighted vs. station skew

- Use weighted skew for:
  - Unregulated sites
  - Generally recommended
- Use station skew for:
  - Mixed population sites
  - Regulated sites
  - Sites with several peaks below gage base
- Chapter C tables indicate skew type used in analyses and reason for deviating from using a weighted skew.

USGS

New regional skew studies

- Performed by USGS Office of Surface Water
  - Unregulated gages with 25+ years of record will be included
  - Pacific Northwest study
    - Completed, includes portions of western Montana
    - Excluded high complexity areas
  - Missouri River basin study
    - Due to complexity along the continental divide, all of Montana will be included in this study.

USGS

Mixed population of flood events

- Does Montana have mixed-population floods and can we separate the populations?
  - Snowmelt vs rain
  - Spring rain events commonly occur at same time as high-elevation snowmelt
  - Most of Montana's largest flood events caused by heavy precipitation on streams already at or near bankfull from snowmelt runoff

USGS

Classic mixed population

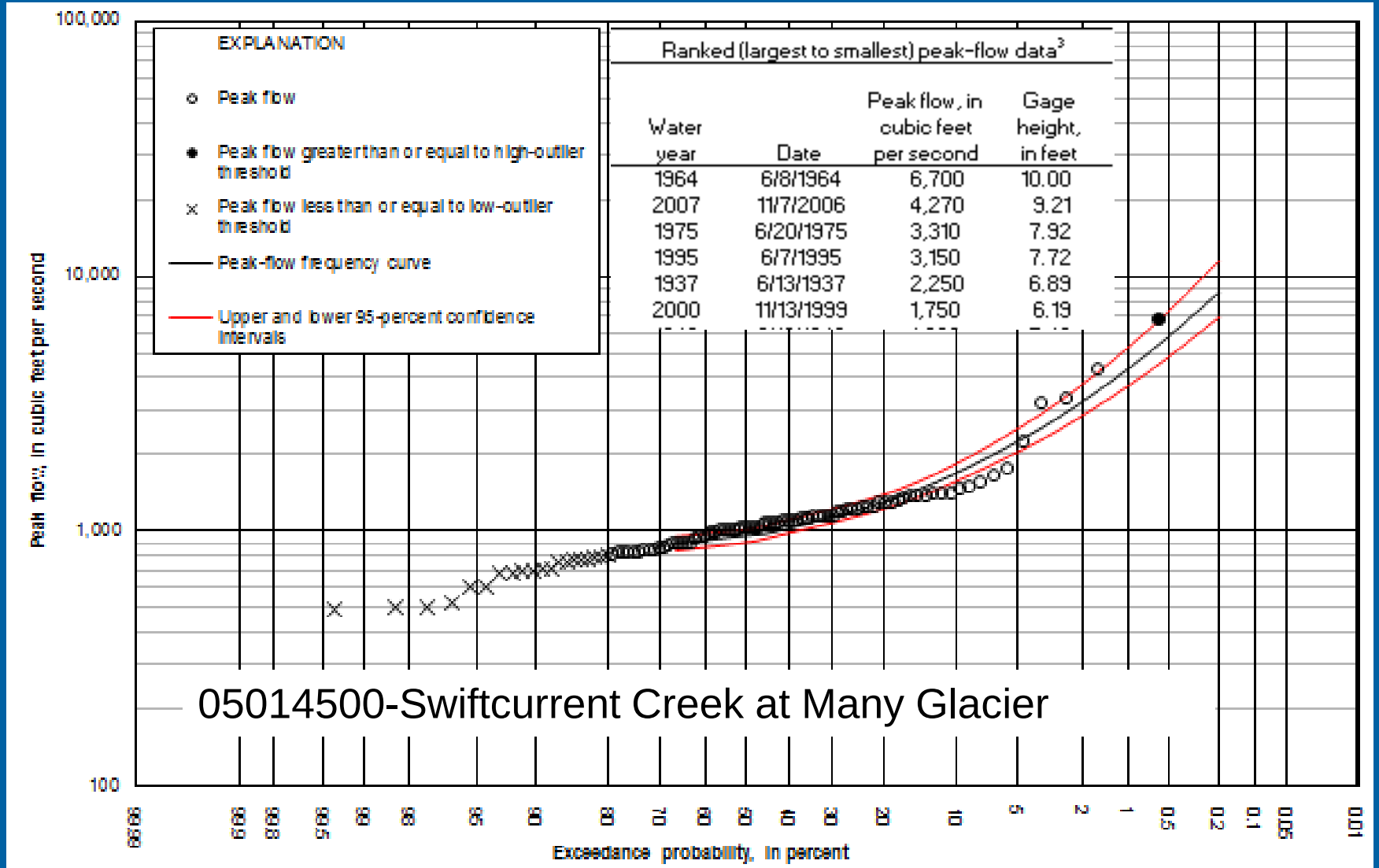


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Addressing mixed populations

- Separate snowmelt vs rainfall and perform at-site mixed population analyses
  - Continuum between snowmelt and runoff as they usually occur during same season.
  - Sites with shorter record may not have rainfall "only" events
- Estimate recurrence interval of extreme events and use as historic length of record
  - What is the recurrence interval for 1964?
  - Need paleo data to truly understand

USGS

Addressing mixed populations

- Regional mixed population analysis
  - Uses normalized and independent peak-flows from all gages.
  - Explored for Northwest foothills, found 500+ events
  - Develop a normalized regional flood frequency curve
  - Apply to each gage
  - Needs homogenous regions

USGS

Addressing mixed populations

- Low-outlier adjustment
  - Use a high low-outlier (cutting off the bottom of peaks)
  - Forces fit to upper end of frequency curve
  - Allows for a site-by-site determination
  - May not fit low end (bankfull) well.
  - Doesn’t address short record sites that don’t include “rainfall” events

USGS

Low-outlier method

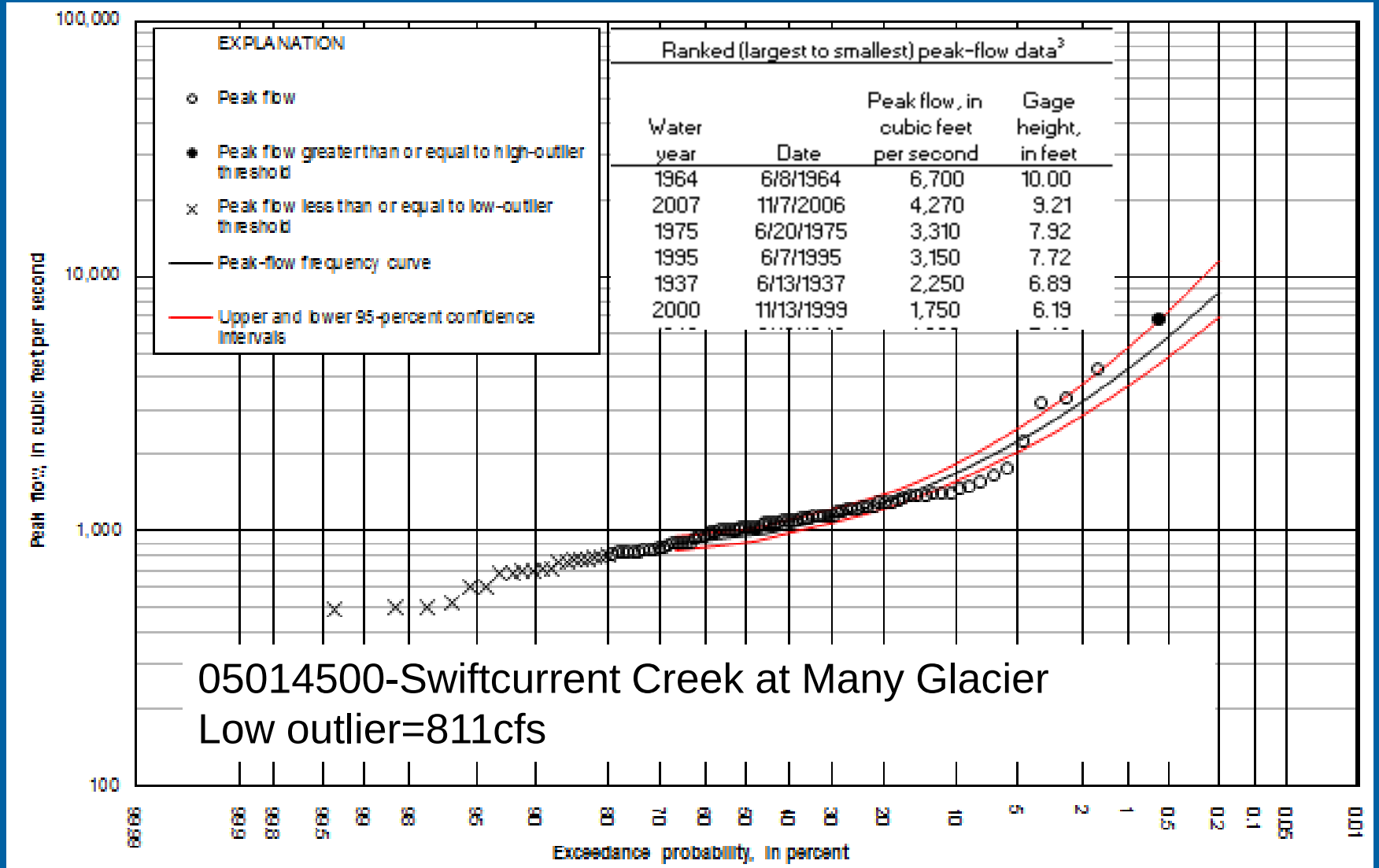


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Low-outlier method

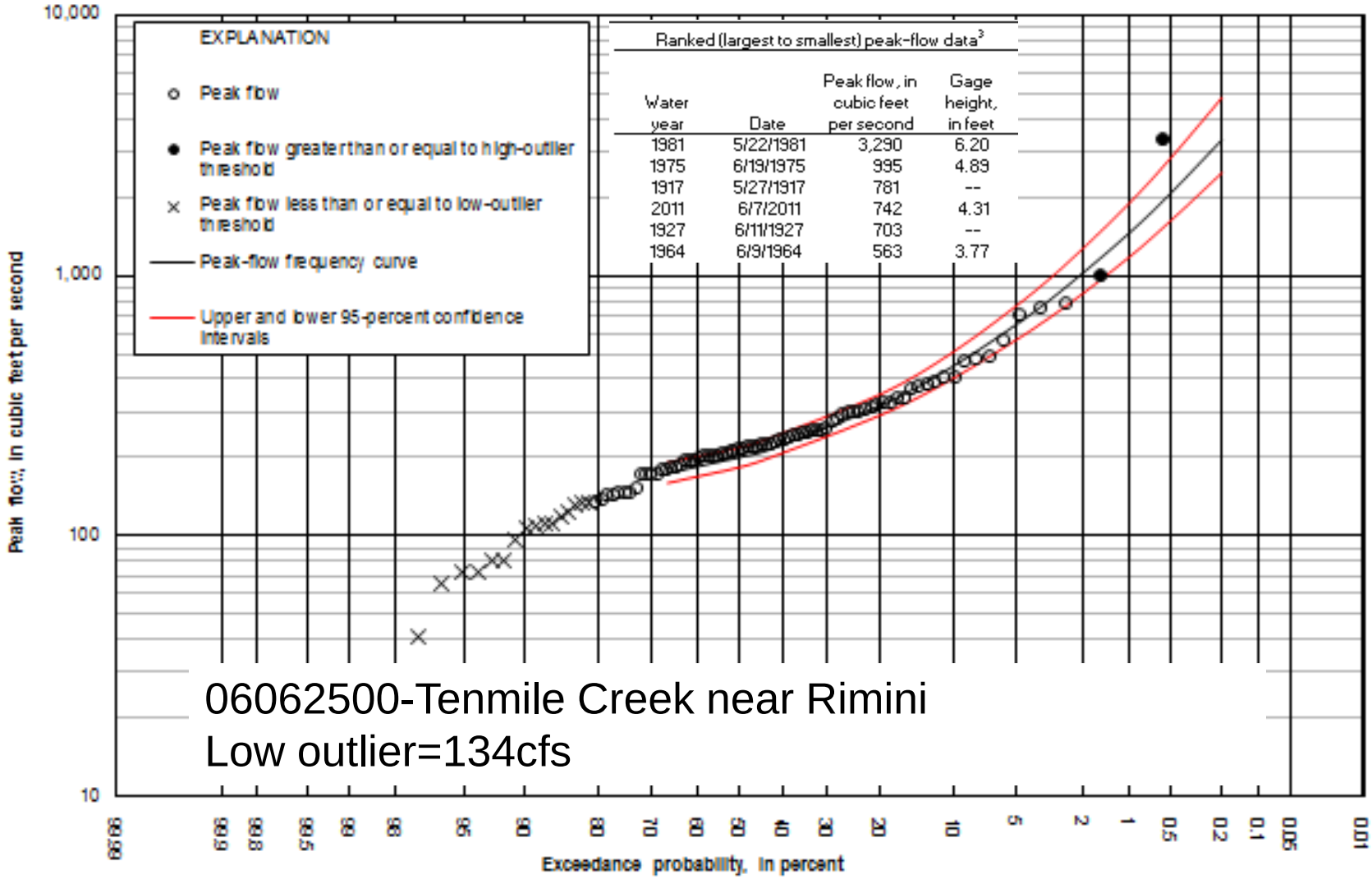


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Low-outlier method

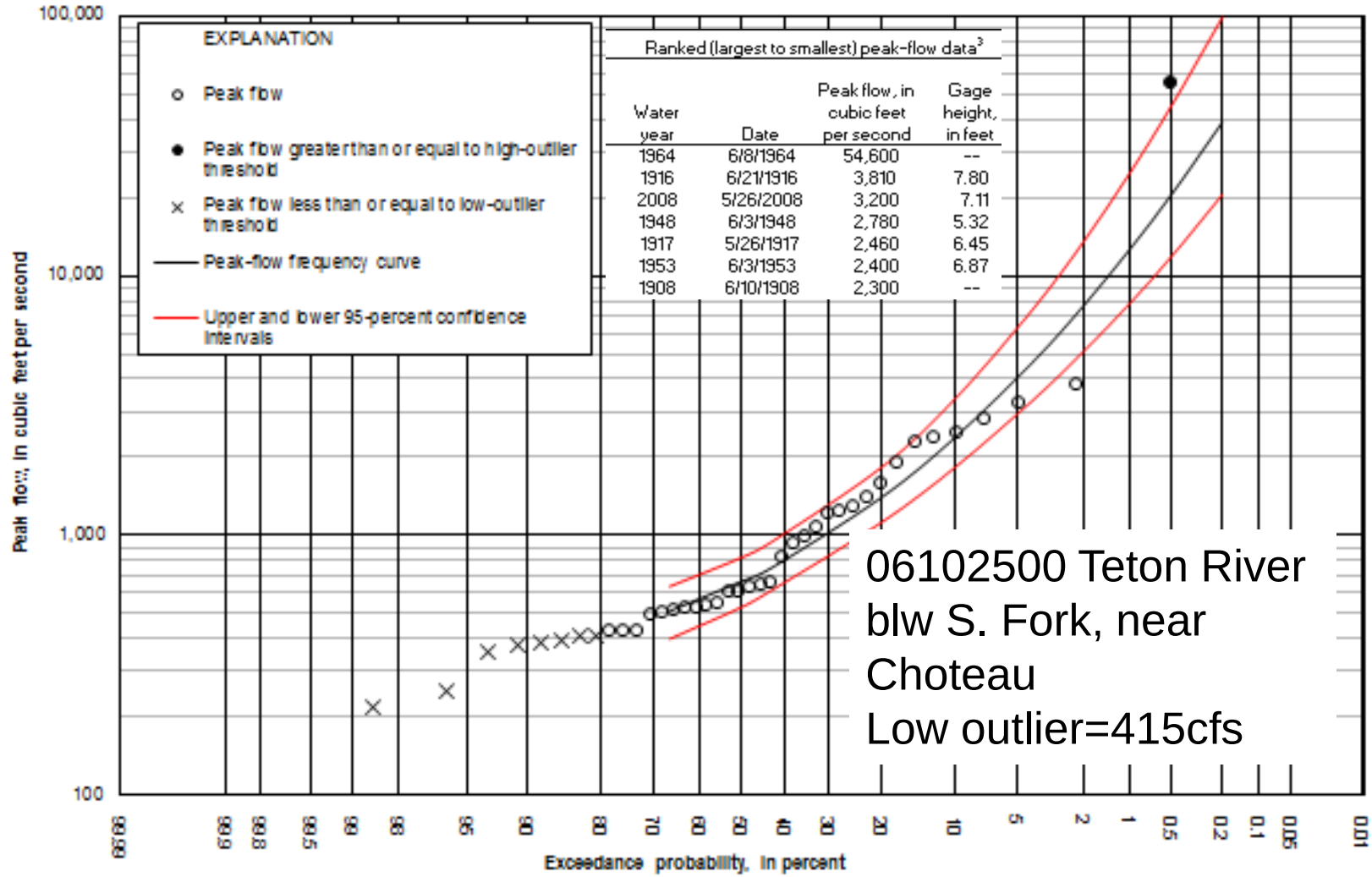
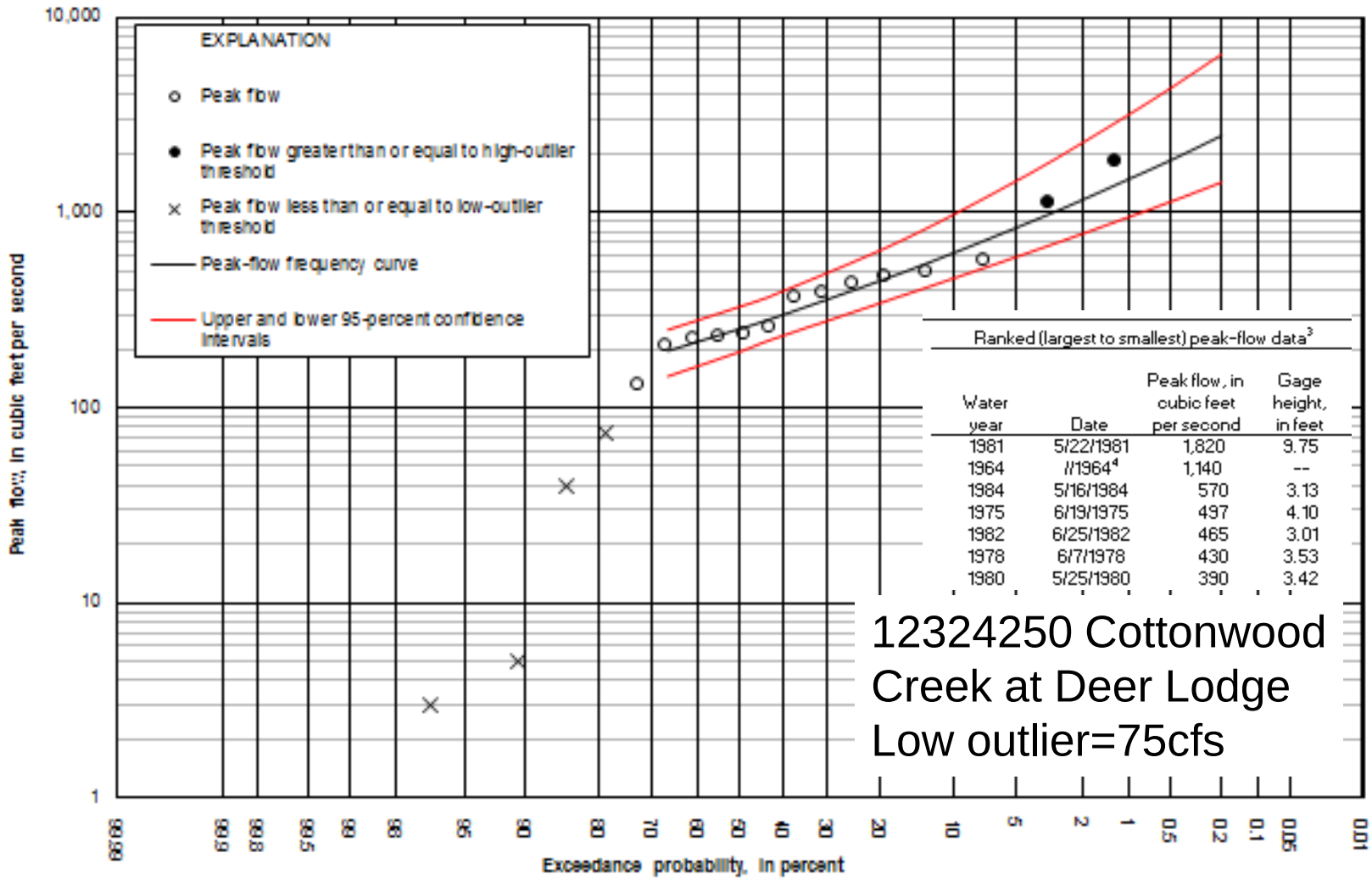


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Low-outlier method



Ranked (largest to smallest) peak-flow data[3]

Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1981	5/22/1981	1,820	9.75
1964	//1964[4]	1,140	--
1984	5/16/1984	570	3.13
1975	6/19/1975	497	4.10
1982	6/25/1982	465	3.01
1978	6/7/1978	430	3.53
1980	5/25/1980	390	3.42

Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Historic peaks – Code 7

- As coded in peak flow file
  - Separate peak from systematic record
  - Largest peak in an ungaged period (not notated)
  - Can be multiple historic peaks
- As used by B17B
  - Only 1 historic value can be used-sometimes this is from a systematic peak
  - Opportunistic peaks should be excluded
  - Historic record length should be determined by evidence

USGS

Below gage base

- Primarily CSGs
- A peak may have occurred, but it was below our ability to measure

Regulation review

- Regulated
  - 20 percent or more of basin is upstream from dams
  - Determined using GIS analyses and NHDPlusV2 dams layer
- Major regulation
  - 20 percent or more of basin is upstream from a single dam
  - Major diversion from stream
- Minor regulation
  - No single dam exceeds 20 percent, but cumulative area exceeds 20 percent

USGS

Classic major regulation

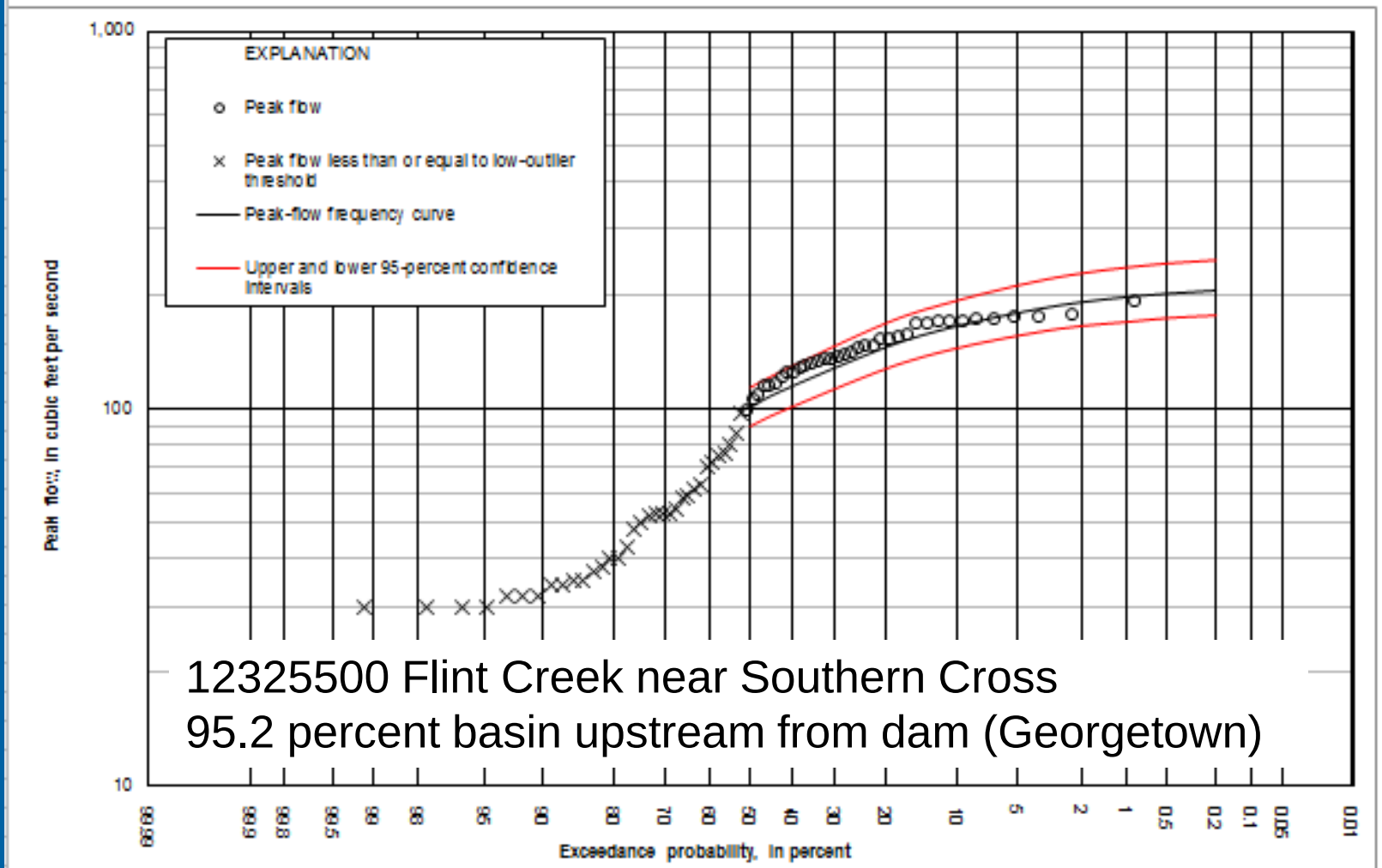
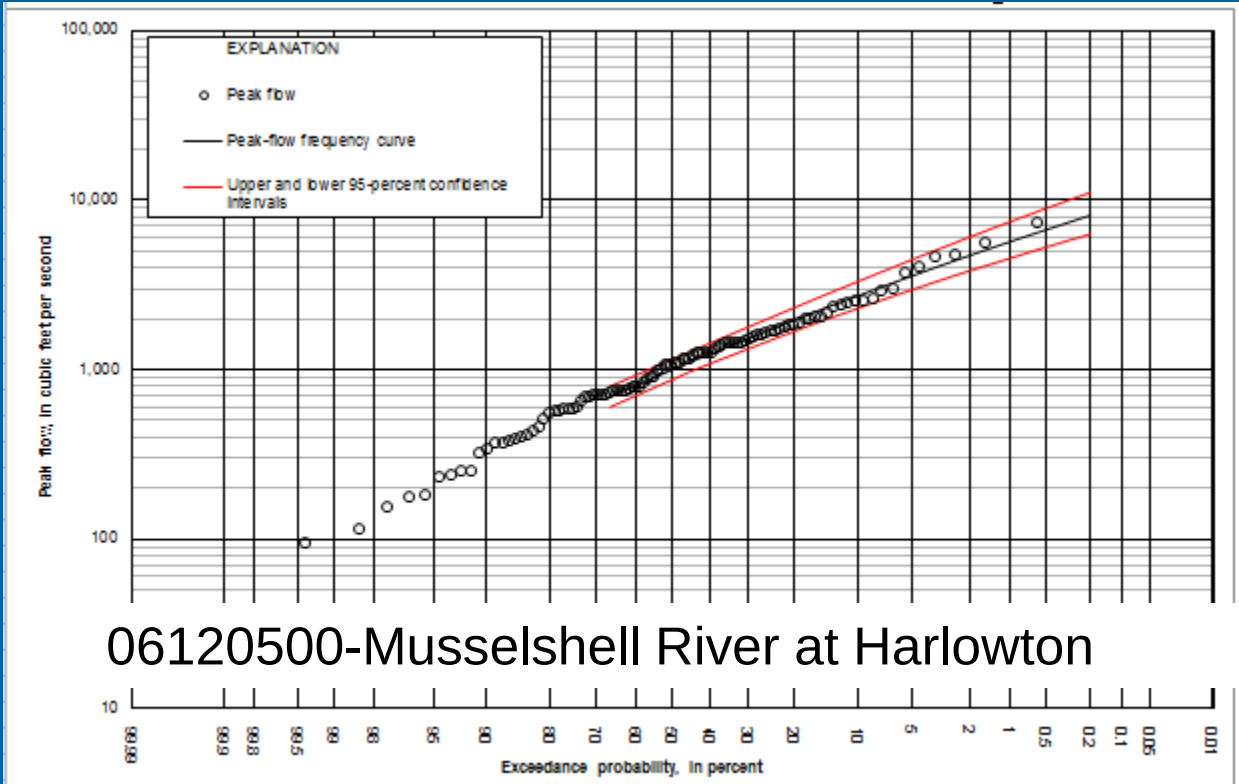


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Minor regulation

- 06120500-Musselshell River at Harlowton
  - 24.7 percent of basin is upstream from dams (R)
  - No single dam exceeds 20 percent=minor
  - Total period of record used in analysis
  - Used in regression equations

19.9% in 1956



06120500-Musselshell River at Harlowton

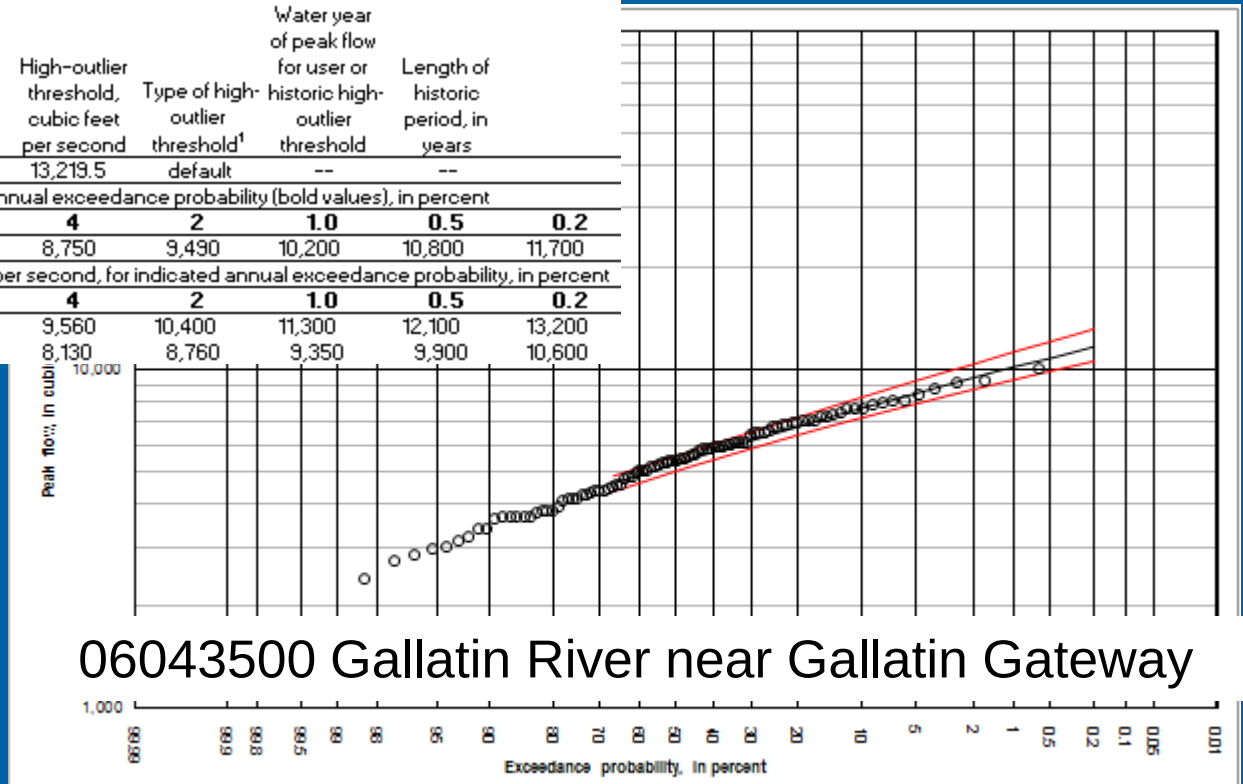
Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

USGS

Confidence Intervals

- **Reported at 95 percent**
- **Longer records typically have tighter confidence intervals**

Drainage area, square miles	Number of years of peak-flow records in analysis period	Skew type used in analysis	Low-outlier threshold, cubic feet per second	Type of low-outlier threshold[1]	High-outlier threshold, cubic feet per second	Type of high-outlier threshold[1]	Water year of peak flow for user or historic high-outlier threshold	Length of historic period, in years	
825	98	WEIGHTED	1,945	default	13,219.5	default	--	--	
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent									
66.7	**50**	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
4,620	5,280	5,580	6,790	7,700	8,750	9,490	10,200	10,800	11,700
Upper and lower 95-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent									
[3]66.7	**50**	**[3]42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
4,860	5,560	5,890	7,240	8,300	9,560	10,400	11,300	12,100	13,200
4,370	5,020	5,300	6,420	7,220	8,130	8,760	9,350	9,900	10,600



06043500 Gallatin River near Gallatin Gateway

Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

USGS

Confidence Intervals

- What is the 1% AEP?

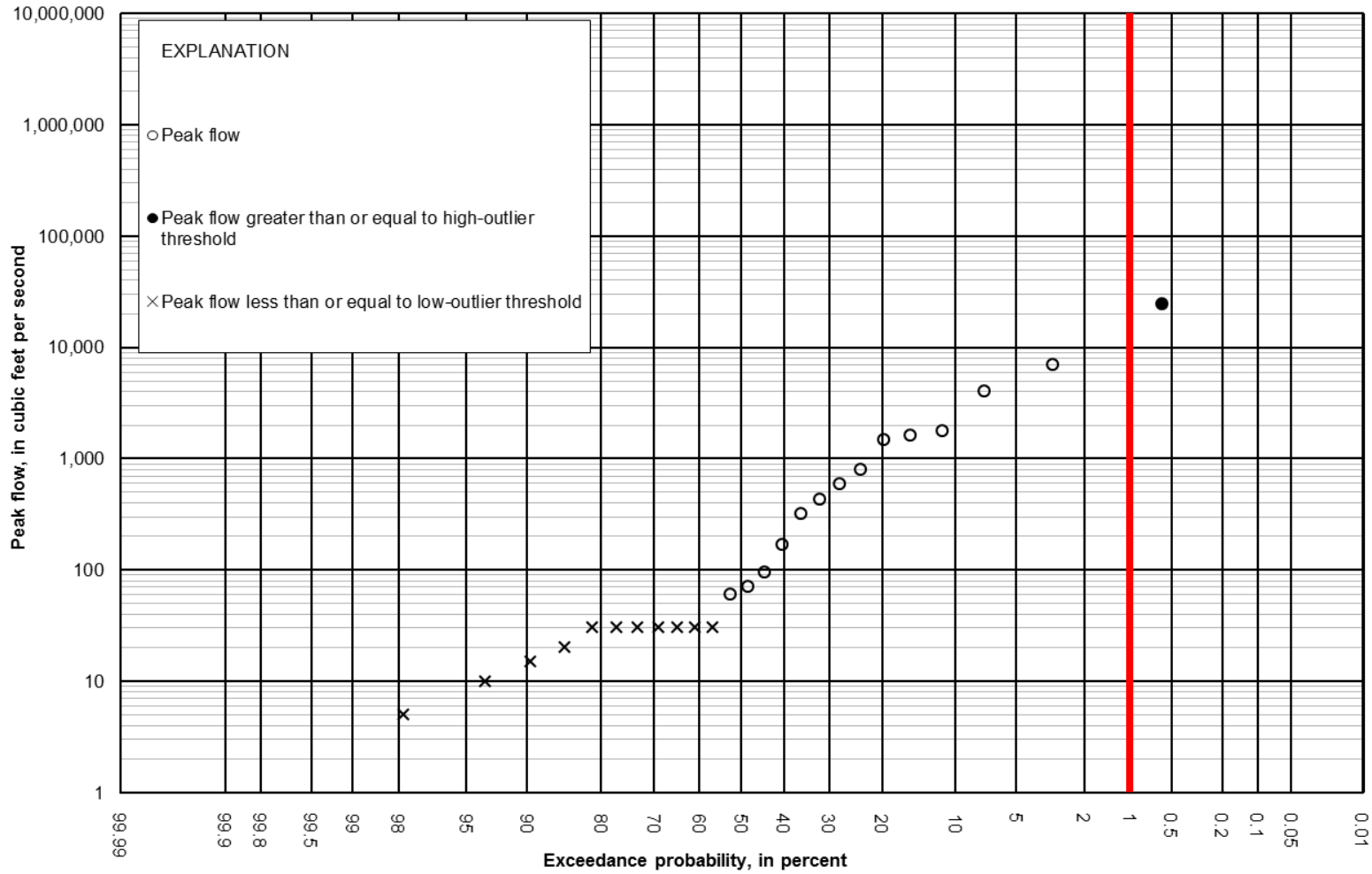


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Confidence Intervals

- **Some sites have extremely large confidence intervals**

Drainage area, square miles	Number of years of peak-flow records in analysis period	Skew type used in analysis	Low-outlier threshold, cubic feet per second	Type of low-outlier threshold[1]	High-outlier threshold, cubic feet per second	Type of high-outlier threshold[1]	Water year of peak flow for user or historic high-outlier threshold	Length of historic period, in years	
90.85	25	WEIGHTED	30	user	24,400	historic	1950	103	
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent									
66.7	**50**	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
NR[5]	66	120	835	2,650	8,010	15,400	26,500	42,200	71,000
Upper and lower 95-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent									
[3]66.7	**50**	**[3]42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
NR[5]	215	393	3,920	16,000	63,600	145,000	288,000	522,000	1,020,000
NR[5]	21	39	254	724	1,920	3,360	5,350	7,940	12,400

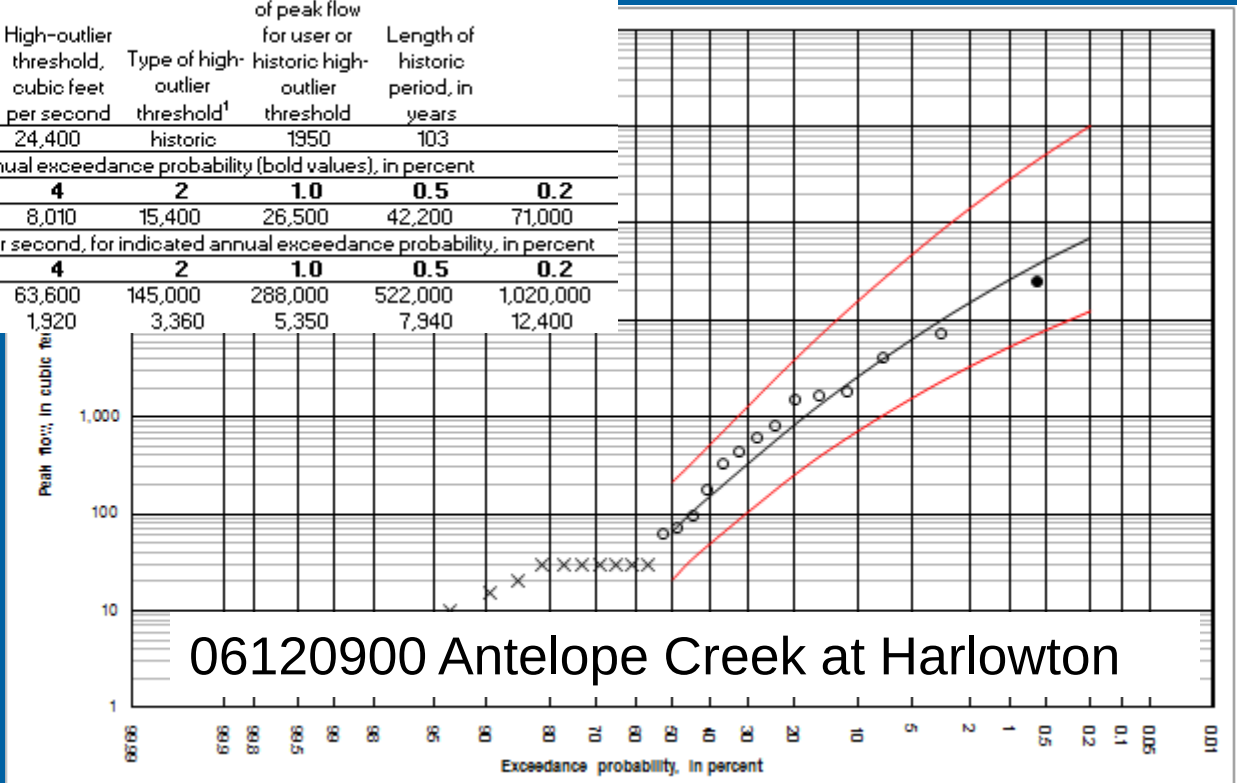


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

1-percent AEP confidence intervals

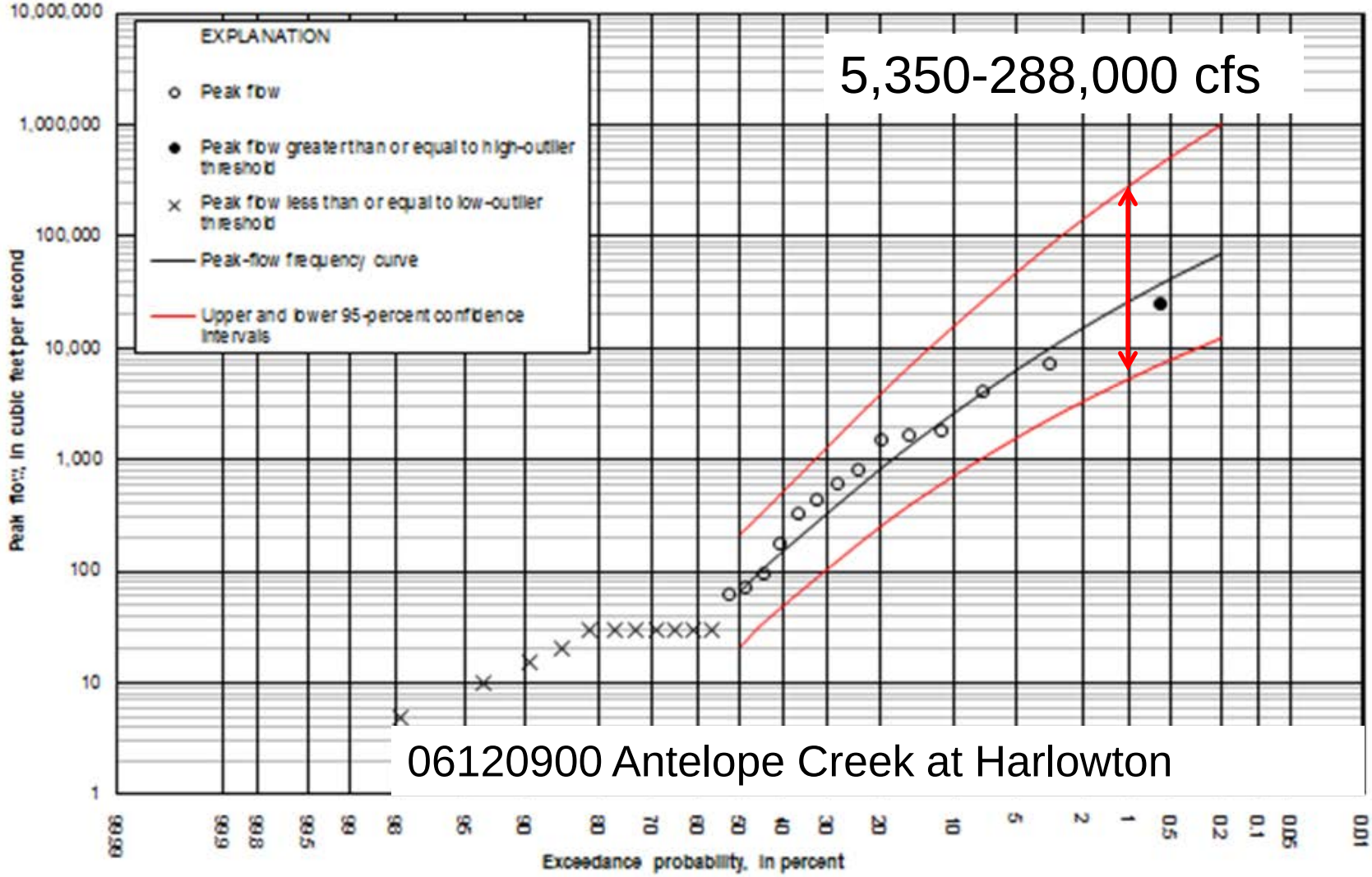


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Q=10,000 cfs What is the AEP?

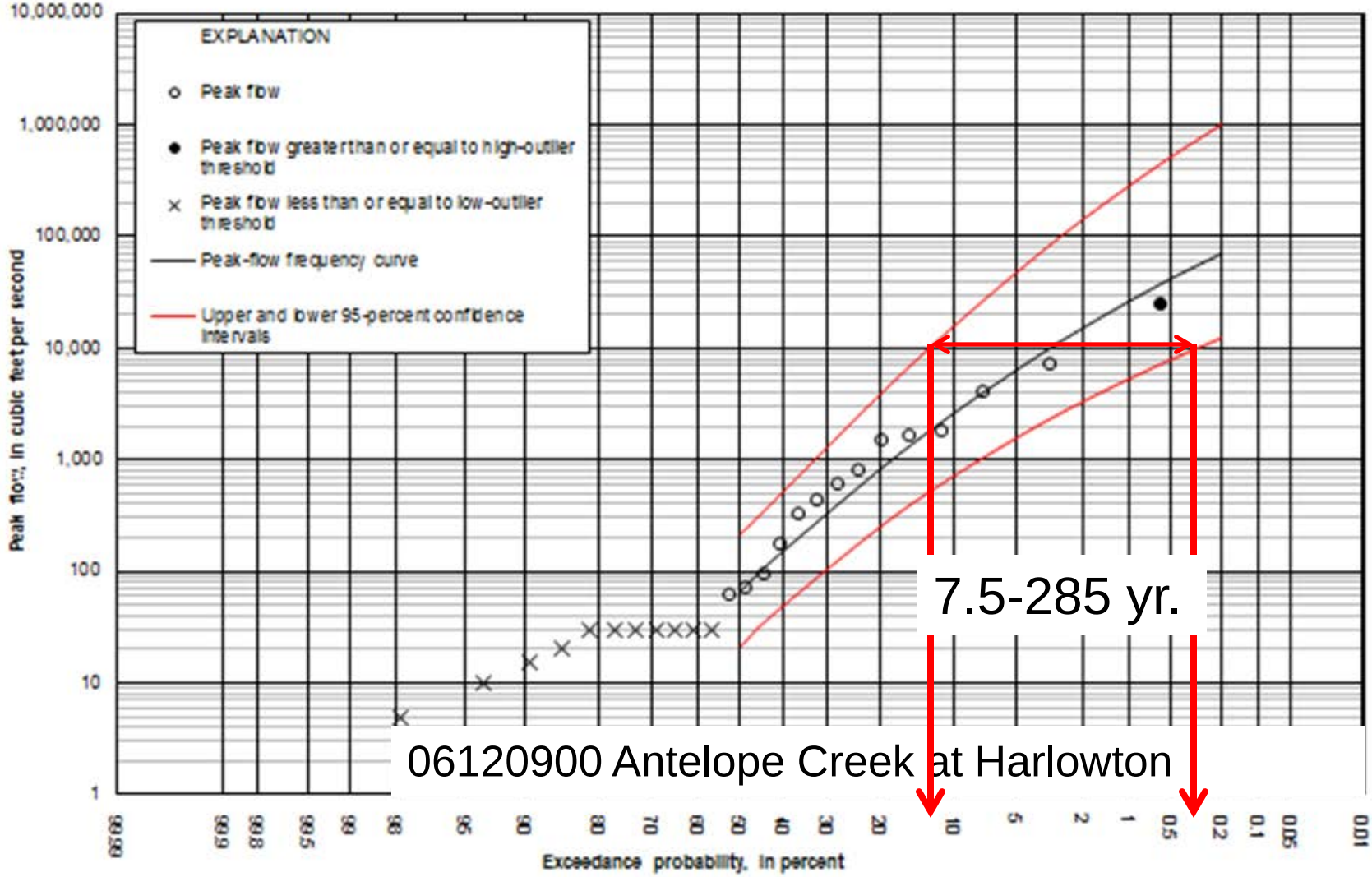


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Confidence Intervals

- Record length

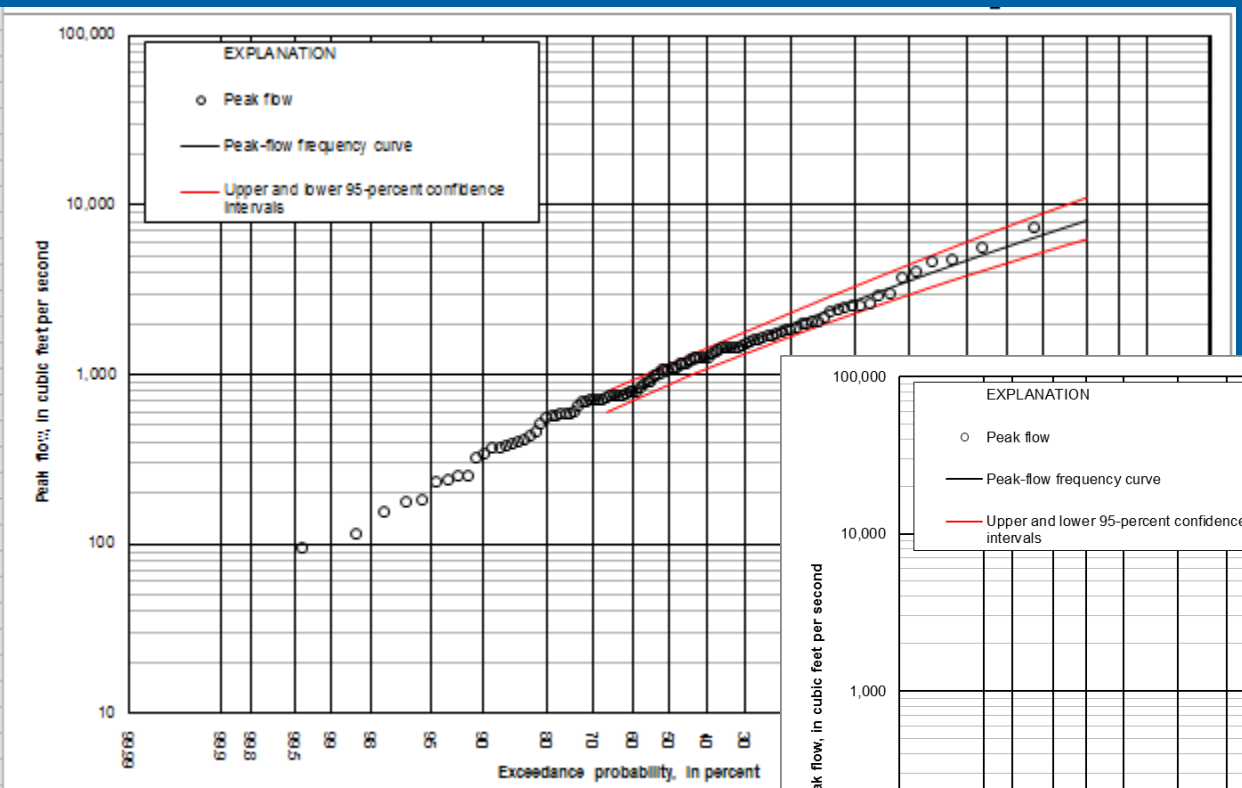


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; He

Musselshell at Harlowton vs. Shawmut

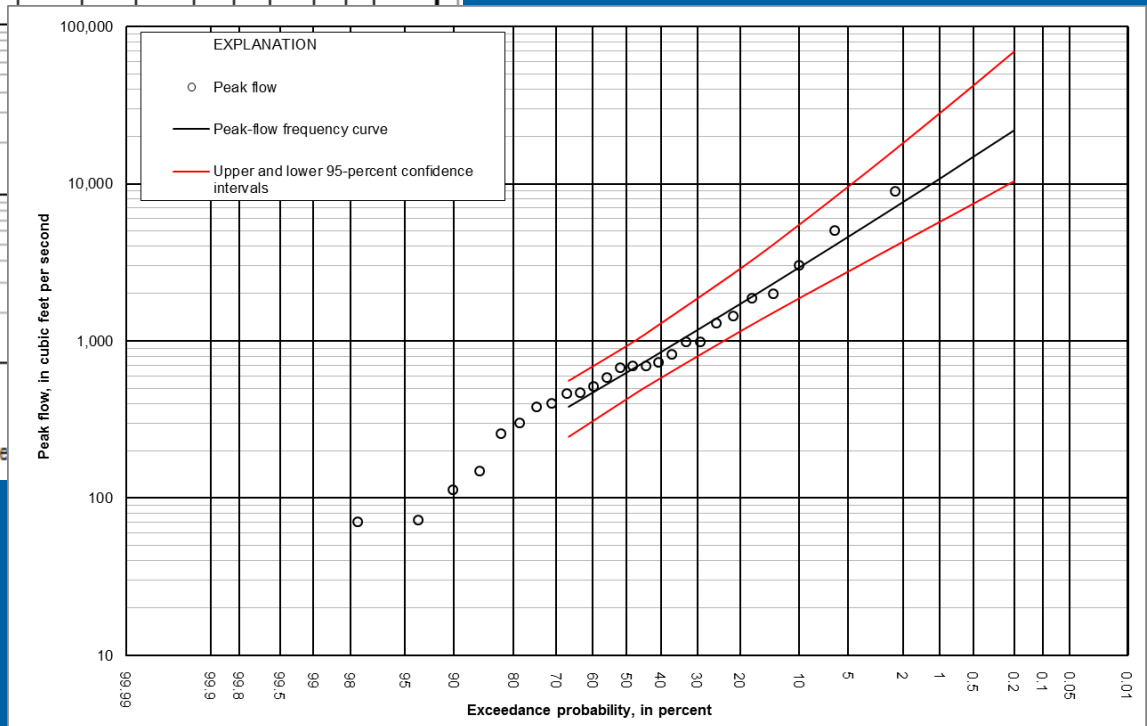


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

USGS

New vs. Old analysis

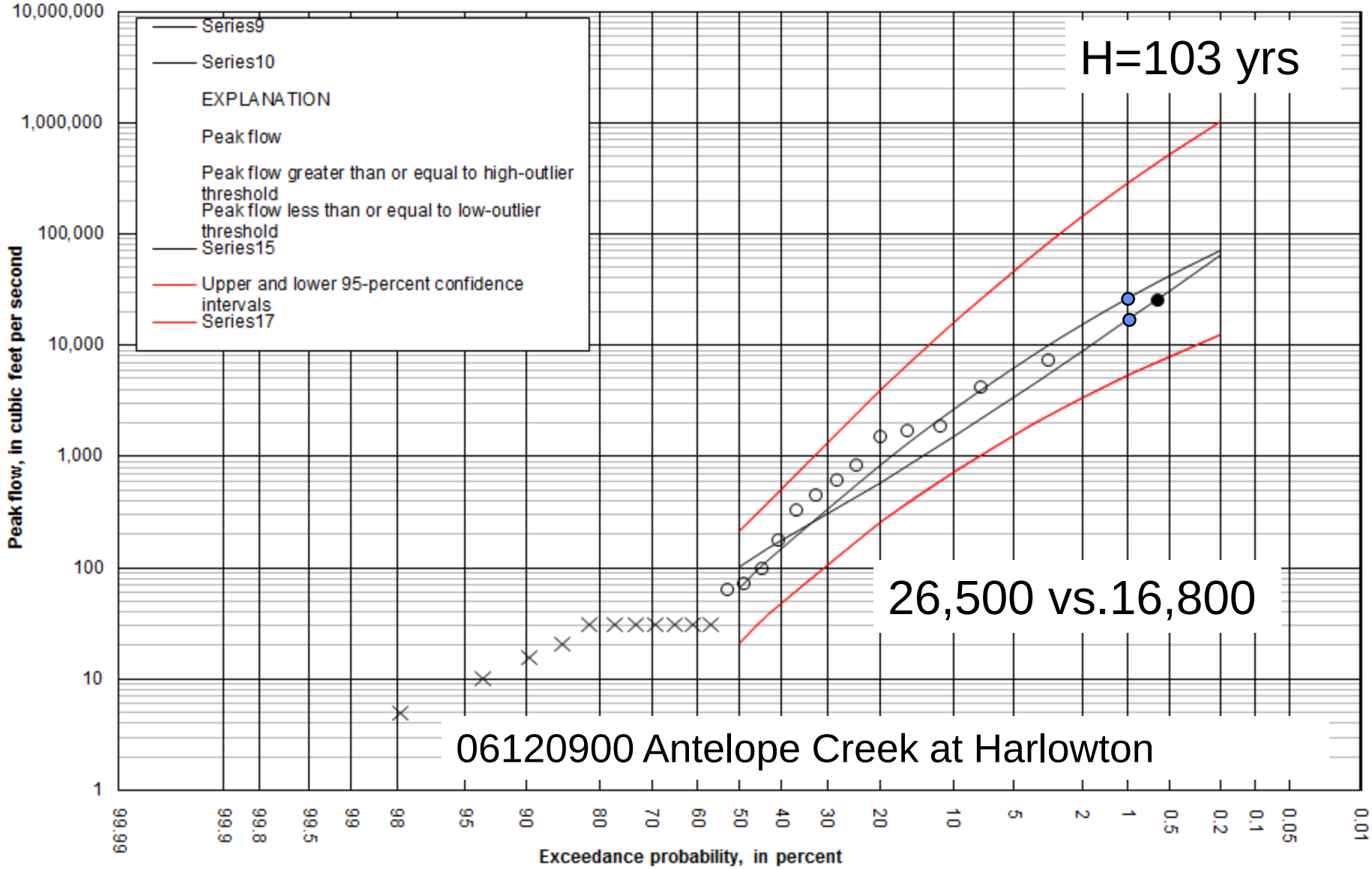


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Chapter C spreadsheets

- Review spreadsheets