Regional regression equations

- Regional Regression Equations provide estimates of flood frequencies at ungaged sites where we don’t have peak-flow data and computed flood frequencies.
- Equations are developed for regions with similar hydrologic characteristics. Unfortunately there are still boundaries.
- Equations also are weighted with at-site flood frequencies for sites with a short period of record

USGS

Regional regression equations

- 8 hydrologic regions
- 537 gaging stations
  - Drainage area less than ~2,500 sq. mi.
  - Systematic record unaffected by major regulation
  - No redundancy with nearby stations
  - Representation of peak-flow characteristics in MT
- 28 candidate basin characteristics

  A, EL_{5000}, EL_{6000}, ET_{SPR}, F, P, SLP_{30}

USGS

Regional regression equations

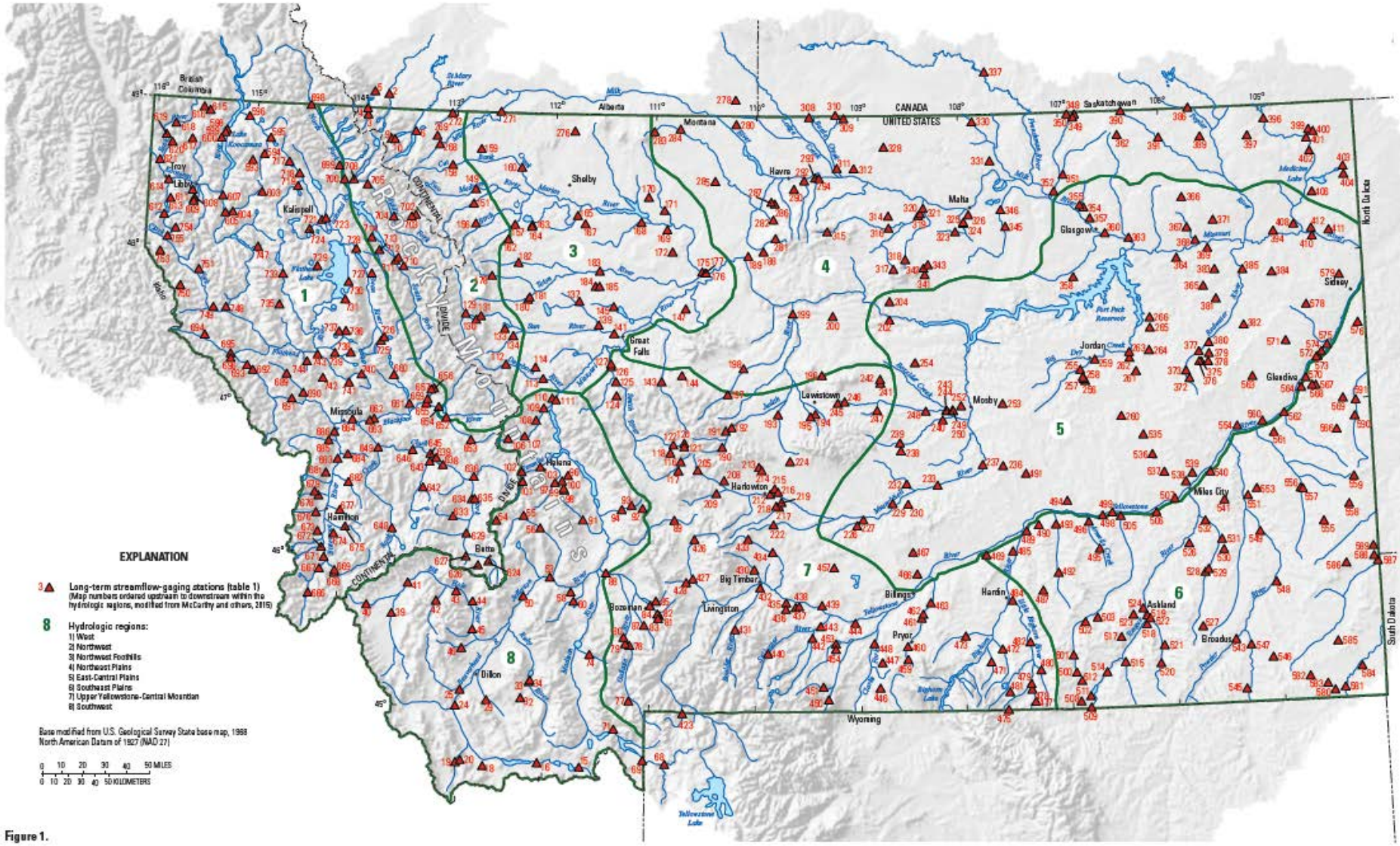
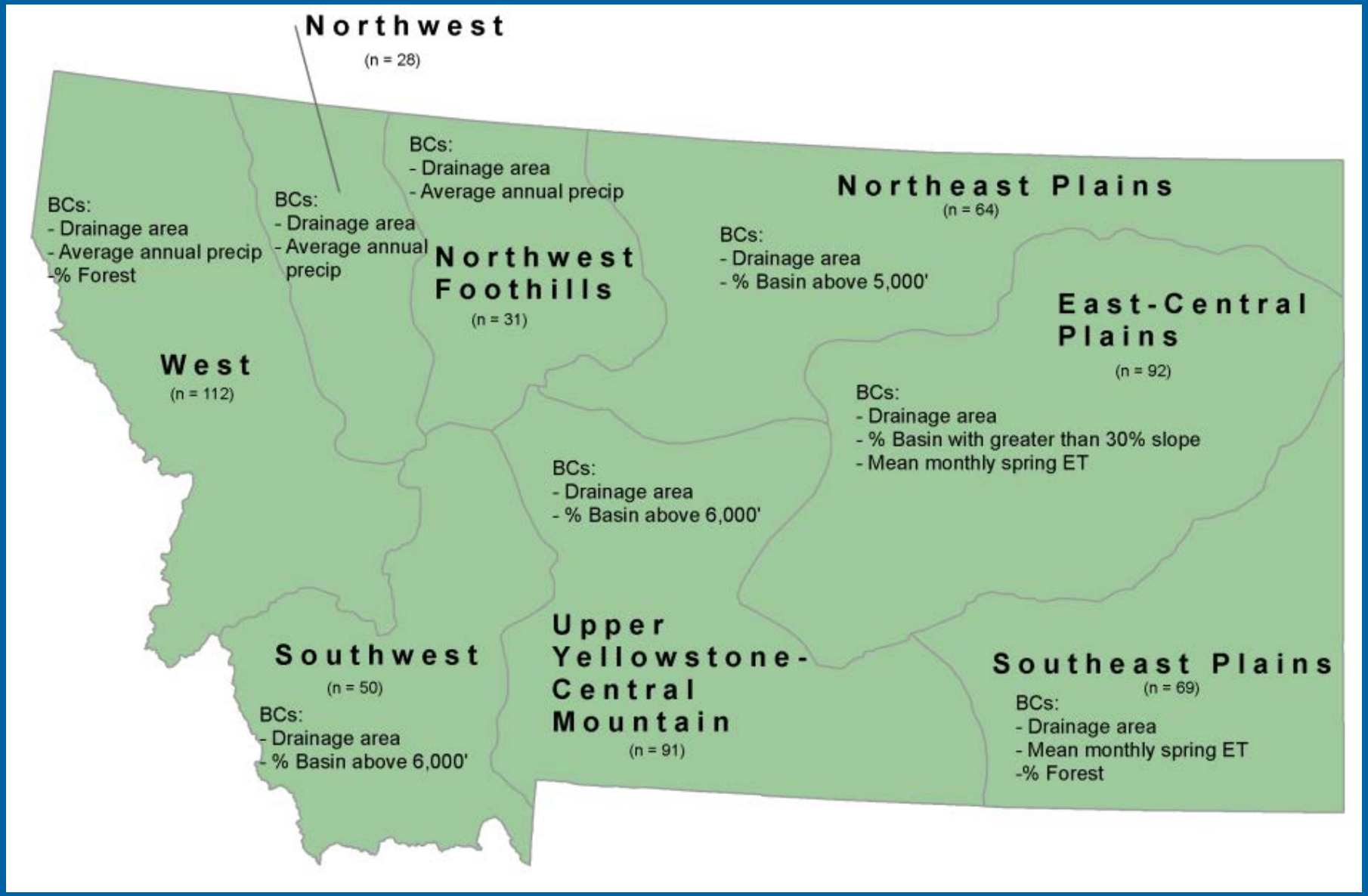
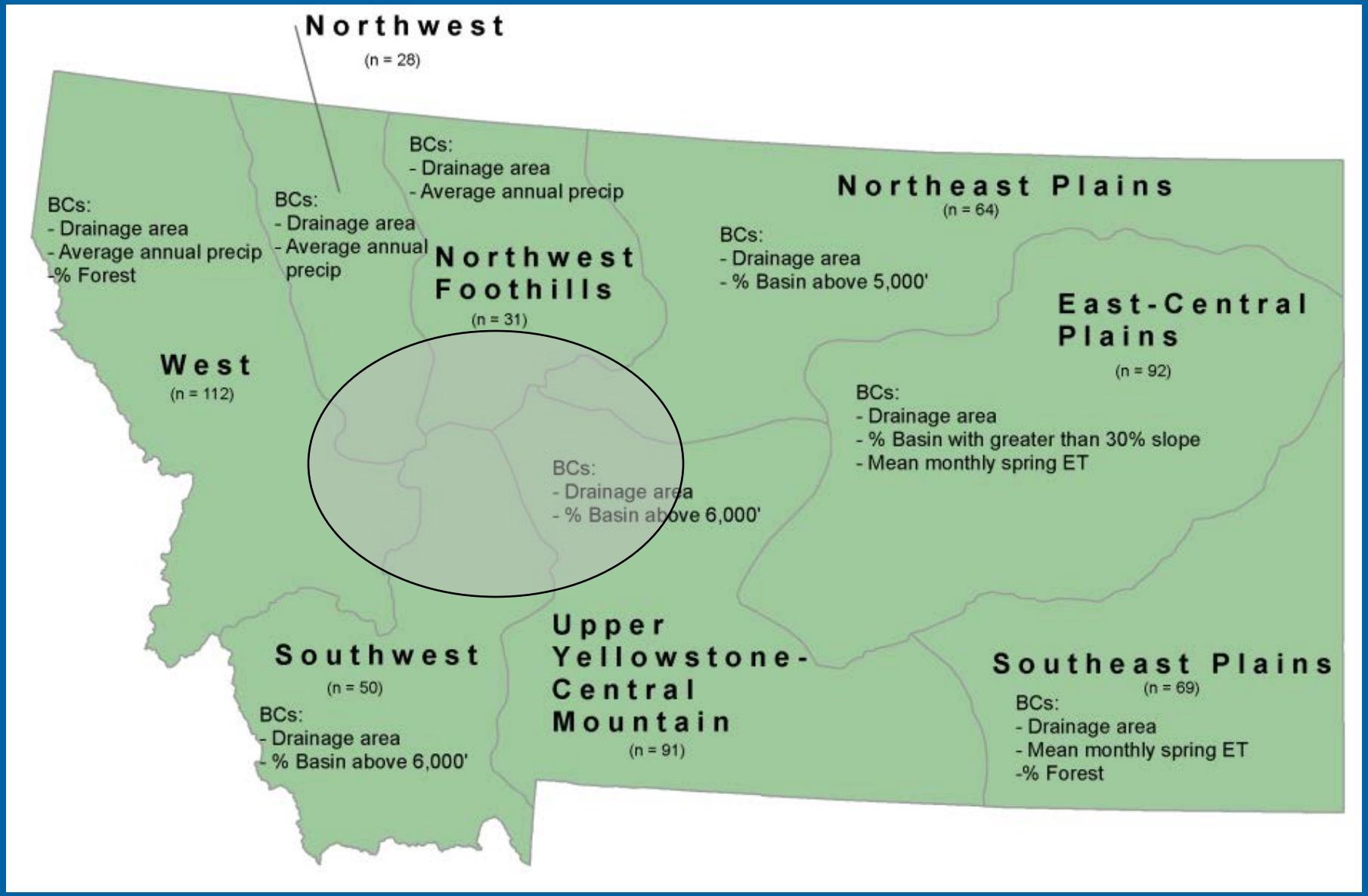


Figure 1.

Regional regression equations



Regional regression equations



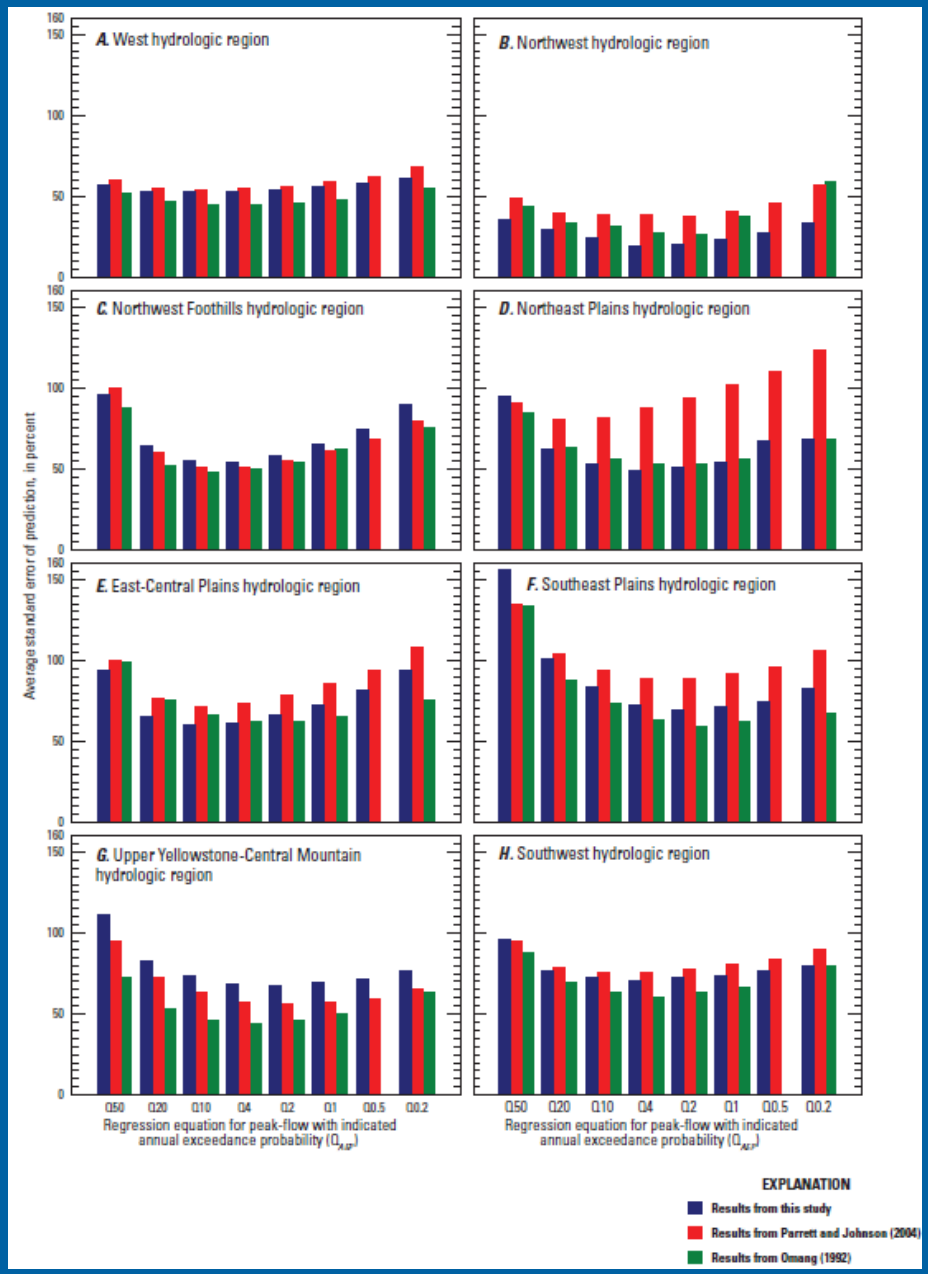
Standard Error of Prediction (SEP)

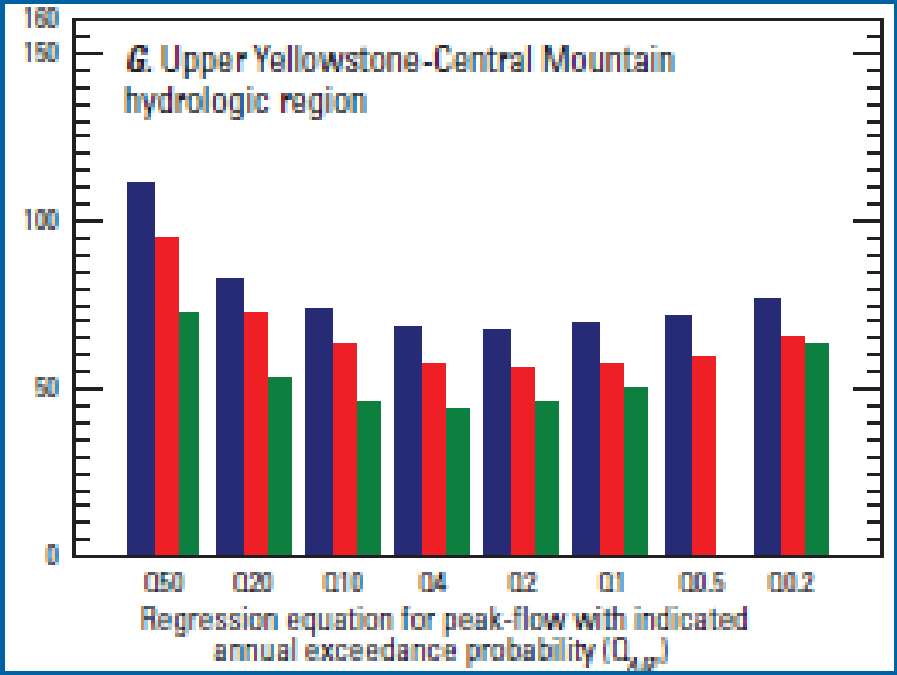
"The 1982 report has a lower SEP so I decided to use those equations…."

- **The <u>standard error of prediction</u> is a measure of how well the regression equations predict flood frequency magnitudes and is used for selecting the best equation <u>for the given data</u>.**
- **New study has <u>*different* SEPs</u> because we are using <u>*different data, gages, and methods*</u>.**
- **Comparing SEPs from 2 data sets, is like apples to oranges.**

USGS

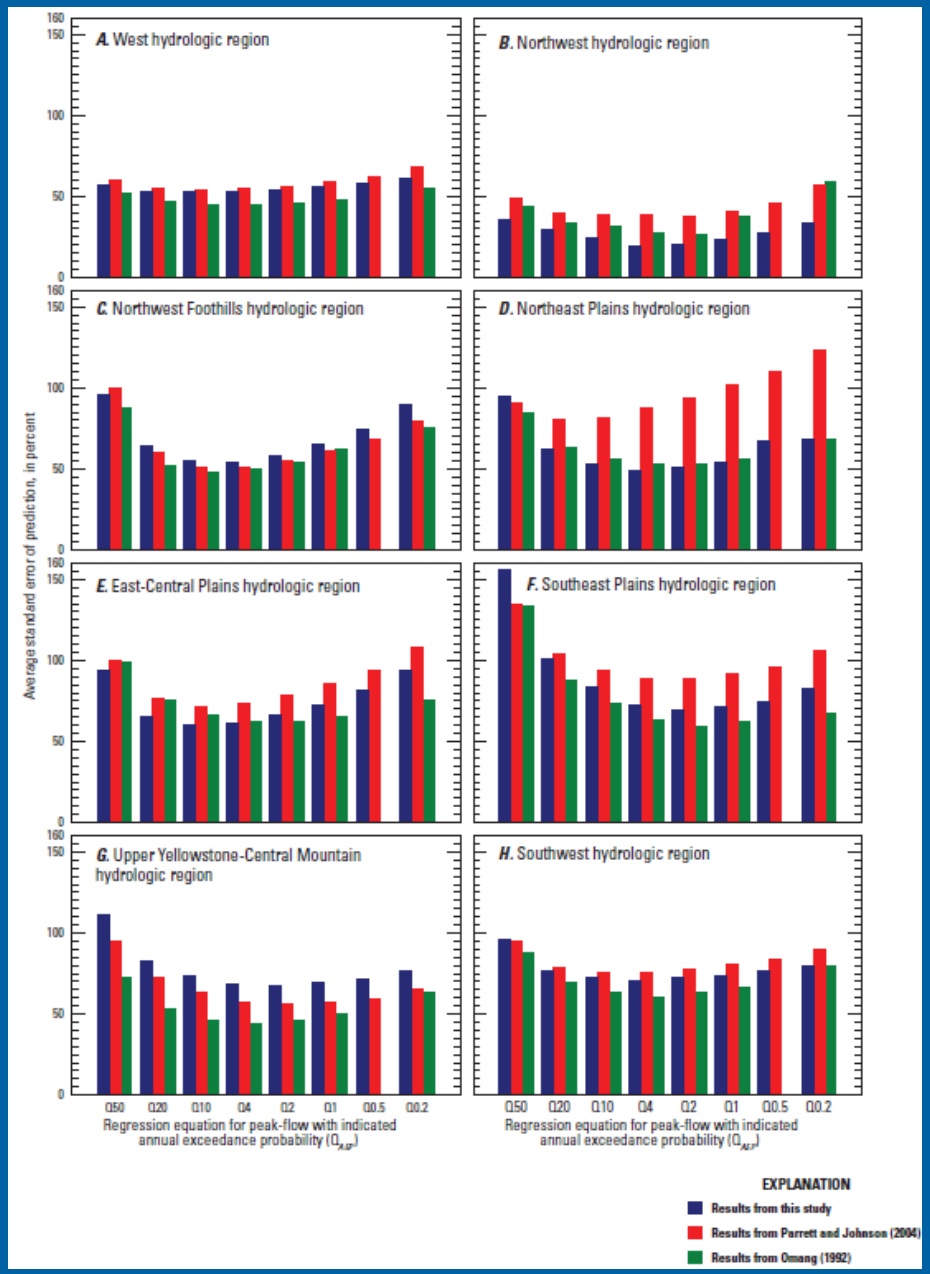
SEP using *different data*

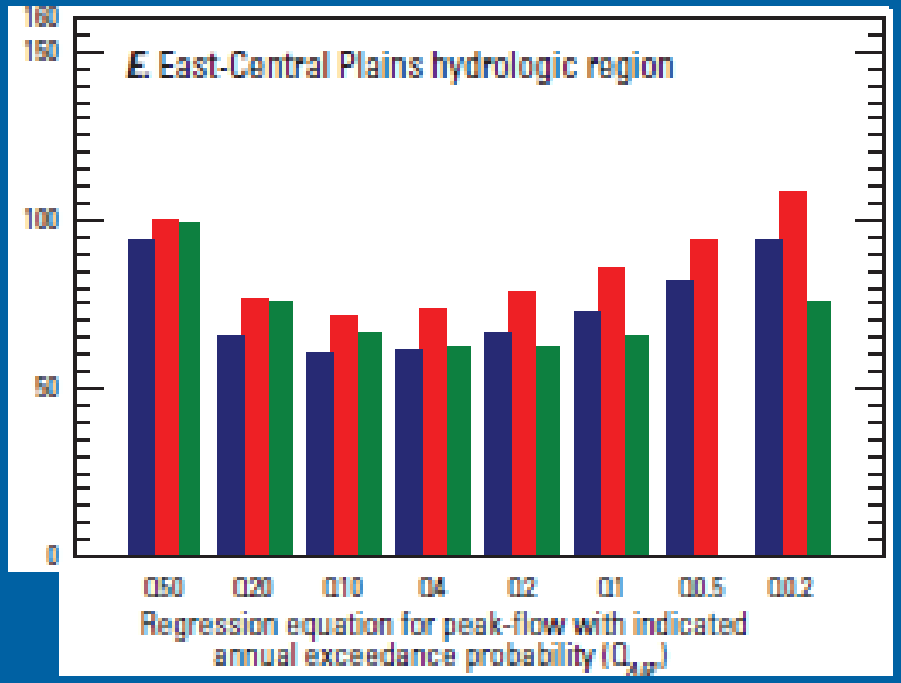




	WRIR 03-4308	Current study
Explanatory variables	Drainage area and percent of basin above 6,000 ft.	
Gages (*n*)	92	91
Peaks	2,819	3,087 (+9.5%)
Avg. peaks per gage	30.6	33.9
Method	Generalized least squares	

SEP using *different data and equations*

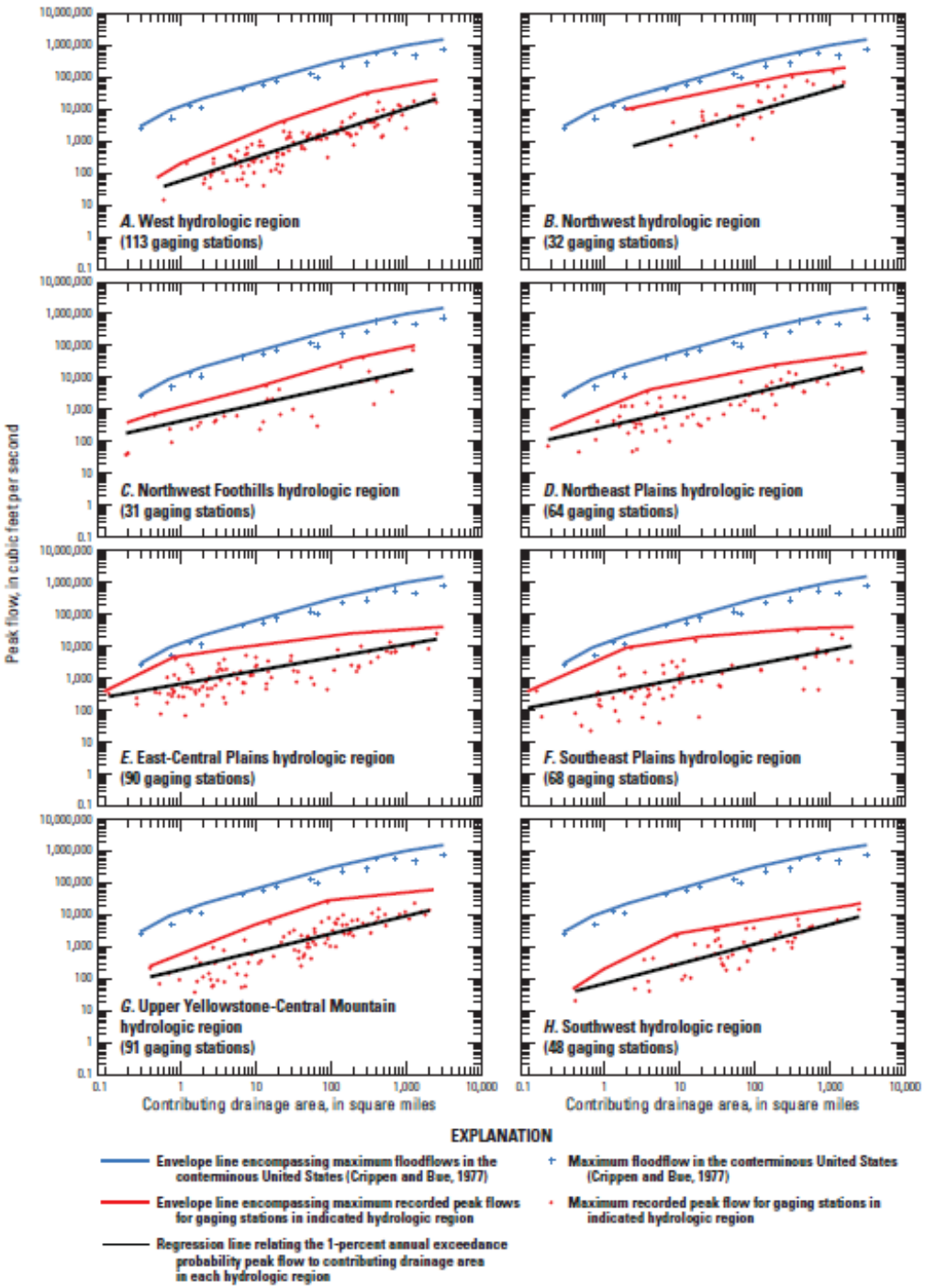




	WRIR 03-4308	Current study
Explanatory variables	DA & Elev/1000	DA, SLP_{30}, ET_{SPR}
Gages (*n*)	85	90
Peaks	1,976	2,464 (+25%)
Avg. peaks per gage	23.2	27.4
Method	Generalized least squares	

Envelope Curves

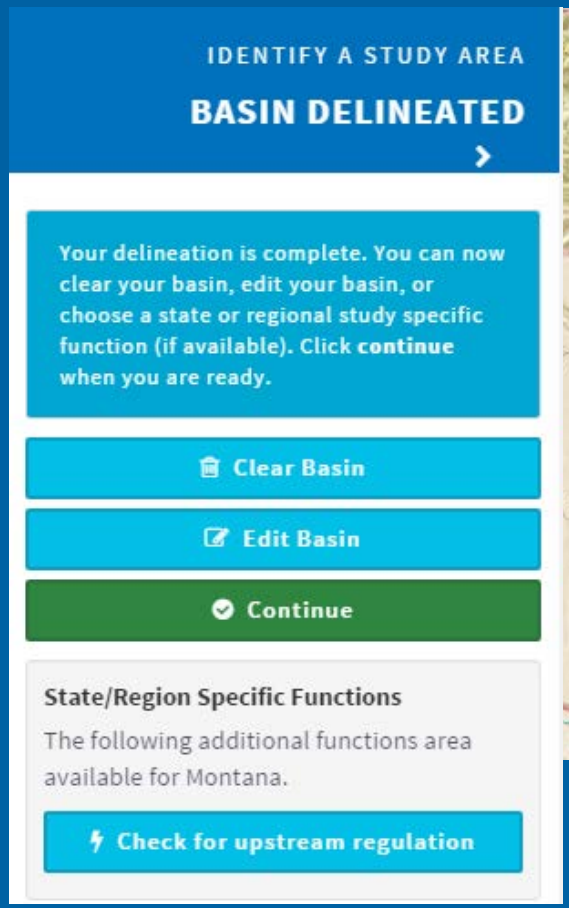
- Number of gages
- Distribution of gages with respect to drainage area in each region

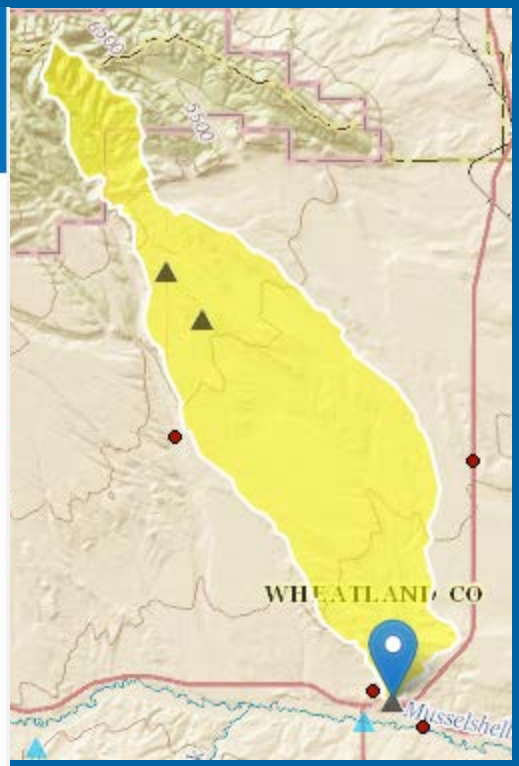


USGS

Example of Regression Equations

- StreamStats
  - Zoom until streamlines are pixels
  - Use the delineation tool and select pixel on streamline
  - Edit basin if needed
  - Check for regulation
  - Compute basin characteristics





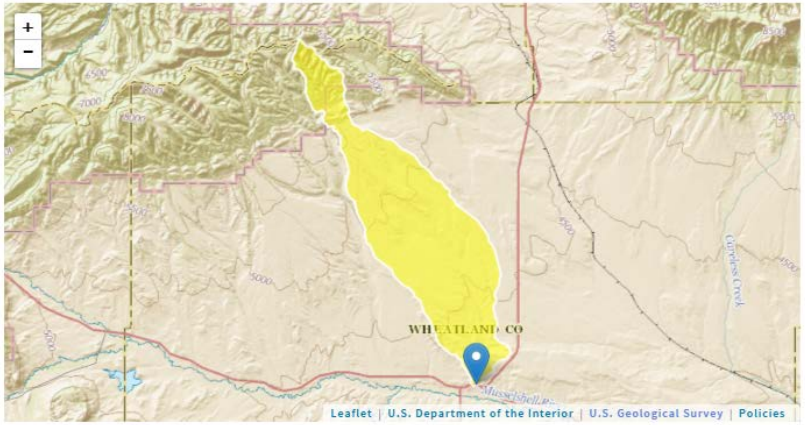
USGS

Example

- StreamStats
  - Will eventually compute AEP
  - Until then….
    - Determine region
    - Determine necessary BCs
    - Compute

StreamStats Report

Region ID:
MT
Workspace ID:
MT20160312154228831000
Clicked Point (Latitude, Longitude):
46.43854,-109.82251
Time:
2016-03-12 15:42:45 -0700



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
CONTDA	Area that contributes flow to a point on a stream (total drainage area minus non-contributing areas within basin)	90.9	square miles
ELEV	Mean Basin Elevation	4940	feet
TEMP	Mean Annual Temperature	41.9	degrees F
ELEVMAX	Maximum basin elevation	7520	feet

USGS

Example

- Excel tools (not reviewed/published but can get from me)
- Input variables
- Predicted Q
- Confidence intervals are generally quite large
- Check leverage

West
Northwest
Northwest Foothills
Northeast Plains
East-Central Plains
Southeast Plains
Upper Yellowstone-Central Mountain
Southwest

A	Needed	90.9	1.958564	
P	Not needed	--	#VALUE!	
F	Not needed	--	#VALUE!	
E5000	Not needed	--	#VALUE!	
SLP30	Not needed	--	#VALUE!	
ETSPR	Not needed	--	#VALUE!	
E6000	Needed	7	0.90309	
	Q	Lower PI	Upper PI	exceed 3p/n?
Q66.7	188.190963	40.04055096	884.4993	False
Q50	263.529254	60.40937288	1149.617	False
Q42.9	316.264749	77.95179362	1283.144	False
Q20	646.680229	198.0976655	2111.056	False
Q10	1042.74227	356.5809749	3049.269	False
Q4	1690.64952	610.0219164	4685.562	False
Q2	2259.54808	825.0870711	6187.902	False
Q1	2870.44213	1030.004113	7999.422	False
Q0.5	3556.30497	1236.544334	10227.94	False
Q0.2	4567.24892	1497.276974	13931.8	False

USGS

Limitations

- Regulation: <20% and no major diversions
- Basin characteristics within limits
- Leverage (combined BCs within limits)

Table 3. Ranges of values of basin characteristics used to develop regional regression equations.

[*A*, contributing drainage area, in square miles; E_{5000}, percent of basin above 5,000 feet; E_{6000}, percent of basin above 6,000 feet; ET_{SPR}, mean spring (March through June) evapotranspiration, in inches per month; *F*, percent of basin that is forest; *P*, mean annual precipitation, in inches; SLP_{30}, percent of basin with slope greater than 30 percent; Min, minimum; Max, maximum; --, not used in regional regression equation]

Hydrologic region (ordered clockwise from northwestern Montana)	*A*		E_{5000}		E_{6000}		ET_{SPR}		*F*		*P*		SLP_{30}	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
West	0.60	2,465.66	--	--	--	--	--	--	20.40	99.04	14.62	62.02	--	--
Northwest	2.43	1,556.17	--	--	--	--	--	--	--	--	20.74	83.16	--	--
Northwest Foothills	0.19	1,238.09	--	--	--	--	--	--	--	--	10.13	23.36	--	--
Northeast Plains	0.18	2,747.31	0.00	30.52	--	--	--	--	--	--	--	--	--	--
East-Central Plains	0.11	2,550.96	--	--	--	--	0.90	1.57	--	--	--	--	0.00	31.87
Southeast Plains	0.10	1,962.05	--	--	--	--	0.96	1.67	0.00	57.64	--	--	--	--
Upper Yellowstone-Central Mountain	0.39	2,039.76	--	--	0.00	100.00	--	--	--	--	--	--	--	--
Southwest	0.42	2,472.17	--	--	0.00	100.00	--	--	--	--	--	--	--	--

USGS

Drainage-area adjustment

- **Gage selection**
  - **Same stream and similar flow regime**
  - **0.5-1.5 DA**
  - **Regulation**

Upstream or downstream of 1 gage

$$Q_{AEP,U} = Q_{AEP,G}\left(\frac{DA_U}{DA_G}\right)^{exp_{AEP}}$$

Between 2 gages

$$\log Q_{AEP,U} = \log Q_{AEP,G1} + \left[\left(\log Q_{AEP,G2} - \log Q_{AEP,G1}\right)/\left(\log DA_{G2} - \log DA_{G1}\right)\right]\left(\log DA_U - \log DA_{G1}\right)$$

Table 5. Regression coefficients for ordinary least squares (OLS) regressions relating *AEP*-percent peak flow (Q_{AEP}) to contributing drainage area for use with ungaged sites on gaged streams.

	Regression coefficient relating Q_{AEP} to drainage area for indicated region							
AEP-percent peak flow	West Region	Northwest Region	Northwest Foothills Region	Northeast Plains Region	East-Central Plains Region	Southeast Plains Region	Upper Yellowstone-Central Mountain Region	Southwest Region
$Q_{66.7}$	0.858	0.922	0.606	0.684	0.500	0.541	0.942	0.999
Q_{50}	0.843	0.904	0.575	0.690	0.488	0.527	0.896	0.939
$Q_{42.9}$	0.836	0.890	0.564	0.681	0.483	0.523	0.866	0.911
Q_{20}	0.813	0.832	0.534	0.639	0.463	0.502	0.761	0.818
Q_{10}	0.794	0.790	0.522	0.611	0.449	0.487	0.697	0.755
Q_{4}	0.777	0.741	0.516	0.579	0.434	0.471	0.634	0.690
Q_{2}	0.766	0.707	0.517	0.557	0.423	0.460	0.595	0.647
Q_{1}	0.755	0.675	0.521	0.537	0.414	0.450	0.561	0.609
$Q_{0.5}$	0.746	0.644	0.526	0.519	0.404	0.441	0.532	0.576
$Q_{0.2}$	0.735	0.605	0.536	0.496	0.393	0.430	0.498	0.533

USGS

Equations vs. drainage area ratio

- Regression equations
  - Only for unregulated sites
  - Hydrologically similar to sites in region
  - Provides prediction intervals
- Drainage area ratio
  - Same stream with similar flow regime?
  - How many years of record for index gage?
  - Extreme floods or variance in flood events?
  - Period of record (wet/dry periods)?
  - Confidence intervals are not computed

USGS

Adjusted at-site frequencies (Chapter D)

- Why?
  - Length of record
  - Period of record (remember Powder River?)
  - Weighting at-site with regression equations no longer uses Equivalent Years of Record (EYR), need USGS Weighted Independent Estimates (WIE) program
  - Generally recommended by USGS OSW
  - Generally improves flood frequency estimates
  - Continuity with gages upstream and downstream

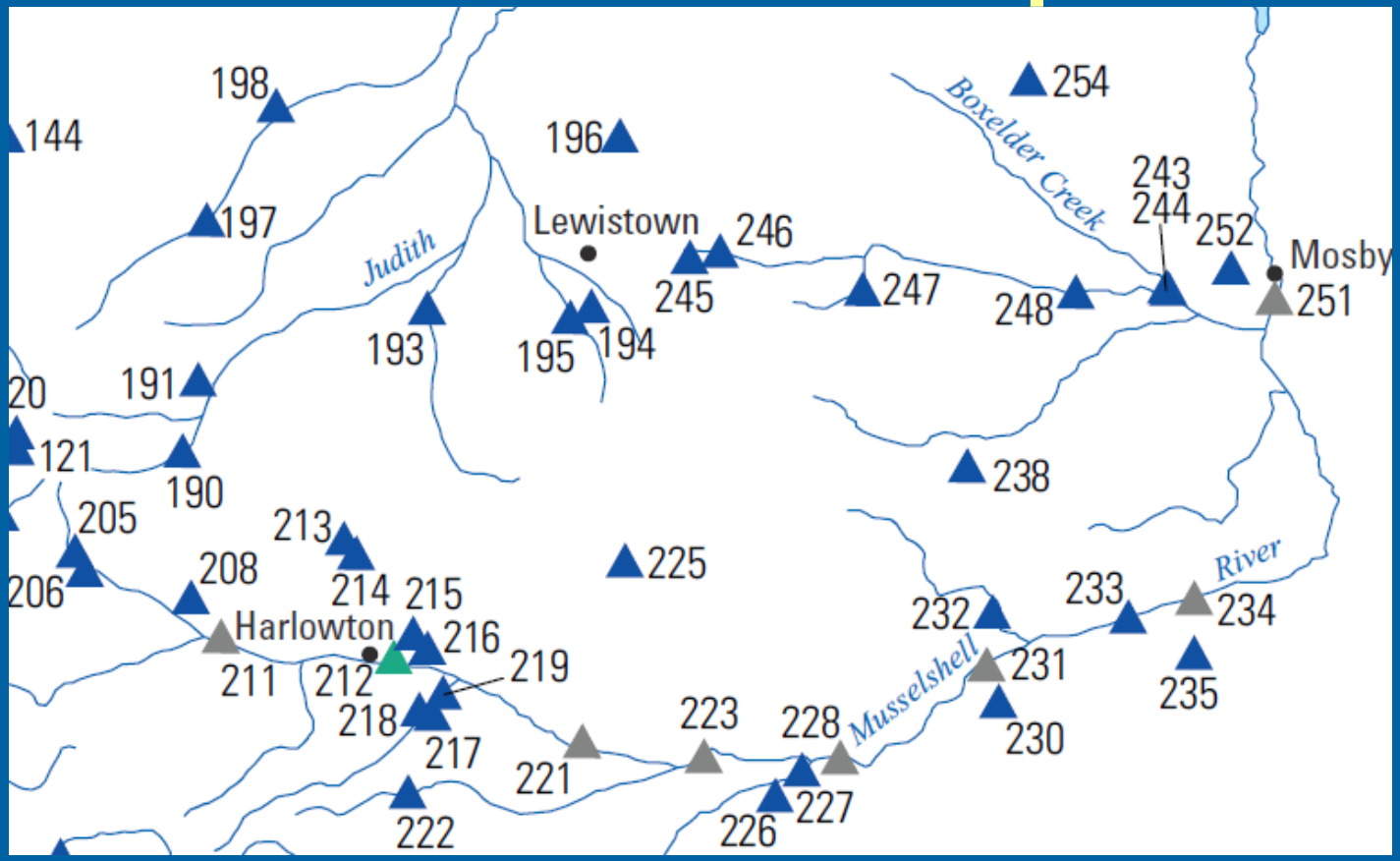
USGS

Adjusted at-site frequencies

- Methods
  - At-site weighted with regression equations
    - 438 sites
    - Less than or equal to 40 years
    - Drainage area less than 2,750 sq. mi.
  - At-site MOVE.1
    - 66 sites on 19 rivers
    - Three or more gages on same river
    - Unregulated and regulated sites
    - Uses a common period of record

USGS

Musselshell basin examples



- Frequencies not adjusted
- Frequencies adjusted by weighting with regression equations
- Frequencies adjusted by record extension procedures

0612200 American Fork blw Lebo Cr.

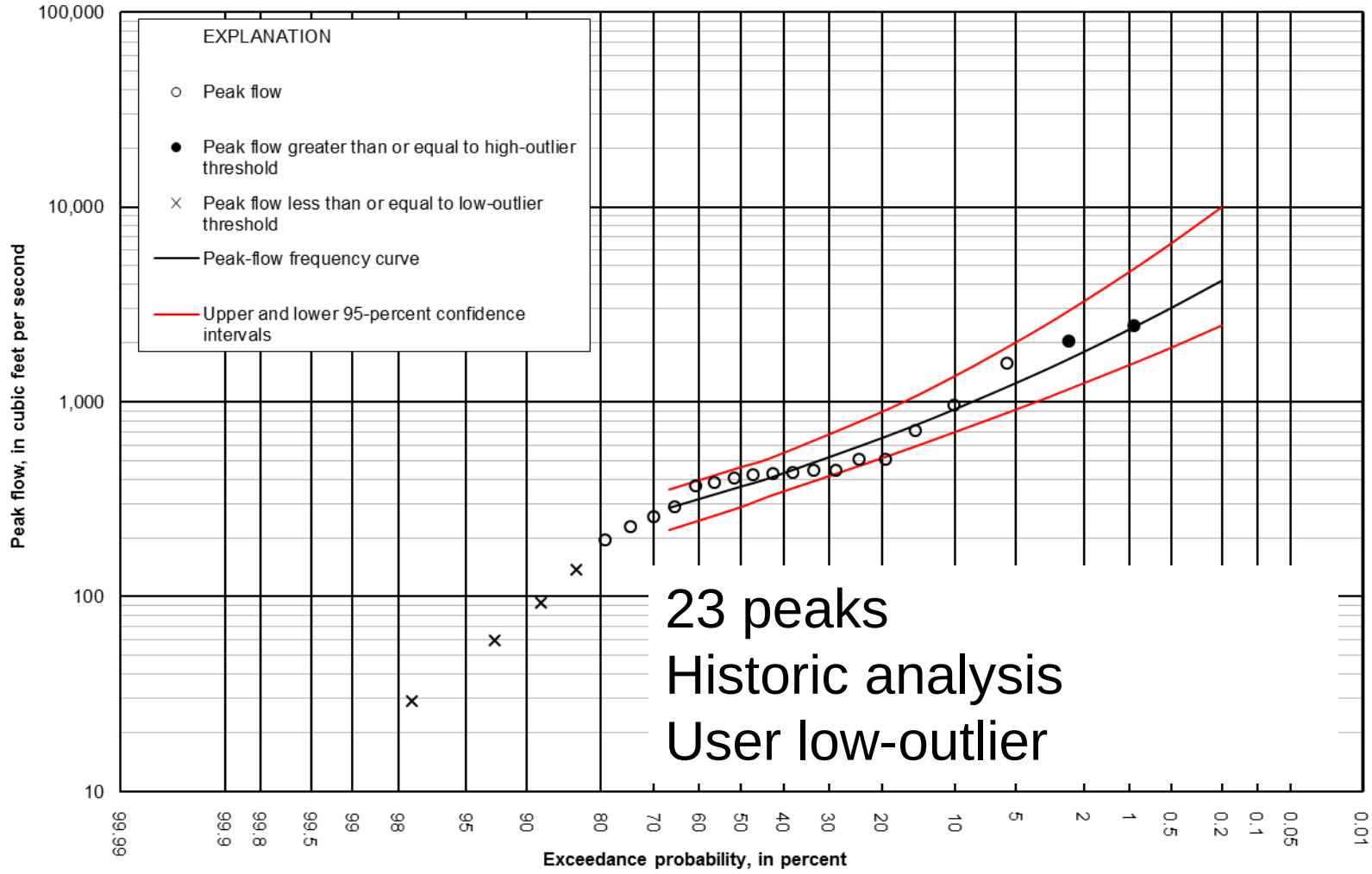


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

0612200 American Fork blw Lebo Cr.

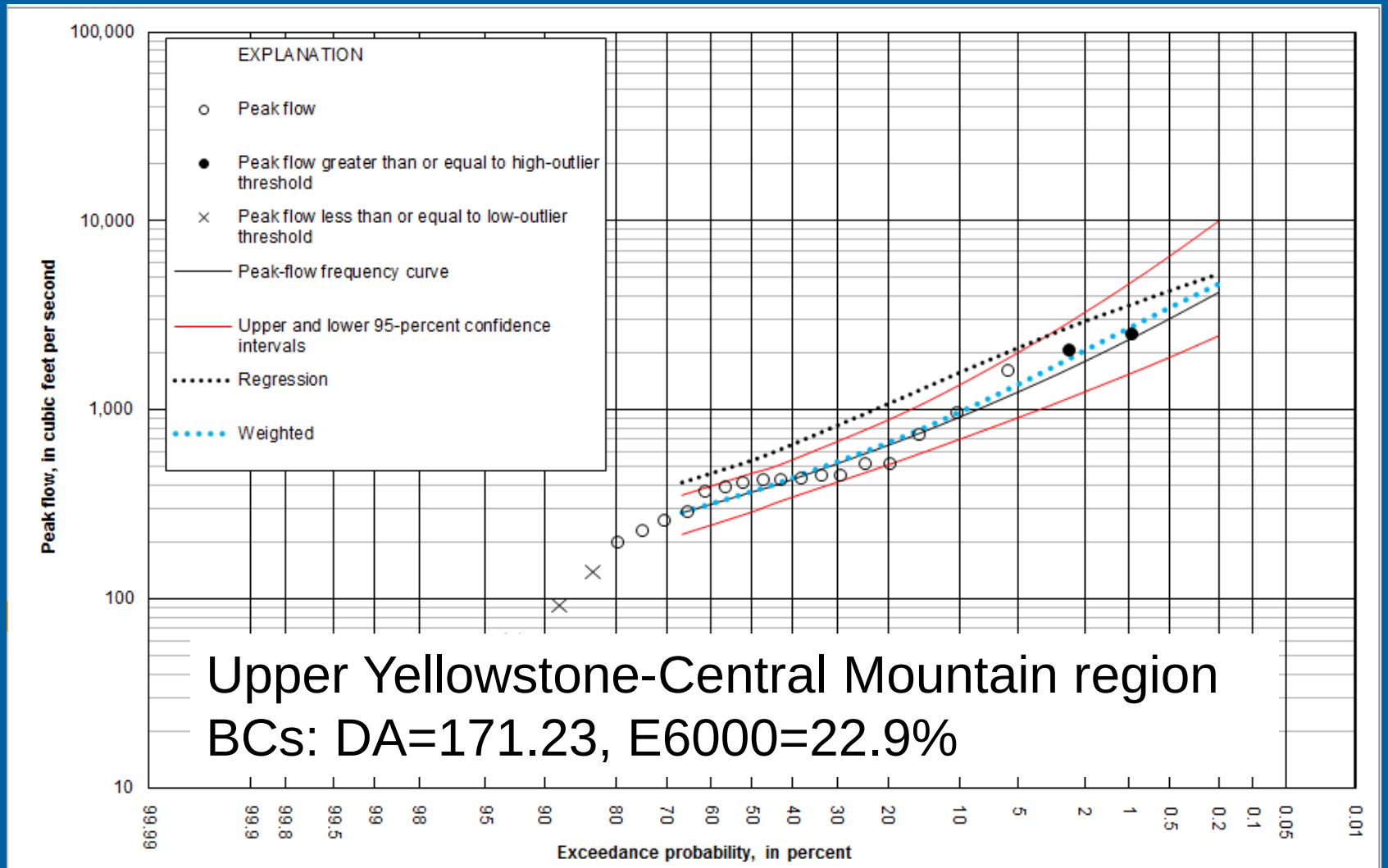
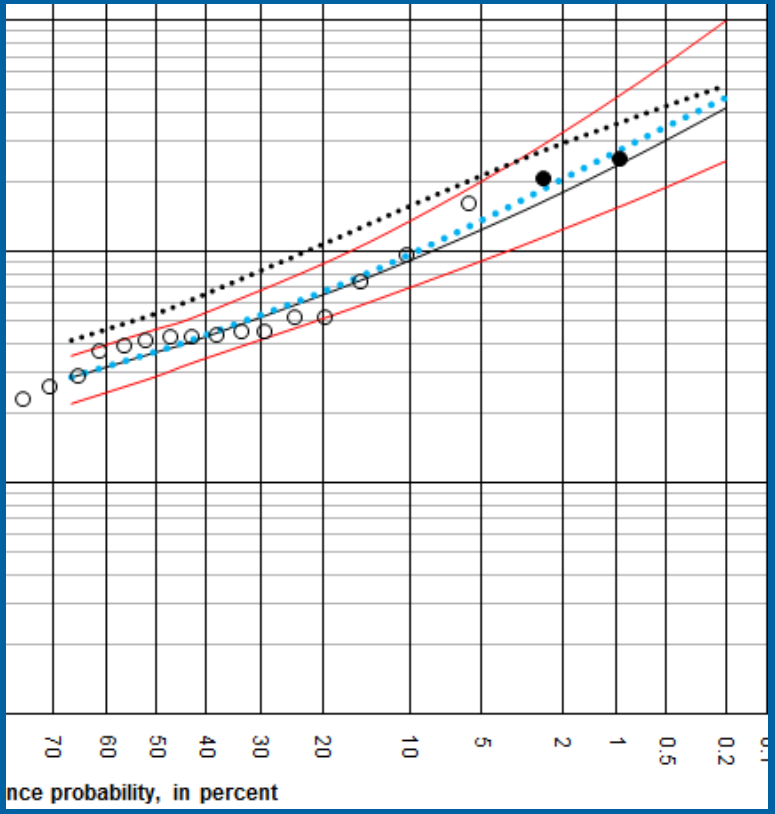


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

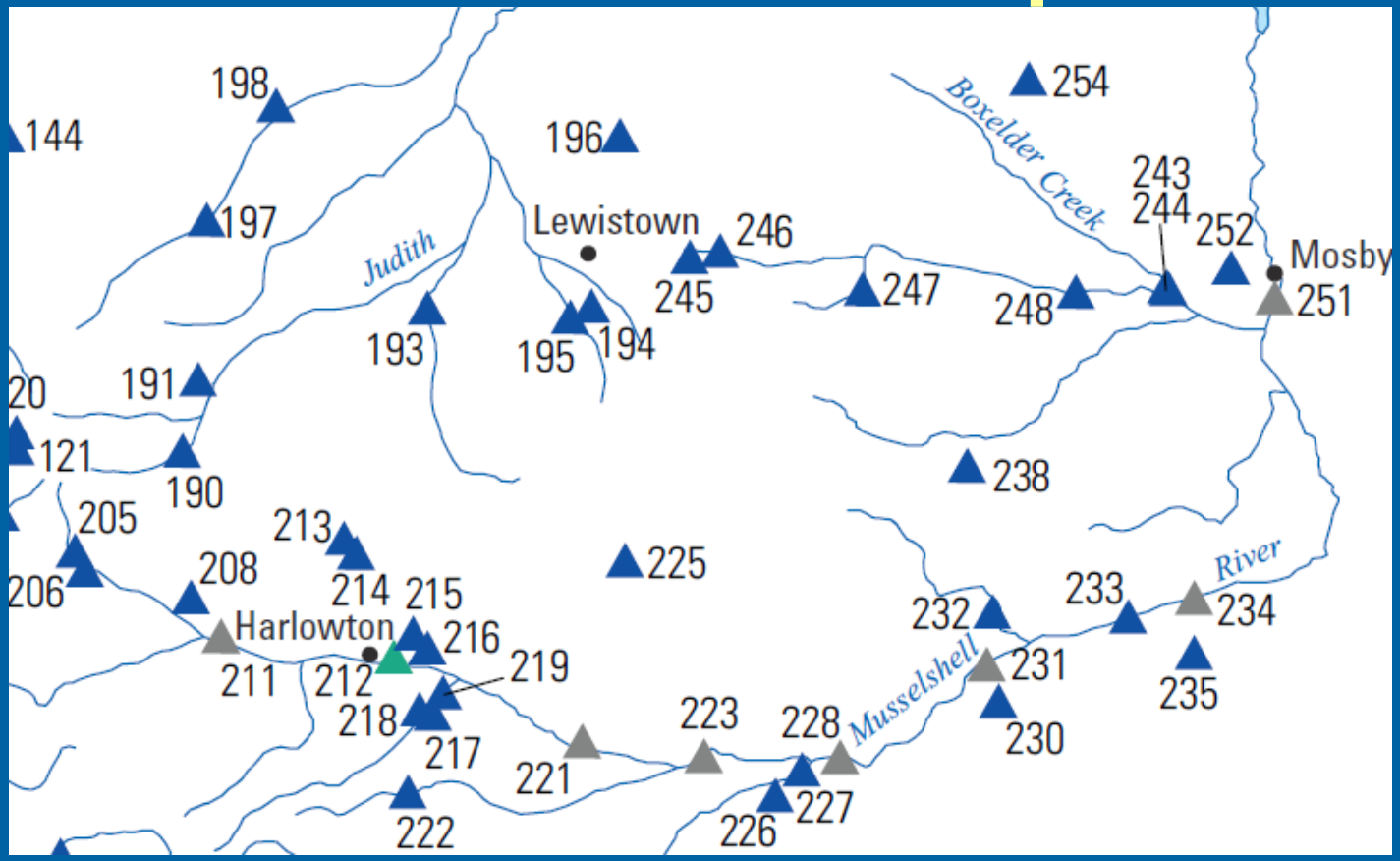
0612200 American Fork blw Lebo Cr.

- Regressions above conf. interval until ~5%AEP
- Weighted ranges from 0-15% larger, but well within conf. intervals
- StreamStats will provide prediction intervals



Type of peak-flow frequency estimate[3]	Annual peak flow, in cubic feet per second, for indicated annual exceedance probability, in percent									
	66.7	50	42.9	20	10	4	2	1	0.5	0.2
-gaging stations)										
at-site	286	368	409	652	919	1,370	1,810	2,360	3,040	4,190
regression	414	542	621	1,080	1,580	2,330	2,950	3,580	4,280	5,260
weighted	287	371	416	673	976	1,520	2,070	2,720	3,480	4,650

Musselshell basin examples



- Frequencies not adjusted
- Frequencies adjusted by weighting with regression equations
- Frequencies adjusted by record extension procedures

Musselshell River at-site analyses

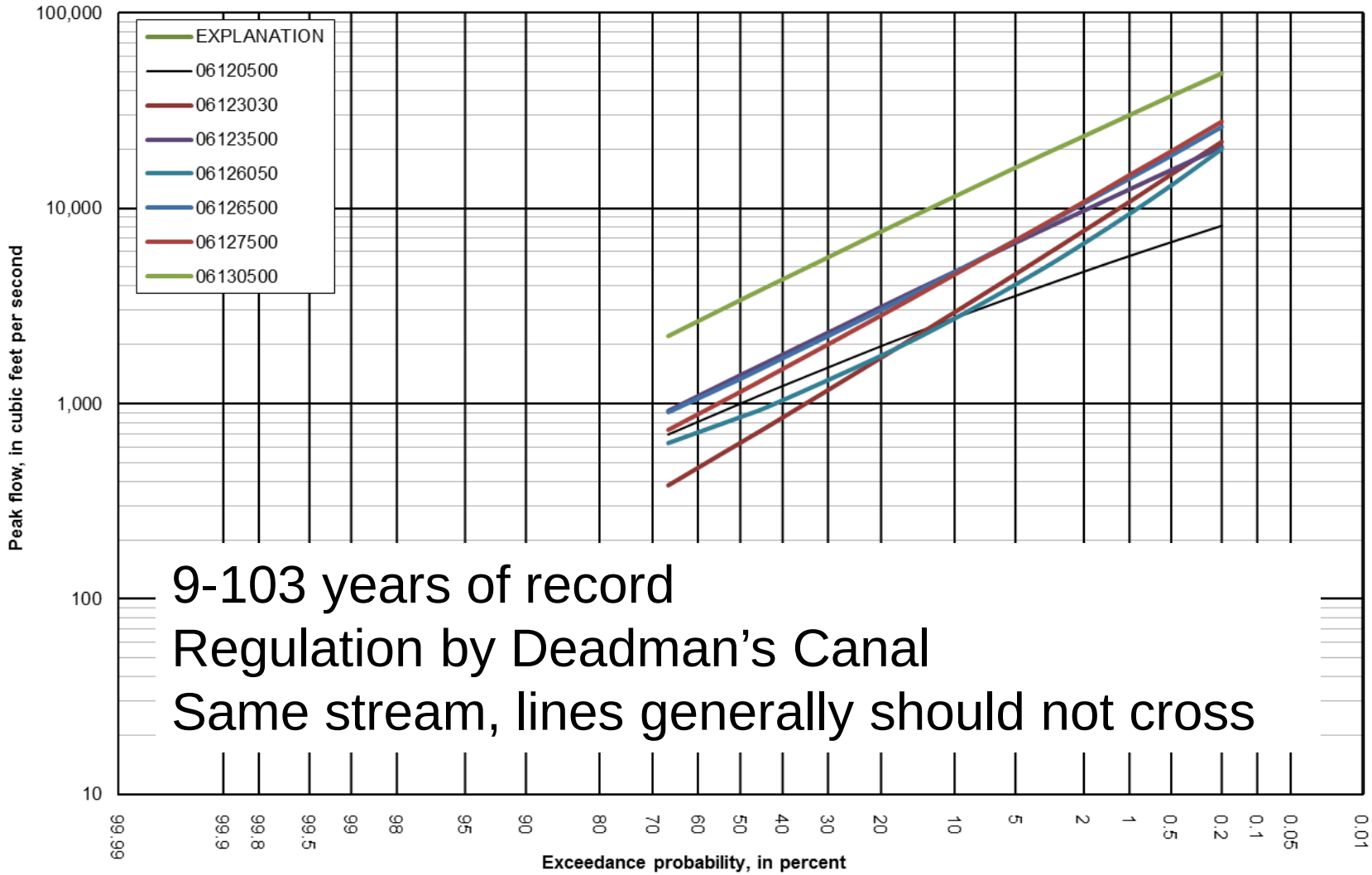


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Musselshell River MOVE.1 analyses

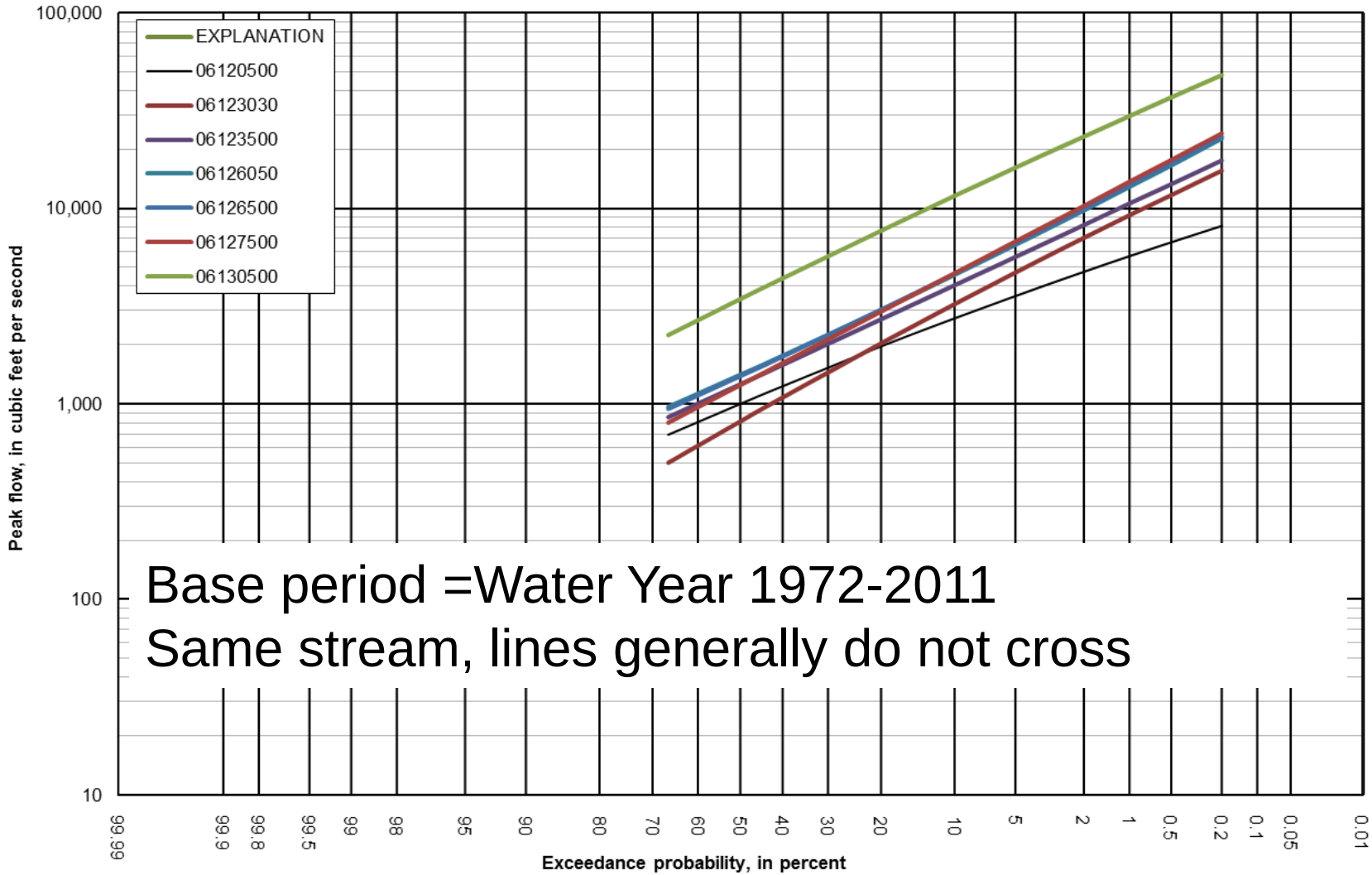


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

Adjusted frequencies

- Weighted analysis
  - Generally provides improved flood frequency analysis
  - Review and understand station data and regional influence of regression equations.
- Record-extension analysis
  - Adjusted to a “base” period, which may not include extreme peaks
  - May not account well for minor changes in regulation along the basin
- Review spreadsheet

USGS

Review

- At-site frequencies
  - Based on gaged data, various record lengths, various methods based on site-specific information and regional flooding mechanisms.
  - At-site frequencies reported for all gages with 10+ years of record
  - Classified as regulated or unregulated based on percent of basin upstream from dams.
  - Computed confidence intervals
  - Weighted or station skew based on regulation and mixed-population.

USGS

Review

- Regional regression equations
  - Regression equations
    - Developed using frequencies from unregulated gaging stations in each of the 8 hydrologic regions.
    - Forced consistent use of variables through all AEPs.
    - Drainage area is always the most influential variable
    - For use on unregulated streams with no gage data
    - Prediction intervals are provided
  - Drainage area adjustments
    - Used for a site of interest on same stream as gage(s) with at-site frequencies
    - Can be used on regulated streams
    - Prediction intervals are not provided

USGS

Review

- Adjusted at-site frequencies
  - Weighted with regression equations
    - Unregulated sites only
    - Sites with less than 40 years of record
    - Prediction intervals provided (StreamStats only)
  - Record extension methods
    - Sites along same stream
    - Done for both regulated and unregulated sites
    - Confidence intervals are not provided (confidence intervals are output from PEAKFQ, but they do not account for record extension methods for filling in peak-flow records)

USGS

Examples

Remember this?

"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.**

USGS

Red Fox Meadows

- Helena valley
- Completely ungaged basin
- Southwest hydrologic region
  - Drainage area=11.7 sq. mi. (at Canyon Ferry Rd)
  - E6000=0.0%
  - Regression equations

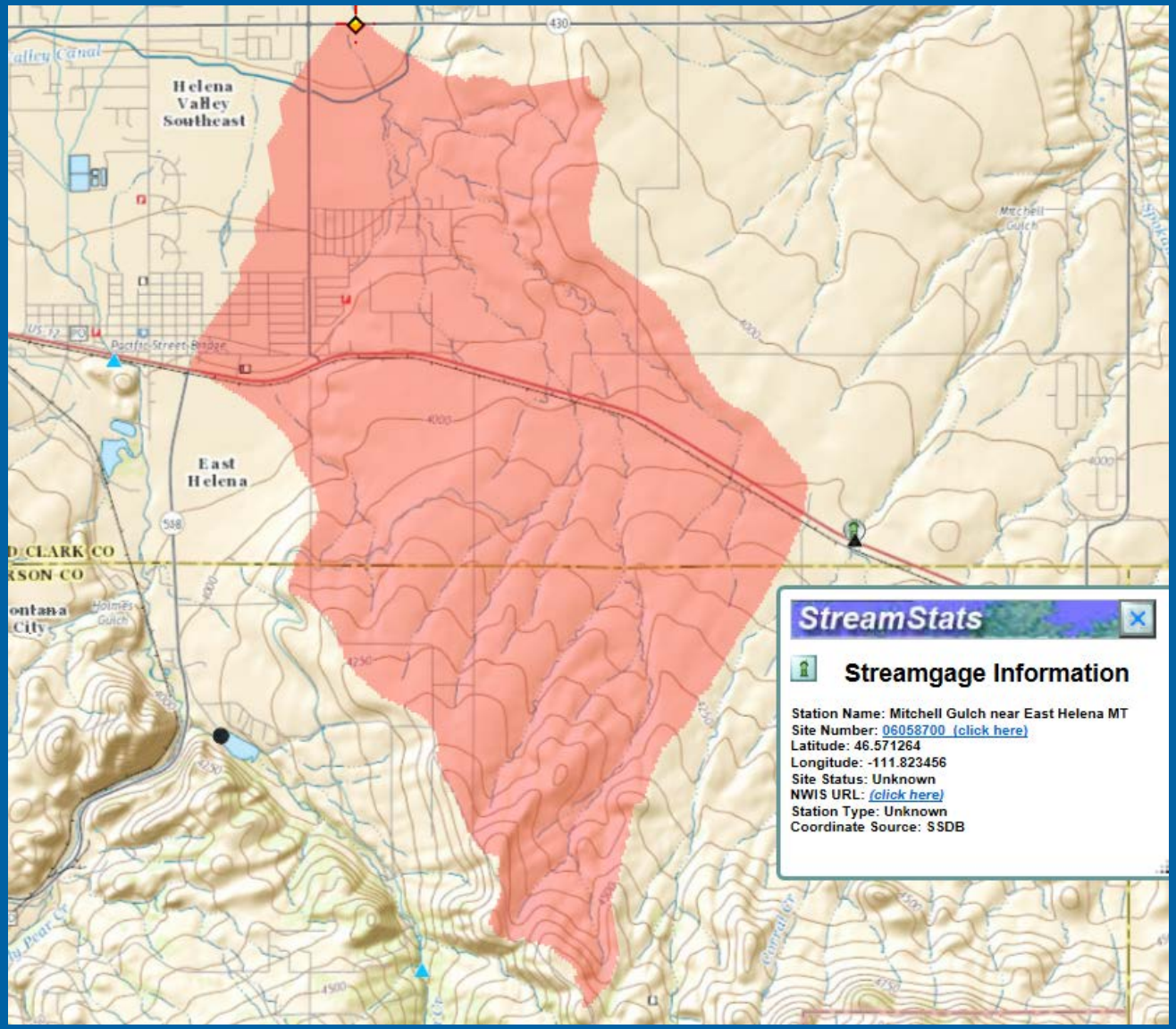
West
Northwest
Northwest Foothills
Northeast Plains
East-Central Plains
Southeast Plains
Upper Yellowstone-Central Mountain
Southwest

A	Needed	11.7	1.068186	
P	Not needed	--	#VALUE!	
F	Not needed	--	#VALUE!	
E5000	Not needed	--	#VALUE!	
SLP30	Not needed	--	#VALUE!	
ETSPR	Not needed	--	#VALUE!	
E6000	Needed	0	0	
	Q	Lower PI	Upper PI	exceed 3p/n?
Q66.7	11.33	1.91	67.23	False
Q50	24.53	5.22	115.13	False
Q42.9	33.85	7.69	149.09	False
Q20	106.30	27.97	403.92	False
Q10	225.98	61.73	827.28	False
Q4	504.83	135.33	1883.22	False
Q2	836.47	218.25	3205.90	False
Q1	1318.36	328.16	5296.50	False
Q0.5	1983.20	467.97	8404.63	False
Q0.2	3232.17	709.37	14727.08	False

USGS

Red Fox Meadows

- Mitchell Gulch



USGS

06058700 Mitchell Gulch nr East Helena

- 45 peaks
- Station skew
- No historic
- Reasonable fit
- Multiple peaks below gage base
- 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	
8.09	45	STATION	0.4	default	1,276	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**
5.9	14	20	63	122	230	333	450	582	774
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**
9.6	24	34	119	254	527	810	1,160	1,560	2,190
3.5	8.7	12	37	69	122	169	221	278	357

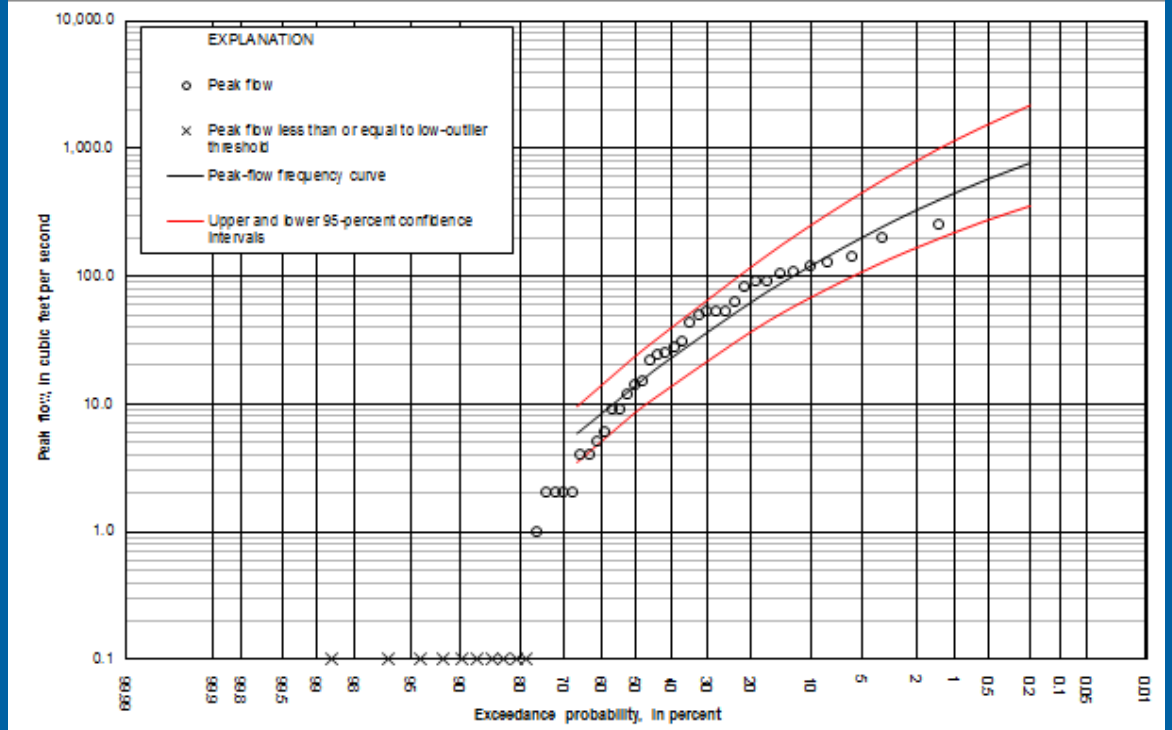


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

USGS

Mitchell Gulch

- 1981? 1964?
- 2003 peak of record
- Top 6 peaks
  - Early snowmelt
  - Thunderstorms
- Limited variability

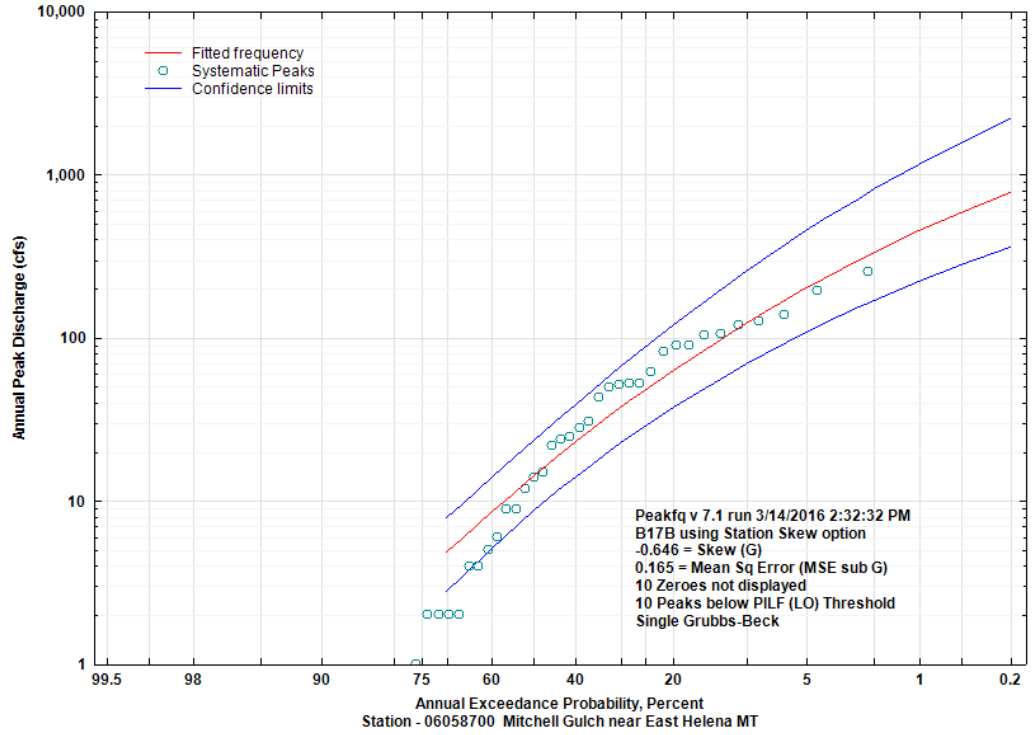
06058700 Mitchell Gulch near East Helena, Montana
Map number 96
Analysis period of record, water years: 1959–2003
Analysis period of record considered unregulated

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.
--, not applicable or not available]

Peak-flow data[3]				Ranked (largest to smallest) peak-flow data[3]			
Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet	Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1959	3//1959[4]	53	0.96	2003	3/13/2003	255	4.14
1960	3/19/1960	6.0	0.32	1986	2/25/1986	195	1.76
1961	6/29/1961	2.0	0.27	1973	9/7/1973	139	0.51
1962	3/20/1962	12	0.43	1990	8/19/1990	127	2.10
1963	2/4/1963	107	1.41	1996	2/7/1996	120	1.86
1964	//1964[4]	#	--	1963	2/4/1963	107	1.41
1965	4/1/1965	28	0.62	1981	5/22/1981	105	0.77
1966	3/10/1966	50	0.93	1969	3/31/1969	90	1.06
1967	3/22/1967	52	0.94	1975	4/20/1975	90	0.24
1968	//1968[4]	#	--	1978	3/20/1978	82	0.46
1969	3/31/1969	90	1.06	1993	3/15/1993	62	0.41
1970	7/12/1970	2.0	-1.28	1959	3//1959[4]	53	0.96
1971	2/10/1971	4.0	-1.07	1974	1/15/1974	53	-0.24
1972	//1972[4]	#	--	1967	3/22/1967	52	0.94
1973	9/7/1973	139	0.51	1966	3/10/1966	50	0.93
1974	1/15/1974	53	-0.24	1979	6/18/1979	43	-0.21
1975	4/20/1975	90	0.24	1989	3/30/1989	31	-0.24
1976	3/17/1976	2.0	-1.19	1965	4/1/1965	28	0.62
1977	//1977[4]	#	--	1980	4/12/1980	25	-0.57
1978	3/20/1978	82	0.46	1985	3/16/1985	24	-0.74
1979	6/18/1979	43	-0.21	1994	3/2/1994	22	-0.93
1980	4/12/1980	25	-0.57	1998	3/24/1998	15	-1.22
1981	5/22/1981	105	0.77	1995	2/1/1995	14	-1.28
1982	5/20/1982	9.0	-0.70	1962	3/20/1962	12	0.43
1983	5/19/1983	9.0	-0.70	1982	5/20/1982	9.0	-0.70
1984	1/5/1984	2.0	-1.17	1983	5/19/1983	9.0	-0.70
1985	3/16/1985	24	-0.74	1960	3/19/1960	6.0	0.32
1986	2/25/1986	195	1.76	1997	3/20/1997	5.0	-1.74
1987	9/24/1987	1.0	-2.06	1971	2/10/1971	4.0	-1.07
1988	//1988[4]	#	--	2001	4/24/2001	4.0	0.18
1989	3/30/1989	31	-0.24	1961	6/29/1961	2.0	0.27
1990	8/19/1990	127	2.10	1970	7/12/1970	2.0	-1.28
1991	//1991[4]	#	--	1976	3/17/1976	2.0	-1.19
1992	//1992[4]	#	--	1984	1/5/1984	2.0	-1.17
1993	3/15/1993	62	0.41	1987	9/24/1987	1.0	-2.06
1994	3/2/1994	22	-0.93	1964	//1964[4]	#	--
1995	2/1/1995	14	-1.28	1968	//1968[4]	#	--
1996	2/7/1996	120	1.86	1972	//1972[4]	#	--
1997	3/20/1997	5.0	-1.74	1977	//1977[4]	#	--
1998	3/24/1998	15	-1.22	1988	//1988[4]	#	--
1999	//1999[4]	#	--	1991	//1991[4]	#	--
2000	//2000[4]	#	--	1992	//1992[4]	#	--
2001	4/24/2001	4.0	0.18	1999	//1999[4]	#	--
2002	//2002[4]	#	--	2000	//2000[4]	#	--
2003	3/13/2003	255	4.14	2002	//2002[4]	#	--

USGS

PEAKFQ comparisons

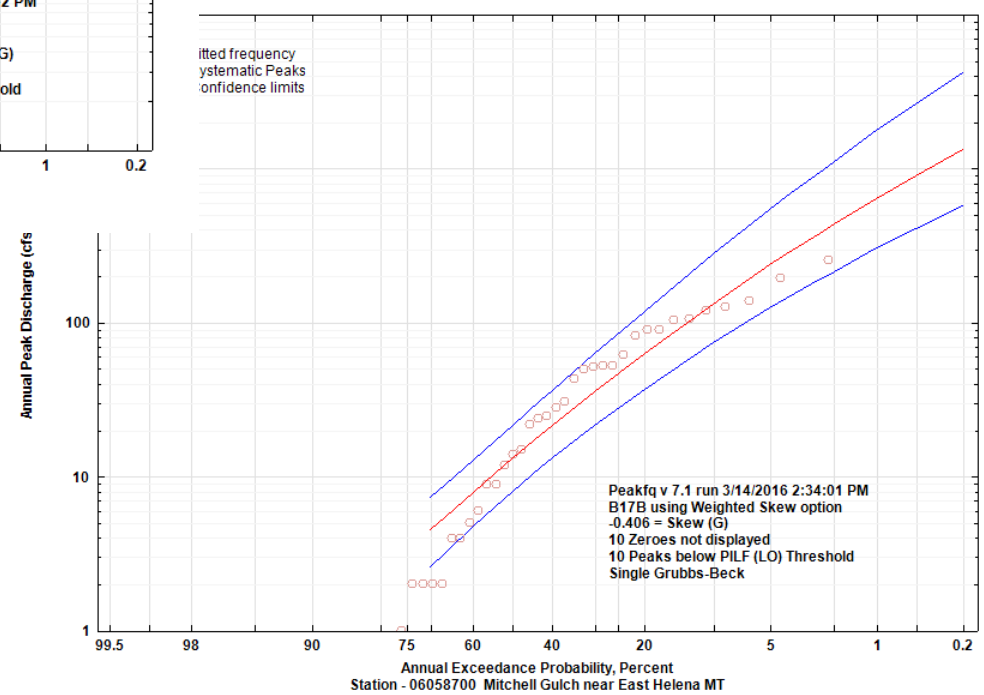


B17B, station skew

1% AEP=450 cfs

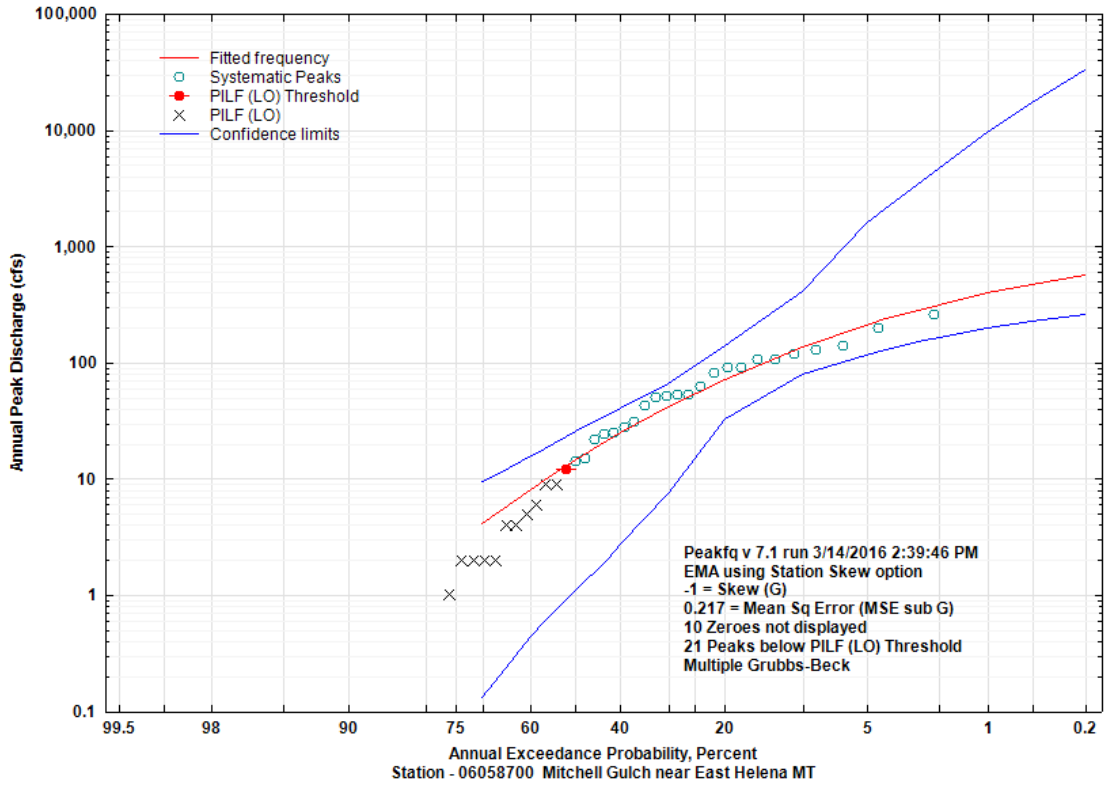
B17B, wtd. skew

1% AEP=643 cfs



USGS

PEAKFQ comparisons

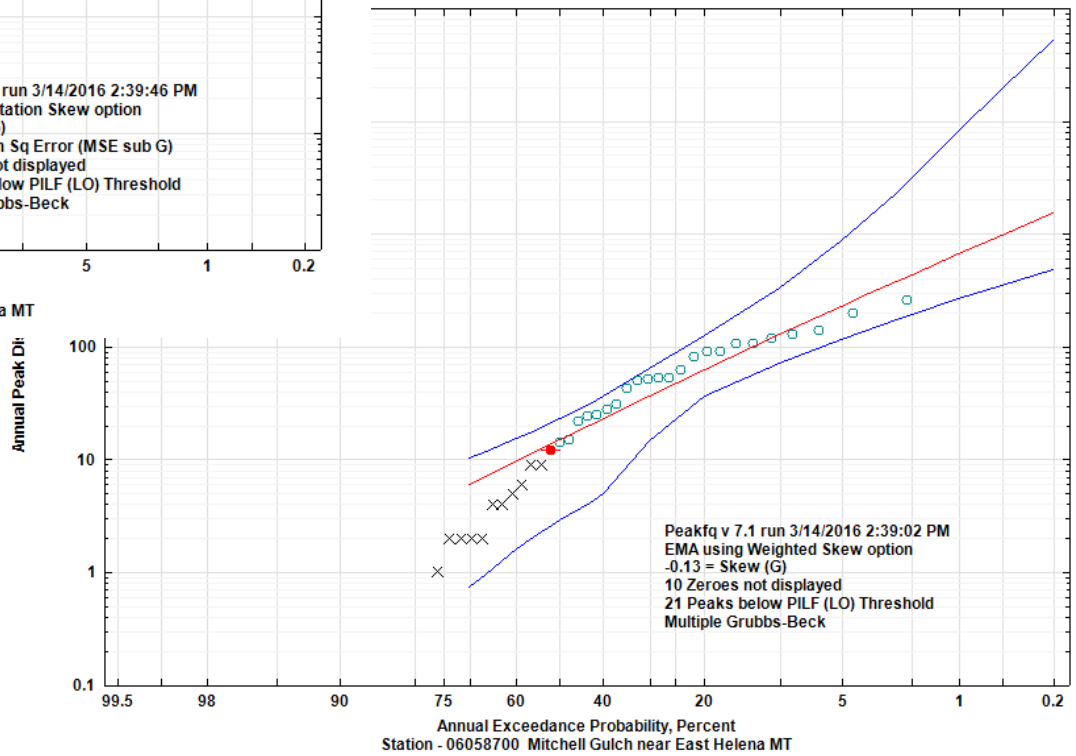


EMA, station skew

1% AEP=393 cfs

EMA, wtd. skew

1% AEP=663 cfs



USGS

06058700 Mitchell Gulch nr East Helena

- Southwest region
  - Drainage area=7.93
  - E6000=7.54%
  - Regression equations

West
Northwest
Northwest Foothills
Northeast Plains
East-Central Plains
Southeast Plains
Upper Yellowstone-Central Mountain
Southwest

A	Needed	7.93	0.899273	
P	Not needed	--	#VALUE!	
F	Not needed	--	#VALUE!	
E5000	Not needed	--	#VALUE!	
SLP30	Not needed	--	#VALUE!	
ETSPR	Not needed	--	#VALUE!	
E6000	Needed	7.54	0.931458	
	Q	Lower PI	Upper PI	exceed 3p/n?
Q66.7	11.80	2.37	58.66	False
Q50	20.94	5.22	83.94	False
Q42.9	26.62	7.05	100.52	False
Q20	92.53	28.45	300.90	False
Q10	113.43	36.63	351.31	False
Q4	209.53	67.84	647.13	False
Q2	307.39	98.60	958.33	False
Q1	434.78	135.30	1397.14	False
Q0.5	591.08	177.31	1970.44	False
Q0.2	857.45	244.29	3009.67	False

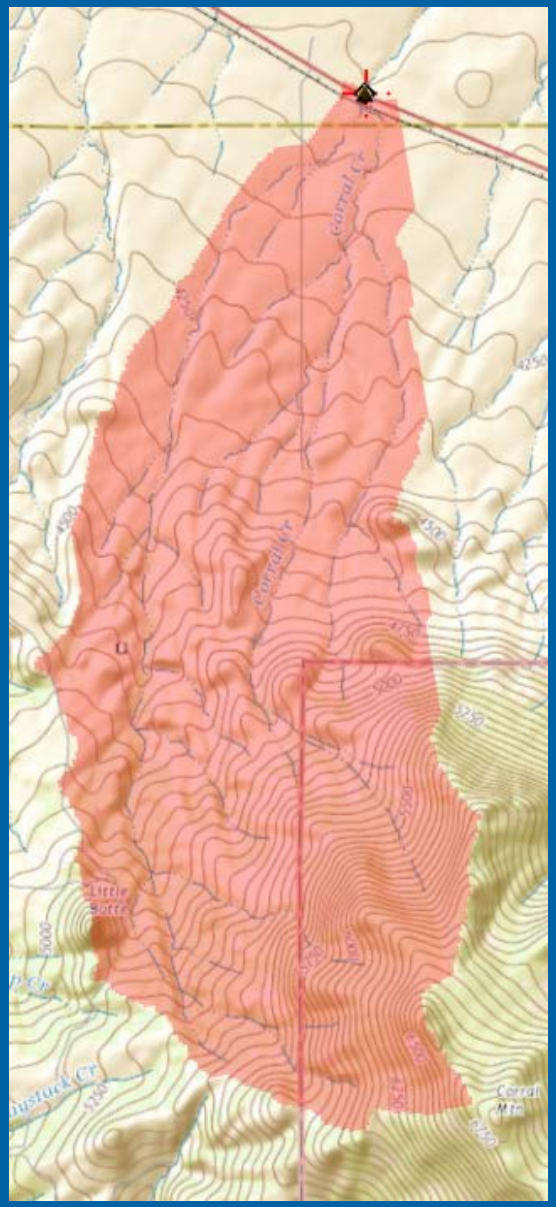
USGS

Red Fox vs. Mitchell Gulch

- Adjoining basins
- Similar aspect
- Similar basin characteristics
- DA drainage area adjustment?

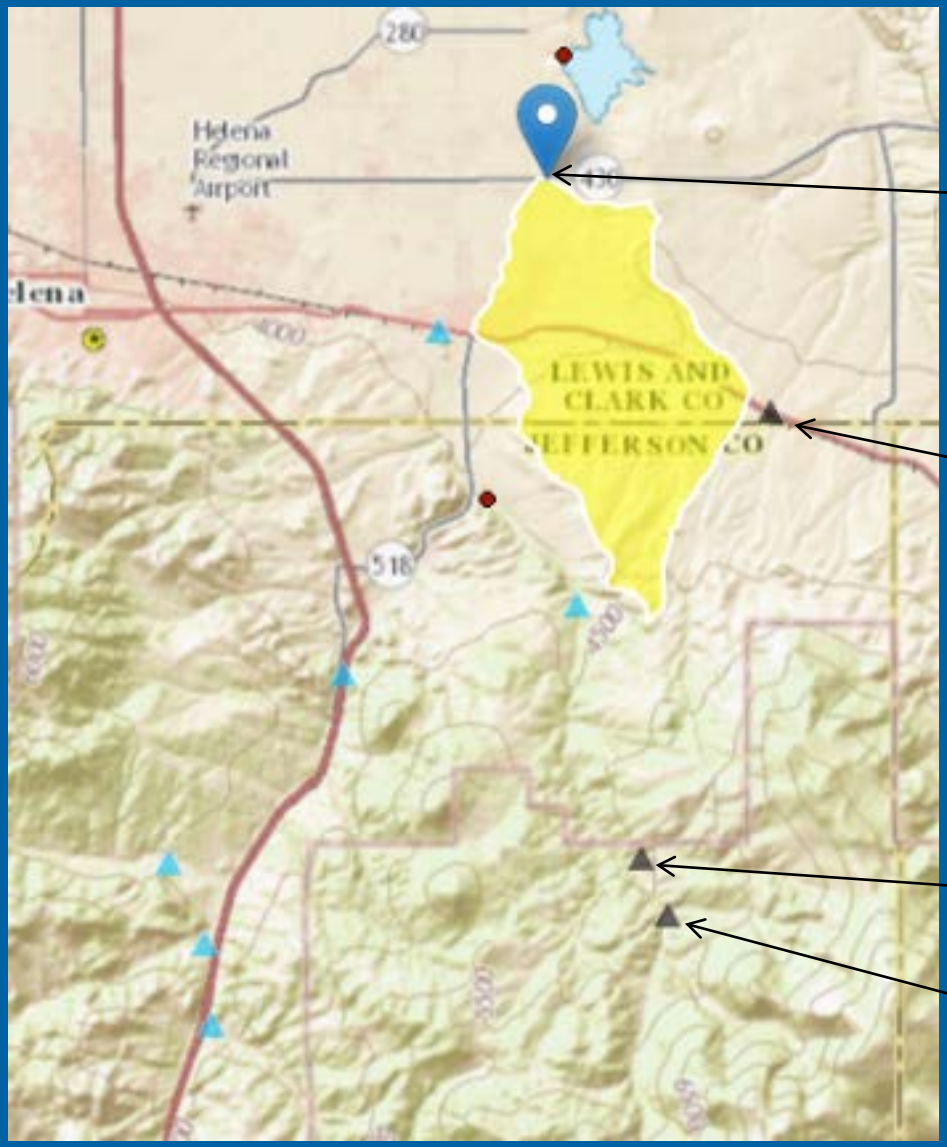
$$Q_{AEP,U} = \left(\frac{DA_U}{DA_G}\right)^{exp_{AEP}}$$

- Not on same stream!
- There are exceptions…



USGS

Adjoining basins comparison



Red Fox Meadows

Mitchell Gulch

06061800

06061700

Adjoining basins comparison

Identical periods of record

06061700

- DA=3.44
- E6000=57.99%
- 18 yrs.
- 1% AEP=193cfs

Peak-flow data[3]				Ranked (largest to smallest) peak-flow data[3]			
Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet	Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1961	5/1/1961	4.0	1.48	1990	8/19/1990	380	--
1962	6/2/1962	16	2.49	1981	5/22/1981	111	4.11
1963	6/4/1963	12	2.21	1975	6/19/1975	33	2.98
1964	6/8/1964	19	2.64	1989	7/26/1989	30	2.30
1965	6/25/1965	14	2.34	1974	6/20/1974	24	2.73
1966	5/10/1966	7.0	1.97	1967	6/8/1967	20	2.73
1967	6/8/1967	20	2.73	1964	6/8/1964	19	2.64
1968	6/10/1968	17	2.27	1968	6/10/1968	17	2.27
1969	6/25/1969	15	2.51	1962	6/2/1962	16	2.49
1970	6/27/1970	10	2.19	1969	6/25/1969	15	2.51
1971	6/4/1971	9.0	2.12	1965	6/25/1965	14	2.34
1972	5/22/1972	9.0	2.16	1963	6/4/1963	12	2.21
1973	6/14/1973	4.0	1.74	1970	6/27/1970	10	2.19
1974	6/20/1974	24	2.73	1971	6/4/1971	9.0	2.12
1975	6/19/1975	33	2.98	1972	5/22/1972	9.0	2.16
1981	5/22/1981	111	4.11	1966	5/10/1966	7.0	1.97
1989	7/26/1989	30	2.30	1961	5/1/1961	4.0	1.48
1990	8/19/1990	380	--	1973	6/14/1973	4.0	1.74

06061800

- DA=3.9
- E6000=32.32%
- 18 yrs.
- 1% AEP=88cfs

Peak-flow data[3]				Ranked (largest to smallest) peak-flow data[3]			
Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet	Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1961	5/1/1961	5.0	1.59	1975	6/19/1975	80	3.33
1962	6/2/1962	11	1.55	1981	5/22/1981	72	3.04
1963	6/4/1963	4.0	1.26	1989	7/26/1989	35	1.12
1964	6/8/1964	21	1.64	1969	6/25/1969	30	1.75
1965	6/25/1965	14	1.46	1967	6/8/1967	28	1.82
1966	5/10/1966	9.0	1.32	1971	5/2/1971	27	1.68
1967	6/8/1967	28	1.82	1964	6/8/1964	21	1.64
1968	6/9/1968	12	1.35	1990	5/7/1990	18	0.57
1969	6/25/1969	30	1.75	1965	6/25/1965	14	1.46
1970	5/5/1970	12	1.34	1968	6/9/1968	12	1.35
1971	5/2/1971	27	1.68	1970	5/5/1970	12	1.34
1972	5/22/1972	3.0	1.07	1962	6/2/1962	11	1.55
1973	5/17/1973	2.0	1.47	1966	5/10/1966	9.0	1.32
1974	6/4/1974	9.0	1.26	1974	6/4/1974	9.0	1.26
1975	6/19/1975	80	3.33	1961	5/1/1961	5.0	1.59
1981	5/22/1981	72	3.04	1963	6/4/1963	4.0	1.26
1989	7/26/1989	35	1.12	1972	5/22/1972	3.0	1.07
1990	5/7/1990	18	0.57	1973	5/17/1973	2.0	1.47

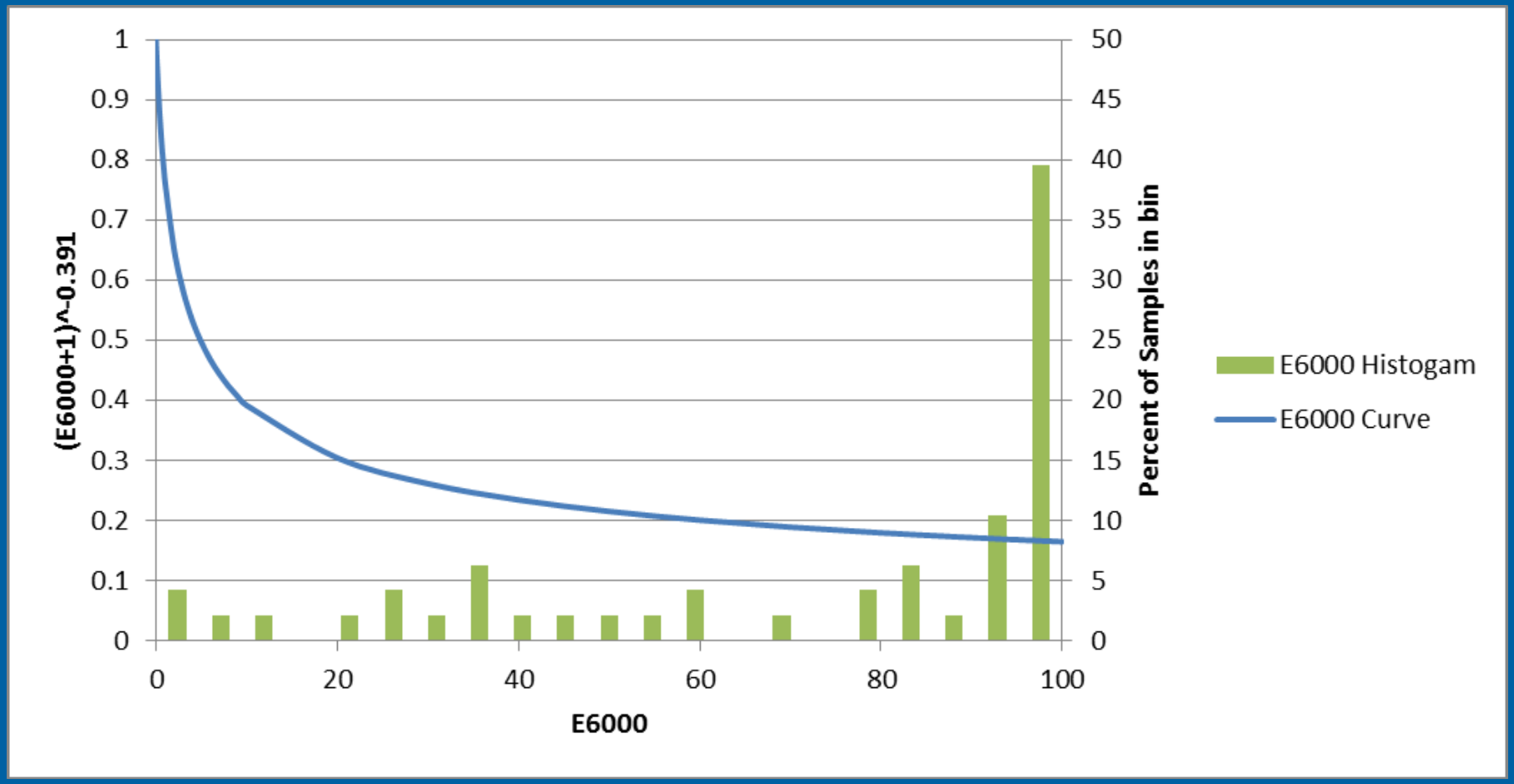
But what about E6000 sensitivity?

Regression equation for indicated Q_{AEP}		Number of streamflow-gaging stations (n)[1]	*MEV*, in log units	*AVP*, in log units	*SEP*, in percent	*SEM*, in percent	Pseudo R^2, in percent
Southwest hydrologic region							
$Q_{66.7} = 1.04\ A^{0.971}\ (E_{6000} + 1)^{0.195}$	+	47	0.153	0.164	117.8	111.6	79.3
$Q_{50} = 2.49\ A^{0.930}\ (E_{6000} + 1)^{0.095}$	+	48	0.114	0.123	96.0	91.3	81.5
$Q_{42.9} = 3.61\ A^{0.910}\ (E_{6000} + 1)^{0.053}$	+	48	0.104	0.112	90.1	85.7	81.9
$Q_{20} = 13.4\ A^{0.842}\ (E_{6000} + 1)^{0.088}$	+	48	0.08	0.088	76.9	72.9	82.5
$Q_{10} = 31.9\ A^{0.796}\ (E_{6000} + 1)^{-0.177}$	−	48	0.072	0.079	72.1	68.1	82.0
$Q_{4} = 79.8\ A^{0.750}\ (E_{6000} + 1)^{-0.274}$	−	48	0.07	0.078	71.3	67.0	80.1
$Q_{2} = 142\ A^{0.721}\ (E_{6000} + 1)^{-0.336}$	−	48	0.07	0.079	72.0	67.3	78.5
$Q_{1} = 238\ A^{0.696}\ (E_{6000} + 1)^{-0.391}$	−	48	0.073	0.082	73.8	68.8	76.6
$Q_{0.5} = 377\ A^{0.675}\ (E_{6000} + 1)^{-0.442}$	−	48	0.077	0.087	76.5	71.0	74.5
$Q_{0.2} = 655\ A^{0.649}\ (E_{6000} + 1)^{-0.501}$	−	48	0.083	0.094	80.3	74.3	72.0

[1]The number of streamflow-gaging stations used in the $Q_{66.7}$ regression equation for a region might differ from the number of gaging stations used in all other regression equations in that region because of streamflow-gaging stations with unreported $Q_{66.7}$ values (table 1–2), which is discussed further in Sando and others (2015a).

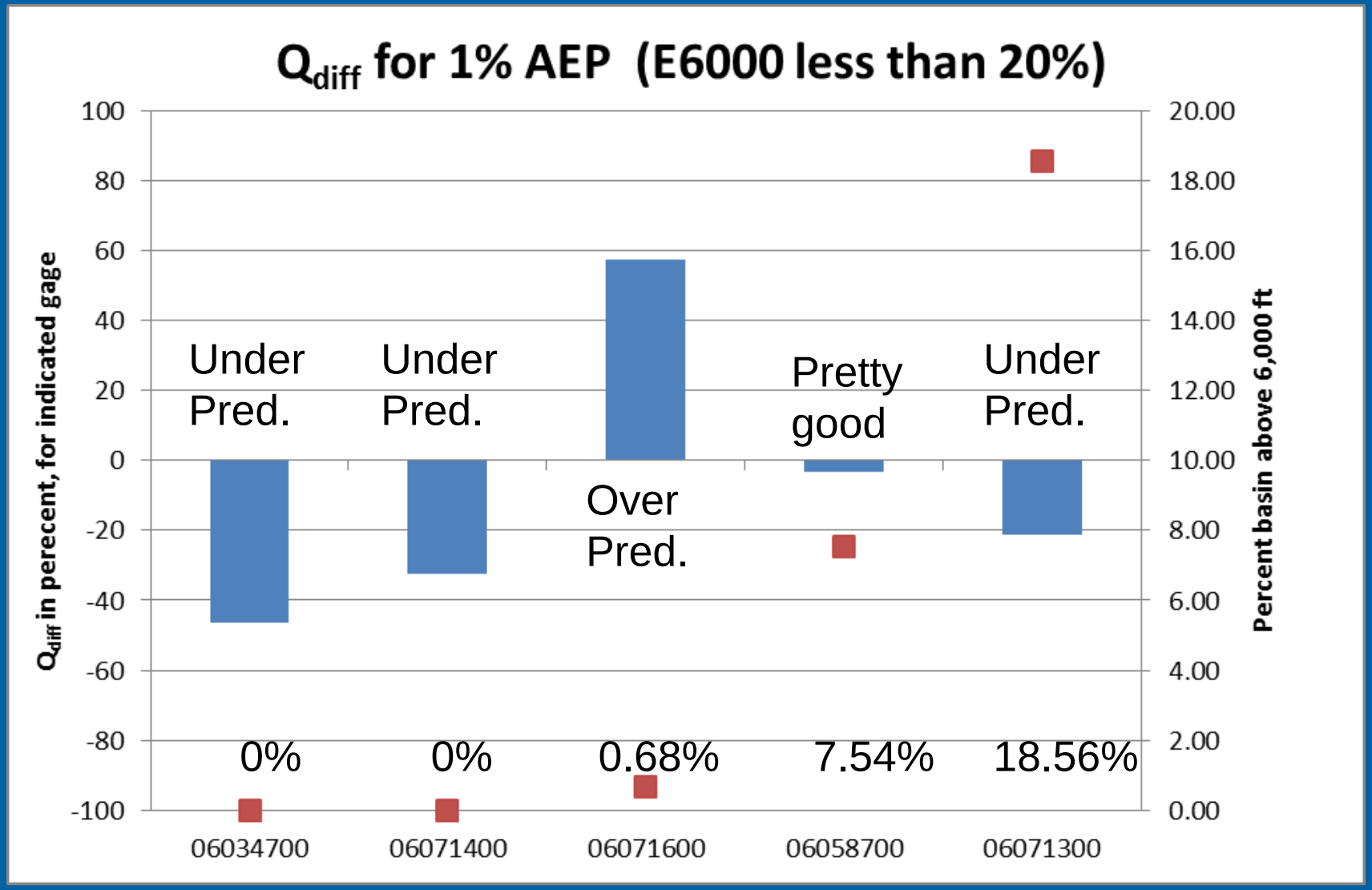
USGS

Southwest E6000 for 1%AEP



USGS

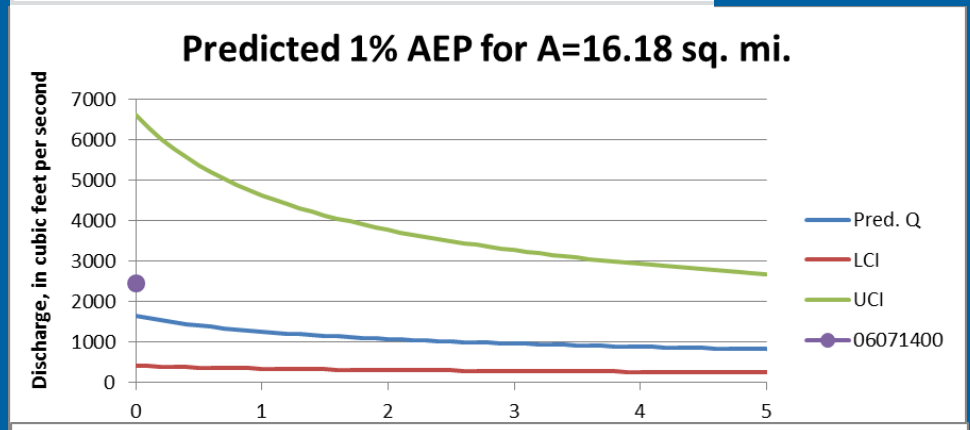
Southwest E6000 for 1%AEP

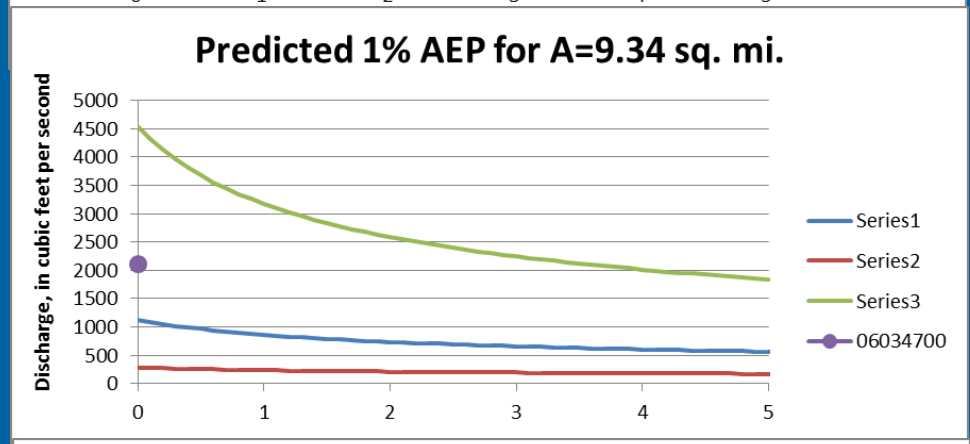


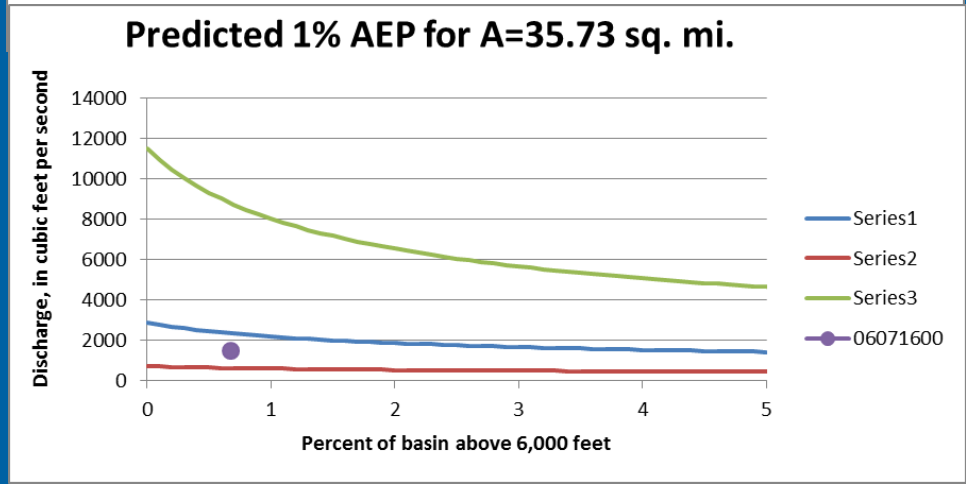
Southwest E6000

- Including DA & PIs
  - Dog Creek near Craig
    Under predicted
  - Sand Creek at Sappington
    Under predicted
  - Wegner Creek at Craig
    Over predicted

$$Q_1 = 238\ A^{0.696}\ (E_{6000} + 1)^{-0.391}$$





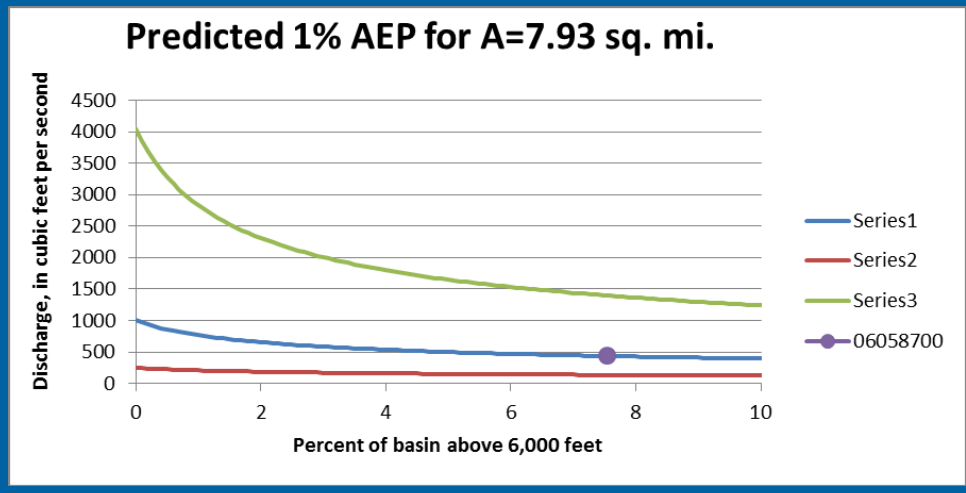


USGS

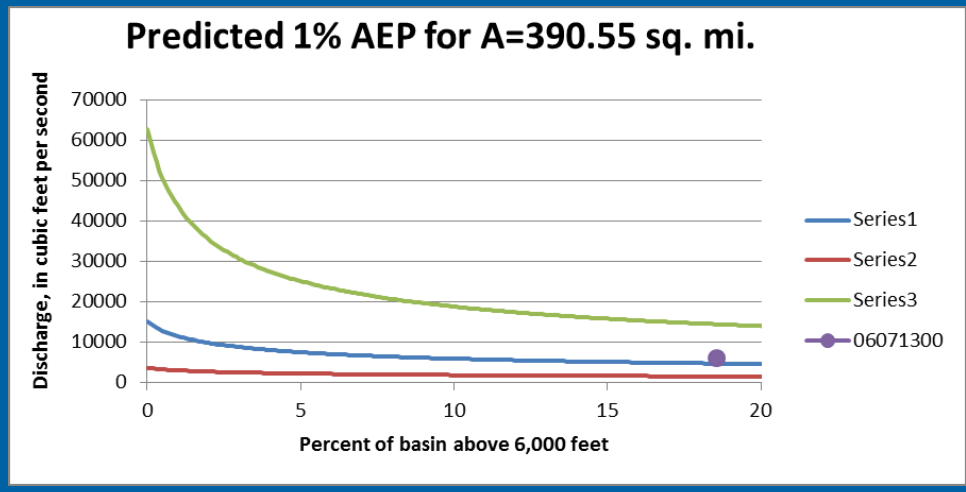
Southwest E6000

$$Q_1 = 238\ A^{0.696}\ (E_{6000} + 1)^{-0.391}$$

- **Mitchell Gulch nr. East Helena**
  - **Pretty good**



- **Little Prickly Pear Creek at Wolf Creek**
  - **Under Predicted**



USGS

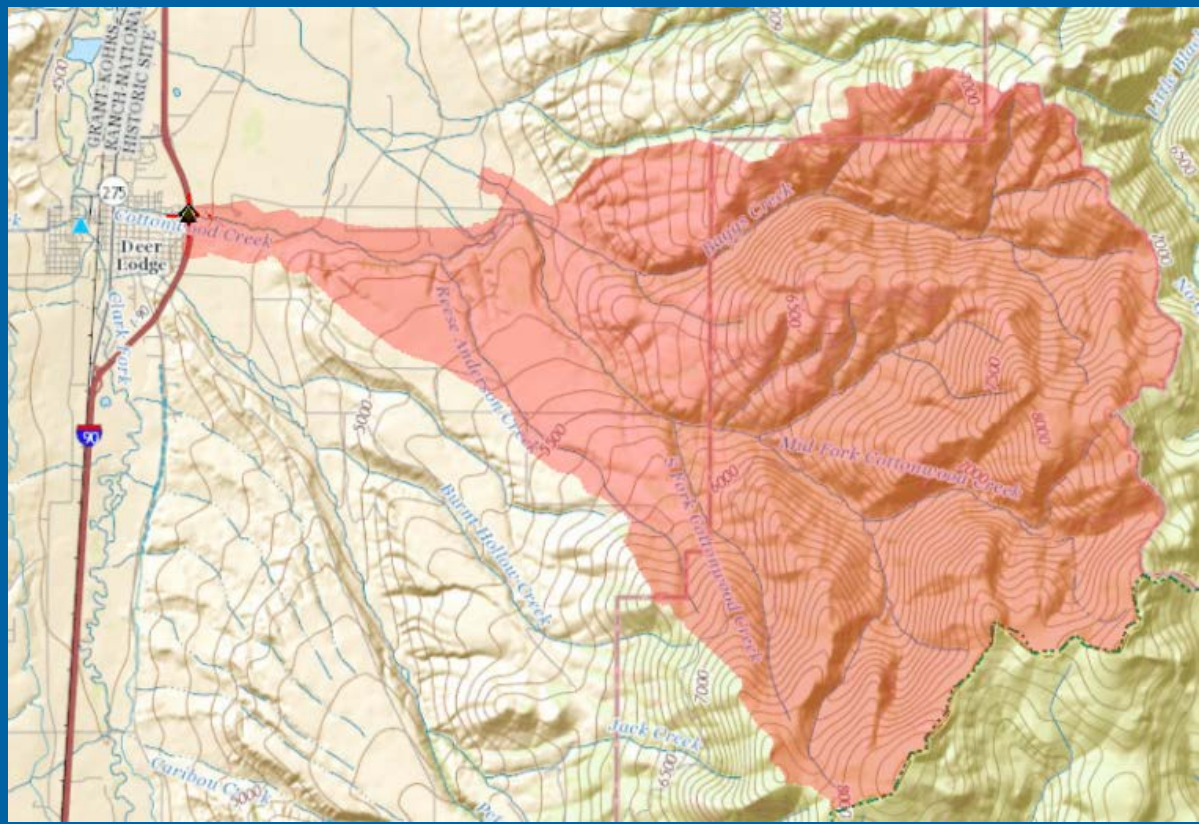
Red Fox Meadows

- Few sites in Southwest region with E6000 less than 20 percent
- These sites have <u>extreme variability</u>
- Regression equations split the difference of sites under 20 percent
- Regression equations vs. adjoining basin?
- Channel width equations?
- Discussion?

USGS

Cottonwood Creek at Deer Lodge

- DA=43.7
- Percent Forest=69.26
- Precipitation=23.26 inches



USGS

Cottonwood Creek at Deer Lodge

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
42.14	18	STATION	75	user	1,140	historic	1964	48

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**
196	254	284	449	624	907	1,170	1,490	1,860	2,480
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**
251	330	372	643	983	1,620	2,300	3,190	4,360	6,480
145	194	222	345	462	635	783	951	1,140	1,430

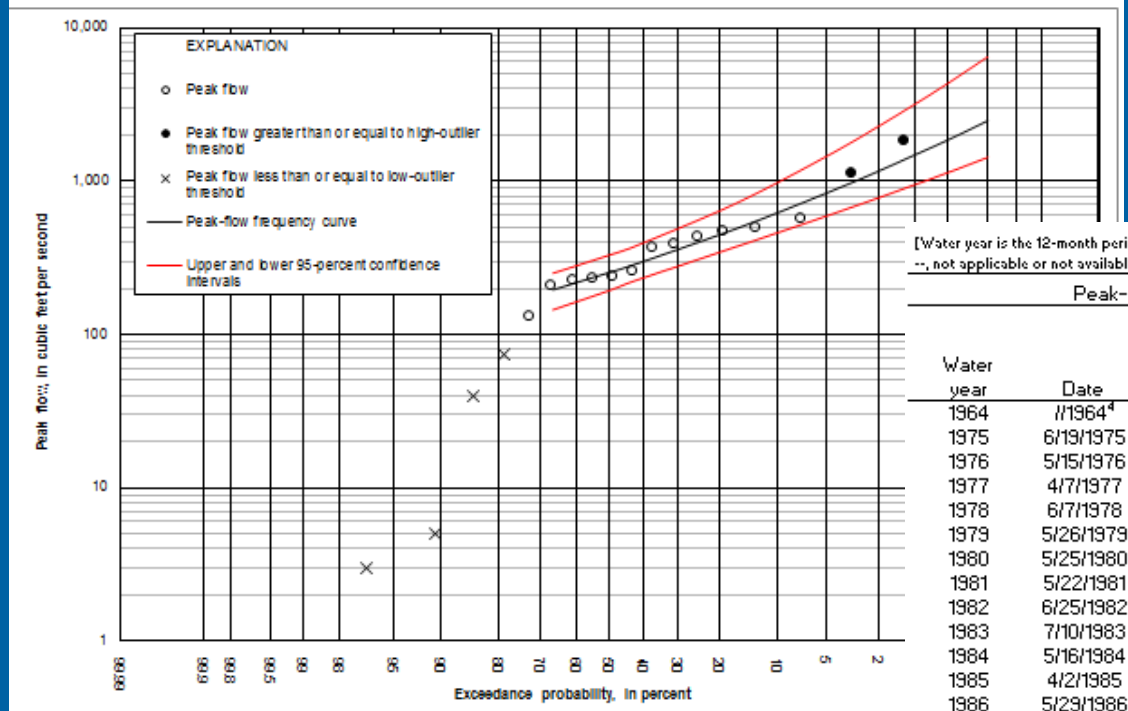


Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and

- **At-site analysis**
  - **Station skew**
  - **Low-outliers**
  - **Historic peaks**
  - **<u>Mixed population analysis</u>**

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.
--, not applicable or not available]

Peak-flow data[3]				Ranked (largest to smallest) peak-flow data[3]			
Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet	Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1964	//1964[4]	1,140	--	1981	5/22/1981	1,820	9.75
1975	6/19/1975	497	4.10	1964	//1964[4]	1,140	--
1976	5/15/1976	240	3.00	1984	5/16/1984	570	3.13
1977	4/7/1977	5.0	--	1975	6/19/1975	497	4.10
1978	6/7/1978	430	3.53	1982	6/25/1982	465	3.01
1979	5/26/1979	210	3.18	1978	6/7/1978	430	3.53
1980	5/25/1980	390	3.42	1980	5/25/1980	390	3.42
1981	5/22/1981	1,820	9.75	1990	5/31/1990	369	2.84
1982	6/25/1982	465	3.01	1983	7/10/1983	257	2.61
1983	7/10/1983	257	2.61	1976	5/15/1976	240	3.00
1984	5/16/1984	570	3.13	1986	5/29/1986	230	2.61
1985	4/2/1985	3.0	--	1989	3/9/1989	224	2.79
1986	5/29/1986	230	2.61	1979	5/26/1979	210	3.18
1987	5/28/1987	75	2.05	1991	6/8/1991	132	2.26
1988	4/19/1988	40	1.76	1987	5/28/1987	75	2.05
1989	3/9/1989	224	2.79	1988	4/19/1988	40	1.76
1990	5/31/1990	369	2.84	1977	4/7/1977	5.0	--
1991	6/8/1991	132	2.26	1985	4/2/1985	3.0	--

Cottonwood Creek at Deer Lodge

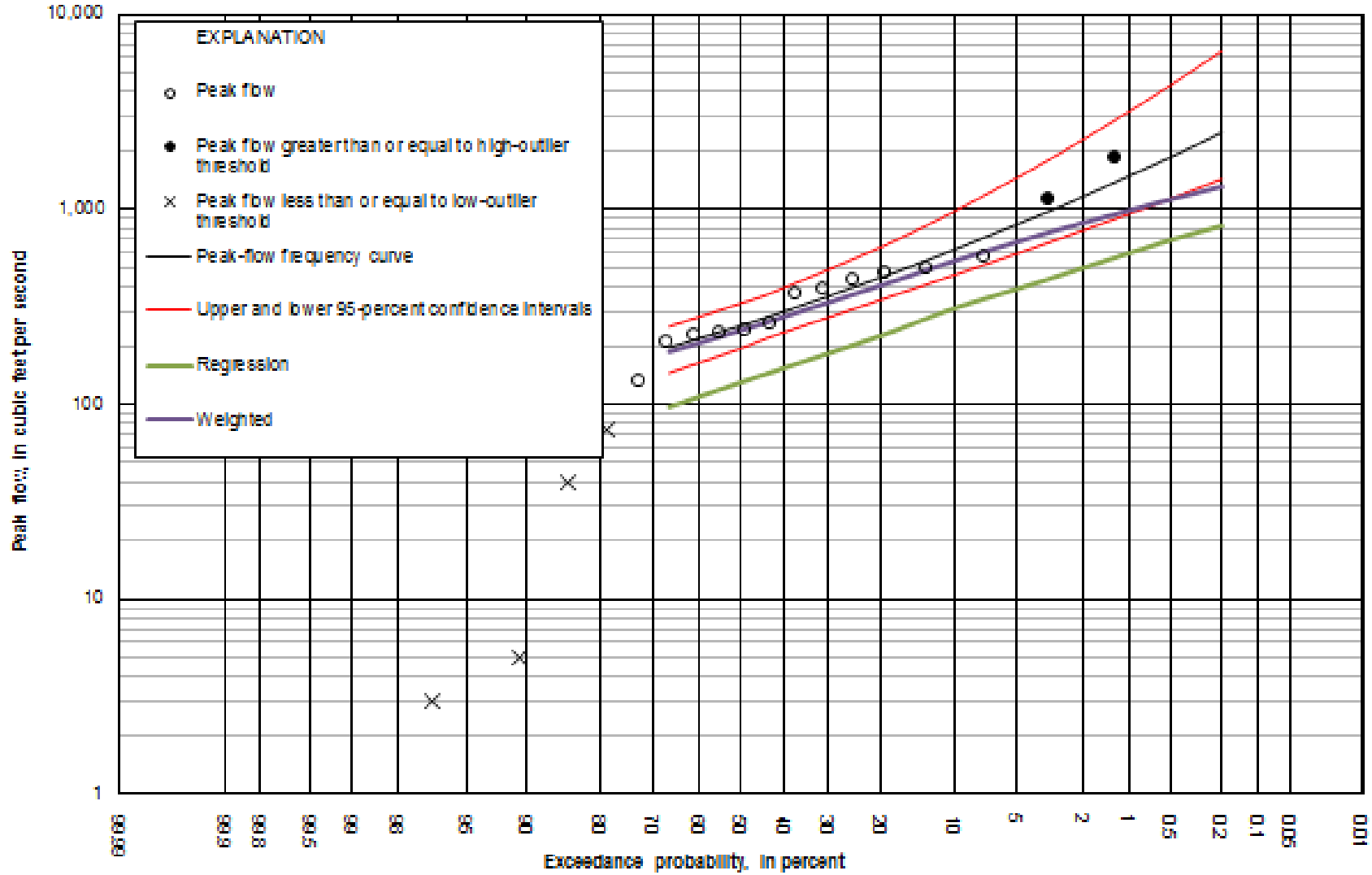
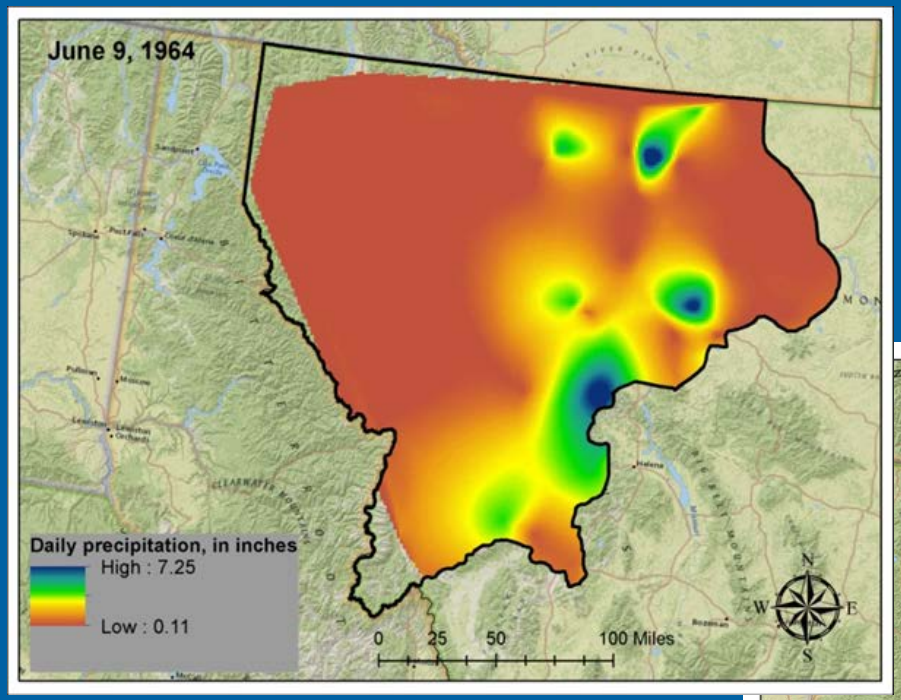
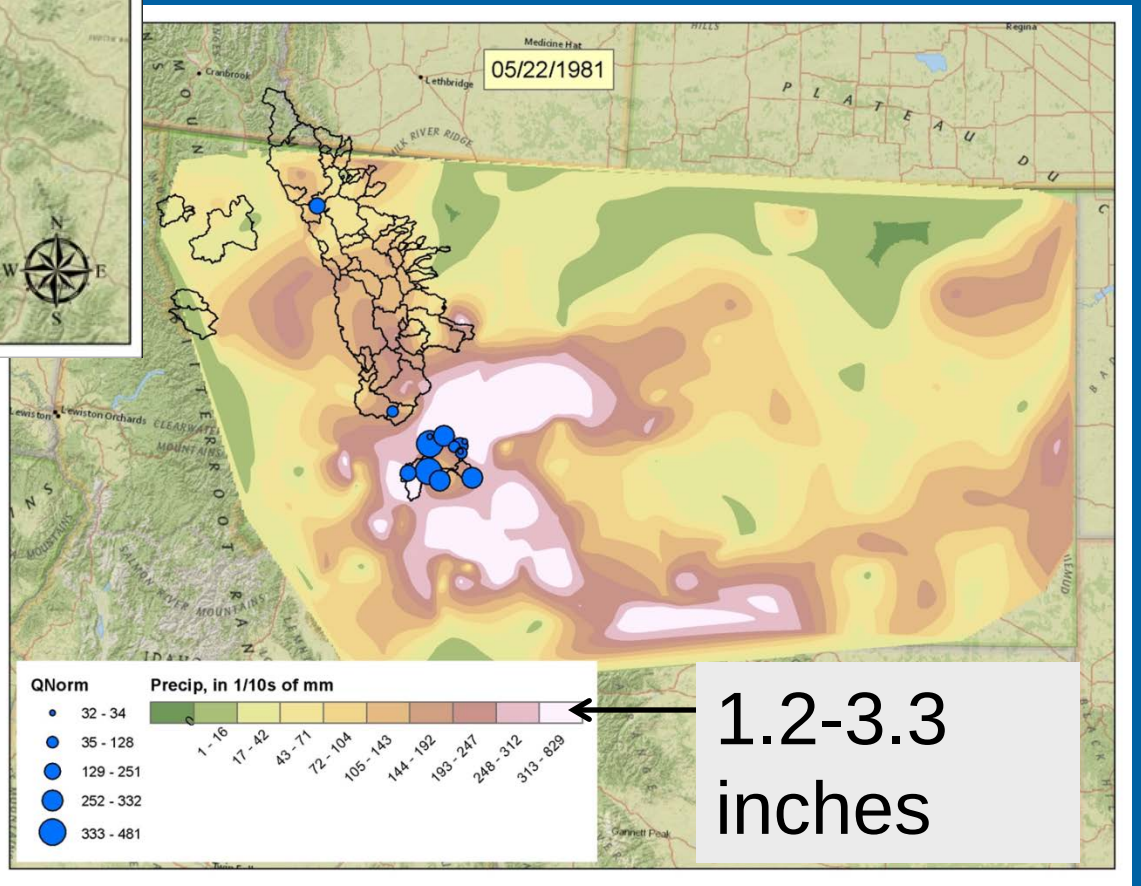


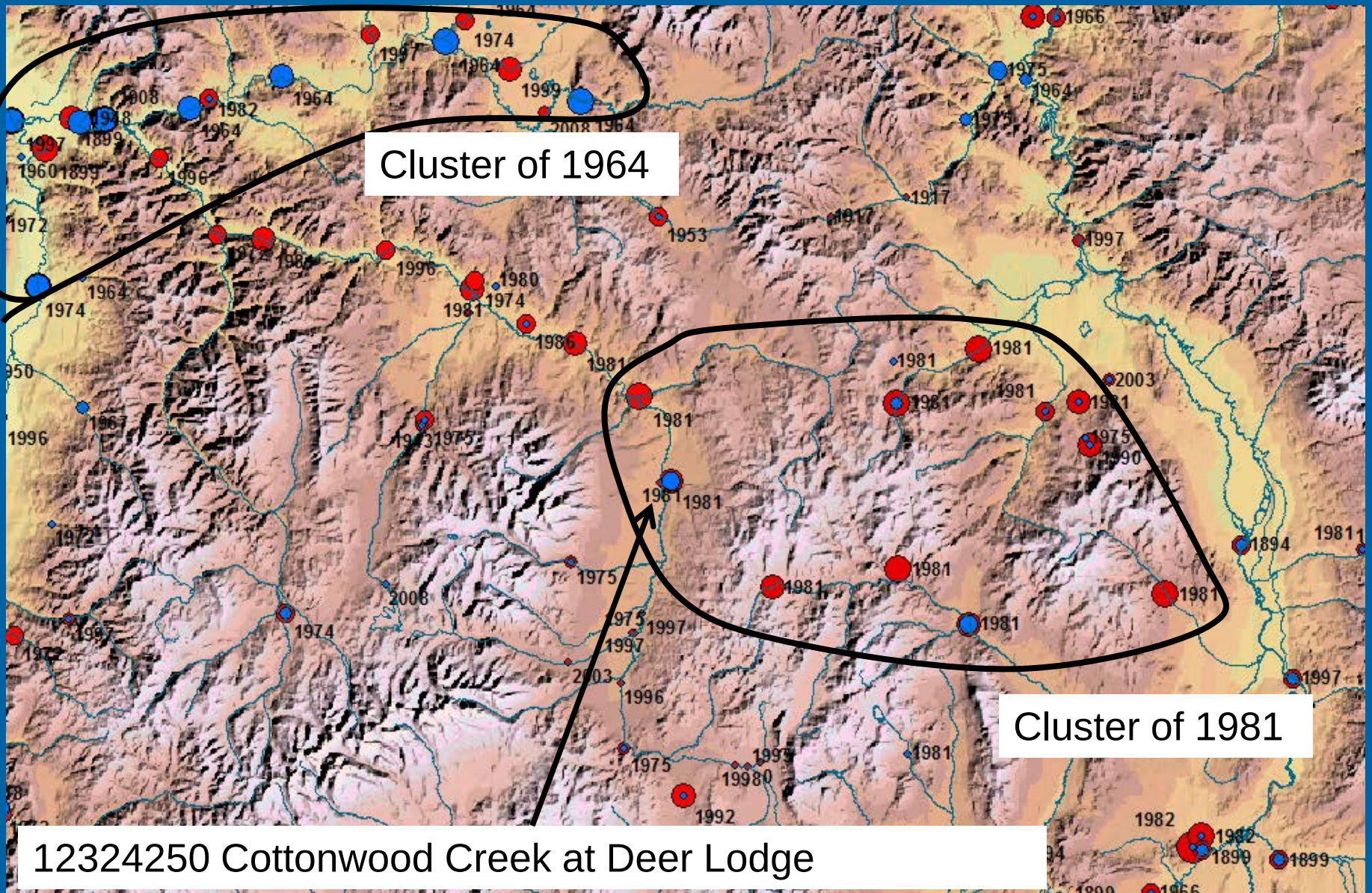
Figure 1-1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and Hirsch, 2002) and peak-flow frequency curve.

1981 and 1964 precipitation maps





USGS



12324250 Cottonwood Creek at Deer Lodge

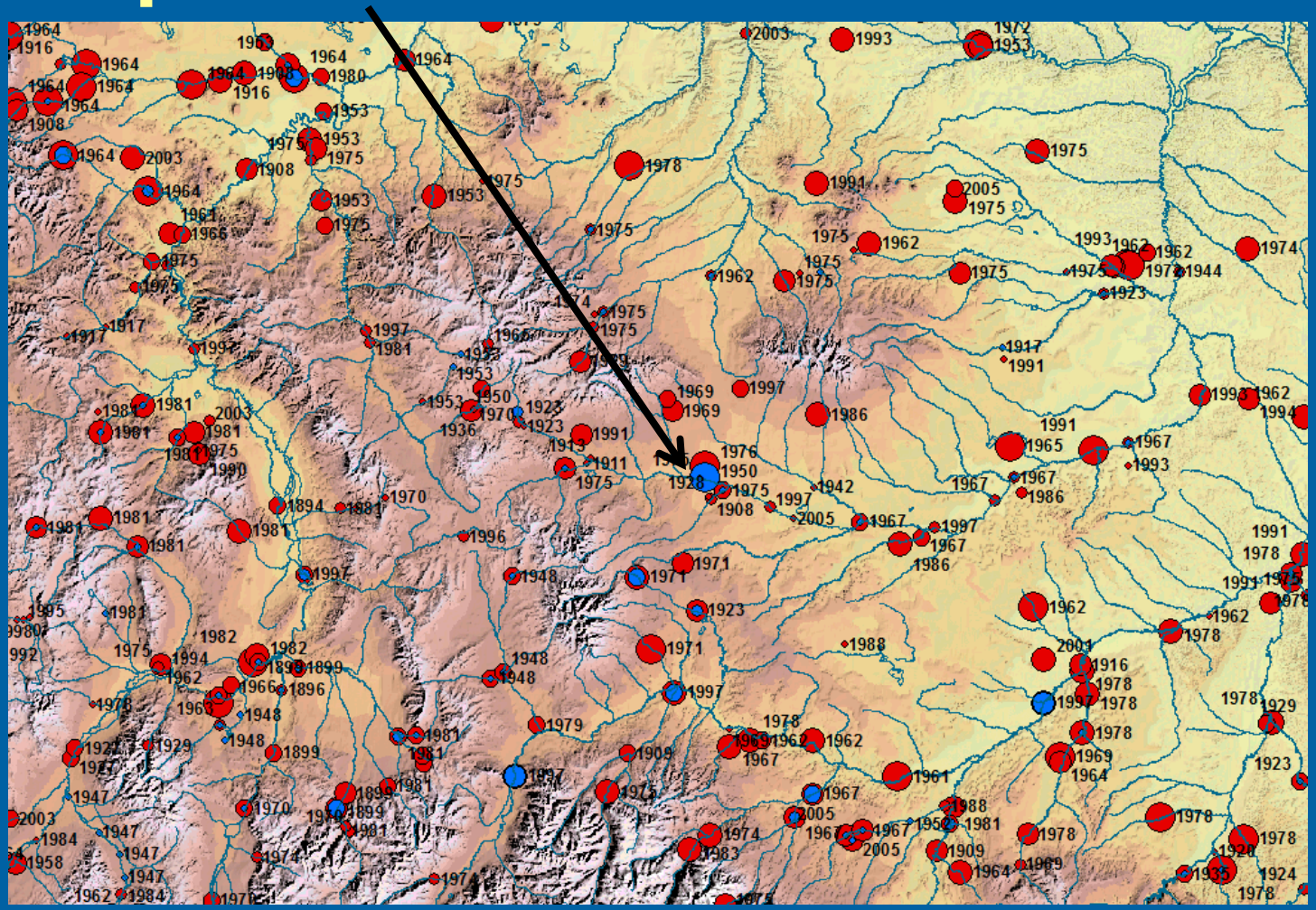
- Maximum peak of record, normalized by drainage area
- 1964 peak (if gaged), normalized by drainage area

Cottonwood Creek at Deer Lodge

- Discussion
- West region not well represented by mixed-population gages; therefore, regression equations likely will not perform well for sites that may be mixed population
- Cottonwood has strong mixed-population events
- No nearby sites with similar record, basin parameters, etc.

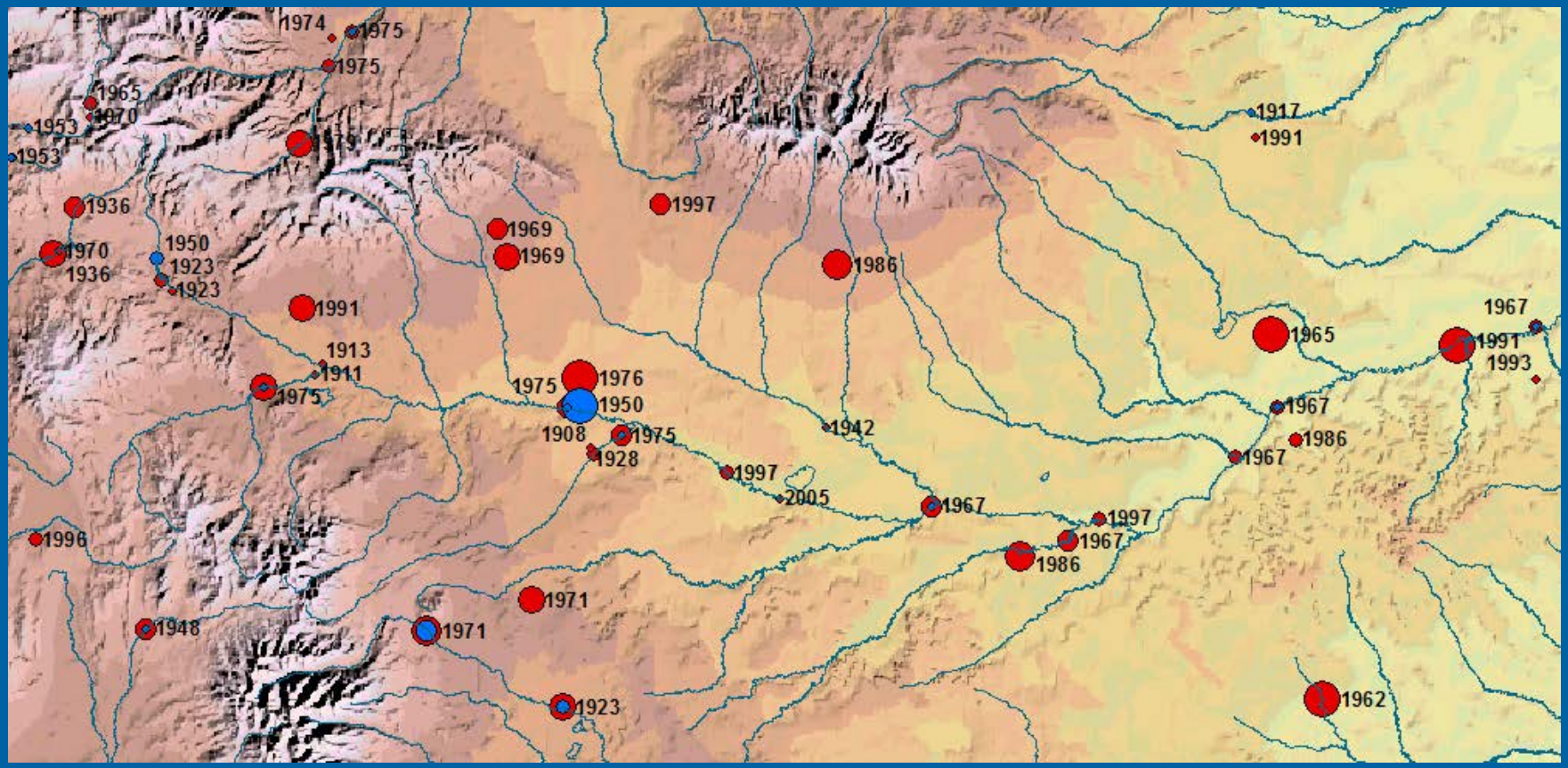
USGS

Antelope Creek-further discussions



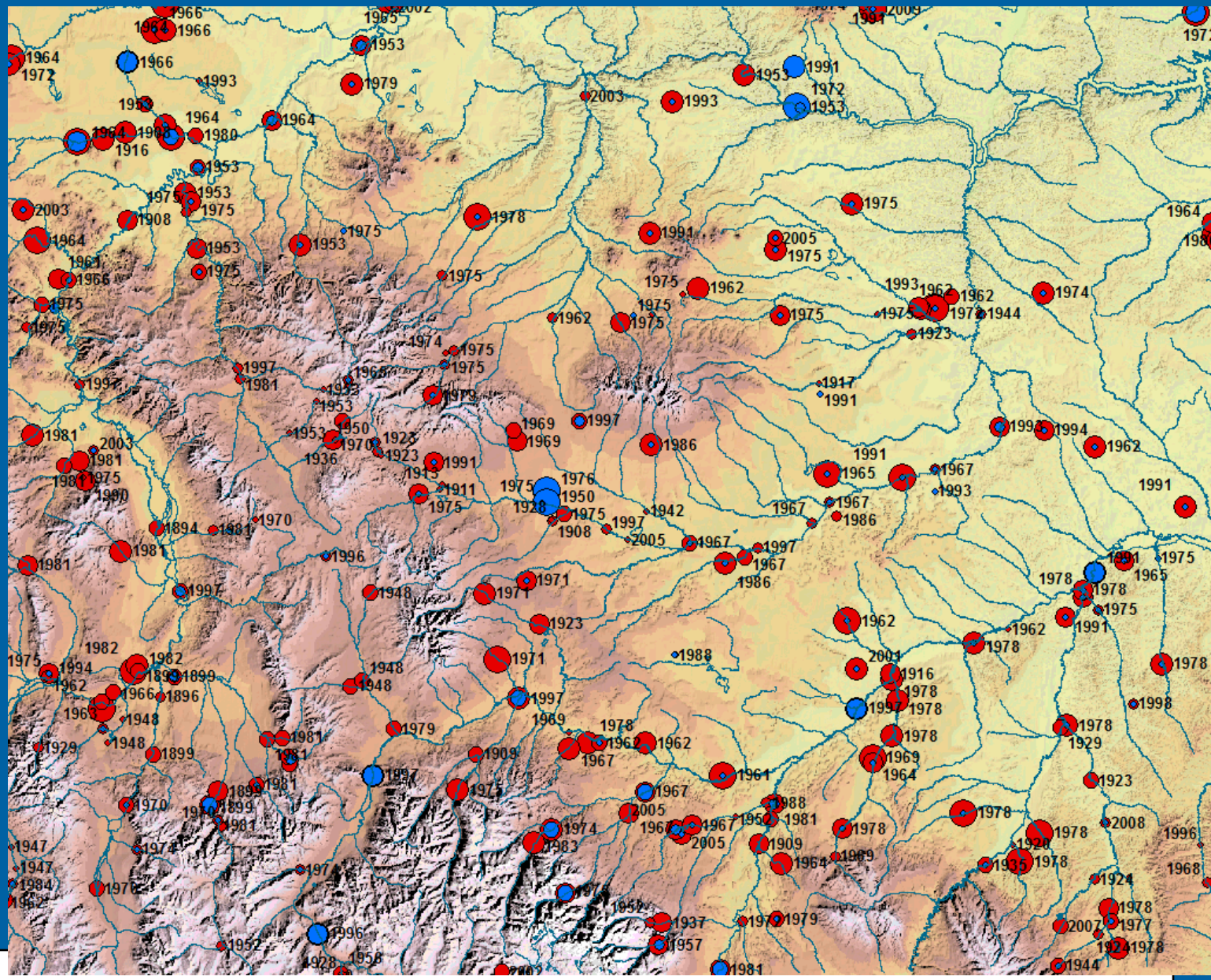
- Maximum peak of record, normalized by drainage area
- 1950 peak (if gaged), normalized by drainage area

Antelope Creek-further discussions



Maximum peak of record, normalized by drainage area

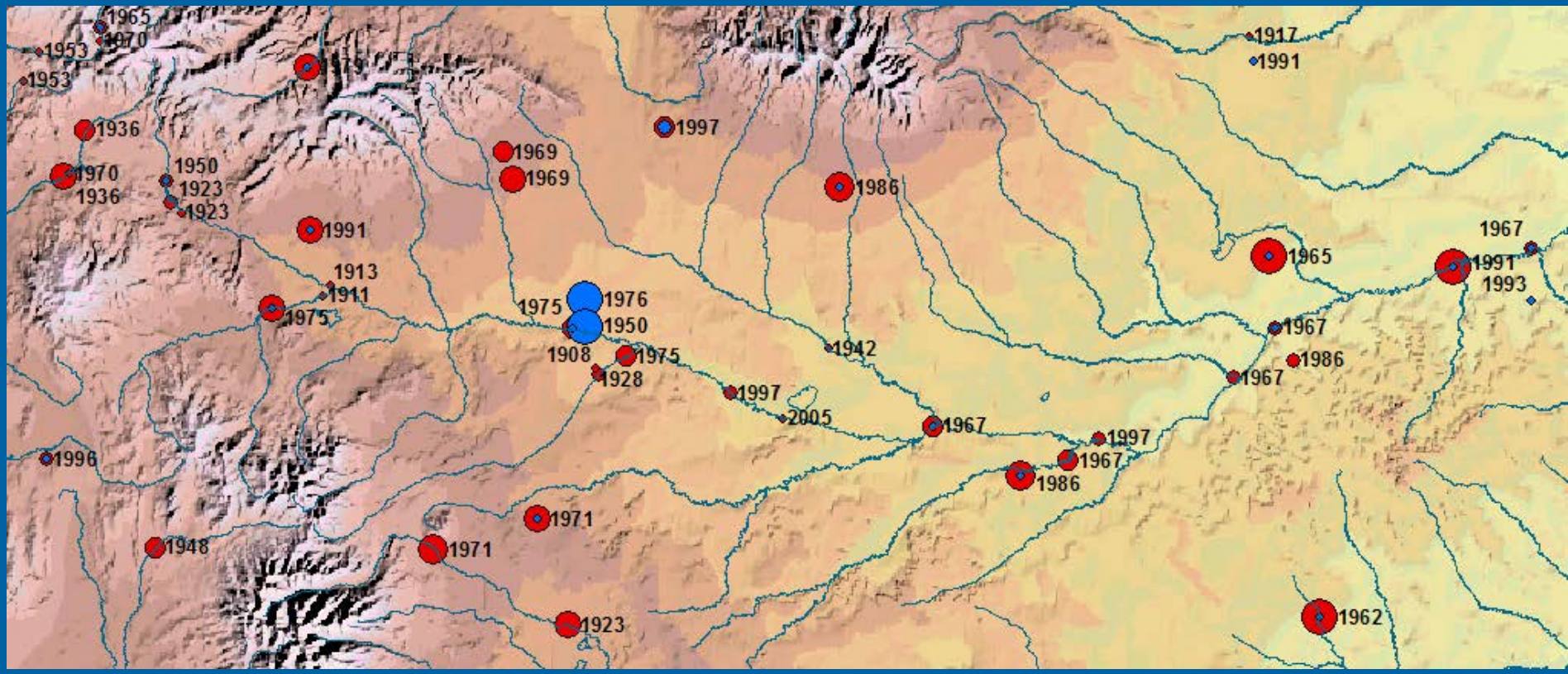
1950 peak (if gaged), normalized by drainage area



Maximum peak of record, normalized by drainage area

1976 peak (if gaged), normalized by drainage area

Antelope Creek-further discussions



Maximum peak of record, normalized by drainage area

1976 peak (if gaged), normalized by drainage area

Antelope Creek-further discussions

- **Top 10 peaks**

06120500 Musselshell River at Harlowton, Montana			
DA=1,125			
Ranked (largest to smallest) peak-flow data[3]			
Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1975	6/20/1975	7,270	10.01
2011	5/25/2011	5,520	10.25
1979	6/20/1979	4,680	9.14
1938	6/24/1938	4,530	--
1917	5/27/1917	4,020	--
1997	6/12/1997	3,720	8.25
1981	5/24/1981	2,940	7.19
1967	6/15/1967	2,880	7.52
1911	6/3/1911	2,590	--
1991	6/6/1991	2,530	7.26

06120800 Alkali Creek near Harlowton, Montana			
DA=15.43			
Ranked (largest to smallest) peak-flow data[3]			
Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1976	6/22/1976	5,390	6.50
1962	6/16/1962	3,230	5.56
1980	6/15/1980	1,100	4.01
1965	6/12/1965	922	3.79
1956	6/15/1956	820	3.51
1987	6/9/1987	480	3.01
1978	3/21/1978	427	2.87
1981	6/16/1981	390	2.76
1975	8/19/1975	345	2.61
1986	7/5/1986	220	2.05

06120900 Antelope Creek at Harlowton, Montana			
DA=90.85			
Ranked (largest to smallest) peak-flow data[3]			
Water year	Date	Peak flow, in cubic feet per second	Gage height, in feet
1950	6/17/1950	24,400	16.73
1976	6/22/1976	7,000	9.28
1962	6/16/1962	4,000	7.00
1980	6/12/1980	1,750	4.20
1954	8/15/1954	1,600	4.52
1978	3/21/1978	1,475	4.33
1956	6/15/1956	800	3.28
1955	6/26/1955	591	3.01
1979	6/19/1979	425	2.57
1965	6/12/1965	318	2.20

1909-2011	1956-1991	1950, 1954-73, 1976, 1978-80
103 peaks	36 peaks	25 peaks

USGS

Antelope Creek at Harlowton

- 1950 peak 24,400 cfs
  - Two indirects performed
    - Slope Area
    - Contracted opening (10 feet of fall through bridge opening)
  - Reviewed multiple times
  - Poor gage coverage for 1950 in region
  - 1950 ranked at 40th on Musselshell
- 1976 peak 7,000 cfs
  - Alkali Creek peak of 5,390 cfs for 15.4 sq. mi.
  - 1976 ranked 21st on Musselshell

USGS

Antelope Creek at Harlowton

- Basin very different from long-term gages in region
- Multiple large peaks in basin for relatively short gage history
  - Adjacent basin (Musselshell) has long history, not extremely large peaks.
  - Orthographic effect?
- Extremely large confidence intervals
- Really need more gage record
- 2011 peak-not substantial

USGS

Comparison of analyses

Table 11. Discharge Estimate Summary for USGS gage 06120900

Recurrence Interval	WRIR 03-4308					SIR 2015-5019			EMA
	Systematic	BC Regression	Weighted BC + AC Regression	Weighted BC + BF Regression	Weighted BC + BF + AC Regression	Systematic At-site	BC Regression	Weighted At-site + BC Regression	
10 yr	1,520	1,040	770	790	770	2,650	1,040	1,610	1,520
25 yr	4,370	1,600	1,330	1,350	1,330	8,010	1,690	2,880	4,920
50 yr	8,820	2,090	1,880	1,890	1,880	15,400	2,260	3,790	10,640
100 yr	16,800	2,650	2,530	2,540	2,530	26,500	2,880	4,670	21,490
500 yr	64,400	4,250	4,250	4,250	4,250	71,000	4,580	6,980	91,550

Selected discharges are shown in RED.

BC = Basin Characteristics

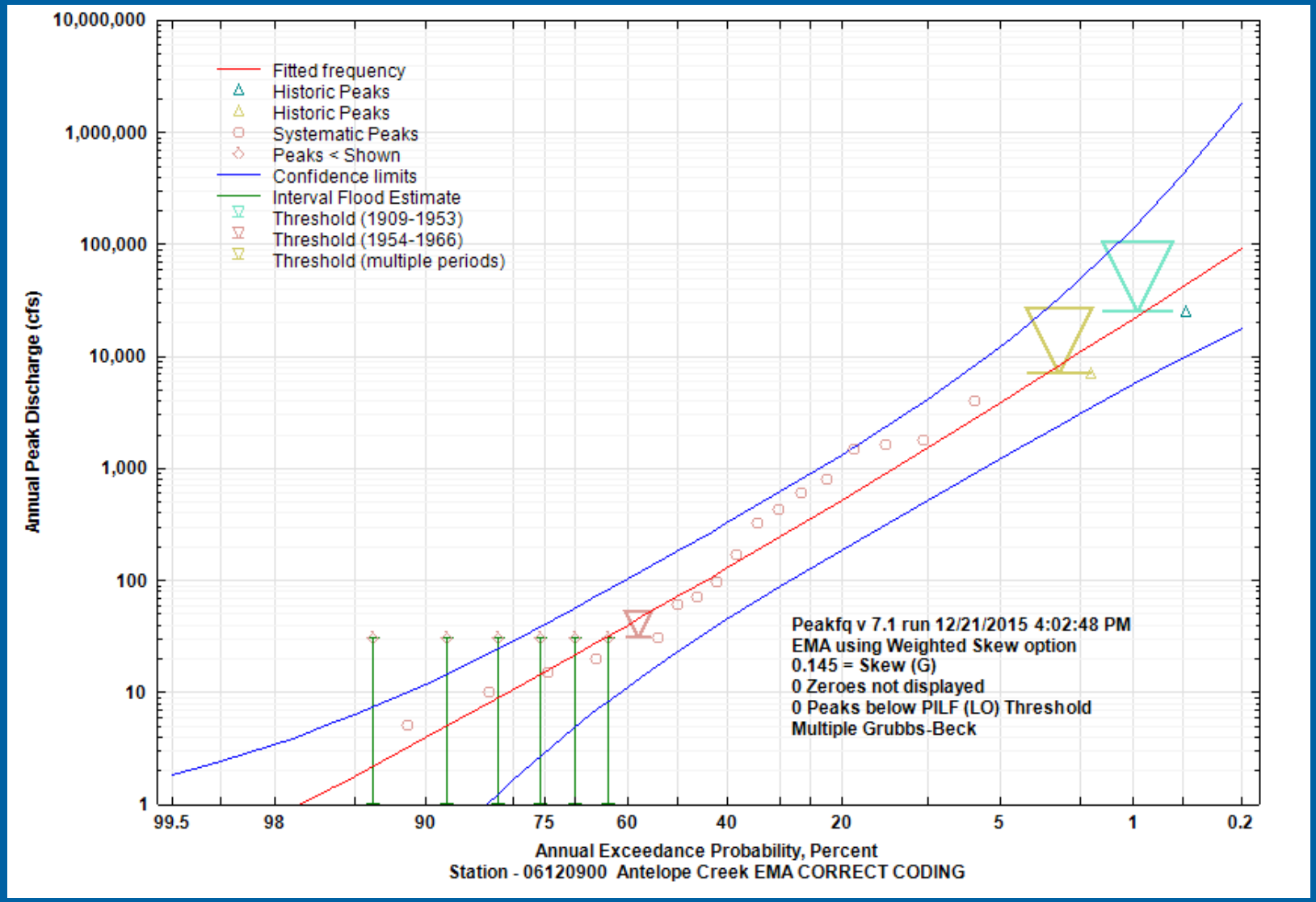
AC = Active Channel

BF = Bankfull Width

Written comm., Steve Story, DNRC

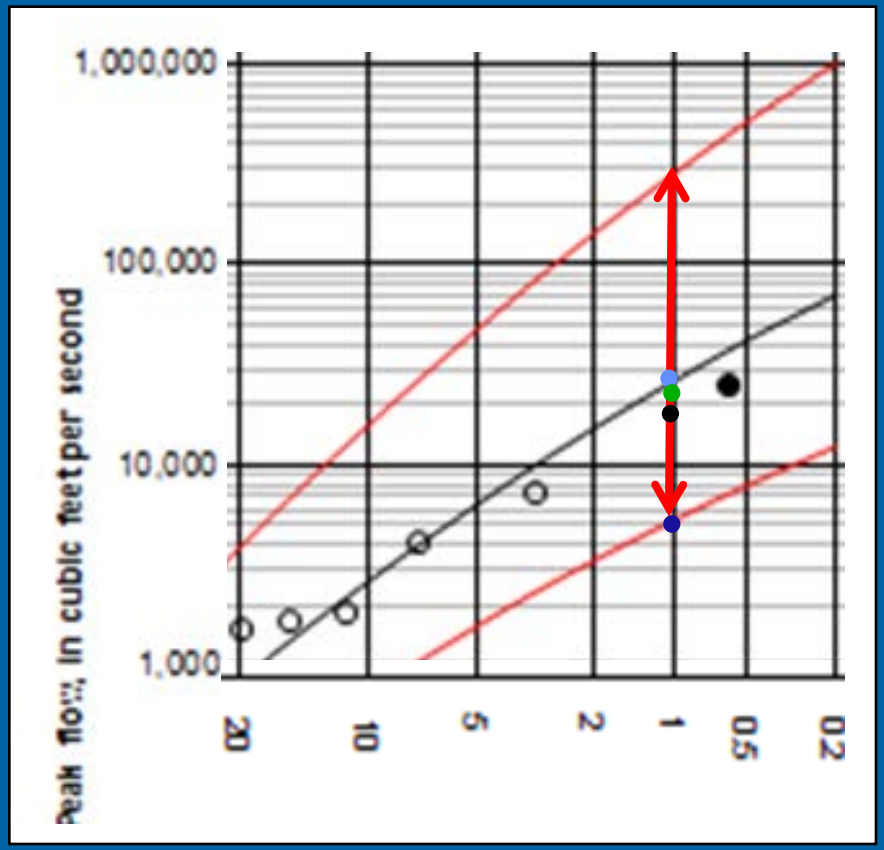
USGS

EMA for Antelope Creek



Comparison of analyses

- **Remember the confidence intervals: 5,350-288,000 cfs**



- **WRIR 03-4308 at-site=16,800 cfs**
- **Current at-site=26,500 cfs**
- **Current at-site weighted=4,670**
- **EMA= 21,490**

Updating at-site frequencies

- Current flood frequency reports used data through 2011. Already outdated?
- When to update at-site?
  - General rule of thumb is if you have 10% new peaks, or a peak in the top 10%.
  - Chapter C table 1-5 includes all specifics of how analyses were performed. Use this as a guideline if you're updating an at-site.
  - Don't forget historic peaks at discontinued sites can be updated as well if the historic period of record is through 2011.

USGS

General Thoughts

- 725 gaging stations with at-site analyses statewide
- Lots of variability within the state, regions, and even locally
- Skew map and station skews provides some insight on complexities in Montana
- Historic analyses, below-gage base peaks, mixed population analysis increase complexity

USGS

General Thoughts

- Regression equations
  - Unregulated sites with 10+ years record included
  - GLS regressions, accounts for time and sampling variability
  - Provides better fits than OLS, but generally results in larger prediction intervals
- New regional skew study
  - All of Montana will be included
  - May address extremes skew issues in mixed population regions
  - EMA analyses of gages with 25+ yrs

USGS

General Thoughts

- EMA methods
  - Handles historic peaks differently
  - Multiple Grubbs-Beck low outlier test
  - Will require additional documentation of peaks and data in the peak flow file.
- Regulation
  - Percent of area not a great indicator of regulation
  - Need to study regulation specifically
    - Storage to mean annual streamflow?
  - Small dams and reservoirs

USGS

General Thoughts

- Trends and stationarity
  - Is there such a thing as stationarity?
  - Long term vs. short term trends
- Channel width based regression equations
  - Update channel width data base
  - Explore remote sensing methods to measure
  - MDT research proposal

USGS