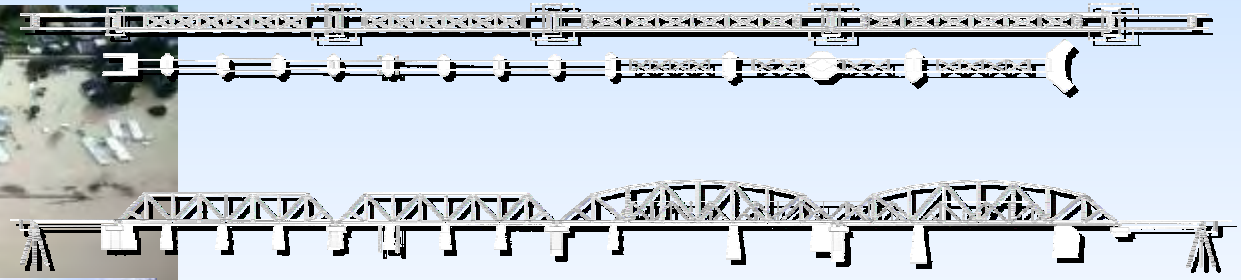
Skagit River Impact Partnership
Hydrology & Hydraulics Workshop
December 1, 2005



PACIFIC INTERNATIONAL ENGINEERING PLLC

SKAGIT RIVER BASIN

~

PUGET SOUND, WASHINGTON

Upper Baker Dam

Ross Dam

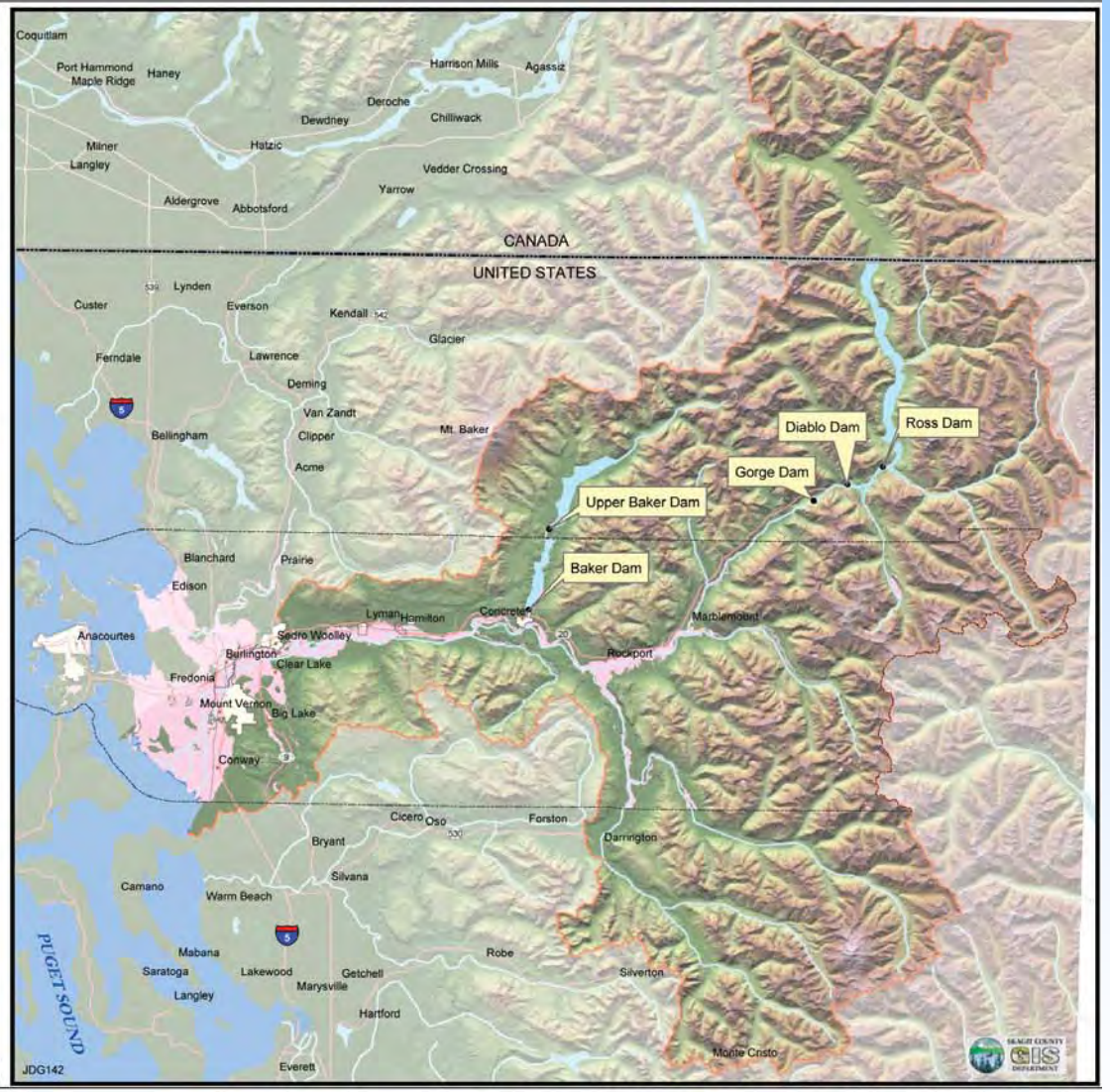
Lower Baker Dam

Skagit Watershed
Major Roads
Railroads
County Boundary
Incorporated Cities
FEMA 100 y flood

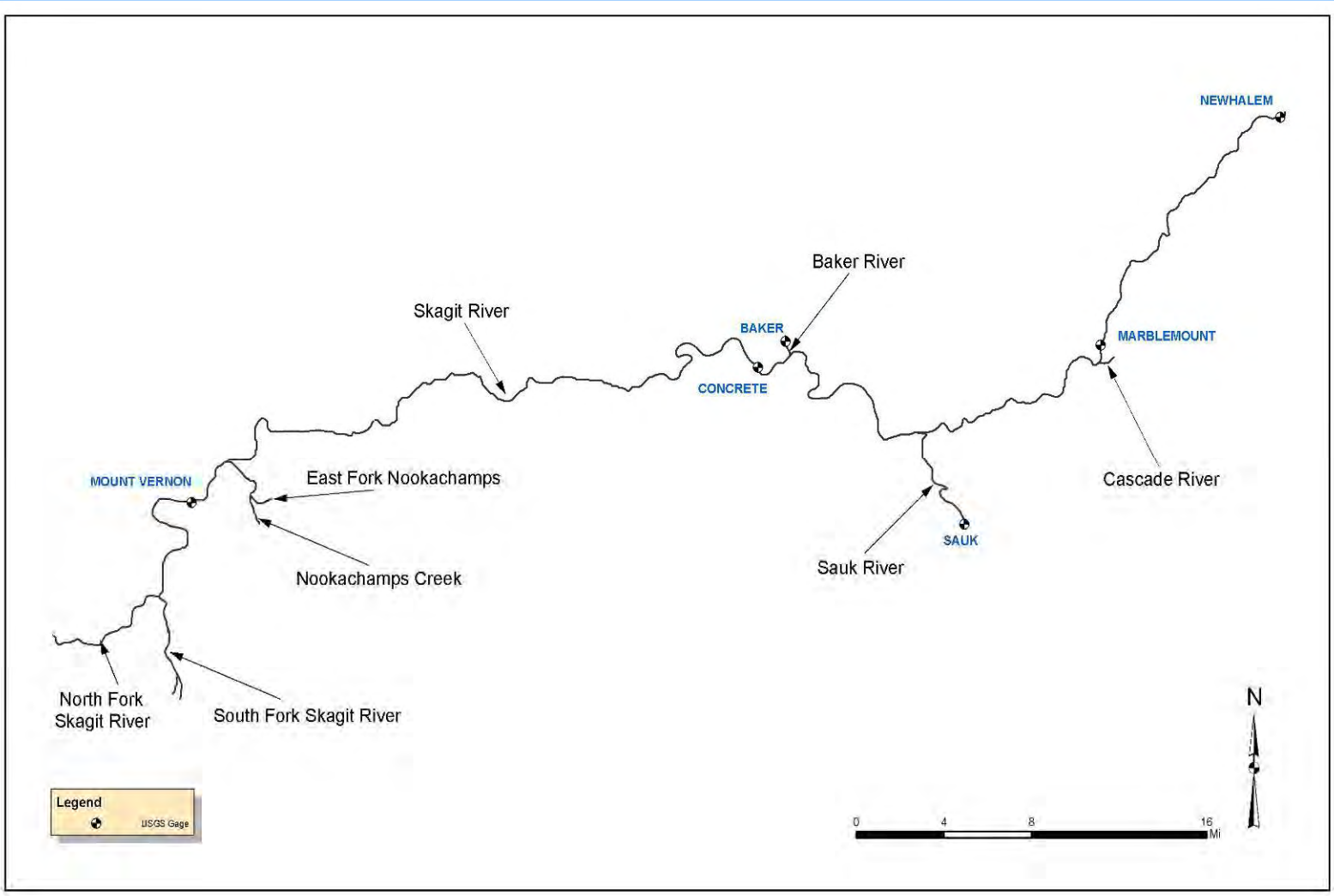
N
W E
S

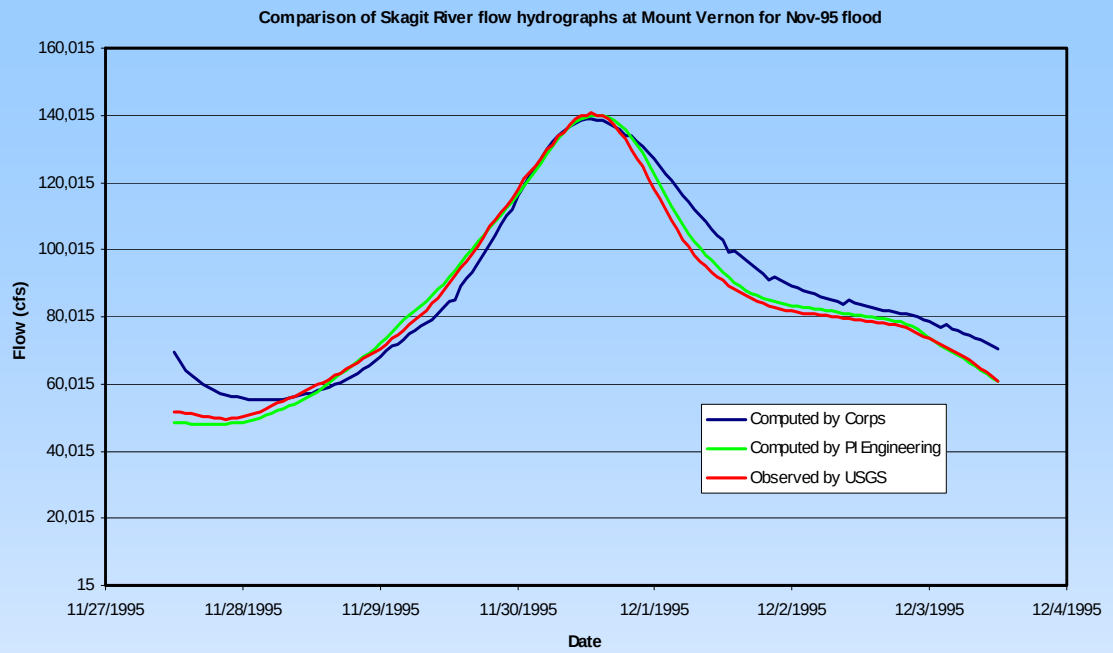
0 25 50 100 150 200
Miles

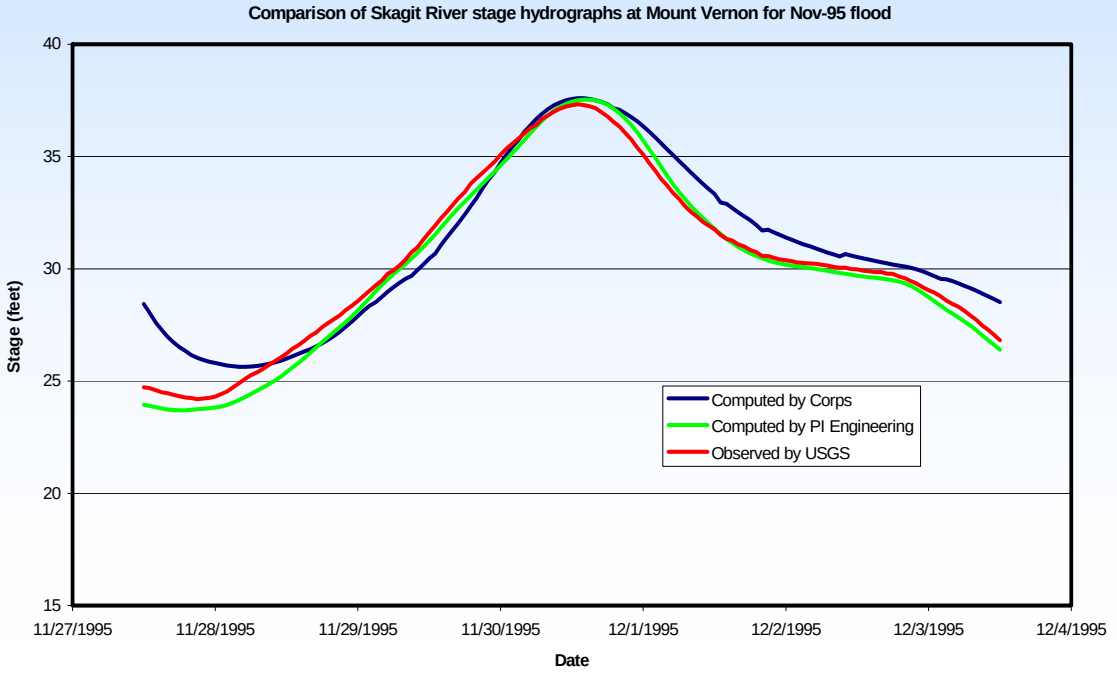
Map Printed: June 5, 2003



Routing reaches of the modified and expanded Skagit River HEC-RAS model




Comparison of Skagit River flow hydrographs at Mount Vernon for Nov-95 flood
160,015
140,015
120,015
100,015
80,015
60,015
40,015
20,015
15
Flow (cfs)
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS


Comparison of Skagit River stage hydrographs at Mount Vernon for Nov-95 flood
40
35
30
25
20
15
Stage (feet)
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

Calculations of Synthetic Floods

Methodology – Development of Frequency Curve

- Skagit River Basin – a “Regulated” Watershed
  - SCL – Ross, Diablo, and Gorge Dams
  - PSE – Upper Baker and Lower Baker Dams
- Flood Control Storage Regulation
  - Ross (120,000 AF) – since 1954
  - Upper Baker (74,000 AF) – since 1980
- FEMA Guidelines
  - Flood frequency curves to be developed for “unregulated” conditions
  - Then converted to “regulated” conditions by utilizing current reservoir operation criteria
  - “synthetic” flood hydrographs are required

Recorded Flow Data

Annual peak and one-day discharge data observed at the USGS gage 12194000 – Skagit River near Concrete for water years 1925 through 2004, compared with the Corps-developed unregulated flows and the assumed unregulated data

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows*	USGS Observed One-Day Flows	Winter Unregulated One-Day Flows*
1925	92,500	92,500	85,400	85,400
1926	51,600	51,600	42,100	42,100
1927	88,900	88,900	56,700	56,700
1928	95,500	95,500	81,200	81,200
1929	74,300	74,300	62,200	62,200
1930	32,200	43,692	29,200	29,200
1931	60,600	64,145	48,900	48,900
1932	147,000	147,000	129,000	129,000
1933	116,000	116,000	97,800	97,800
1934	101,000	101,000	85,000	85,000
1935	131,000	131,000	120,000	120,000
1936	60,000	28,223	14,300	14,300
1937	68,300	35,698	21,500	21,500
1938	89,600	89,600	63,500	63,500
1939	79,600	70,686	55,200	55,200

(Continued)

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows*	USGS Observed One-Day Flows	Winter Unregulated One-Day Flows*
1940	48,200	48,200	38,900	38,900
1941	51,000	51,000	42,200	42,200
1942	76,300	76,300	56,100	56,100
1943	54,000	54,000	45,000	45,000
1944	65,200	67,639	49,000	52,266
1945	70,800	70,077	61,200	54,614
1946	102,000	108,844	87,500	91,954
1947	82,200	81,490	62,000	65,607
1948	95,200	85,040	69,000	69,026
1949	55,700	45,180	52,100	30,632
1950	154,000	163,325	123,000	144,431
1951	139,000	151,668	128,000	133,202
1952	43,500	41,628	36,700	27,212
1953	66,000	79,612	60,700	63,798
1954	58,000	61,187	46,900	46,051
1955	56,300	63,268	51,200	48,055

(Continued)

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows*	USGS Observed One-Day Flows	Winter Unregulated One-Day Flows*
1956	106,000	124,179	94,100	106,725
1957	61,000	66,910	49,700	51,563
1958	41,400	48,846	34,600	34,164
1959	90,700	82,998	58,200	67,059
1960	89,300	101,118	77,500	84,512
1961	79,000	92,134	60,300	75,859
1962	56,000	73,870	48,900	58,267
1963	114,000	107,280	81,700	90,448
1964	73,800	82,130	58,600	66,224
1965	52,600	65,127	49,500	49,846
1966	36,800	44,836	29,000	30,302
1967	72,300	82,256	53,900	66,345
1968	84,200	86,529	60,200	70,460
1969	49,500	65,525	44,100	50,229
1970	38,400	43,335	29,000	28,855
1971	62,200	83,194	54,700	67,248
1972	91,900	63,640	40,400	48,414

(Continued)

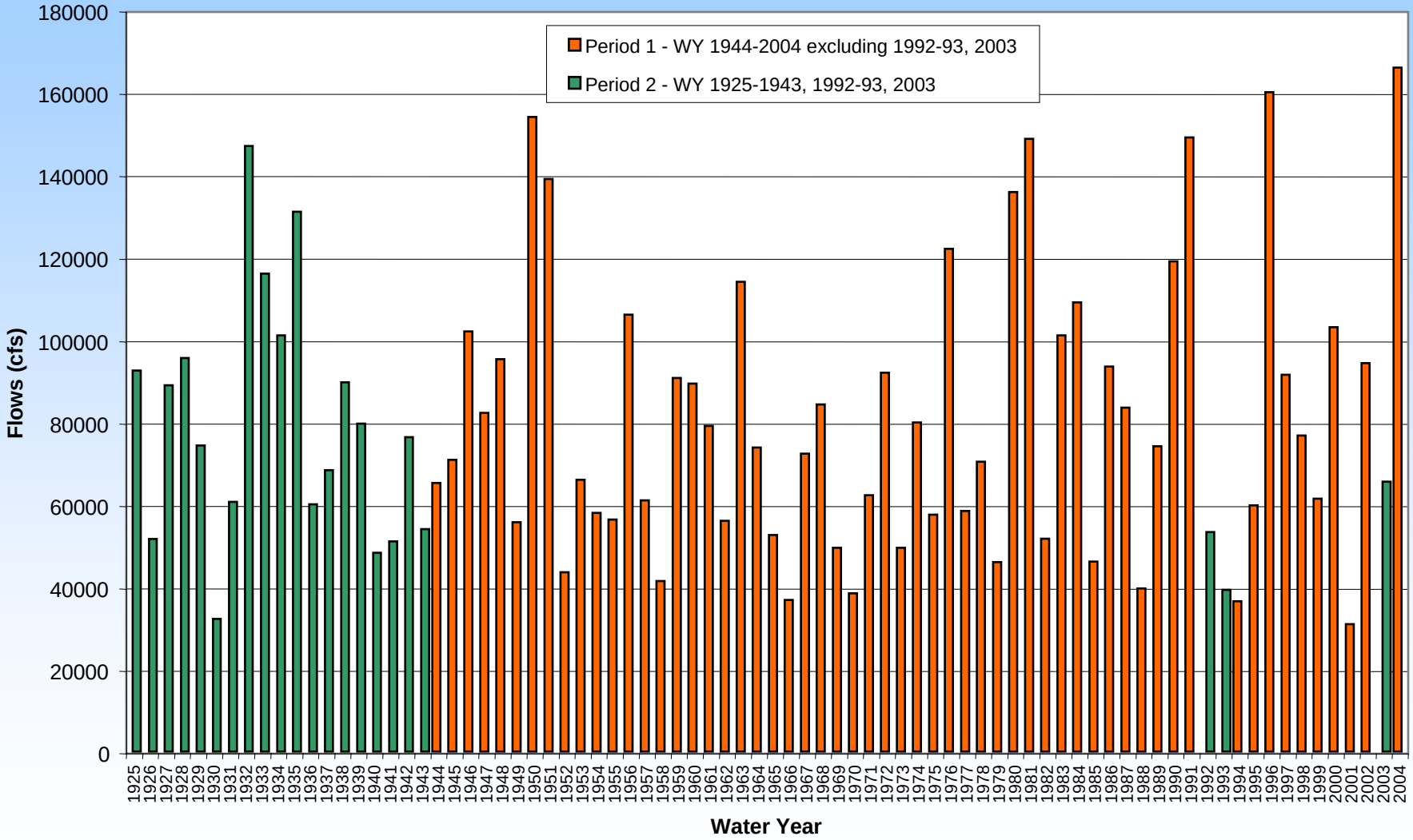
Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows*	USGS Observed One-Day Flows	Winter Unregulated One-Day Flows*
1973	49,500	58,079	43,100	43,057
1974	79,900	122,033	73,400	104,658
1975	57,500	63,929	42,500	48,692
1976	122,000	150,068	108,200	131,661
1977	58,400	70,984	45,800	55,487
1978	70,300	74,635	57,800	59,004
1979	46,000	59,164	35,300	44,103
1980	135,800	144,608	113,700	126,402
1981	148,700	163,438	104,900	144,540
1982	51,700	67,853	49,000	52,472
1983	101,000	83,792	61,500	67,824
1984	109,000	111,577	79,600	94,587
1985	46,100	42,000	23,900	27,569
1986	93,400	104,351	70,100	87,627
1987	83,500	78,609	60,300	62,832
1988	39,600	44,891	29,000	30,355
1989	74,100	89,300	55,900	73,130

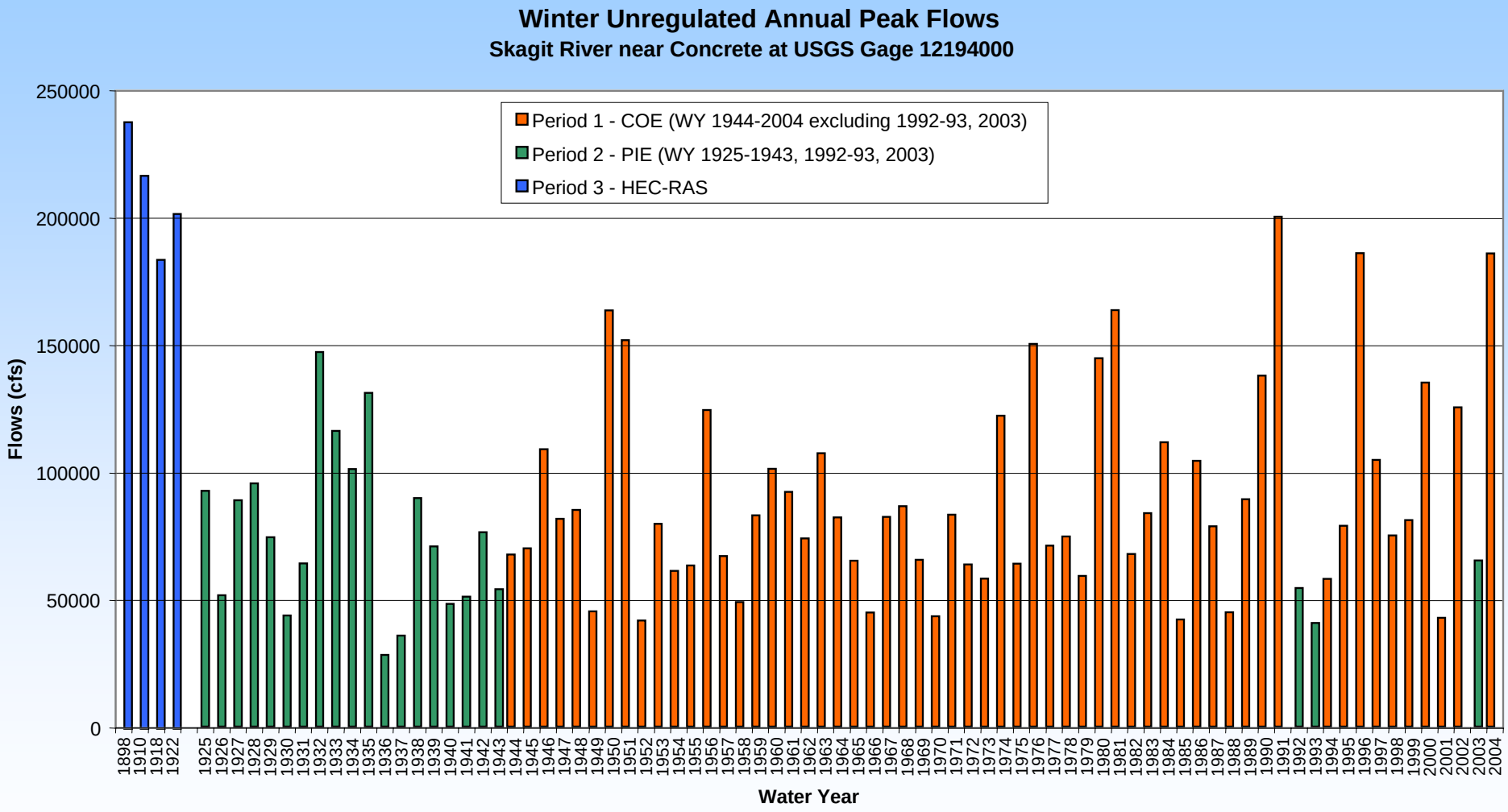
(Continued)

Water Year	USGS Observed Annual Peak Flows (cfs)	Winter Unregulated Annual Peak Flows*	USGS Observed One-Day Flows	Winter Unregulated One-Day Flows*
1990	119,000	137,739	86,100	119,787
1991	149,000	200,072	135,000	179,826
1992	53,300	54,343	35,300	39,459
1993	39,300	40,637	25,300	26,257
1994	36,500	57,927	31,400	42,911
1995	59,800	78,793	51,800	63,009
1996	160,000	185,733	131,000	166,014
1997	91,400	104,655	63,000	87,919
1998	76,700	75,040	61,400	59,394
1999	61,400	81,043	45,100	65,176
2000	103,000	135,037	86,000	117,183
2001	30,900	42,670	22,800	28,215
2002	94,300	125,293	79,700	107,798
2003	65,500	65,171	43,200	49,889
2004	166,000	185,685	131,000	165,968

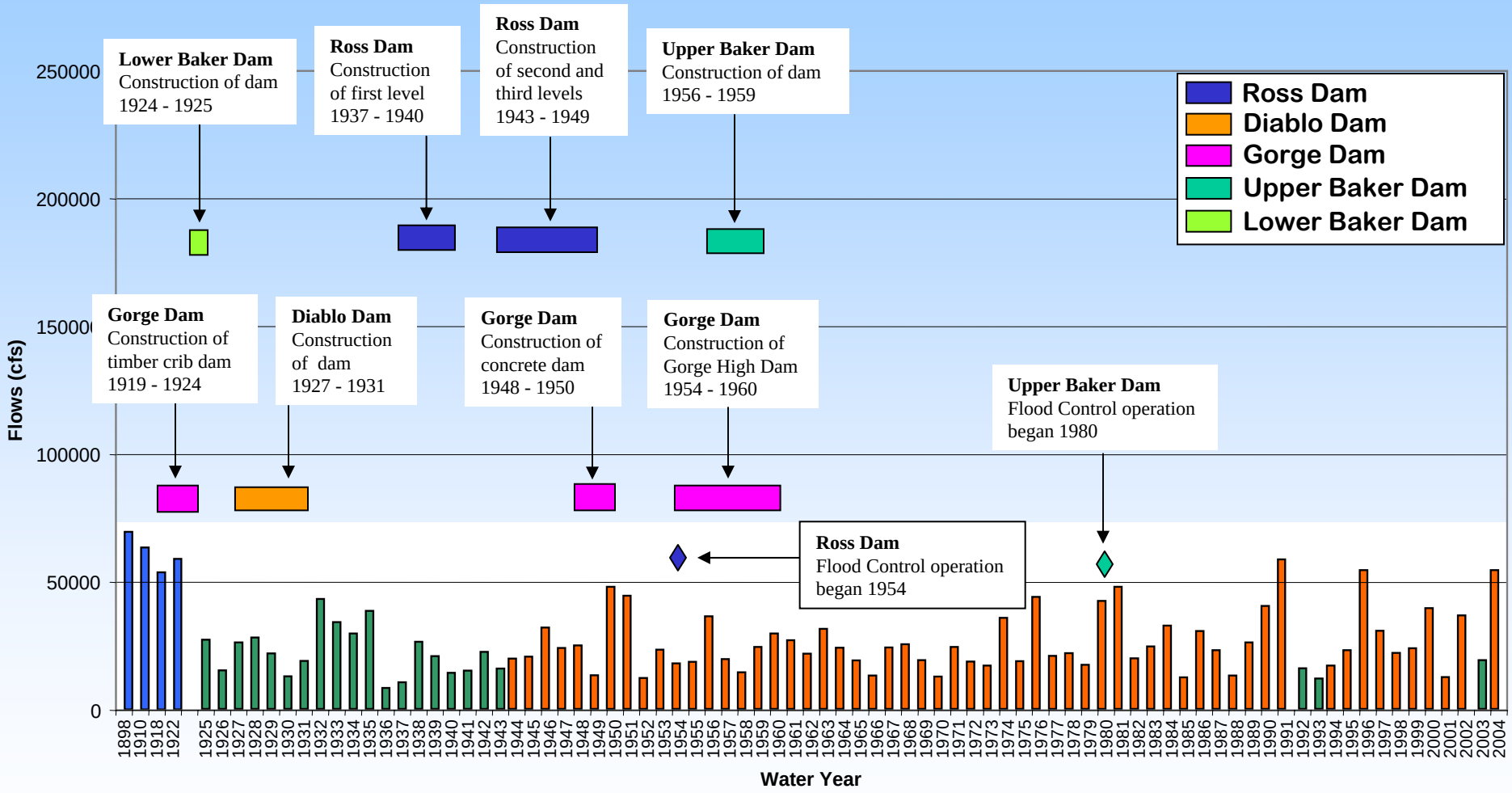
USGS Observed Annual Peak Flows

Skagit River near Concrete at USGS Gage 12194000




Winter Unregulated Annual Peak Flows
Skagit River near Concrete at USGS Gage 12194000
Period 1 - COE (WY 1944-2004 excluding 1992-93, 2003)
Period 2 - PIE (WY 1925-1943, 1992-93, 2003)
Period 3 - HEC-RAS
Flows (cfs)
250000
200000
150000
100000
50000
0
Water Year
1898 1910 1918 1922 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004

Skagit River Dams Chronology



Unrecorded Flow Data

USGS Unrecorded Data

Estimated Peak Discharges (cfs) of Four Historical Floods in the Skagit River

Water Year	Flood Date	Concrete Gage (RM 54.15)*	Sedro Woolley (RM 22.40)*	Concretre Staff Gage (RM 54.19)**
1898	Nov. 19, 1897	275,000	190,000	238,000
1910	Nov. 30, 1909	260,000	220,000	217,000
1918	Dec. 30, 1917	220,000	195,000	184,000
1922	Dec. 13, 1921	240,000	210,000	202,000

* Peak discharges published in USGS Water Supply Paper 1527 (USGS 1961)
** Peak discharge modeled by HEC-RAS.

Stewart's estimated peak stages and discharges of Skagit River near Concrete for four historical floods (Drainage Area = 2,700 sq. mi.)

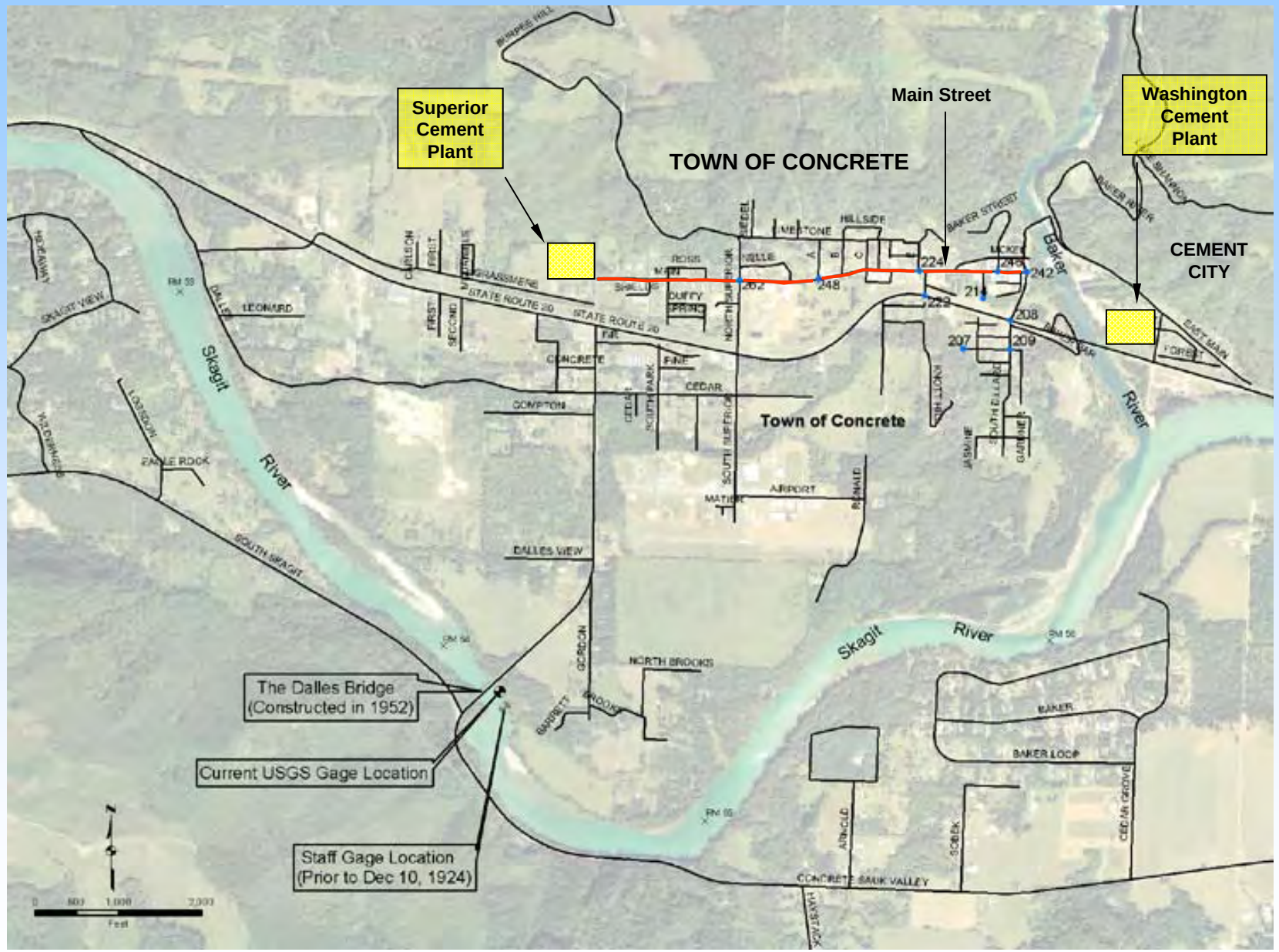
Flood	Gage Height at Current Gage* as Published in 1961** (ft)	Staff Gage Height*** Estimated by Stewart in 1923**** (ft)	Discharge Estimated by Stewart in 1923**** (cfs)
1897	51.1	38.4	275,000
1909	49.1	36.4	260,000
1917	45.7	33.0	220,000
1921	47.6	34.9	240,000

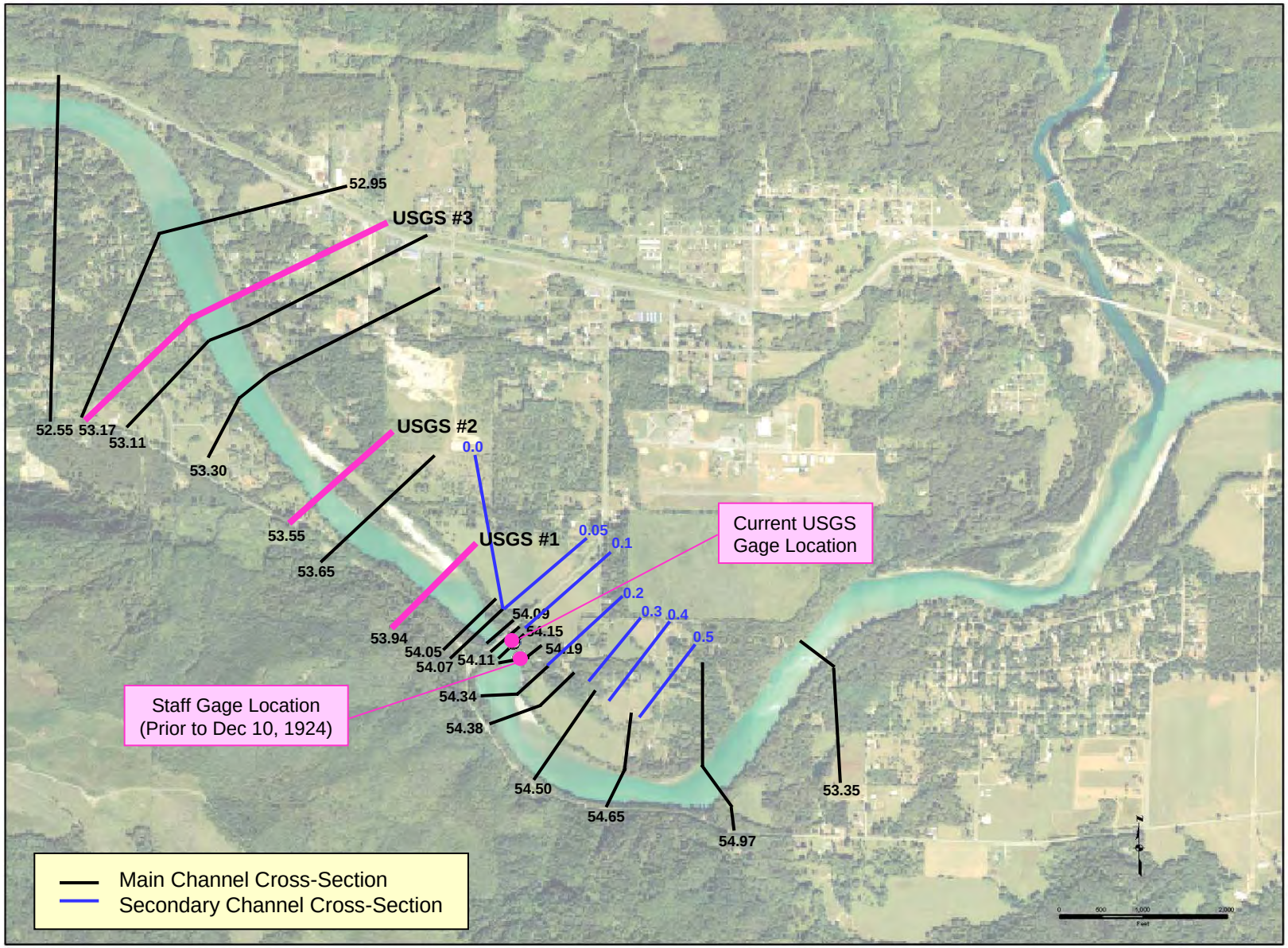
* Current gage datum El. 130.00 (NGVD29) at RM 54.15

** These numbers are an extrapolation performed and published by USGS in WSP 1527 (USGS 1961), based on Stewart's 1923 estimated gage heights presented in column 3 of this table

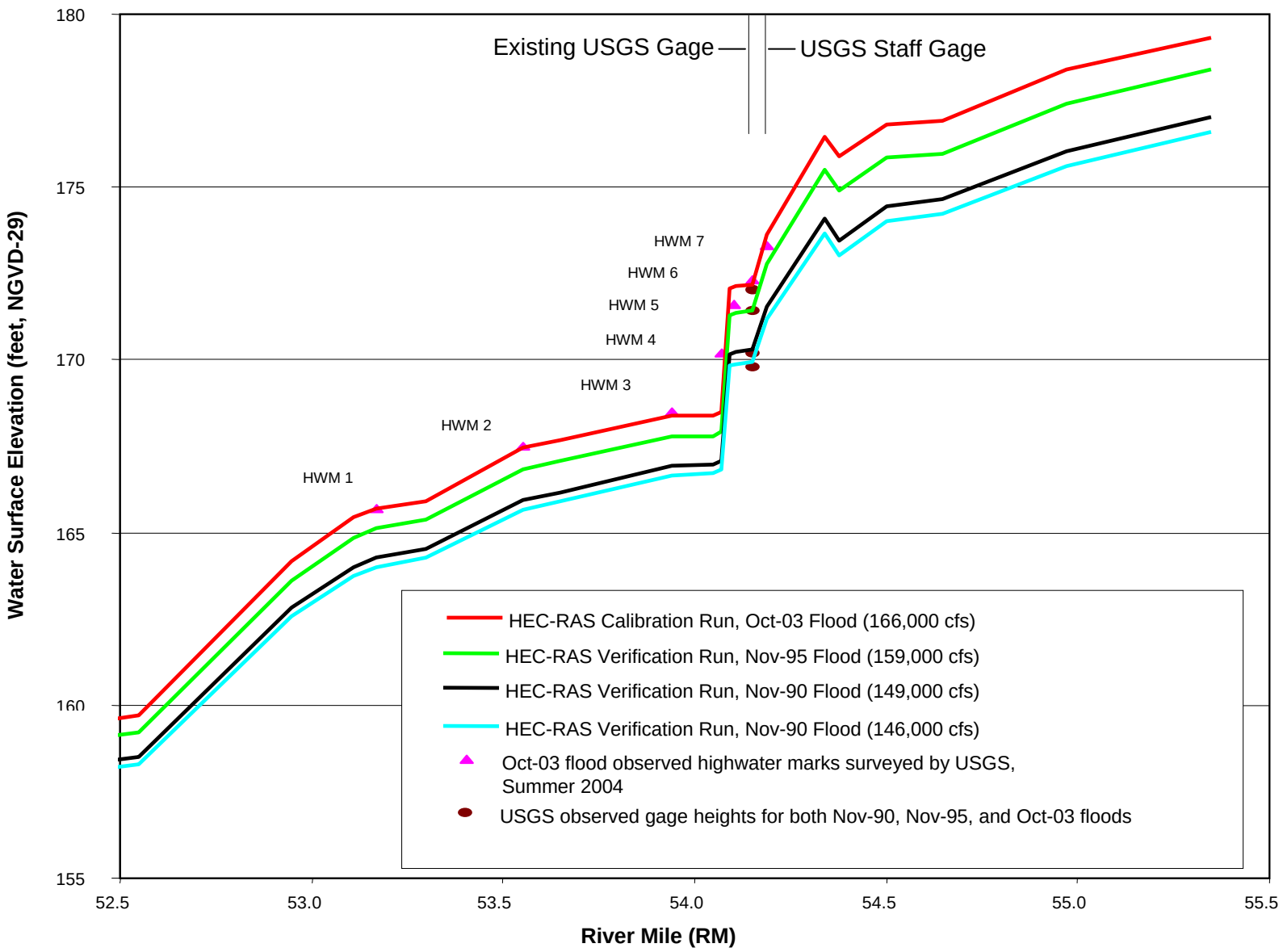
*** Prior to Dec. 10, 1924, a staff gage was located at RM 54.19, 200 feet upstream of the current gage location and at datum 12.7 feet higher than the current gage site (Flynn 1954)

**** These unpublished 1923 estimates by James Stewart were documented in the 1961 U.S. Geological Survey Water Supply Paper (WSP) 1527 (USGS 1961).


Superior Cement Plant
Main Street
Washington Cement Plant
TOWN OF CONCRETE
CEMENT CITY
Town of Concrete
Skagit River
The Dalles Bridge (Constructed in 1952)
Current USGS Gage Location
Staff Gage Location (Prior to Dec 10, 1924)


52.95
USGS #3
52.55
53.17
53.11
53.30
USGS #2
0.0
53.55
53.65
USGS #1
0.05
0.1
0.2
0.3
0.4
0.5
Current USGS Gage Location
53.94
54.09
54.15
54.05
54.07
54.11
54.19
Staff Gage Location (Prior to Dec 10, 1924)
54.34
54.38
54.50
54.65
54.97
53.35
Main Channel Cross-Section
Secondary Channel Cross-Section

Water Surface Profiles of the Skagit River near Concrete



Comparison of Skagit River Peak Stage near Concrete

Flood	Station	Location (RM)	Observed * by USGS (ft)	HEC-RAS (ft)	Difference (ft)
2003	HWM 7	54.19	173.30	173.61	-0.31
	HWM 6	54.15	172.30	172.19	0.11
	HWM 5	54.09	171.70	172.06	-0.36
	HWM 4	54.08	170.20	170.28	-0.08
	HWM 3	53.94	168.50	168.39	0.11
	HWM 2	53.55	167.50	167.47	0.03
	HWM 1	53.17	165.70	165.68	0.02
2003	Concrete gage	54.15	172.04	172.19	-0.15
1995		54.15	171.43	171.42	0.01
1990 (1)		54.15	170.18	170.30	-0.12
1990 (2)		54.15	169.79	169.96	-0.17

*Scaled from a profile plot provided by USGS

CALCULATION OF FLOW AT STAFF GAGE FOR 1921 USING CALIBRATED HEC-RAS MODEL

- The calibrated HEC-RAS model was run with progressively increasing flows.
- The flow at the staff gage location and elevation equivalent to Stewart's 1921 observed HWM is **202,000 cfs**.
- Stewart's estimated flood flow for the 1921 event using the slop/area approximation method is **240,000 cfs**

STEWART'S ESTIMATES OF THE PEAK FLOW FOR THE 1897 & 1909 FLOODS

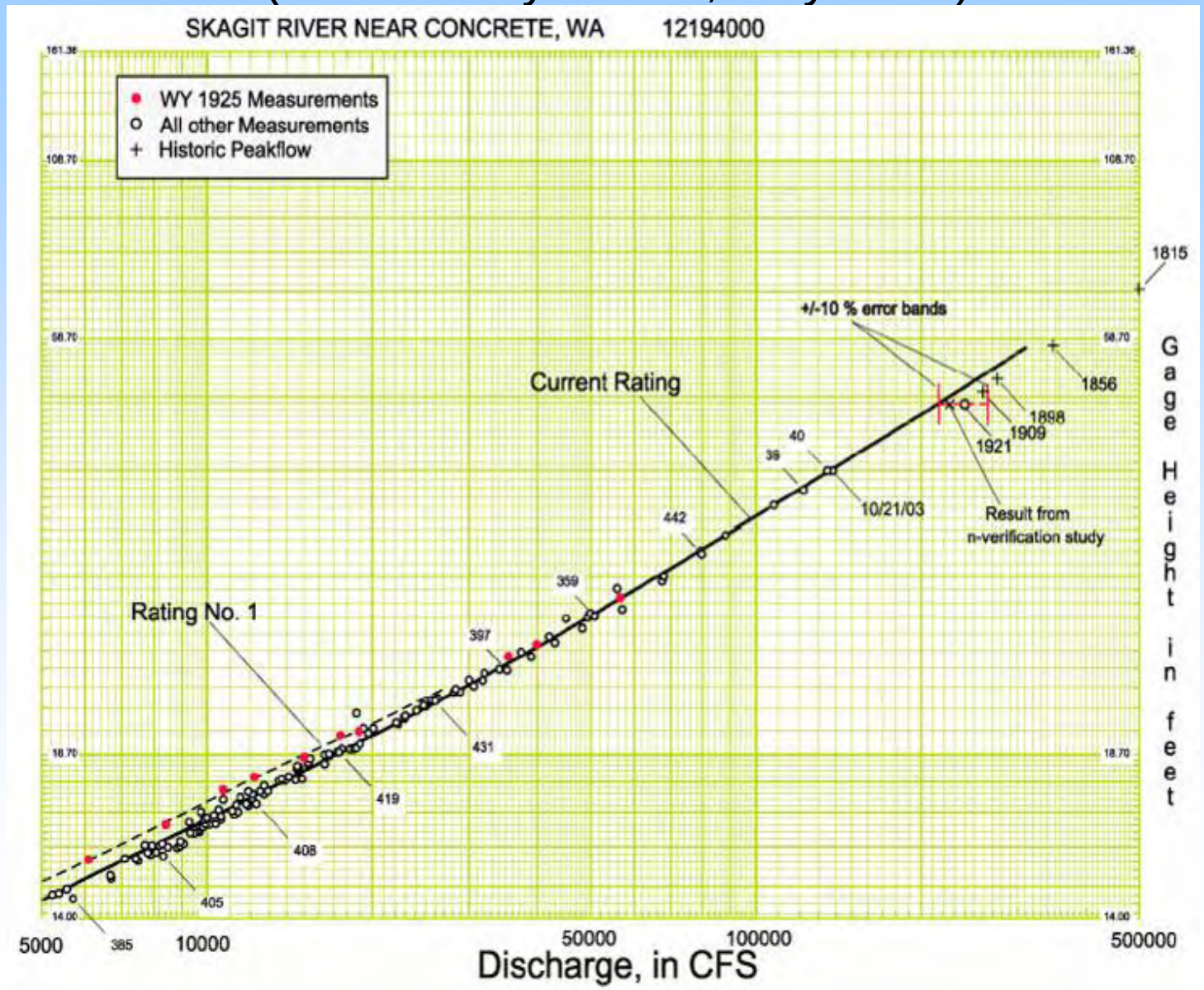
- Stewart also stated that "in this portion of the river, all floods since that of 1856 have been confined within the main banks of the main channel".

- Backwater calculations using HEC-RAS demonstrate that Stewart's flow estimates at elevations at the staff gage for the 1897 and 1909 floods would have entered the secondary channel about 1/2mile upstream of the gage.

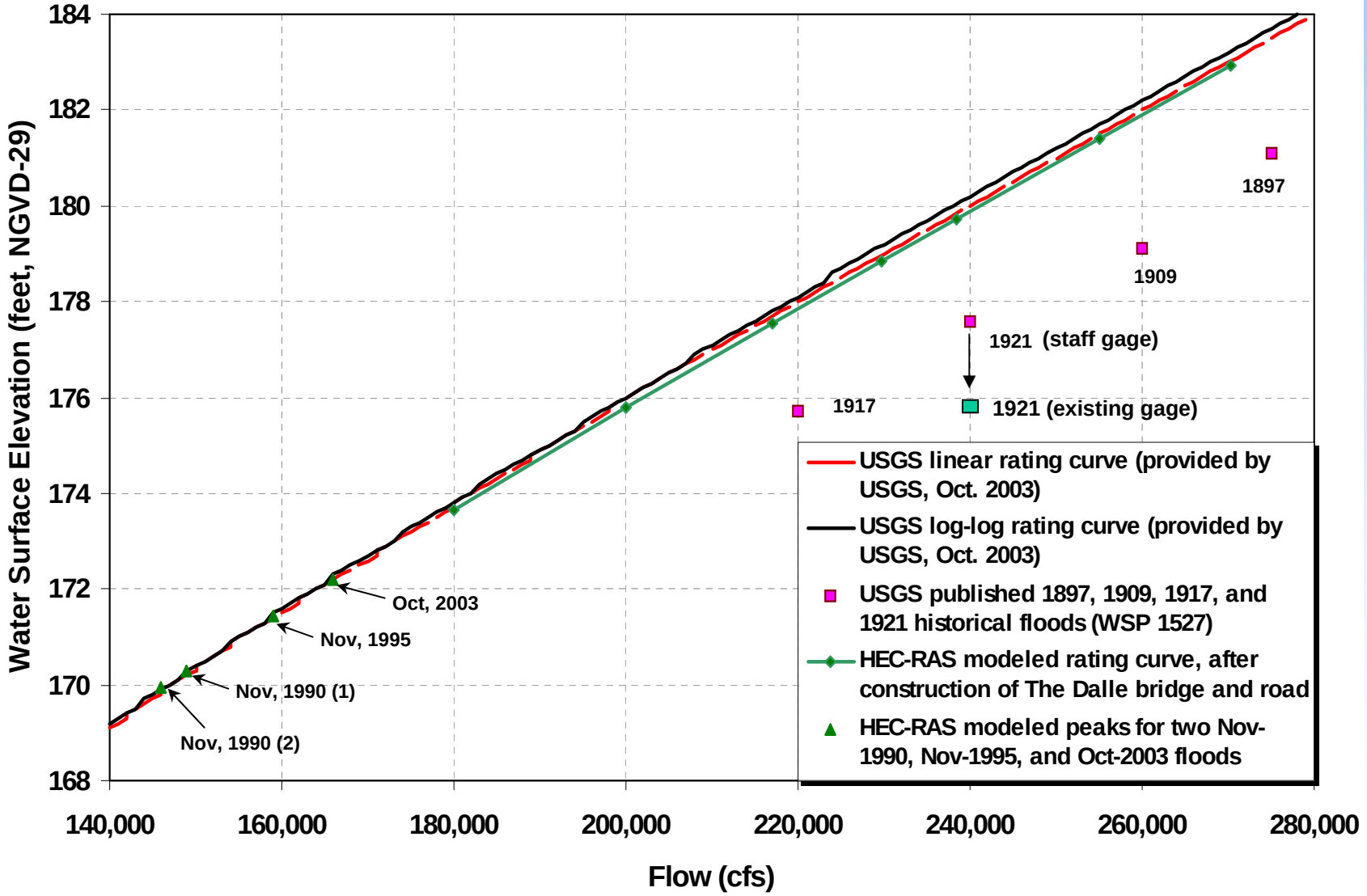
USGS RATING CURVE EXTENSION METHODS

- USGS rating curves are based on measured data. This curve does not extend past the largest measured flow and gage height.
- Extension of the USGS rating curve using log-log methodology.
- Extension of the USGS rating curve by linear extension.
- Development of extended rating curve using numerical modeling.

Stage-discharge Rating Curve for the Skagit River near Concrete
(Provided by USGS, May 2004)



Rating Curves of the Skagit River near Concrete (Existing Gage)



Comparison of peak discharge estimates for unrecorded floods at Skagit River staff gage near Concrete (RM 54.19) – Stewart's 1923 gage height data vs. HEC-RAS modeled rating curve at staff gage location

Flood	Water Surface Elevation at Old Staff Gage Location* (ft)	USGS Published** Peak Discharge Estimate (cfs)	Peak Discharge Estimate based on HEC-RAS Modeled Rating Curve (cfs)	Difference (cfs)	Difference (%)
1897	181.1	275,000	238,000	37,000	16
1909	179.1	260,000	217,000	43,000	20
1917	175.7	220,000	184,000	36,000	20
1921	177.6	240,000	202,000	38,000	19

* Converted from USGS gage heights as published in WSP 1527 (USGS 1961)

** James Stewart's 1923 unpublished estimates as documented by USGS in 1961 in WSP 1527 (USGS 1961)

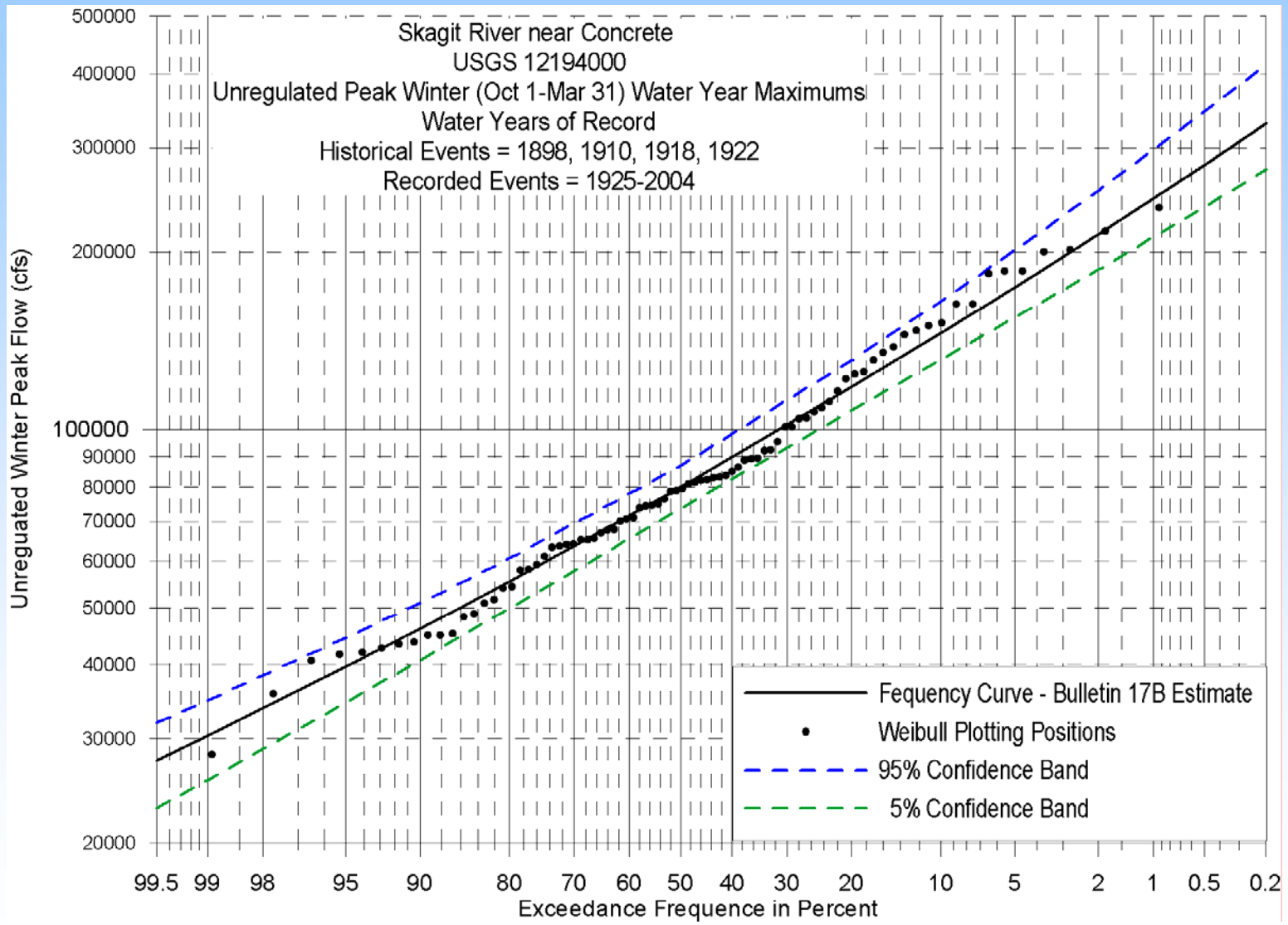
Correlation of unrecorded peak flows between Sedro-Woolley and Concrete

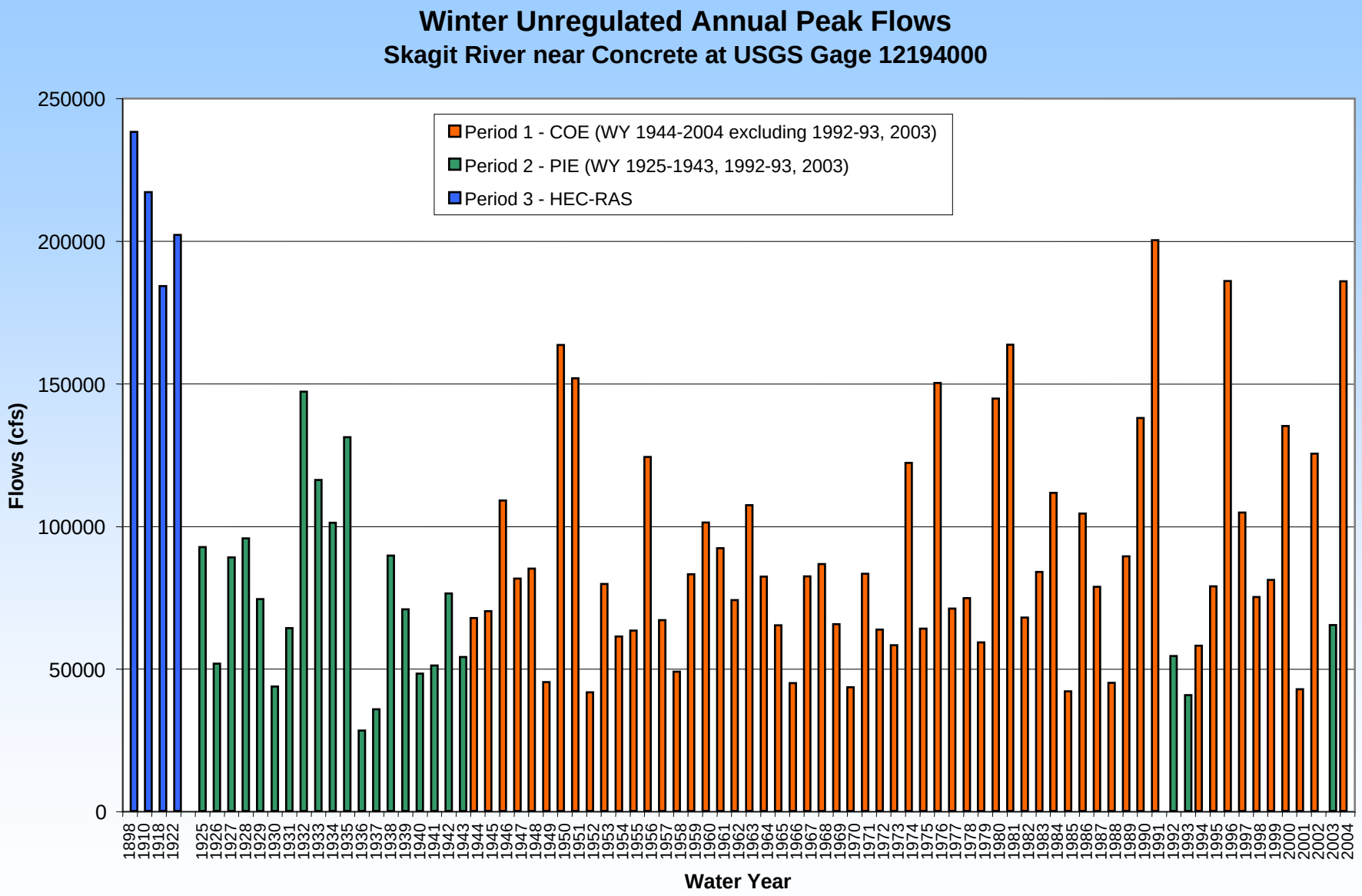
Flood Date	Stewart Estimates @ Sedro- Woolley	Stewart Estimates @ Concrete	% Diff	PI Engineering Estimates @ Concrete	% Diff
Nov. 19, 1897	190,000	275,000	-45%	238,000	-25%
Nov. 30, 1909	220,000	260,000	-18%	217,000	+1%
Dec. 30, 1917	195,000	220,000	-13%	184,000	+6%
Dec. 13, 1921	210,000	240,000	-14%	202,000	+4%

Flood Frequency Sensitivity Analysis – Unregulated Flood Peaks in the Skagit River Near Concrete

Sensitivity Run No.	Number of Systematic Record Events Included*	Number of Historical Events Included*	Peak Discharges (cfs)			
			10-year	50-year	100-year	500-year
1	58	4 – USGS-Published at Concrete (RM 54.15)	157,500	239,600	280,200	390,000
2	58	4 – USGS-Published at Sedro Woolley (RM 22.40)	150,500	219,800	252,500	337,300
3	58	4 – HEC-RAS-Modeled at Concrete (RM 54.19)	147,900	216,100	248,500	332,900
4	58	None	142,400	202,100	229,600	299,000
5	58	3 – USGS-Published at Concrete (RM 54.15)	154,400	231,200	268,600	368,000
6	58	3 – USGS-Published at Sedro Woolley (RM 22.40)	149,700	218,400	250,800	334,900
7	58	3 – HEC-RAS-Modeled at Concrete (RM 54.19)	146,100	211,000	241,400	319,600
8	80	4 – USGS-Published at Concrete (RM 54.15)	152,100	232,200	271,600	377,200
9	80	4 – USGS-Published at Sedro Woolley (RM 22.40)	146,200	214,100	245,900	327,300
10	80	4 – HEC-RAS-Modeled at Concrete (RM 54.19)	145,700	214,100	246,300	329,400
11	80	None	136,200	192,000	217,200	279,600
12	80	3 – USGS-Published at Concrete (RM 54.15)	148,800	223,400	259,300	354,000
13	80	3 – USGS-Published at Sedro Woolley (RM 22.40)	145,400	212,600	244,000	324,600
14	80	3 – HEC-RAS-Modeled at Concrete (RM 54.19)	143,900	208,900	239,100	316,000

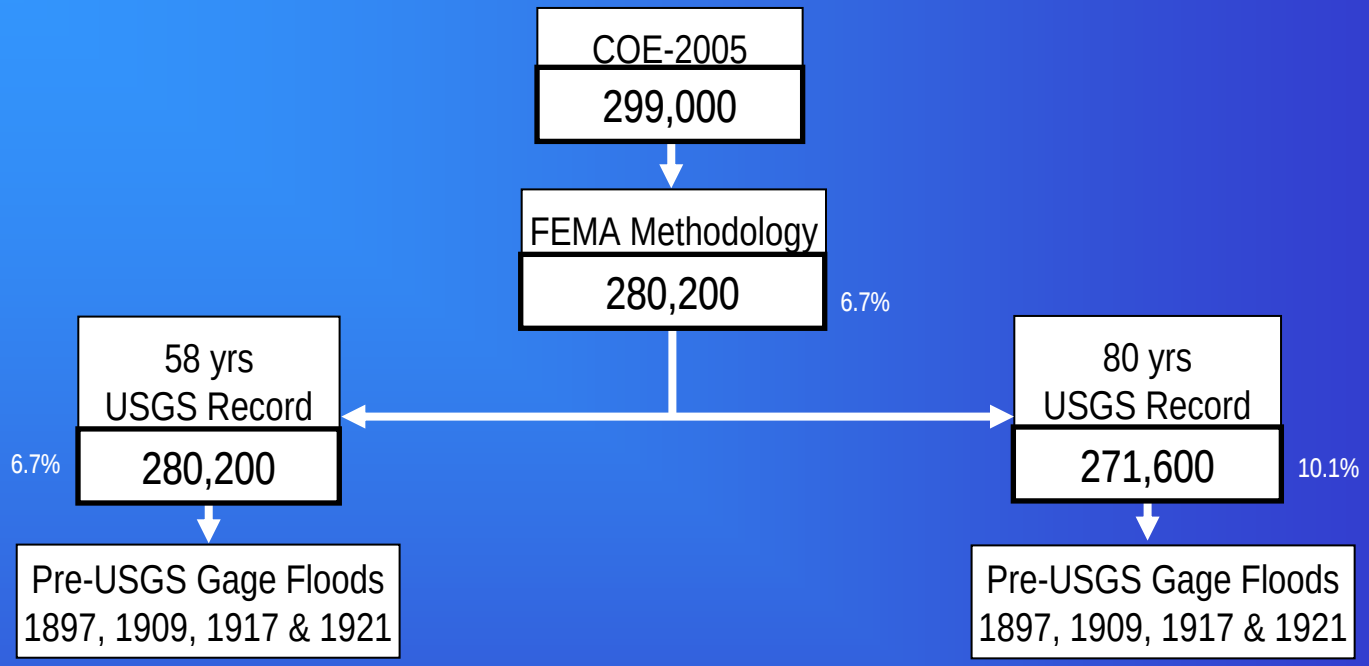
Run #10 – Unregulated Peak Flow Frequency Curve and the Confidence Band Together with all Data Used in the Frequency Analysis



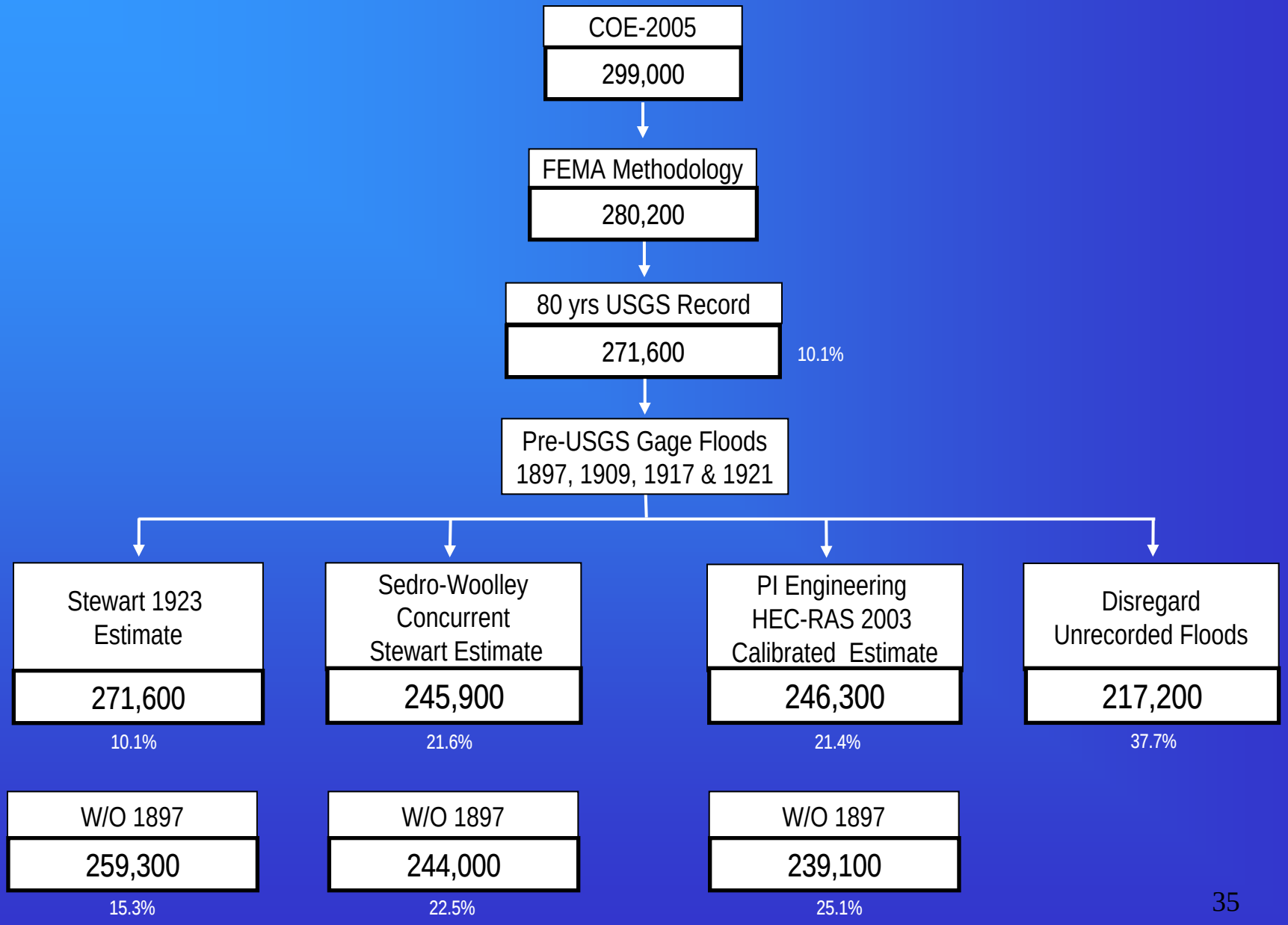

Winter Unregulated Annual Peak Flows
Skagit River near Concrete at USGS Gage 12194000
Period 1 - COE (WY 1944-2004 excluding 1992-93, 2003)
Period 2 - PIE (WY 1925-1943, 1992-93, 2003)
Period 3 - HEC-RAS
Flows (cfs)
250000
200000
150000
100000
50000
0
1898 1910 1918 1922 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Water Year

Summary of Estimates of Unregulated Peak Flows at Concrete

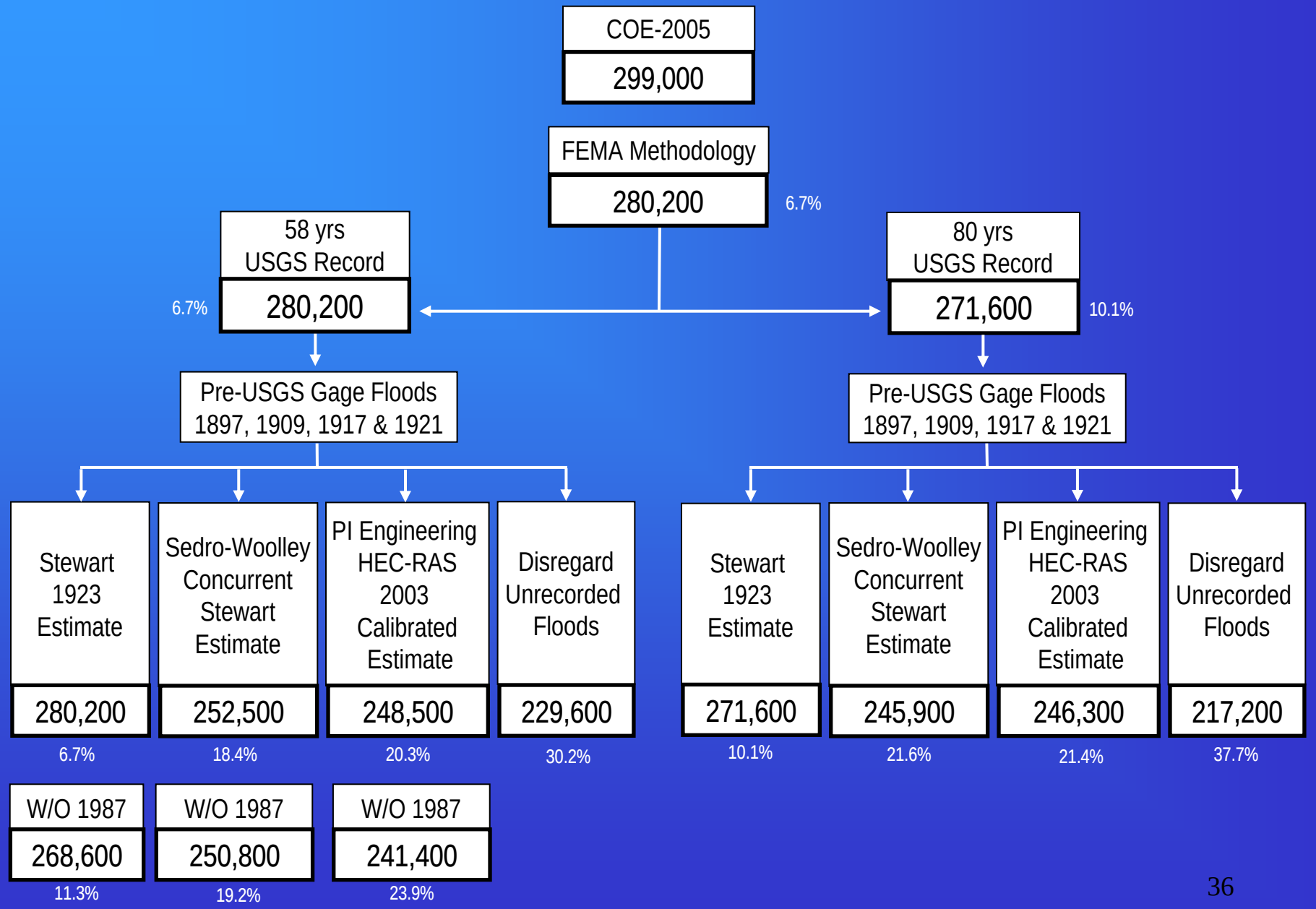
Unregulated 100 Year Flood Peak Flow at USGS Concrete Gage



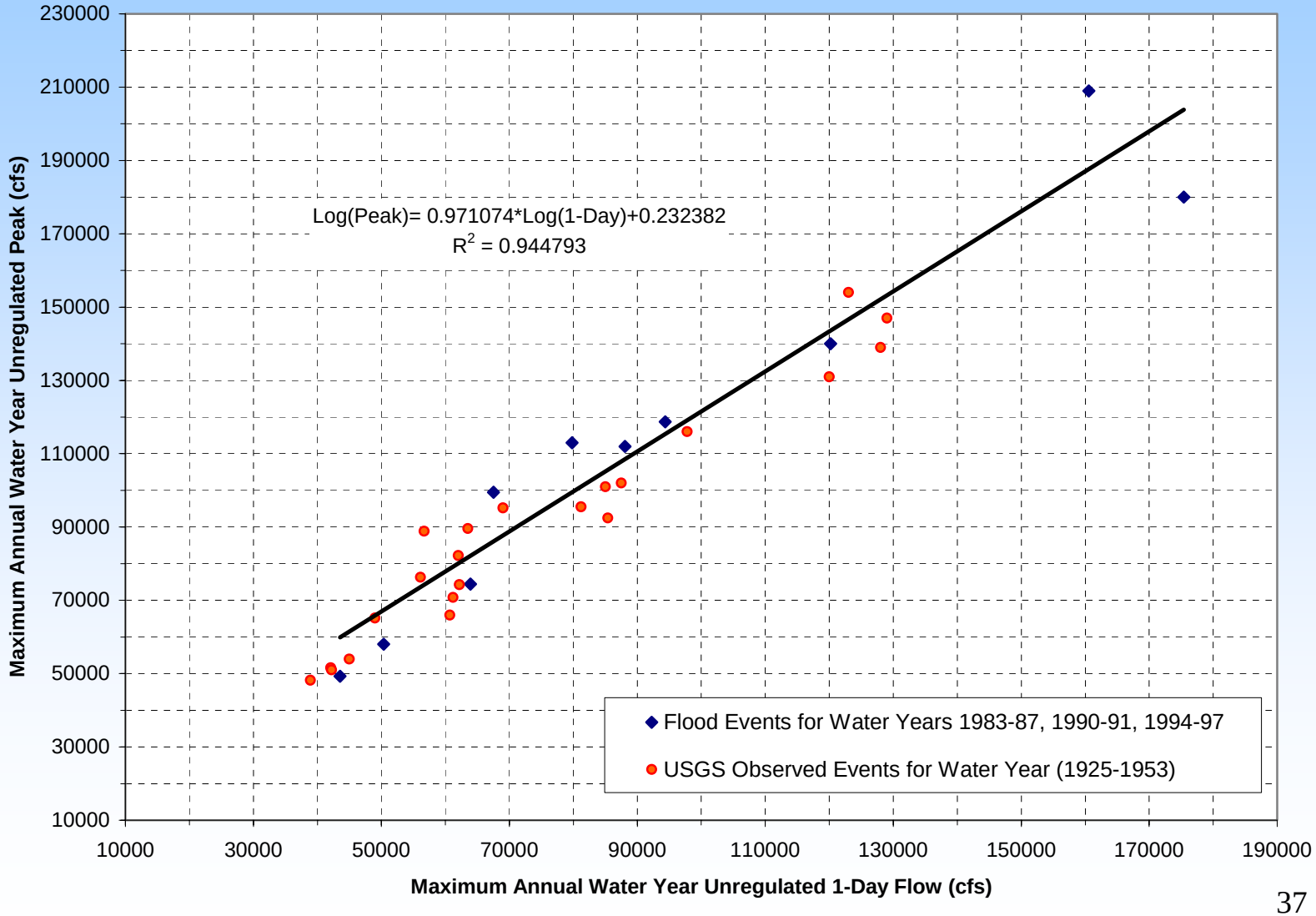
Unregulated 100 Year Flood Peak Flow at USGS Concrete Gage



Unregulated 100 Year Flood Peak Flow at USGS Concrete Gage



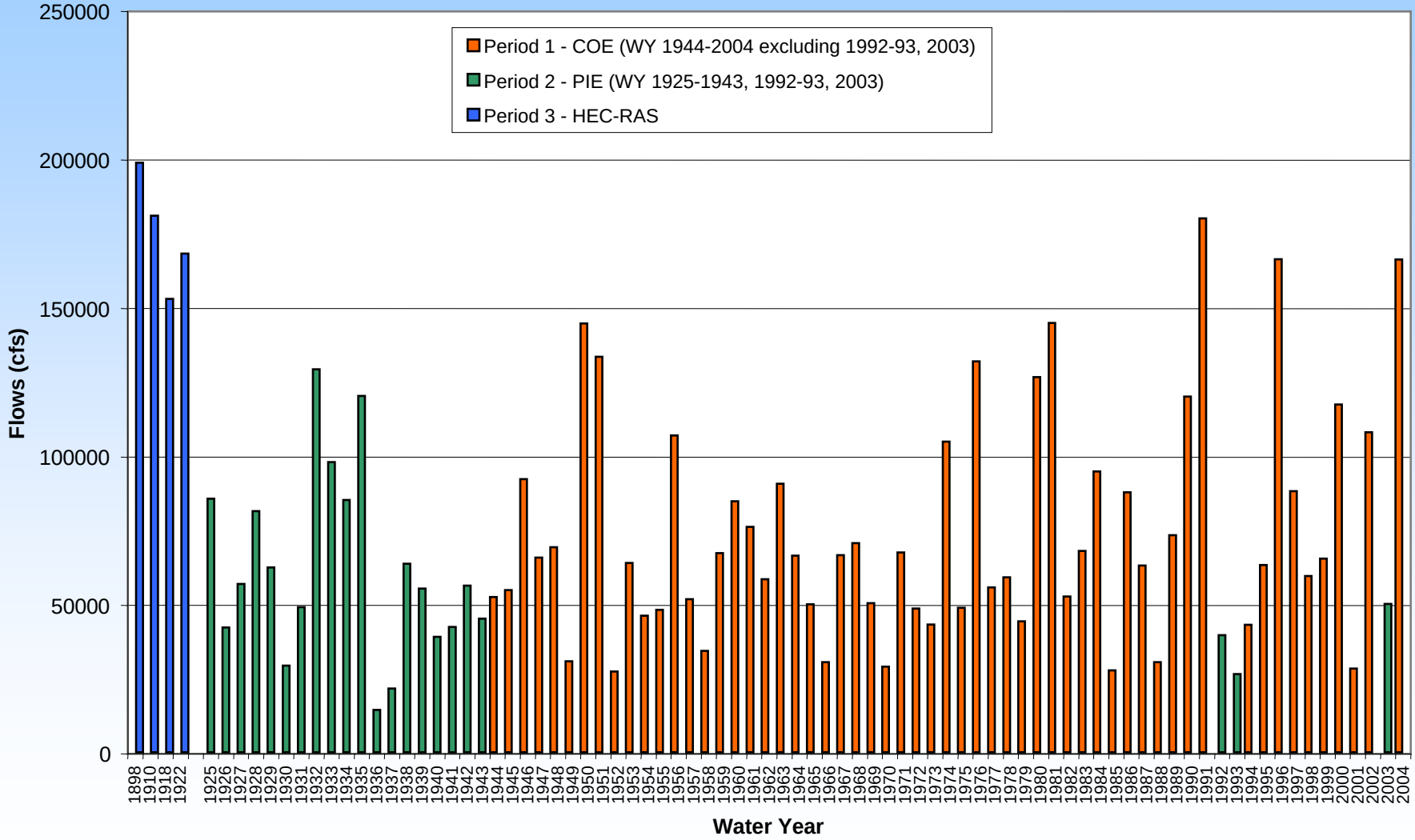
Regression curve of peak to one-day flow for the ten recent flood events (1983-87, 1990-91, 1994-97) unregulated by the Corps; and plots of annual peak and one-day flow data for water years 1925 through 1953.



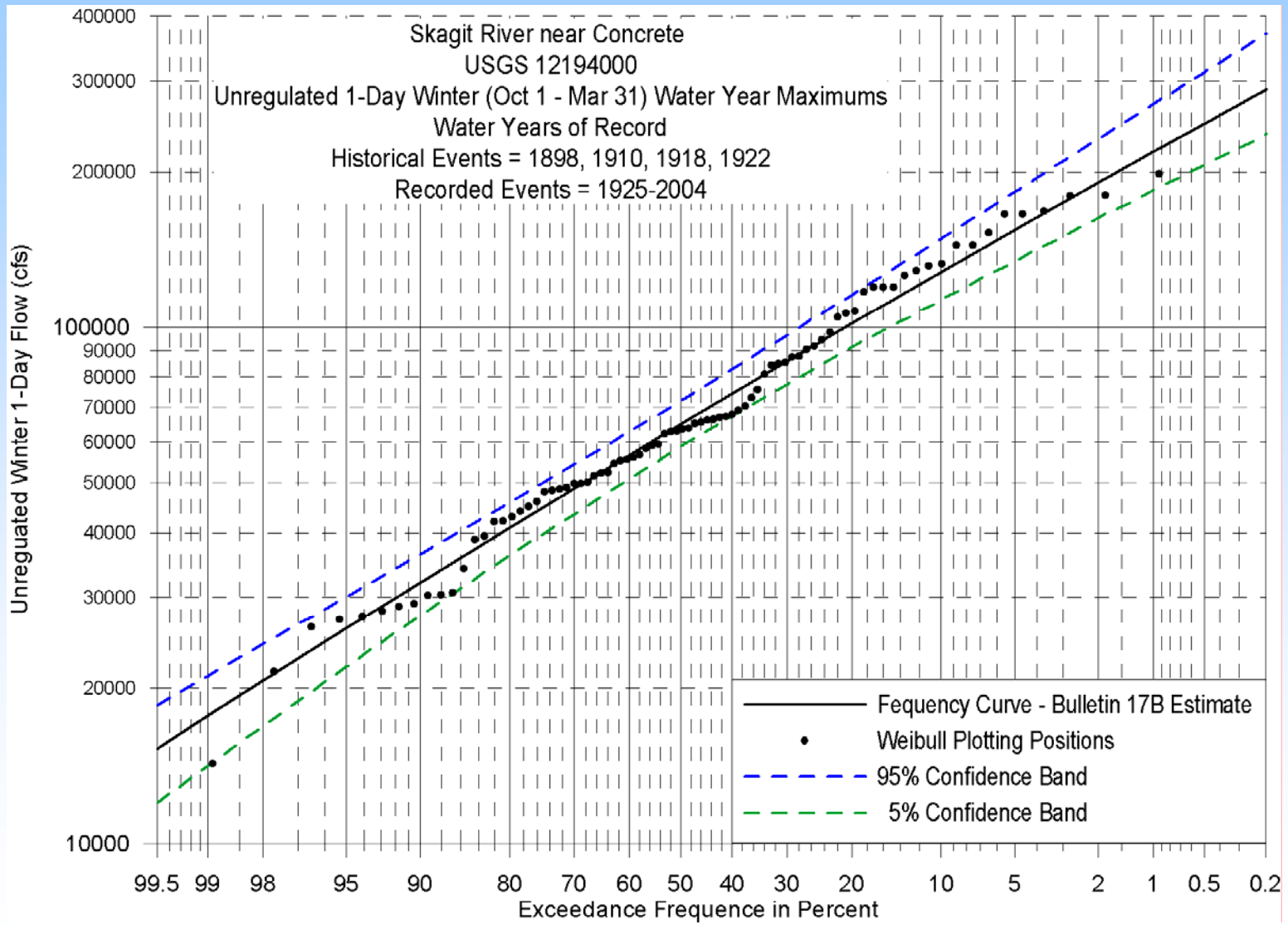
Estimated Unregulated One-Day Discharges for Four Historical Floods in the Skagit River near Concrete

Water Year	Date	Peak Discharges (cfs) Estimated by HEC-RAS	One-Day Discharges (cfs) Estimated by Regression
1898	Nov. 19, 1897	238,000	198,600
1910	Nov. 30, 1909	217,000	180,700
1918	Dec. 30, 1917	184,000	152,700
1922	Dec. 13, 1921	202,000	168,000

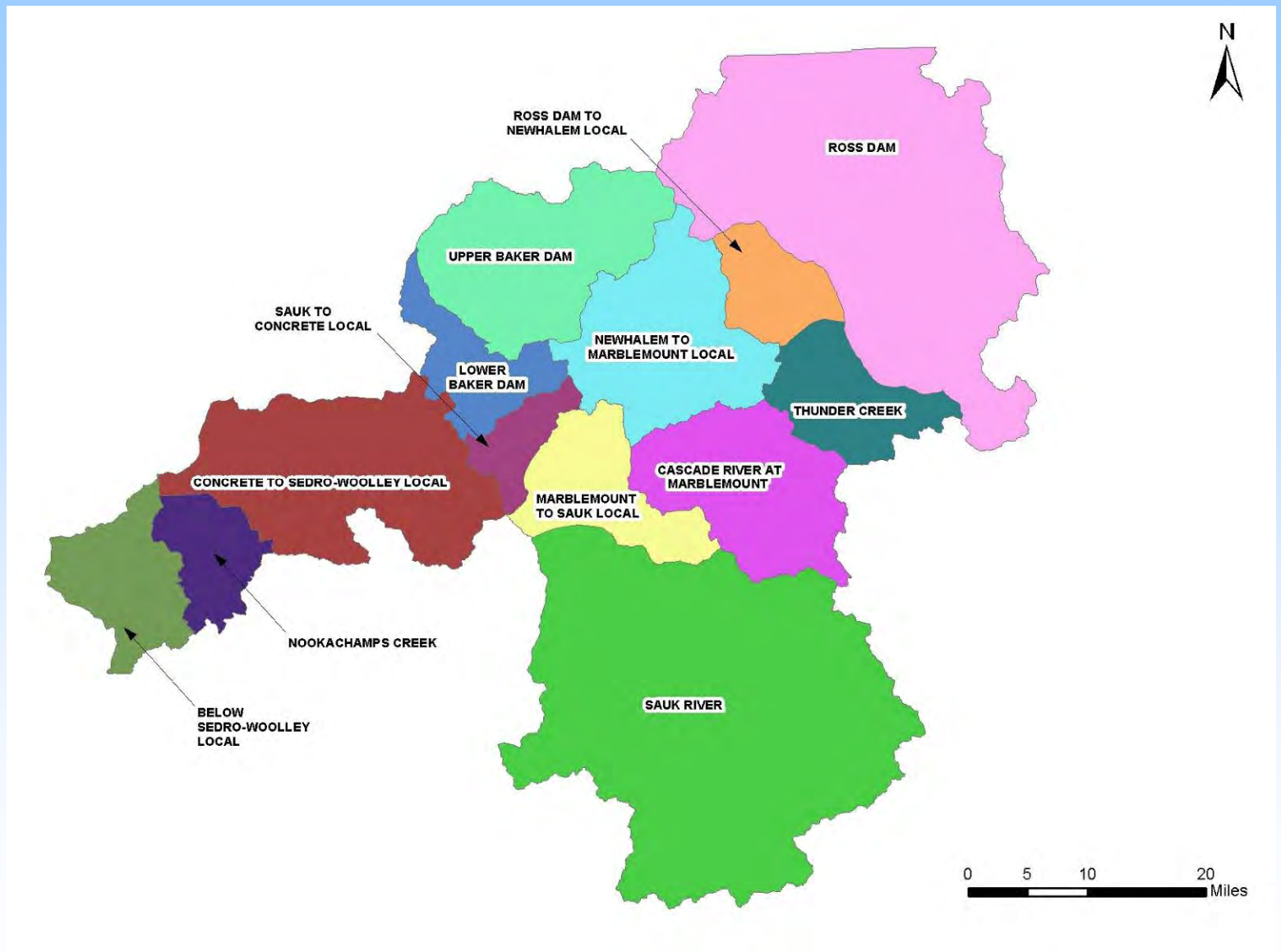
Winter Unregulated One-Day Flows
Skagit River near Concrete at USGS Gage 12194000



Unregulated One-Day Flow Frequency Curve and the Confidence Band Together with all Data Used in the Frequency Analysis at Concrete

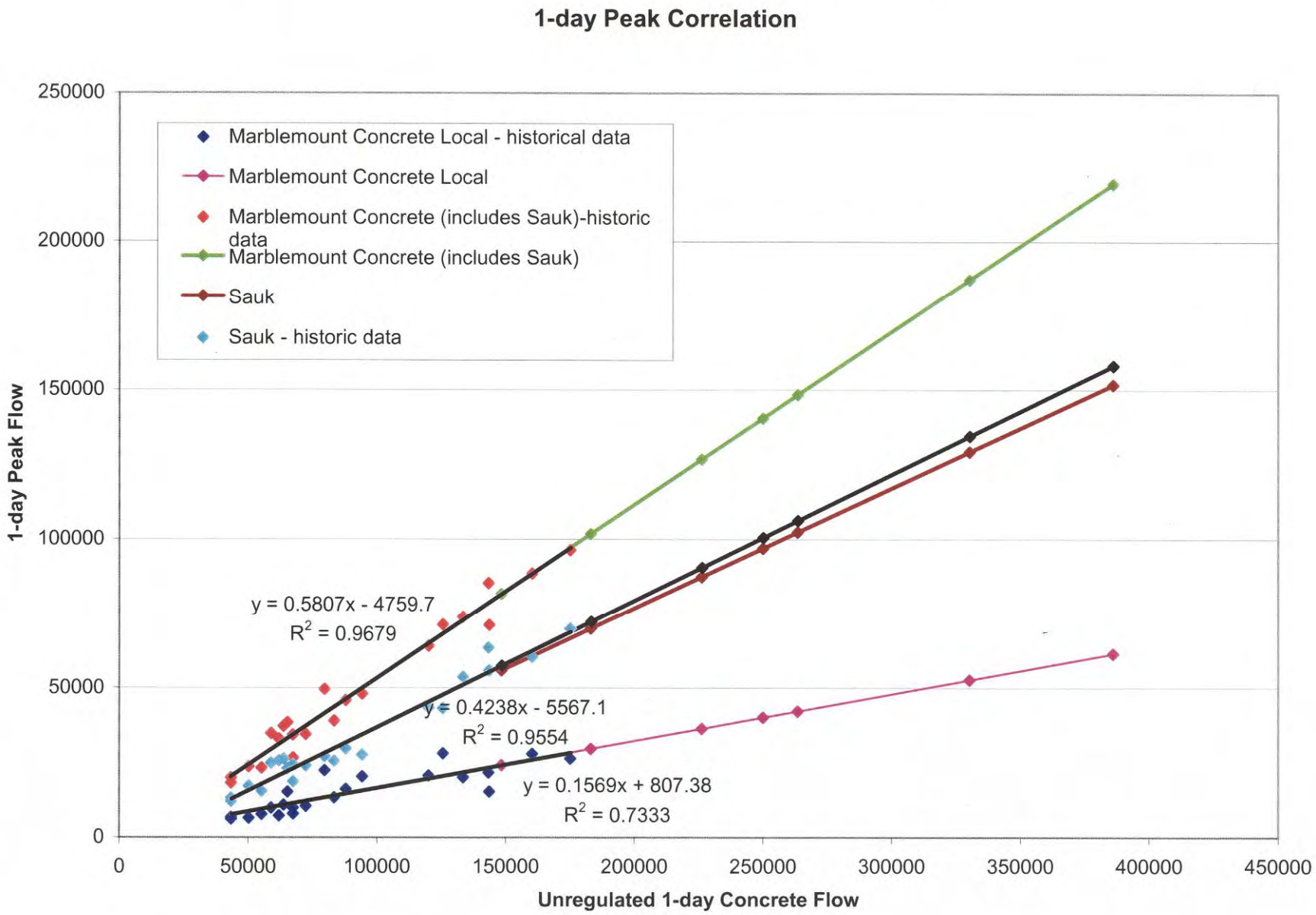


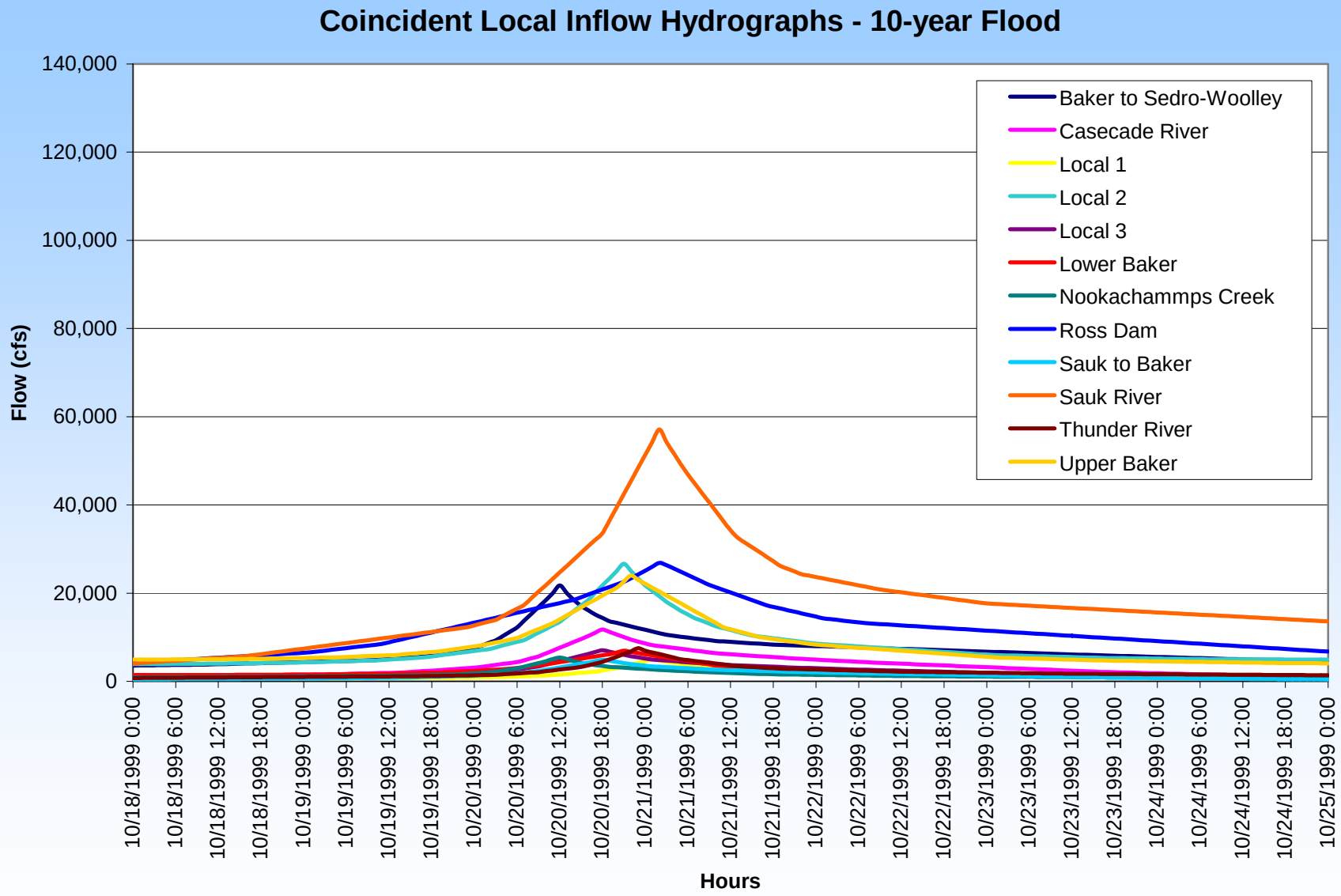
Unregulated Synthetic Flood Hydrographs at Concrete

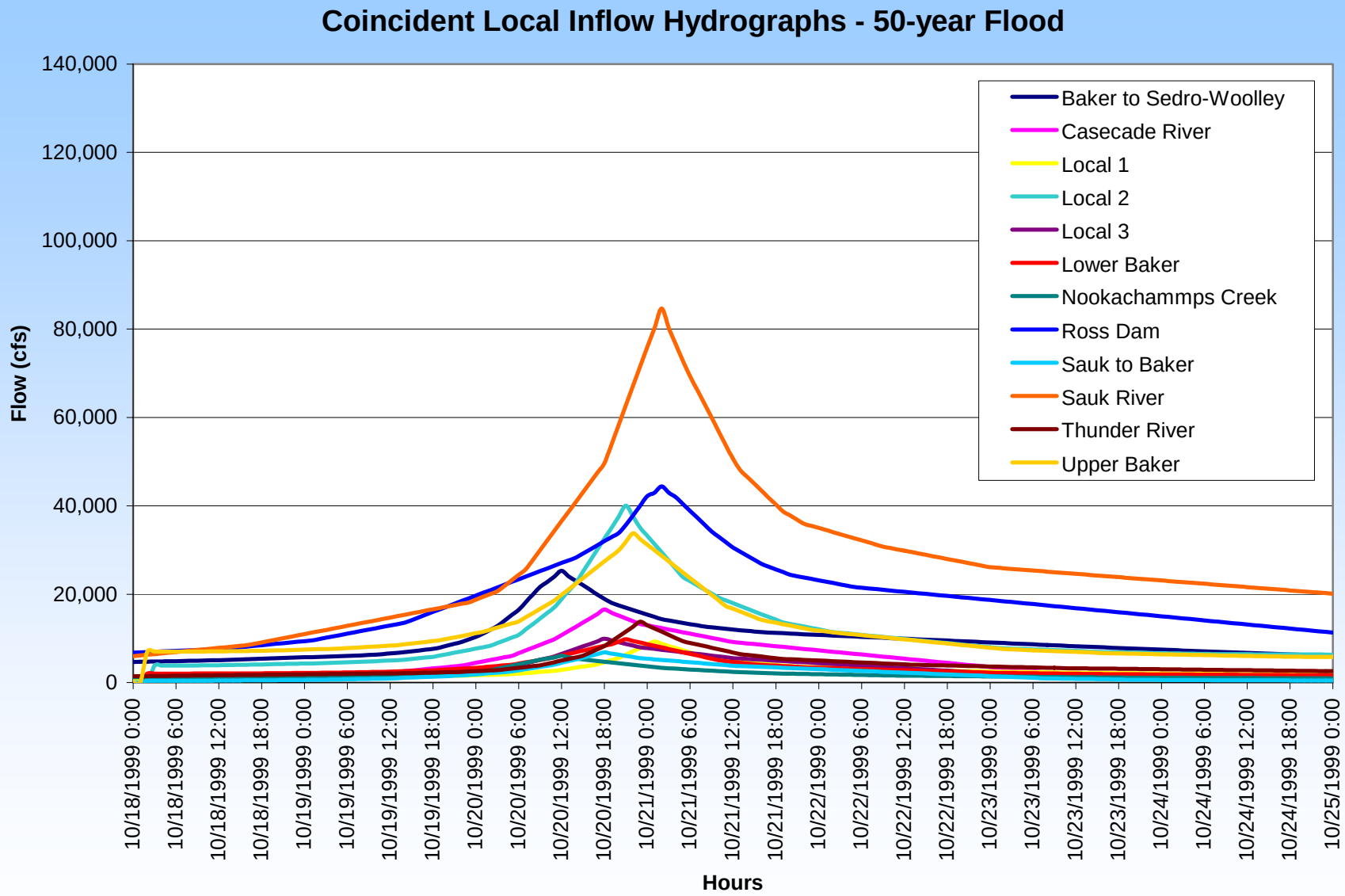

N
ROSS DAM TO NEWHALEM LOCAL
ROSS DAM
UPPER BAKER DAM
SAUK TO CONCRETE LOCAL
NEWHALEM TO MARBLEMOUNT LOCAL
LOWER BAKER DAM
THUNDER CREEK
CASCADE RIVER AT MARBLEMOUNT
CONCRETE TO SEDRO-WOOLLEY LOCAL
MARBLEMOUNT TO SAUK LOCAL
NOOKACHAMPS CREEK
BELOW SEDRO-WOOLLEY LOCAL
SAUK RIVER
0 5 10 20
Miles

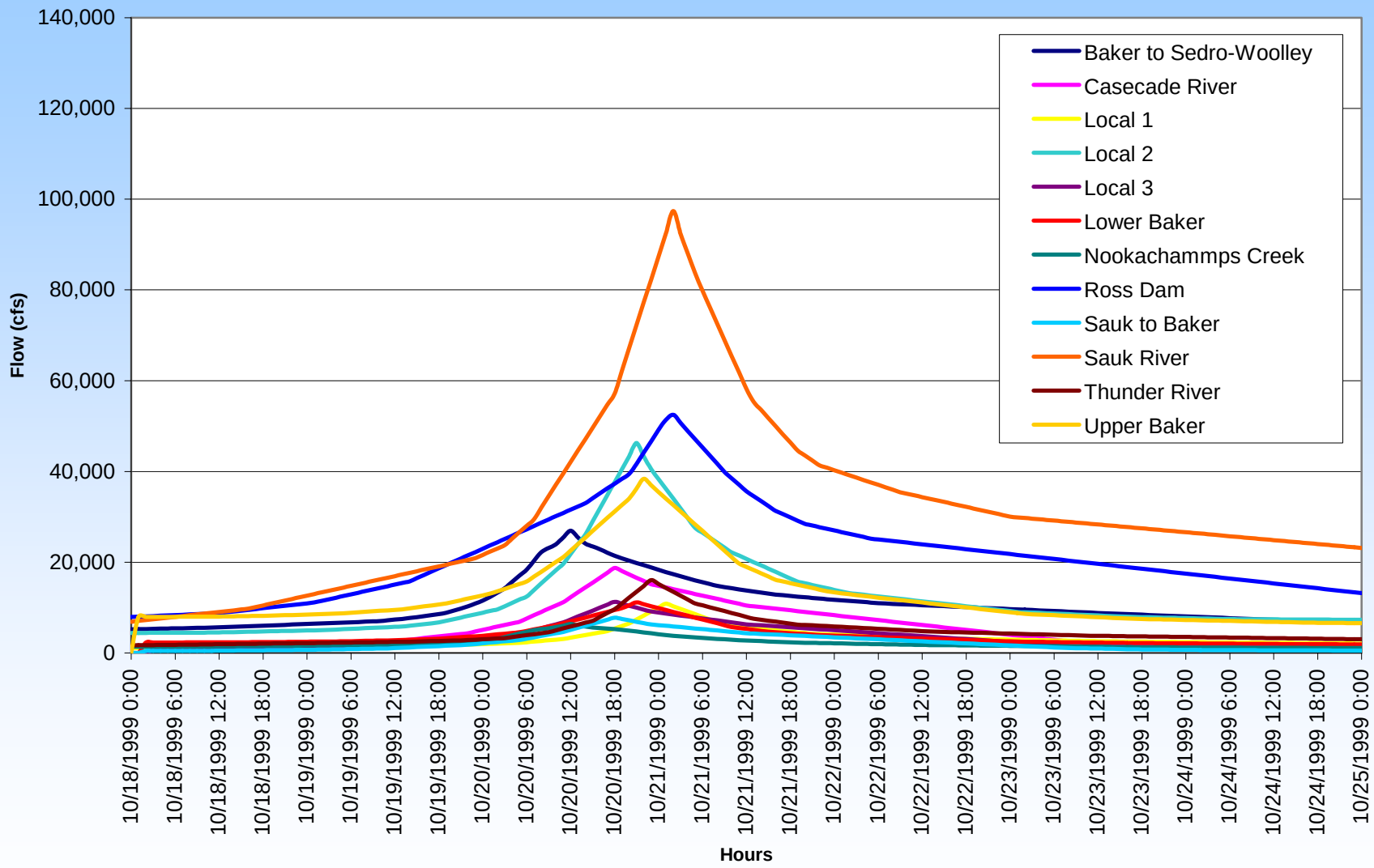
Unregulated Synthetic Flood One-Day Coincident Flows (cfs) for Upper Skagit River Subbasins

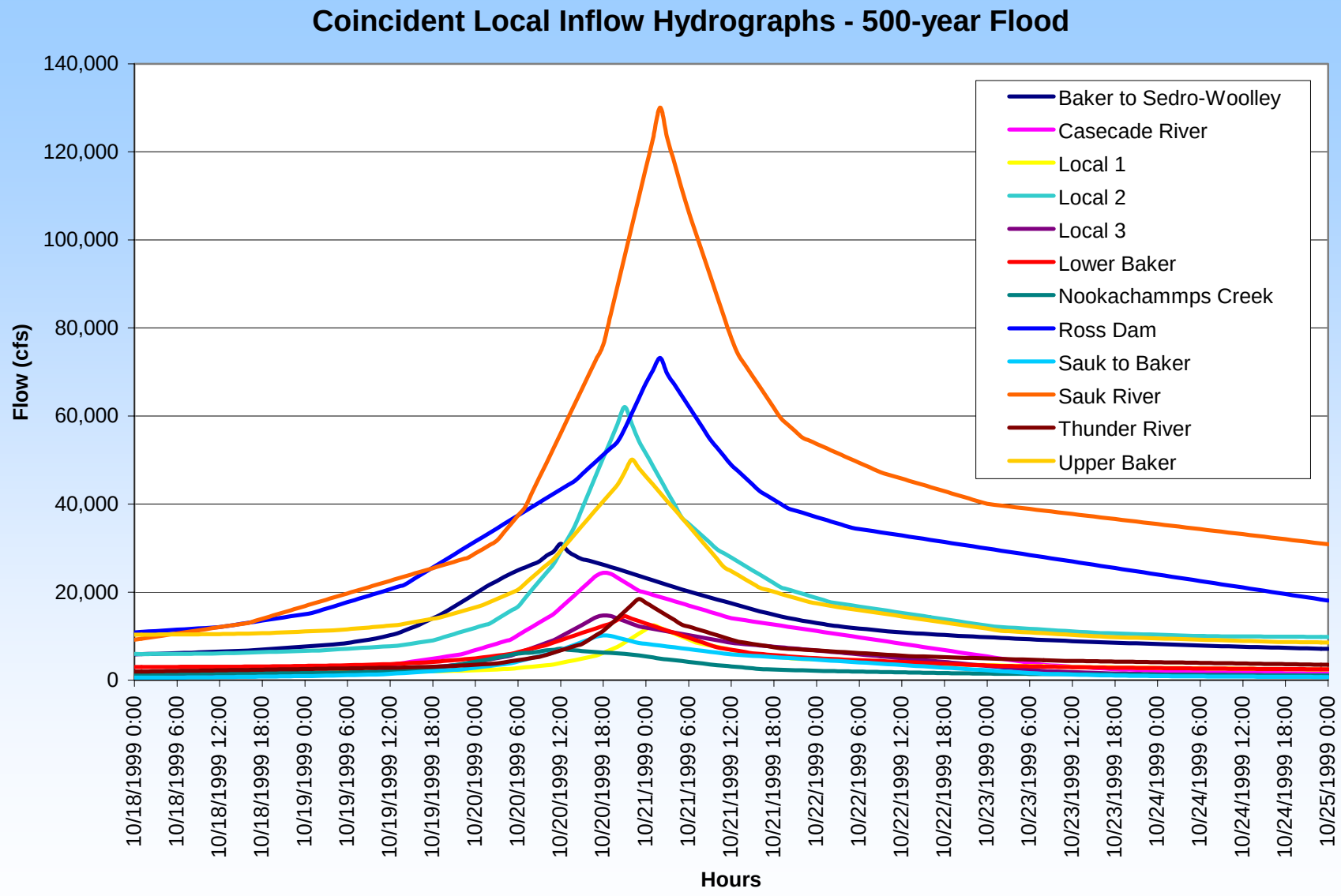
Location	Flood Event					
	10-year	25-year	50-year	100-year	200-year	500-year
Unregulated Skagit River Near Concrete	128,300	163,400	190,600	218,800	247,900	288,000
Ross Dam Inflow	22,500	29,700	35,700	41,800	48,500	57,400
Thunder Creek	4,900	7,700	9,200	10,800	10,500	12,500
Ross Dam to Newhalem Local	3,300	5,200	6,200	7,300	7,100	8,400
Newhalem to Marblemount Local	18,300	23,300	27,400	31,700	36,200	42,500
Cascade River at Marblemount	8,600	18,800	12,600	14,400	16,500	19,300
Marblemount to Sauk Local	5,200	6,500	7,600	8,700	9,900	11,600
Sauk to Concrete Local	3,600	4,500	5,200	6,000	6,800	8,000
Sauk River at Sauk	41,900	52,900	61,900	71,300	81,100	95,000
Upper Baker Dam Inflow	18,200	22,300	25,600	29,100	32,700	38,000
Lower Baker Dam Inflow	5,300	6,500	7,400	8,400	9,500	11,000

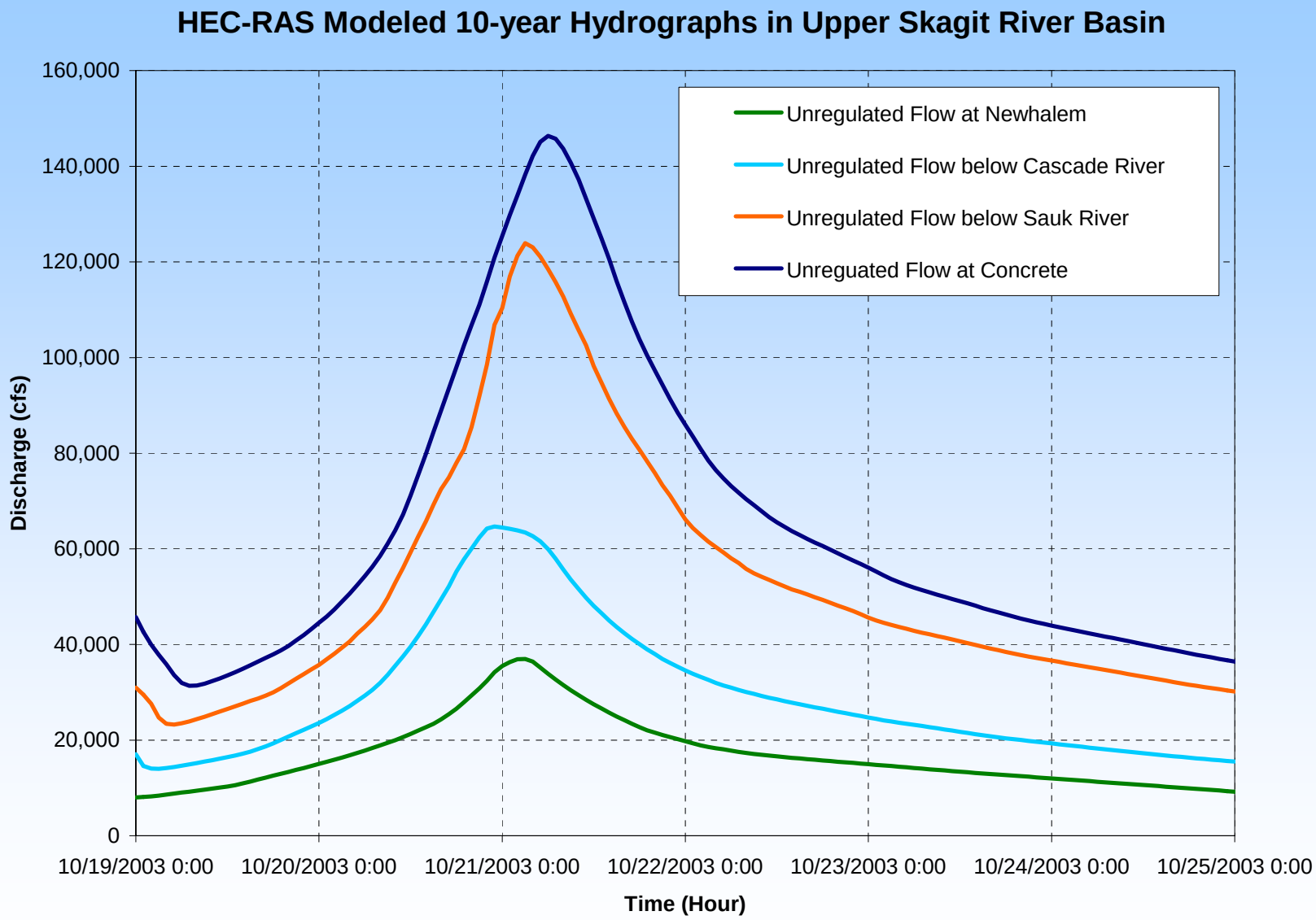

1-day Peak Correlation
Marblemount Concrete Local - historical data
Marblemount Concrete Local
Marblemount Concrete (includes Sauk)-historic data
Marblemount Concrete (includes Sauk)
Sauk
Sauk - historic data
y = 0.5807x - 4759.7
R2 = 0.9679
y = 0.4238x - 5567.1
R2 = 0.9554
y = 0.1569x + 807.38
R2 = 0.7333
1-day Peak Flow
Unregulated 1-day Concrete Flow
0
50000
100000
150000
200000
250000
300000
350000
400000
450000

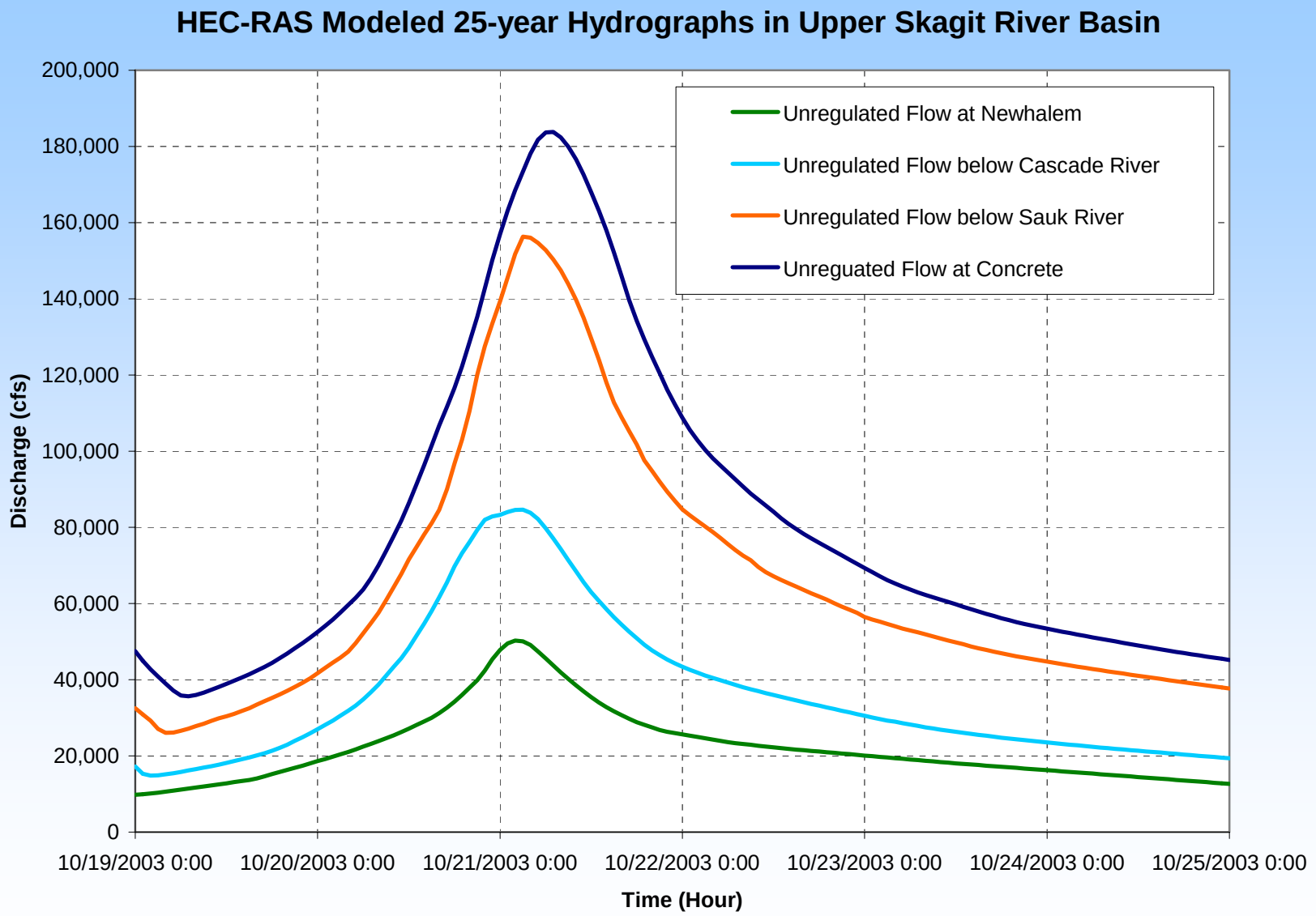

Coincident Local Inflow Hydrographs - 10-year Flood
Flow (cfs)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/18/1999 0:00
10/18/1999 6:00
10/18/1999 12:00
10/18/1999 18:00
10/19/1999 0:00
10/19/1999 6:00
10/19/1999 12:00
10/19/1999 18:00
10/20/1999 0:00
10/20/1999 6:00
10/20/1999 12:00
10/20/1999 18:00
10/21/1999 0:00
10/21/1999 6:00
10/21/1999 12:00
10/21/1999 18:00
10/22/1999 0:00
10/22/1999 6:00
10/22/1999 12:00
10/22/1999 18:00
10/23/1999 0:00
10/23/1999 6:00
10/23/1999 12:00
10/23/1999 18:00
10/24/1999 0:00
10/24/1999 6:00
10/24/1999 12:00
10/24/1999 18:00
10/25/1999 0:00
Hours
Baker to Sedro-Woolley
Casecade River
Local 1
Local 2
Local 3
Lower Baker
Nookachammps Creek
Ross Dam
Sauk to Baker
Sauk River
Thunder River
Upper Baker

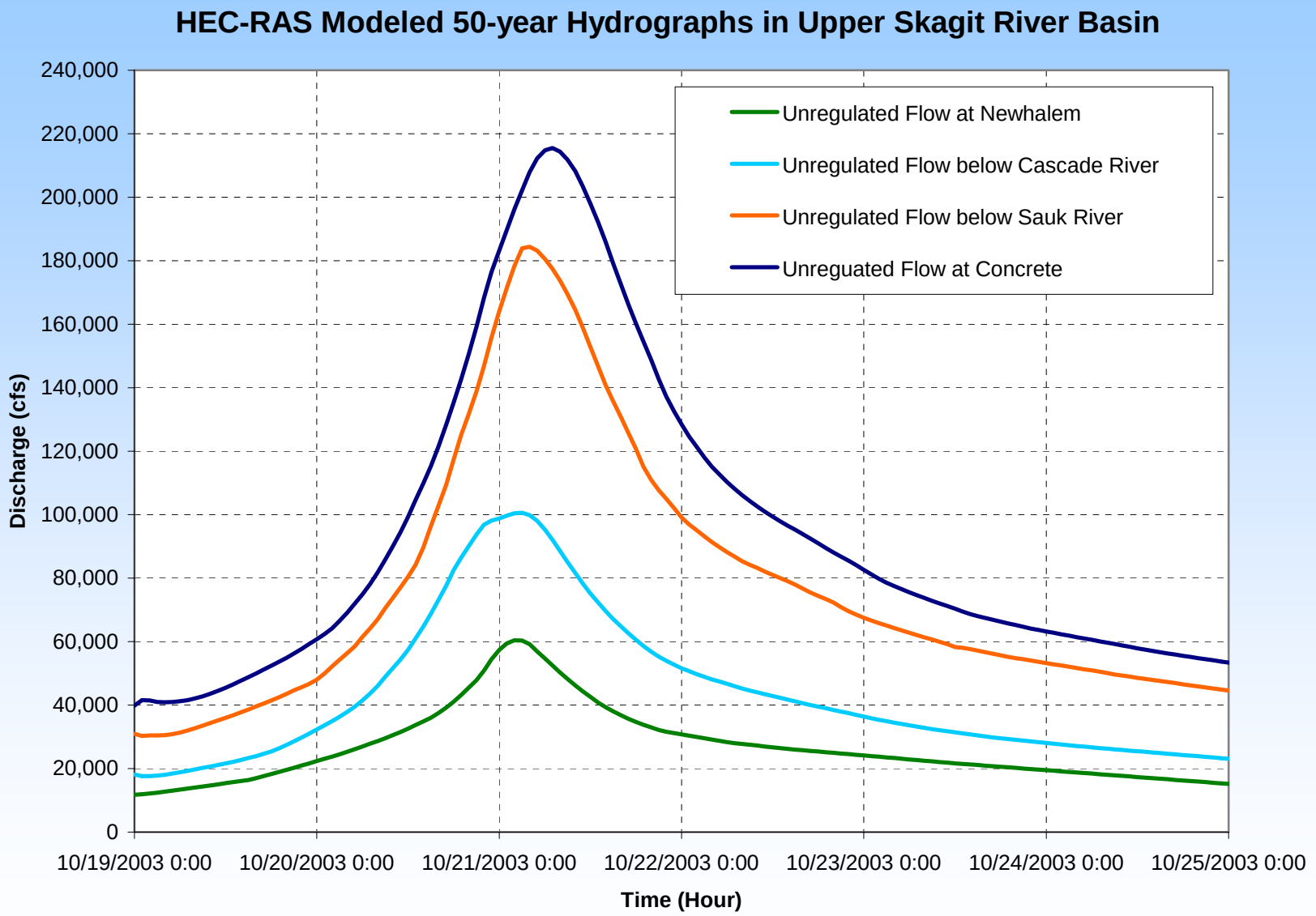

Coincident Local Inflow Hydrographs - 50-year Flood
Flow (cfs)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/18/1999 0:00
10/18/1999 6:00
10/18/1999 12:00
10/18/1999 18:00
10/19/1999 0:00
10/19/1999 6:00
10/19/1999 12:00
10/19/1999 18:00
10/20/1999 0:00
10/20/1999 6:00
10/20/1999 12:00
10/20/1999 18:00
10/21/1999 0:00
10/21/1999 6:00
10/21/1999 12:00
10/21/1999 18:00
10/22/1999 0:00
10/22/1999 6:00
10/22/1999 12:00
10/22/1999 18:00
10/23/1999 0:00
10/23/1999 6:00
10/23/1999 12:00
10/23/1999 18:00
10/24/1999 0:00
10/24/1999 6:00
10/24/1999 12:00
10/24/1999 18:00
10/25/1999 0:00
Hours
Baker to Sedro-Woolley
Casecade River
Local 1
Local 2
Local 3
Lower Baker
Nookachammps Creek
Ross Dam
Sauk to Baker
Sauk River
Thunder River
Upper Baker

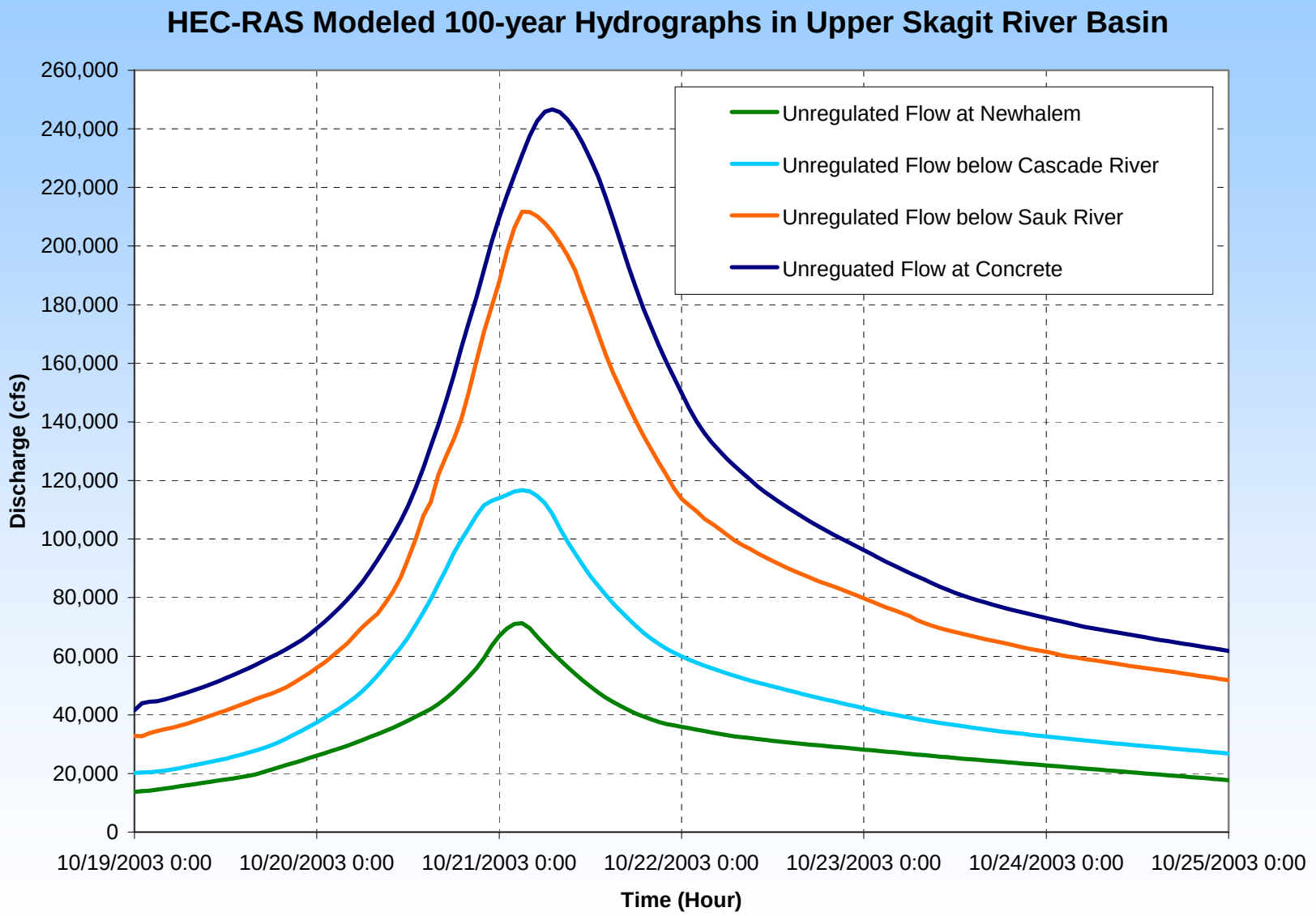

Coincident Local Inflow Hydrographs - 100-year Flood
Flow (cfs)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/18/1999 0:00
10/18/1999 6:00
10/18/1999 12:00
10/18/1999 18:00
10/19/1999 0:00
10/19/1999 6:00
10/19/1999 12:00
10/19/1999 18:00
10/20/1999 0:00
10/20/1999 6:00
10/20/1999 12:00
10/20/1999 18:00
10/21/1999 0:00
10/21/1999 6:00
10/21/1999 12:00
10/21/1999 18:00
10/22/1999 0:00
10/22/1999 6:00
10/22/1999 12:00
10/22/1999 18:00
10/23/1999 0:00
10/23/1999 6:00
10/23/1999 12:00
10/23/1999 18:00
10/24/1999 0:00
10/24/1999 6:00
10/24/1999 12:00
10/24/1999 18:00
10/25/1999 0:00
Hours
Baker to Sedro-Woolley
Casecade River
Local 1
Local 2
Local 3
Lower Baker
Nookachammps Creek
Ross Dam
Sauk to Baker
Sauk River
Thunder River
Upper Baker

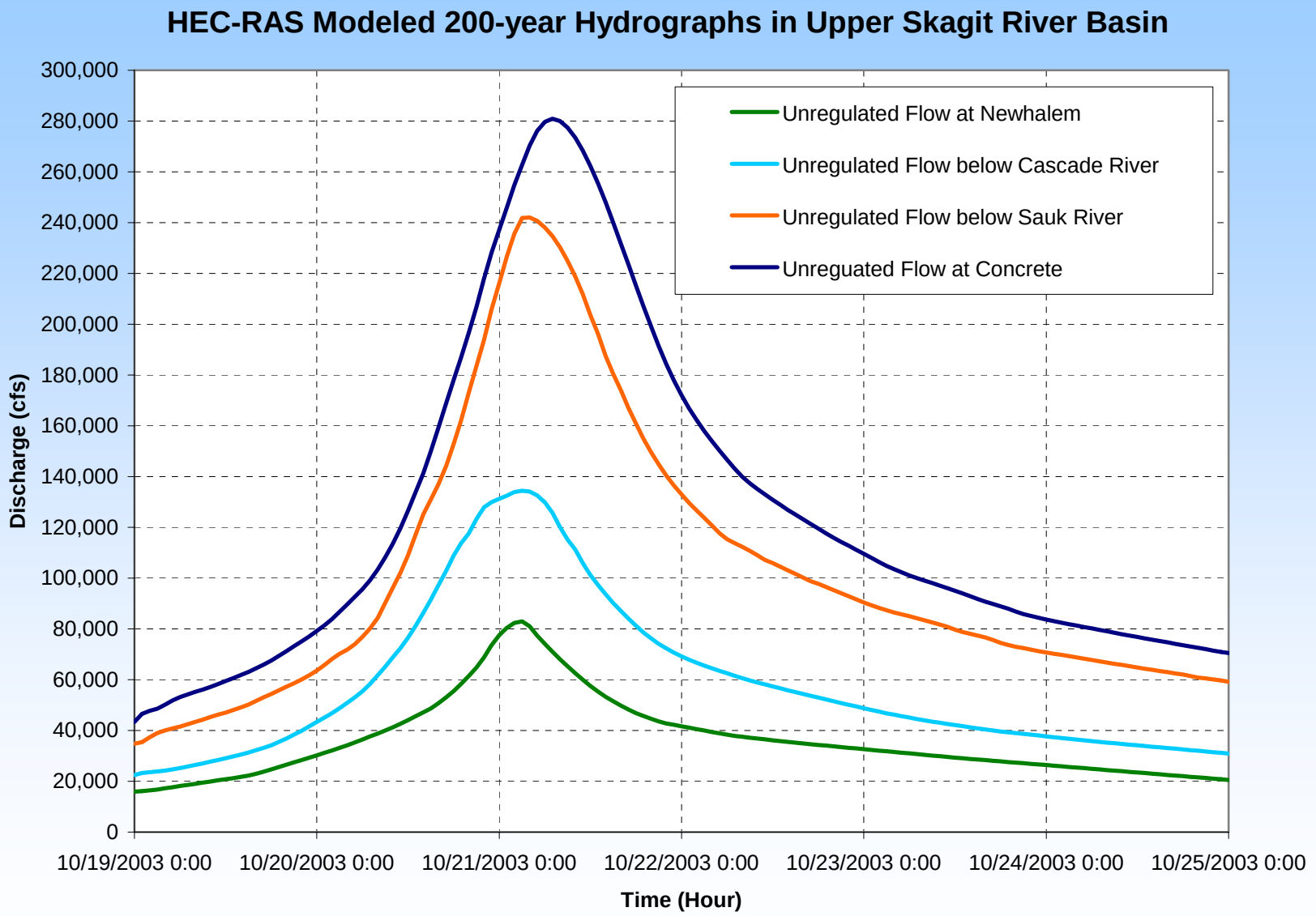

Coincident Local Inflow Hydrographs - 500-year Flood
Flow (cfs)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/18/1999 0:00
10/18/1999 6:00
10/18/1999 12:00
10/18/1999 18:00
10/19/1999 0:00
10/19/1999 6:00
10/19/1999 12:00
10/19/1999 18:00
10/20/1999 0:00
10/20/1999 6:00
10/20/1999 12:00
10/20/1999 18:00
10/21/1999 0:00
10/21/1999 6:00
10/21/1999 12:00
10/21/1999 18:00
10/22/1999 0:00
10/22/1999 6:00
10/22/1999 12:00
10/22/1999 18:00
10/23/1999 0:00
10/23/1999 6:00
10/23/1999 12:00
10/23/1999 18:00
10/24/1999 0:00
10/24/1999 6:00
10/24/1999 12:00
10/24/1999 18:00
10/25/1999 0:00
Hours
Baker to Sedro-Woolley
Casecade River
Local 1
Local 2
Local 3
Lower Baker
Nookachammps Creek
Ross Dam
Sauk to Baker
Sauk River
Thunder River
Upper Baker

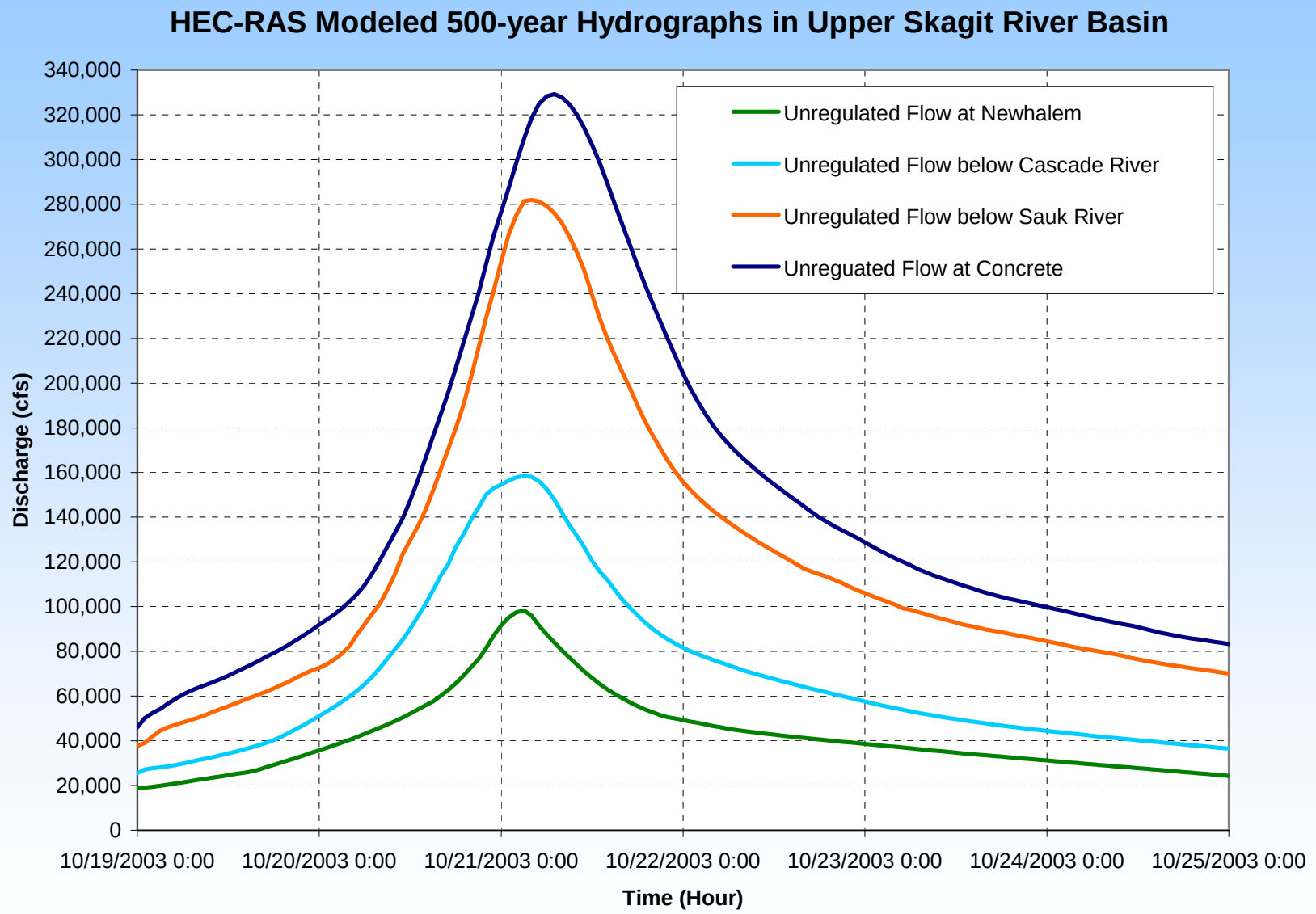

HEC-RAS Modeled 10-year Hydrographs in Upper Skagit River Basin
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Discharge (cfs)
Unregulated Flow at Newhalem
Unregulated Flow below Cascade River
Unregulated Flow below Sauk River
Unreguated Flow at Concrete
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)


HEC-RAS Modeled 25-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Unregulated Flow below Cascade River
Unregulated Flow below Sauk River
Unreguated Flow at Concrete

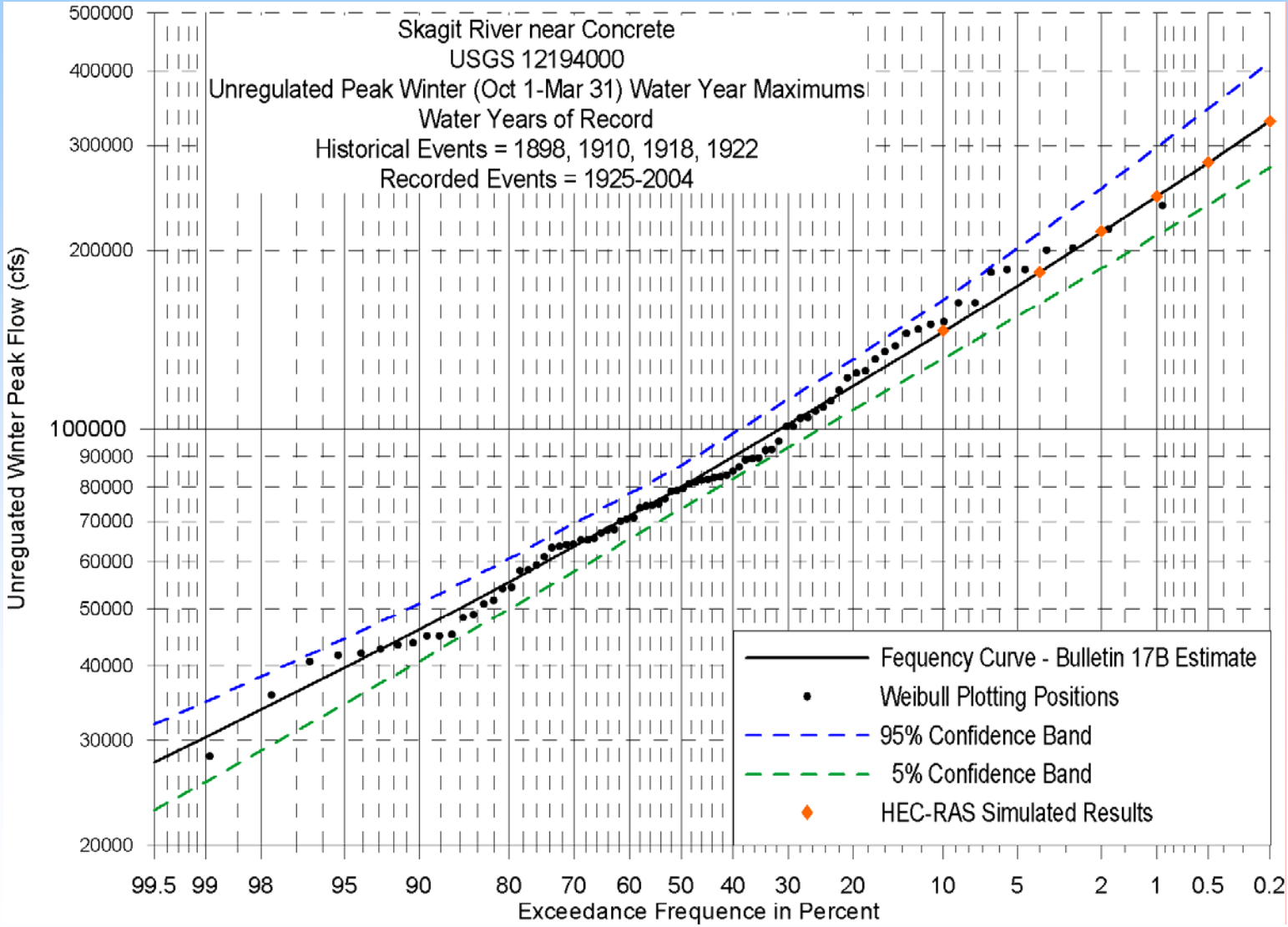

HEC-RAS Modeled 50-year Hydrographs in Upper Skagit River Basin
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Discharge (cfs)
Unregulated Flow at Newhalem
Unregulated Flow below Cascade River
Unregulated Flow below Sauk River
Unreguated Flow at Concrete
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)


HEC-RAS Modeled 100-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Unregulated Flow below Cascade River
Unregulated Flow below Sauk River
Unreguated Flow at Concrete

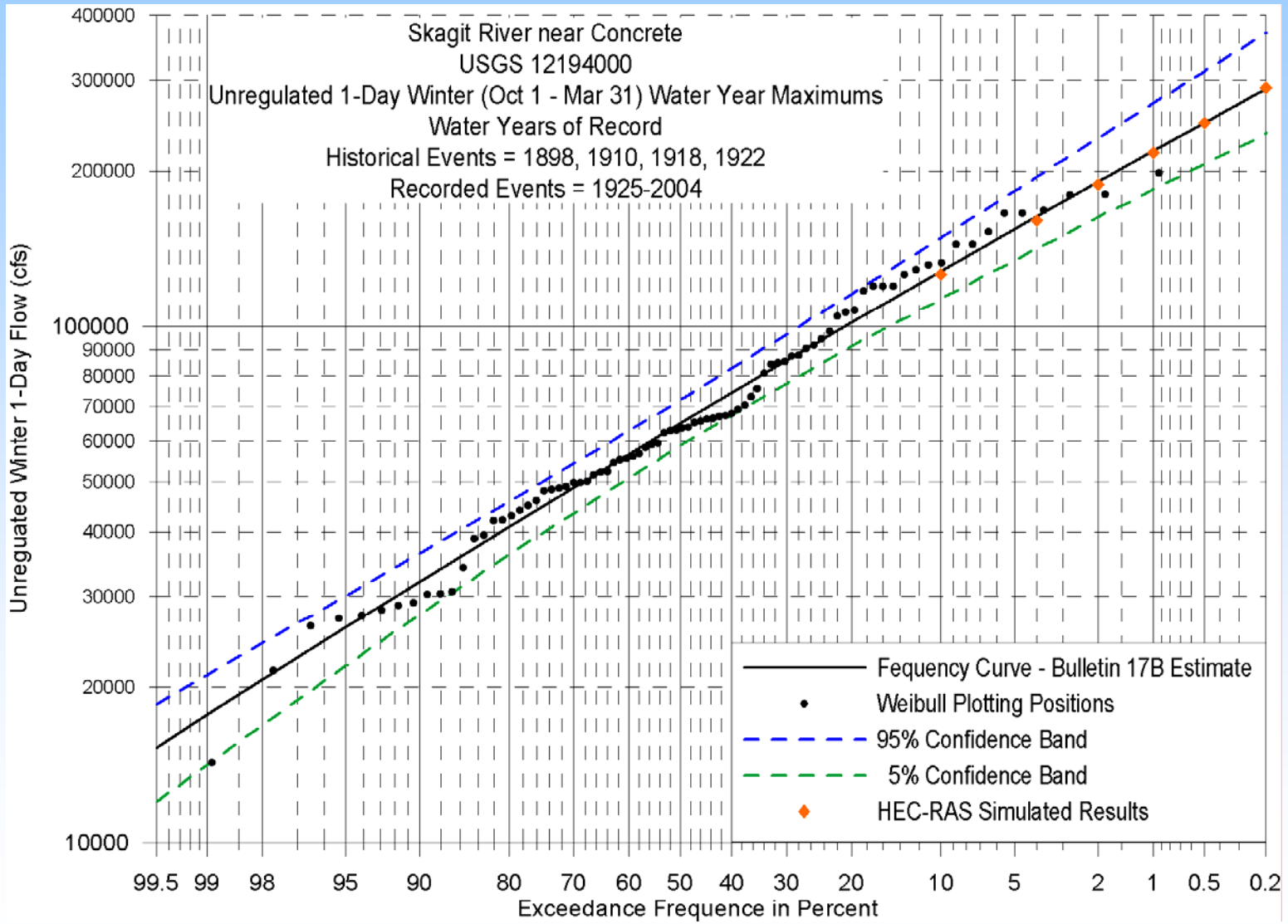

HEC-RAS Modeled 200-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
300,000
280,000
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Unregulated Flow below Cascade River
Unregulated Flow below Sauk River
Unreguated Flow at Concrete


HEC-RAS Modeled 500-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
340,000
320,000
300,000
280,000
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Unregulated Flow below Cascade River
Unregulated Flow below Sauk River
Unreguated Flow at Concrete

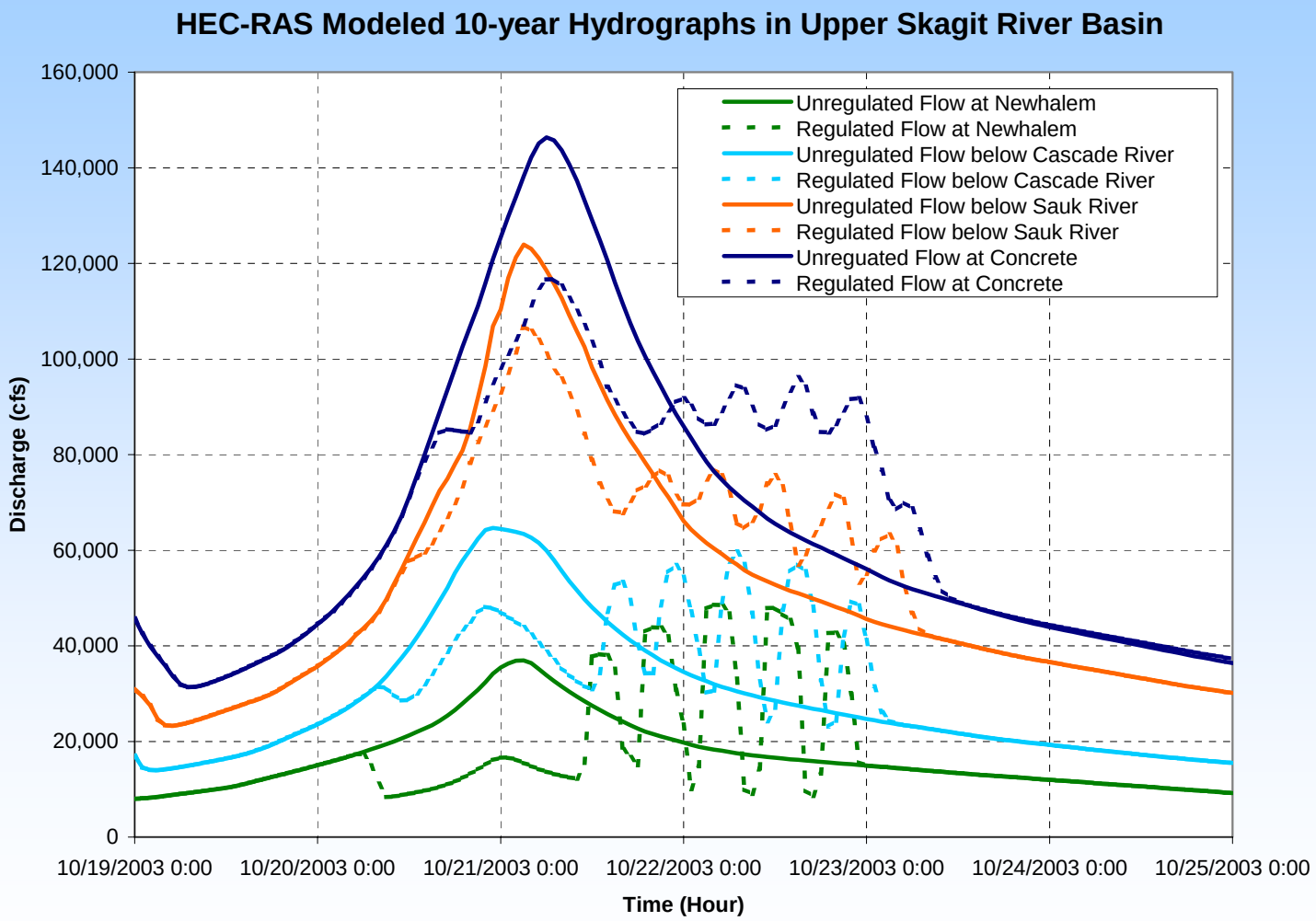
Flood Frequency Curve for Unregulated Peak Discharges at Concrete, Compared with the HEC-RAS Simulated Peak Flows at Concrete for the 10-, 25-, 50-, 100-, 200-, and 500-Year Synthetic Events

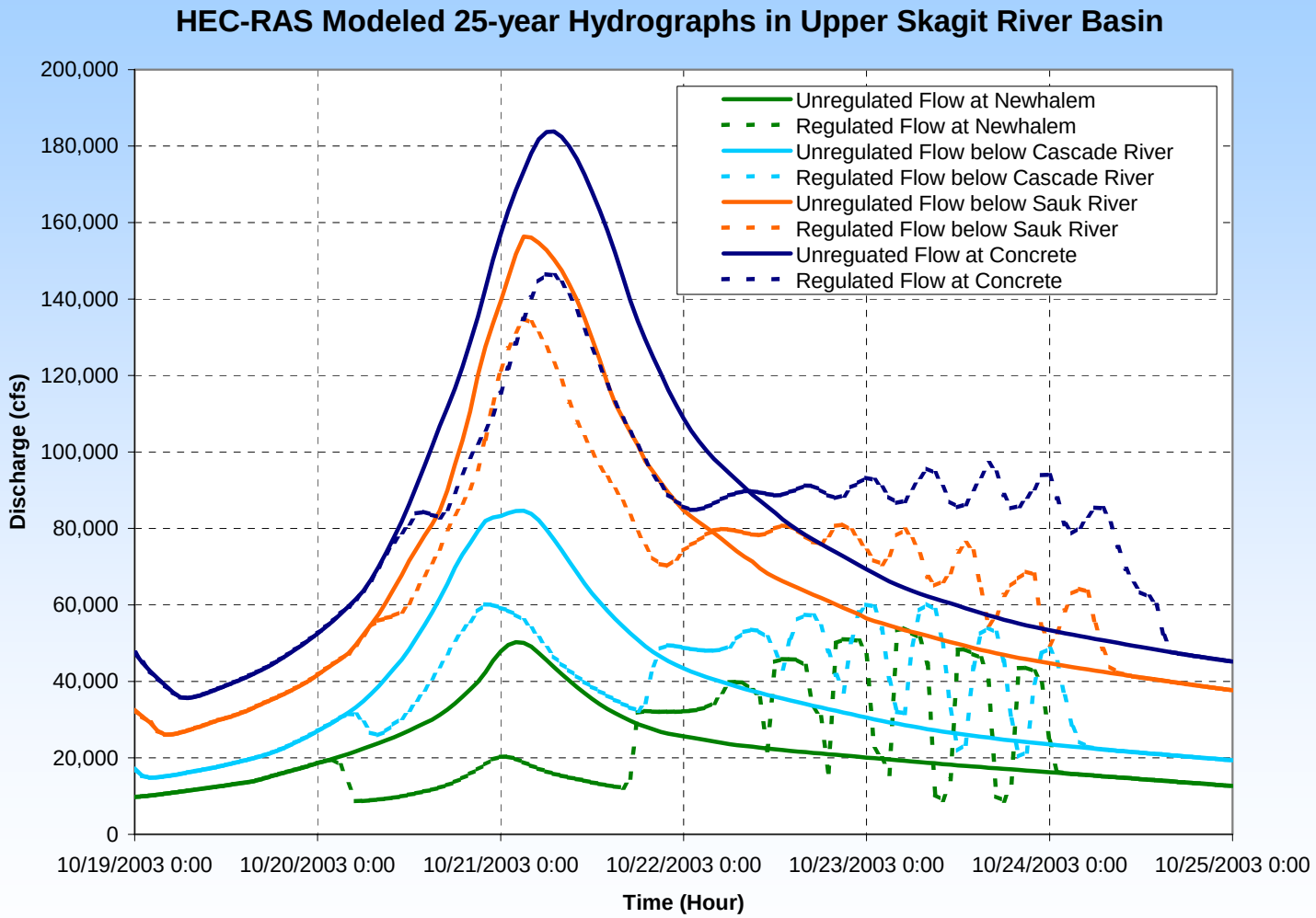


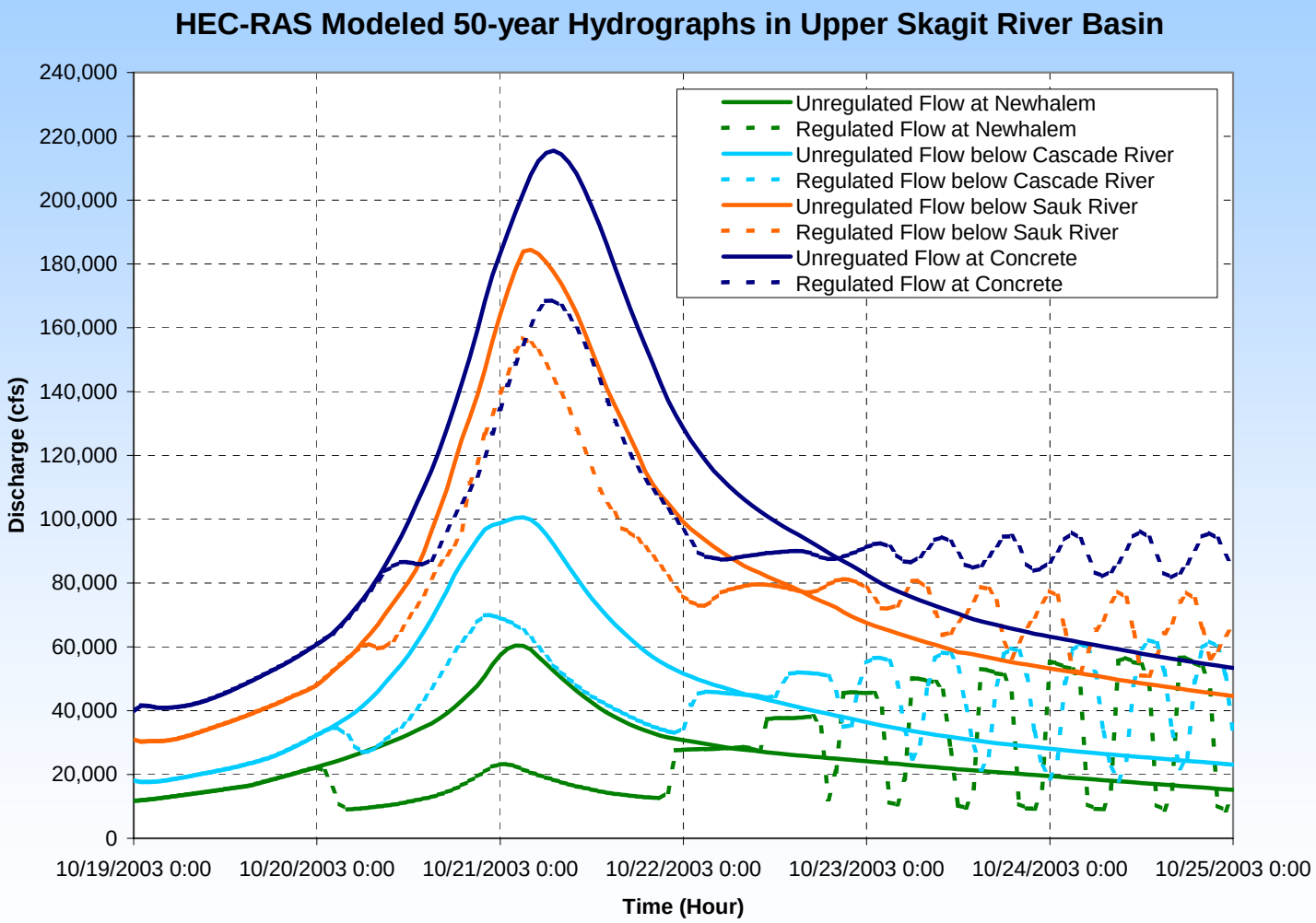
Flood Frequency Curve for Unregulated One-Day Discharges at Concrete, Compared with the HEC-RAS Simulated Peak Flows at Concrete for the 10-, 25-, 50-, 100-, 200-, and 500-Year Synthetic Events

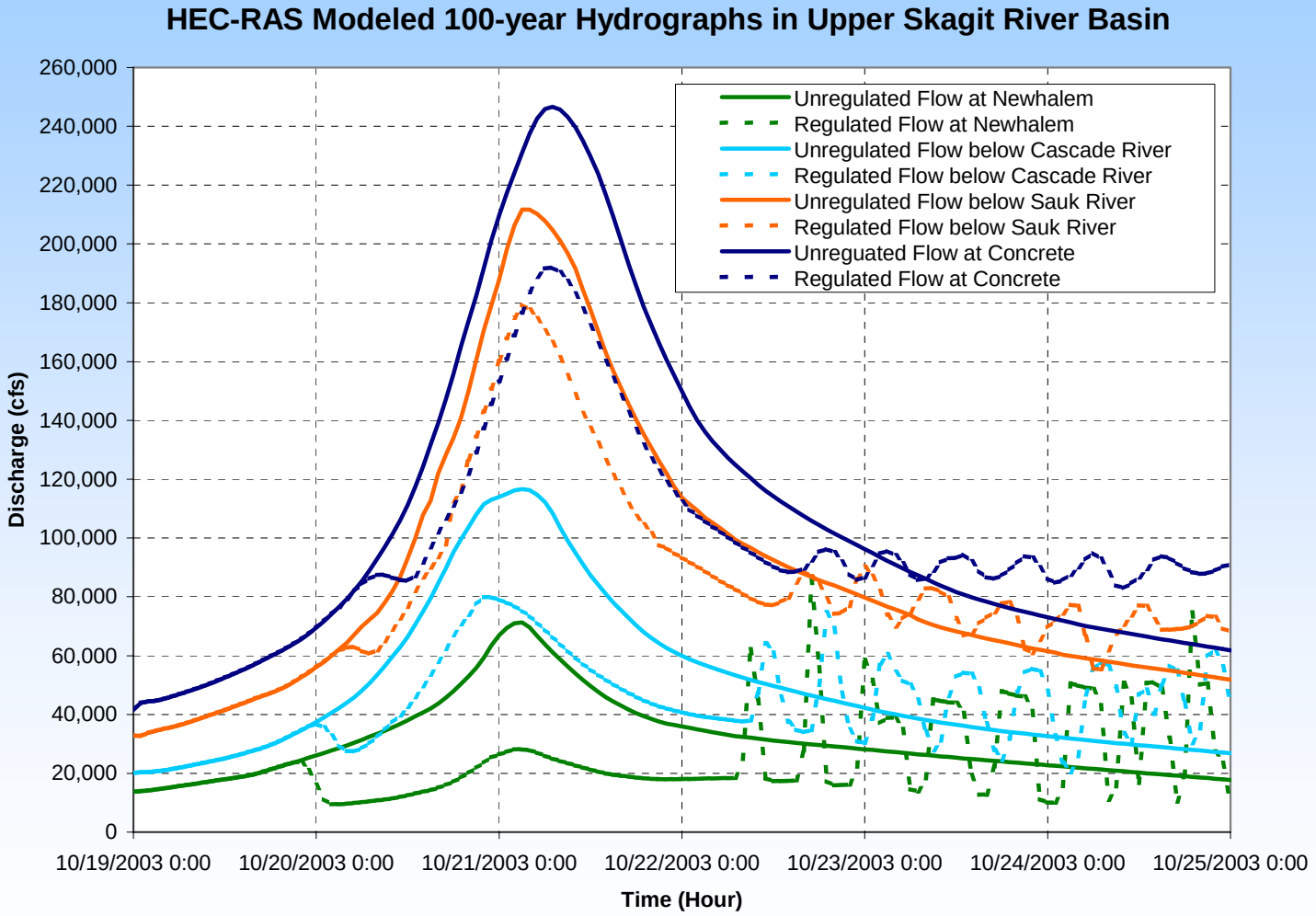


Regulated Synthetic Flood Hydrographs at Concrete

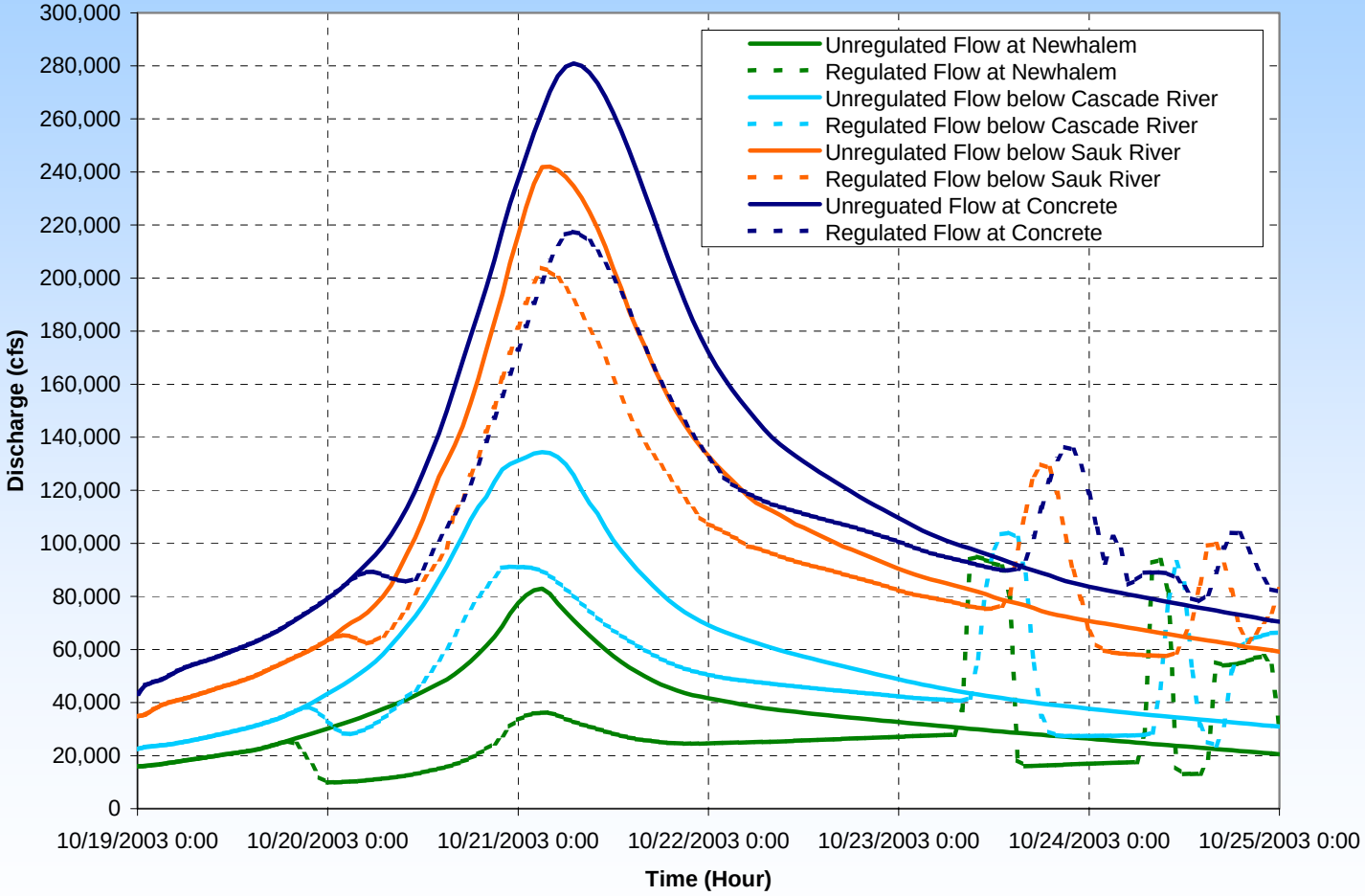

HEC-RAS Modeled 10-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Regulated Flow at Newhalem
Unregulated Flow below Cascade River
Regulated Flow below Cascade River
Unregulated Flow below Sauk River
Regulated Flow below Sauk River
Unreguated Flow at Concrete
Regulated Flow at Concrete

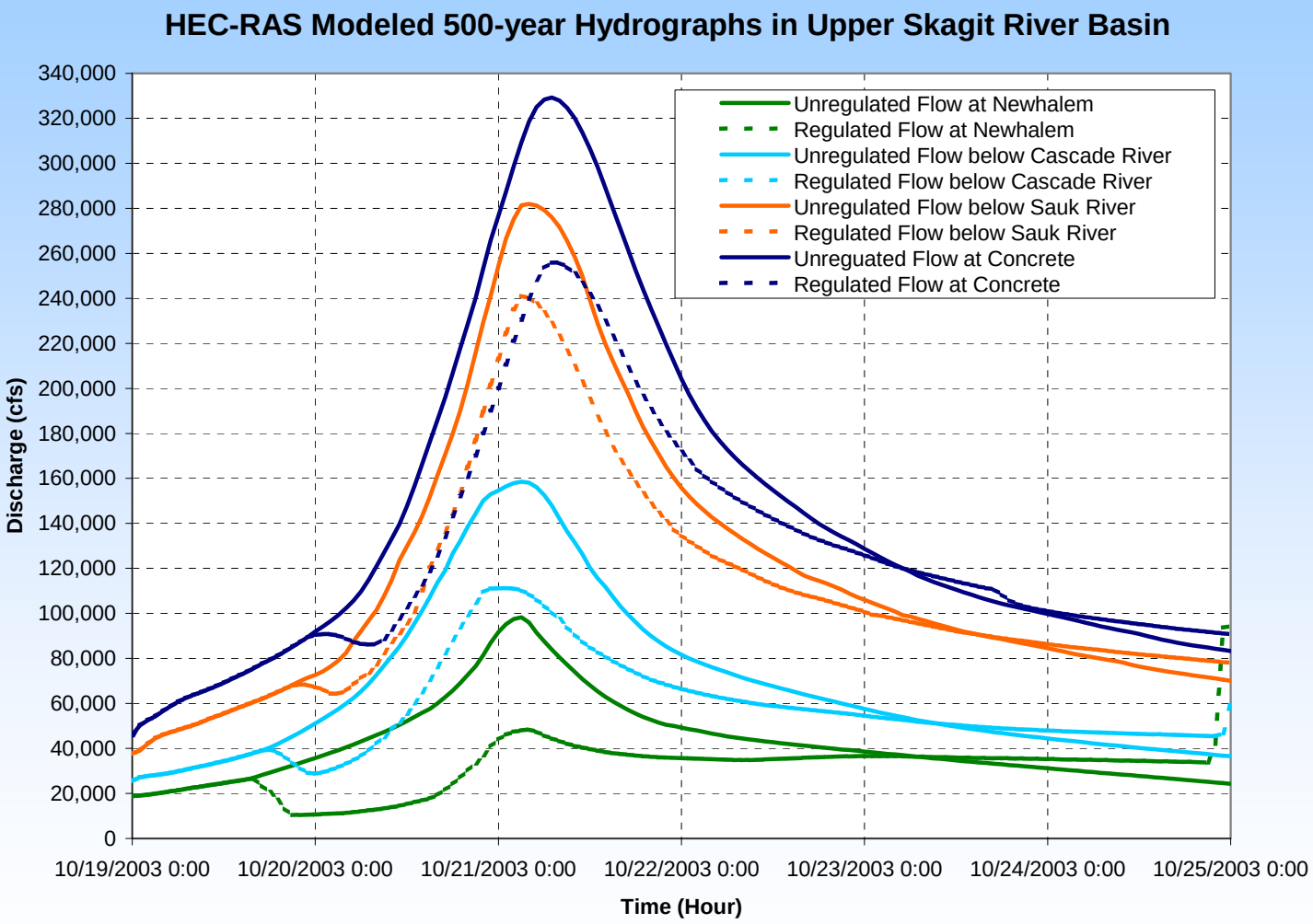

HEC-RAS Modeled 25-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Regulated Flow at Newhalem
Unregulated Flow below Cascade River
Regulated Flow below Cascade River
Unregulated Flow below Sauk River
Regulated Flow below Sauk River
Unreguated Flow at Concrete
Regulated Flow at Concrete


HEC-RAS Modeled 50-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Regulated Flow at Newhalem
Unregulated Flow below Cascade River
Regulated Flow below Cascade River
Unregulated Flow below Sauk River
Regulated Flow below Sauk River
Unreguated Flow at Concrete
Regulated Flow at Concrete

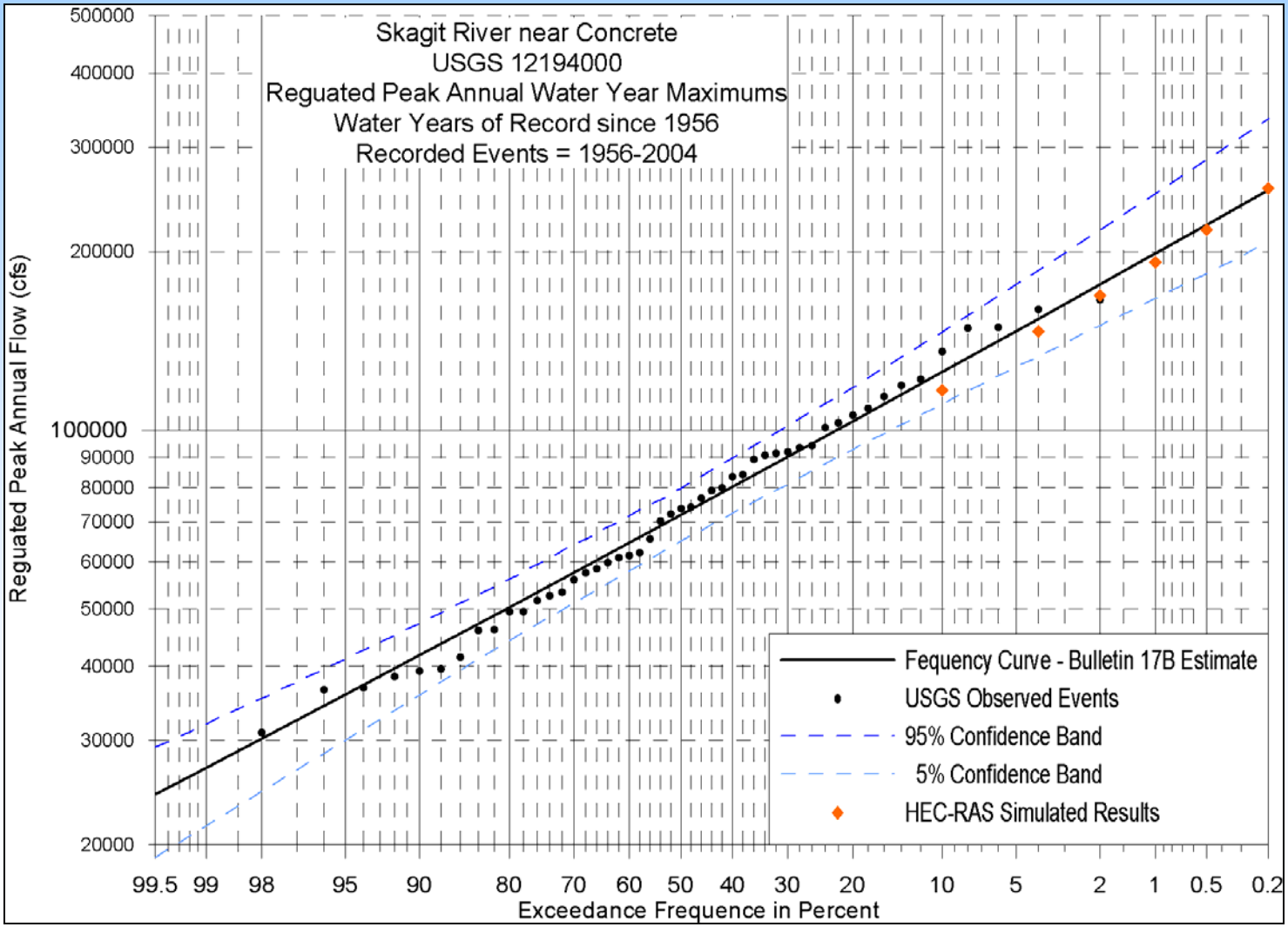

HEC-RAS Modeled 100-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Regulated Flow at Newhalem
Unregulated Flow below Cascade River
Regulated Flow below Cascade River
Unregulated Flow below Sauk River
Regulated Flow below Sauk River
Unreguated Flow at Concrete
Regulated Flow at Concrete

HEC-RAS Modeled 200-year Hydrographs in Upper Skagit River Basin

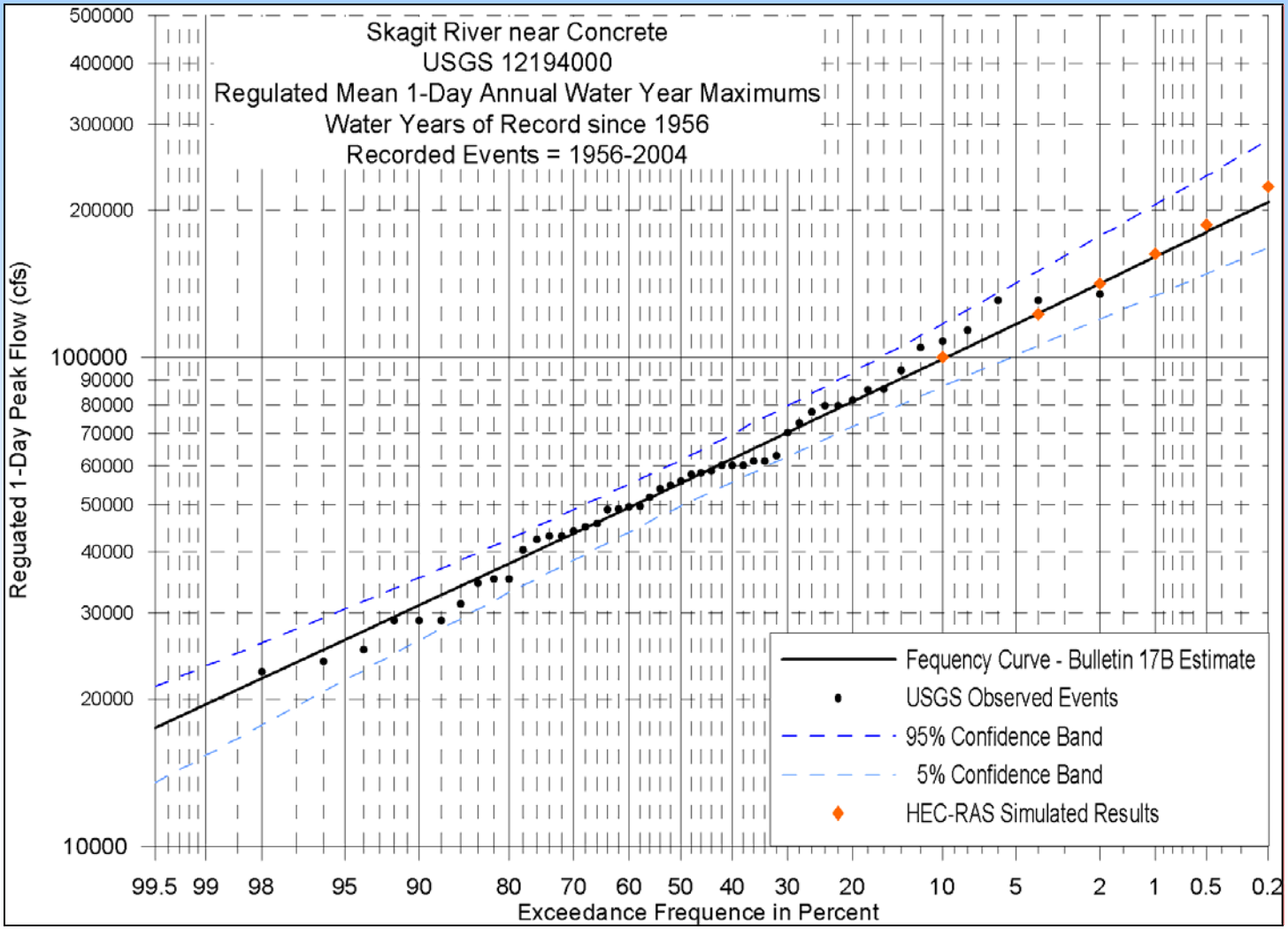



HEC-RAS Modeled 500-year Hydrographs in Upper Skagit River Basin
Discharge (cfs)
340,000
320,000
300,000
280,000
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Unregulated Flow at Newhalem
Regulated Flow at Newhalem
Unregulated Flow below Cascade River
Regulated Flow below Cascade River
Unregulated Flow below Sauk River
Regulated Flow below Sauk River
Unreguated Flow at Concrete
Regulated Flow at Concrete

Flood frequency curve for regulated peak discharges observed by USGS at Concrete, compared with the HEC-RAS simulated regulated peak flows at Concrete for the 10-, 25-, 50-, 100-, 200- and 500-year synthetic events



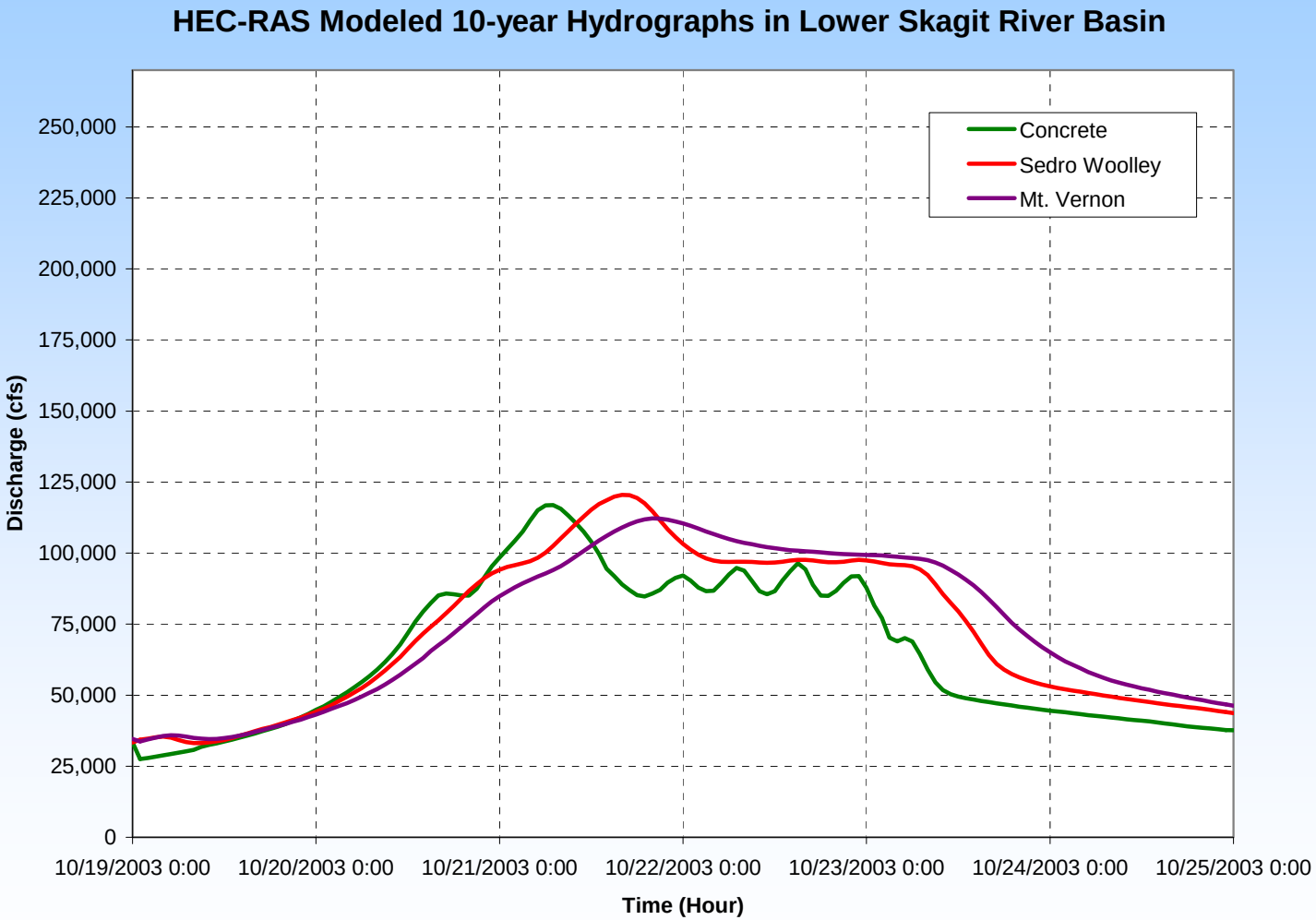
Flood frequency curve for regulated one-day discharges observed by USGS at Concrete, compared with the HEC-RAS simulated regulated one-day flows at Concrete for the 10-, 25-, 50-, 100-, 200- and 500-year synthetic events

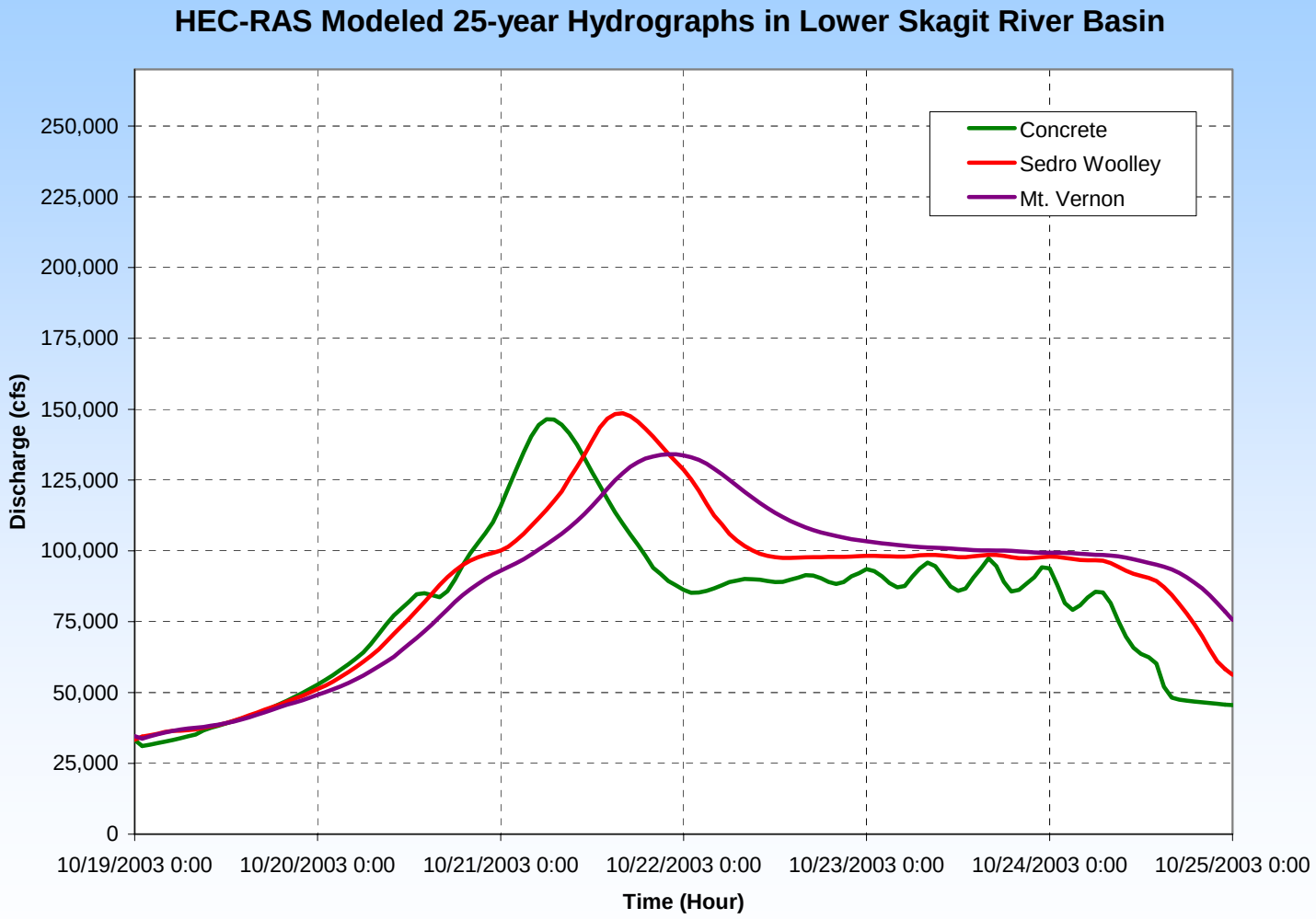


Regulated Synthetic Flood Hydrographs at Sedro-Woolley and Mount Vernon

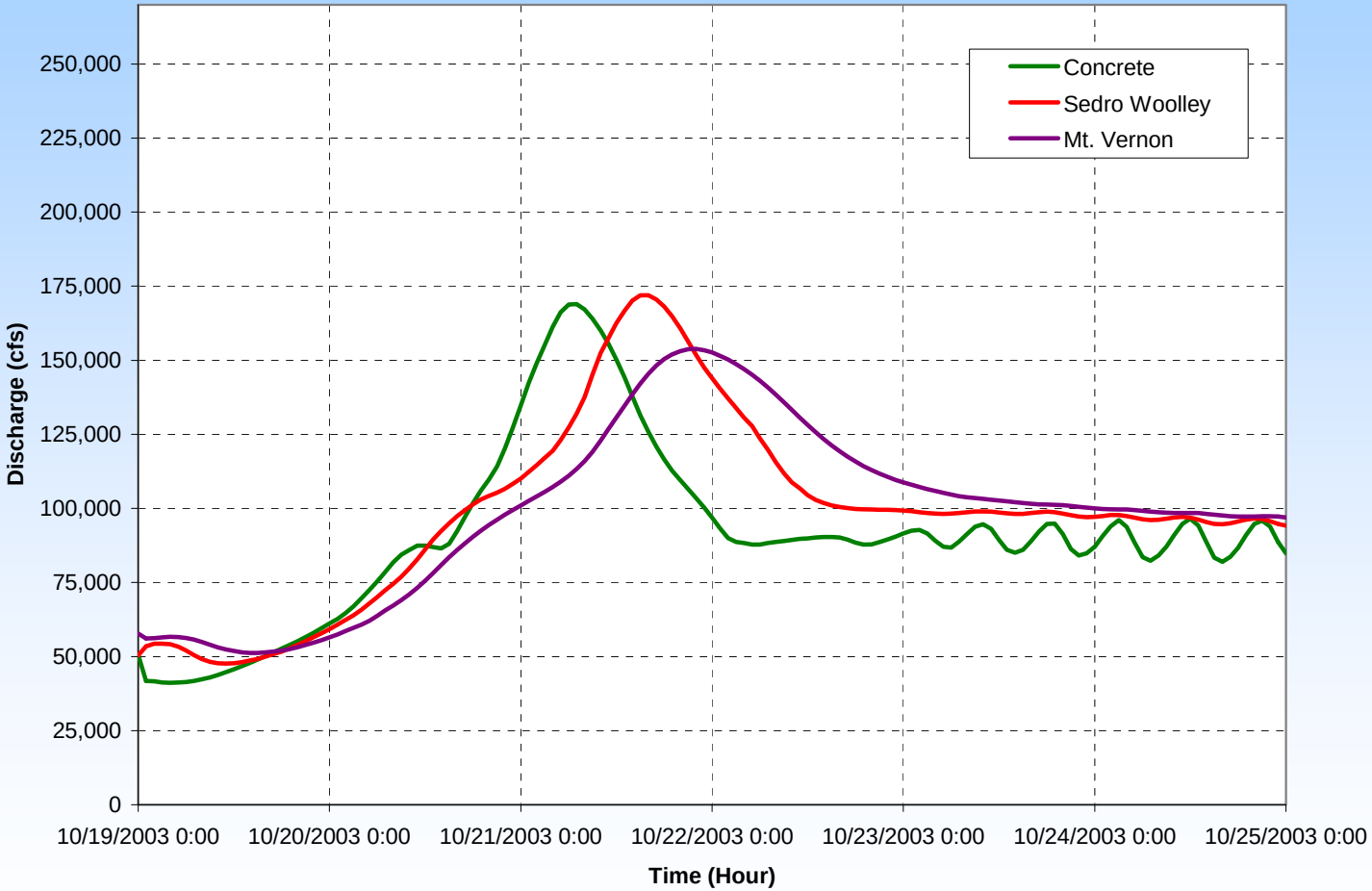
Unregulated Synthetic Flood One-Day Coincident Flows (cfs) for Lower Skagit River Subbasins

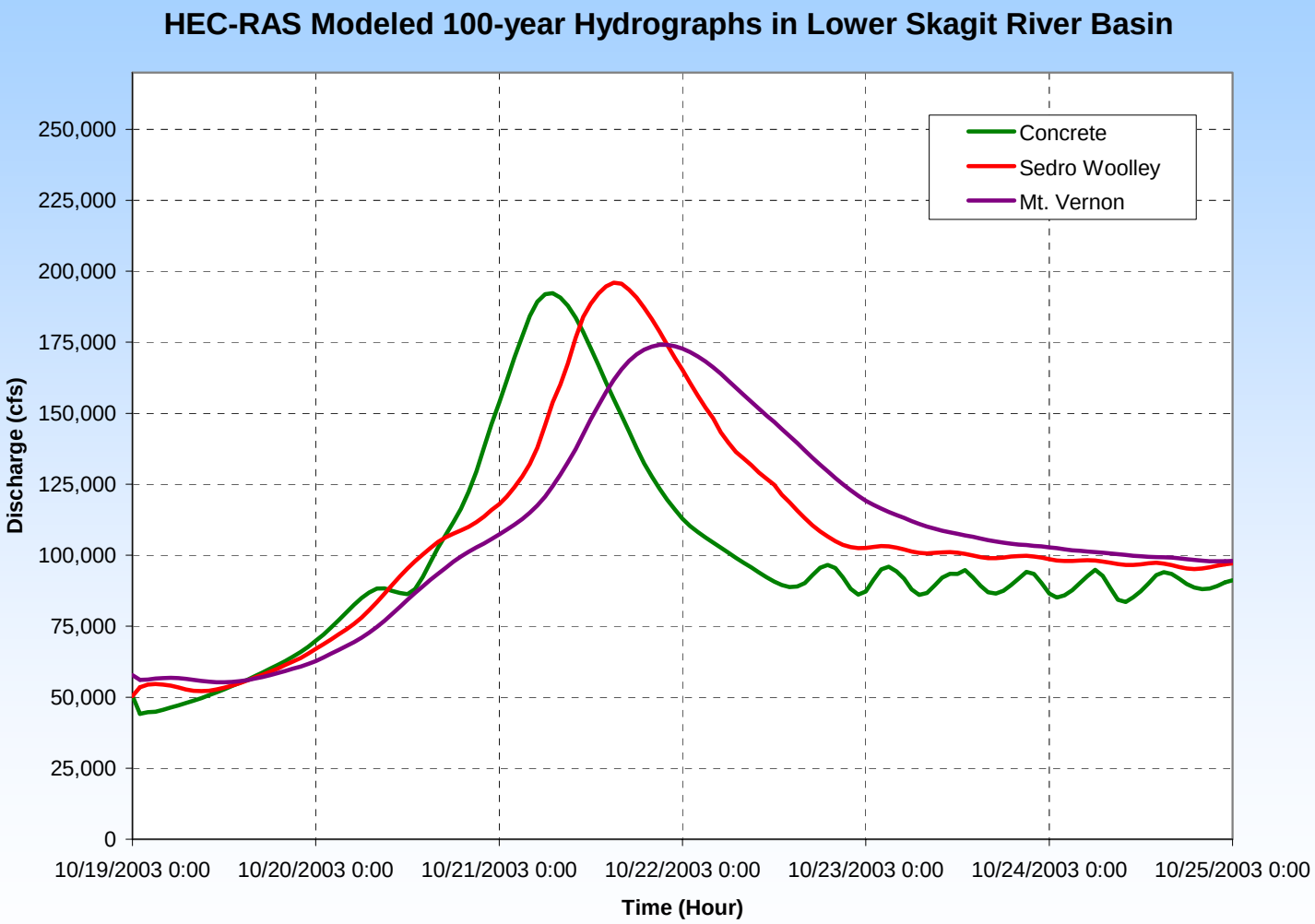
Location	Flood Event					
	10-year	25-year	50-year	100-year	200-year	500-year
Unregulated Skagit River Near Concrete	128,300	163,400	190,600	218,800	247,900	288,000
Concrete to Sedro Woolley Local	14,600	16,800	18,800	21,000	23,000	25,800
Nookachamps Creek	3,500	4,100	4,500	5,000	5,500	6,100

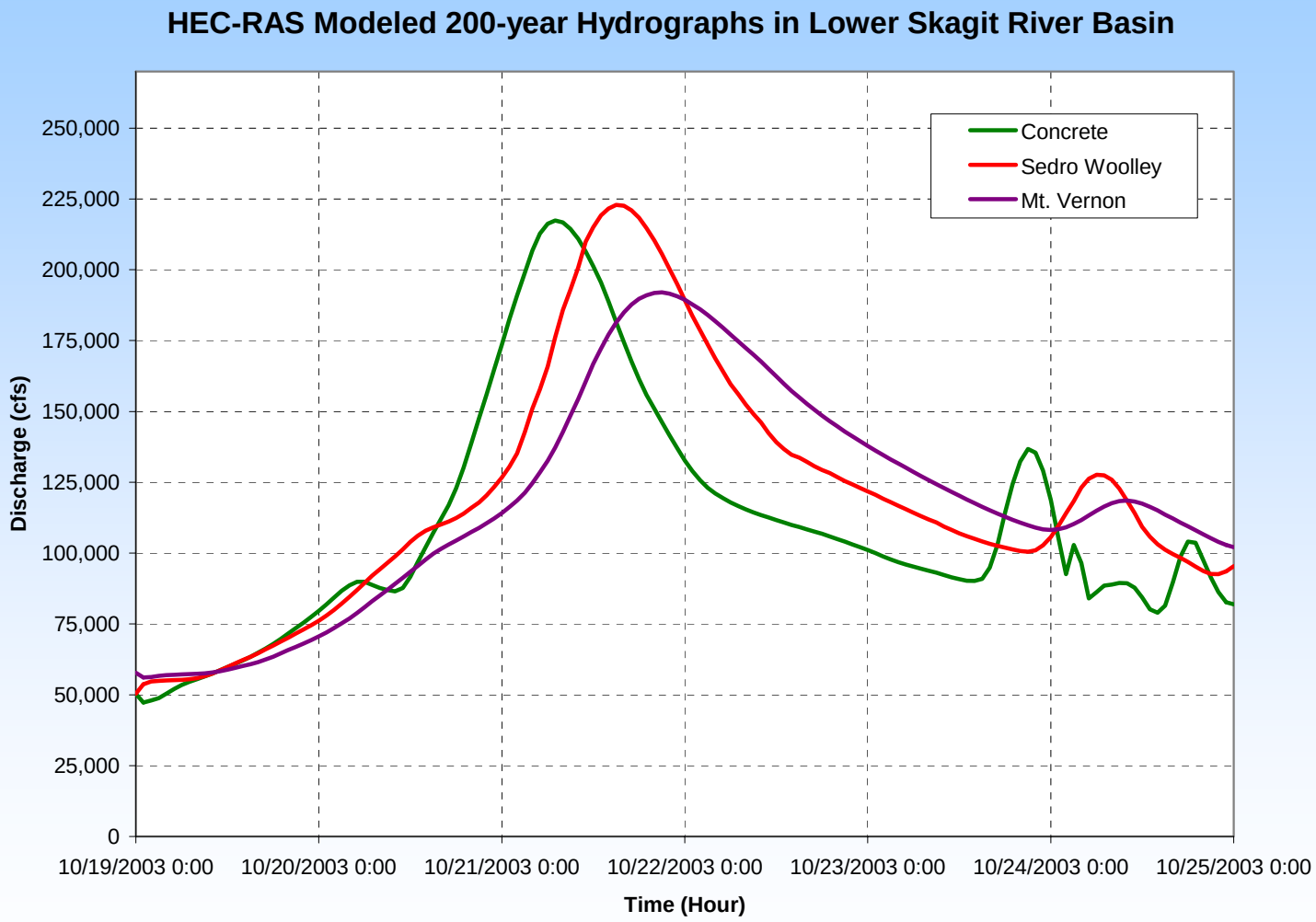

HEC-RAS Modeled 10-year Hydrographs in Lower Skagit River Basin
Discharge (cfs)
250,000
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Concrete
Sedro Woolley
Mt. Vernon

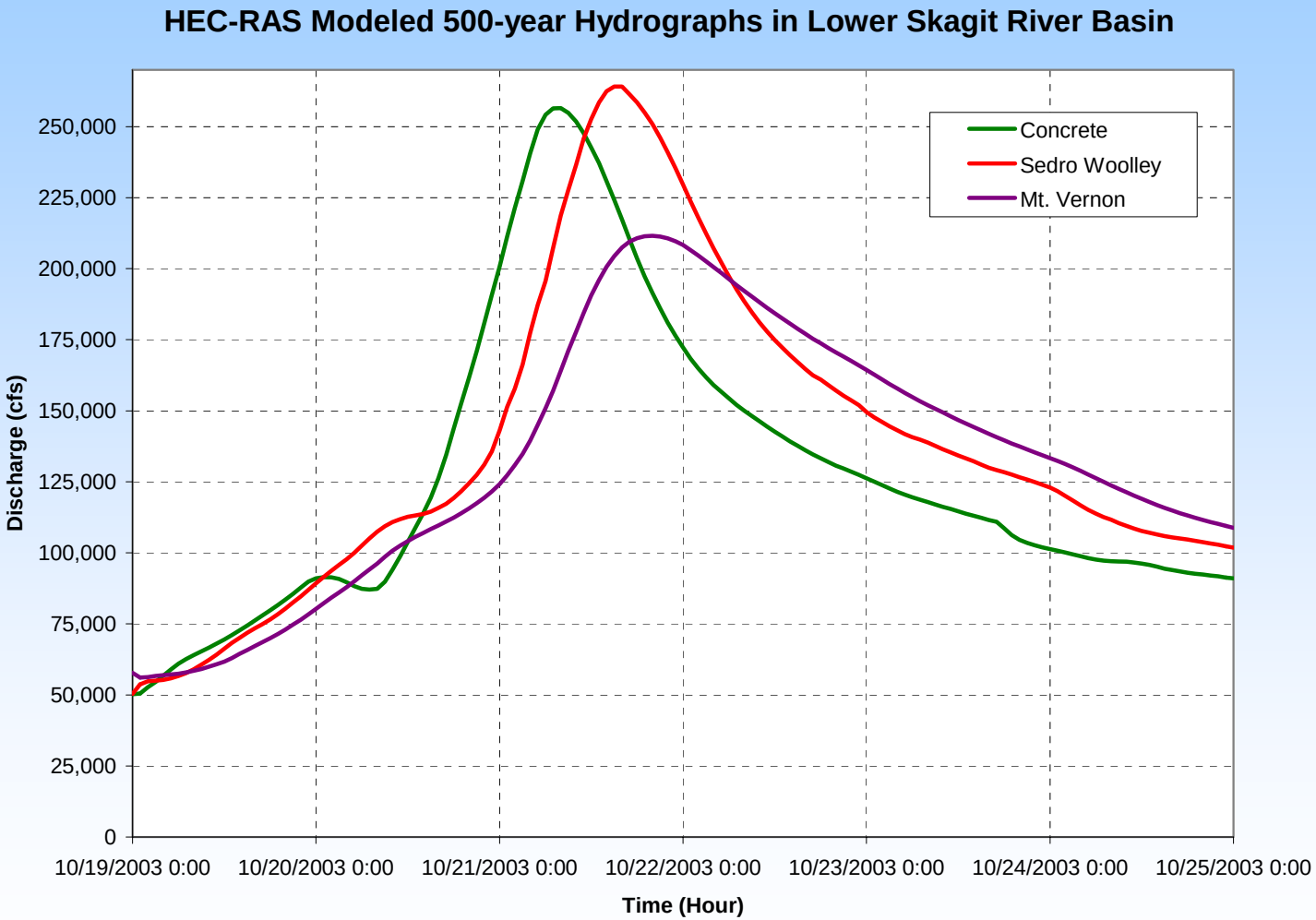

HEC-RAS Modeled 25-year Hydrographs in Lower Skagit River Basin
Concrete
Sedro Woolley
Mt. Vernon
Discharge (cfs)
250,000
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)

HEC-RAS Modeled 50-year Hydrographs in Lower Skagit River Basin

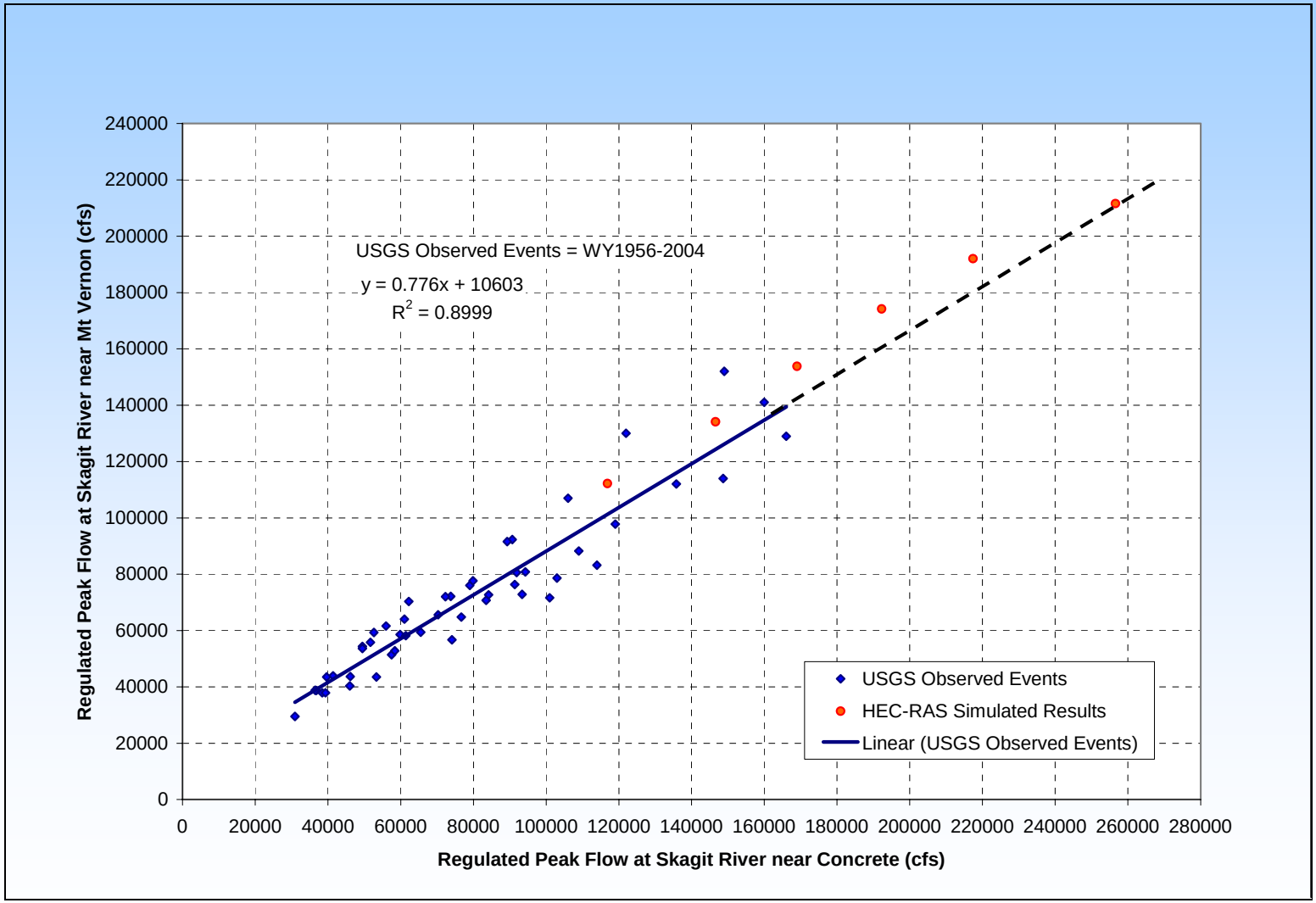



HEC-RAS Modeled 100-year Hydrographs in Lower Skagit River Basin
Discharge (cfs)
250,000
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
Concrete
Sedro Woolley
Mt. Vernon
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)

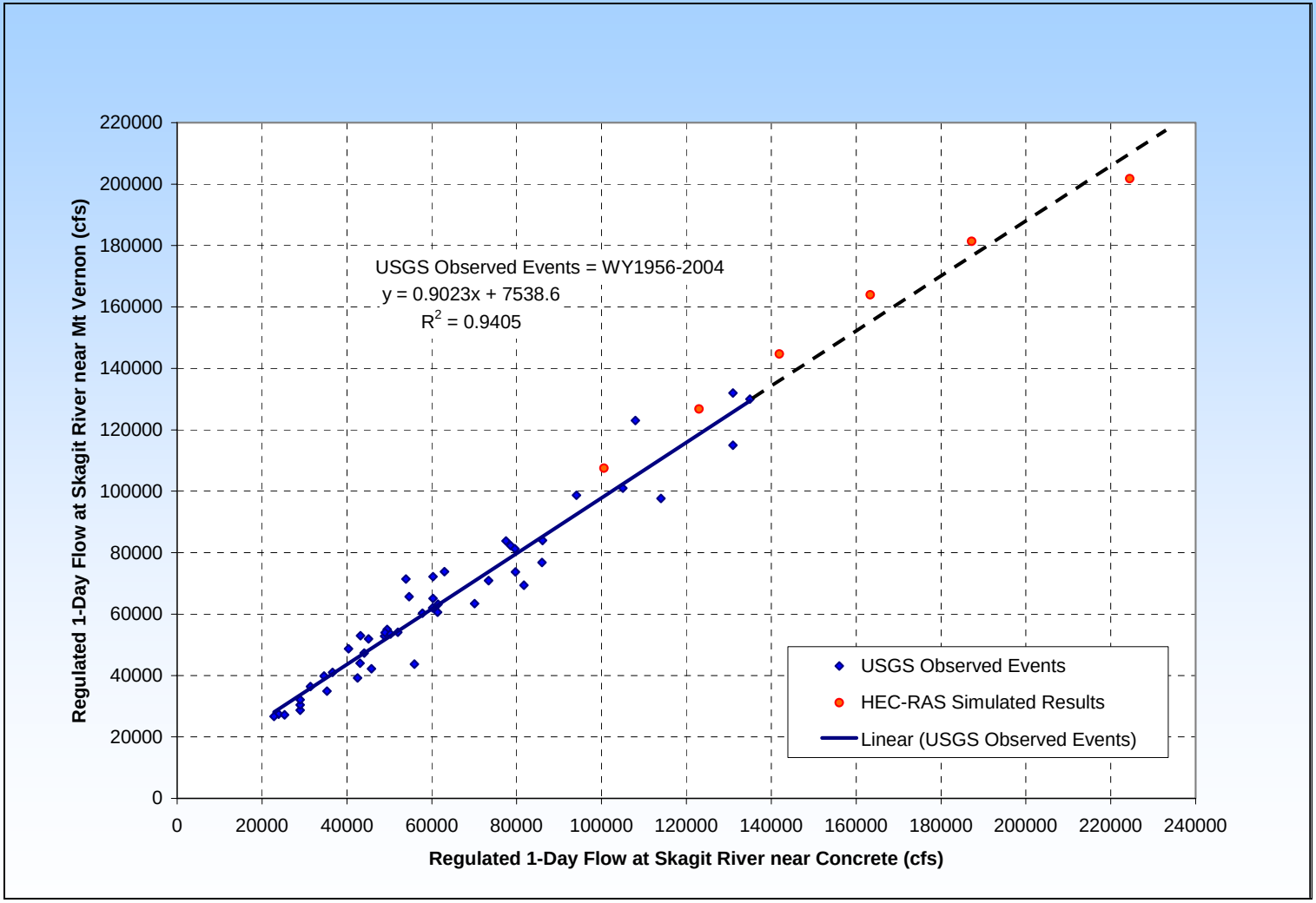

HEC-RAS Modeled 200-year Hydrographs in Lower Skagit River Basin
Discharge (cfs)
250,000
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Concrete
Sedro Woolley
Mt. Vernon


HEC-RAS Modeled 500-year Hydrographs in Lower Skagit River Basin
Discharge (cfs)
250,000
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
10/19/2003 0:00
10/20/2003 0:00
10/21/2003 0:00
10/22/2003 0:00
10/23/2003 0:00
10/24/2003 0:00
10/25/2003 0:00
Time (Hour)
Concrete
Sedro Woolley
Mt. Vernon

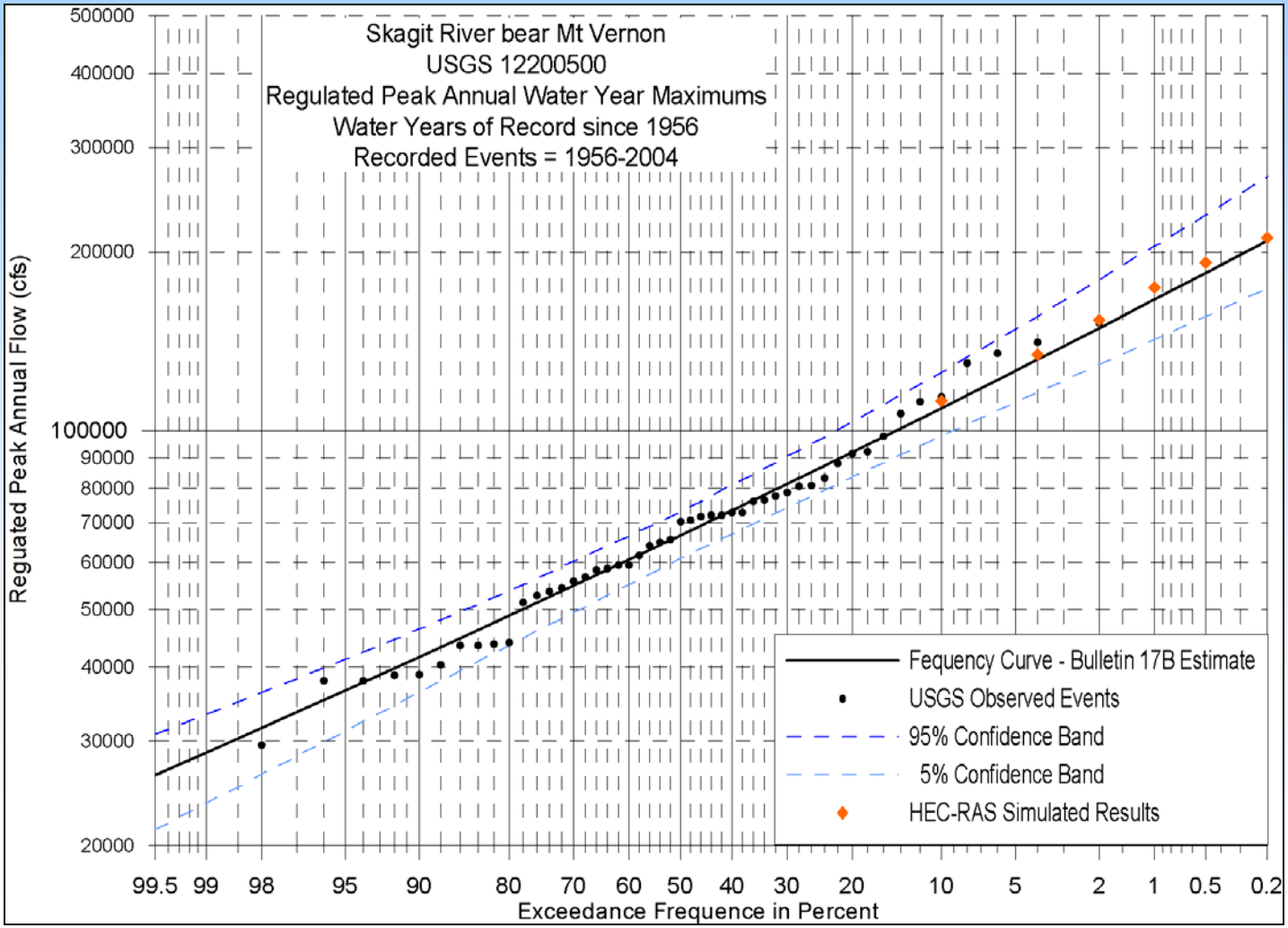
Regression of regulated peak flows observed by USGS at Concrete and Mount Vernon, compared with the HEC-RAS simulated peak values for the 10-, 25-, 50-, 100-, 200-, and 500-year synthetic events



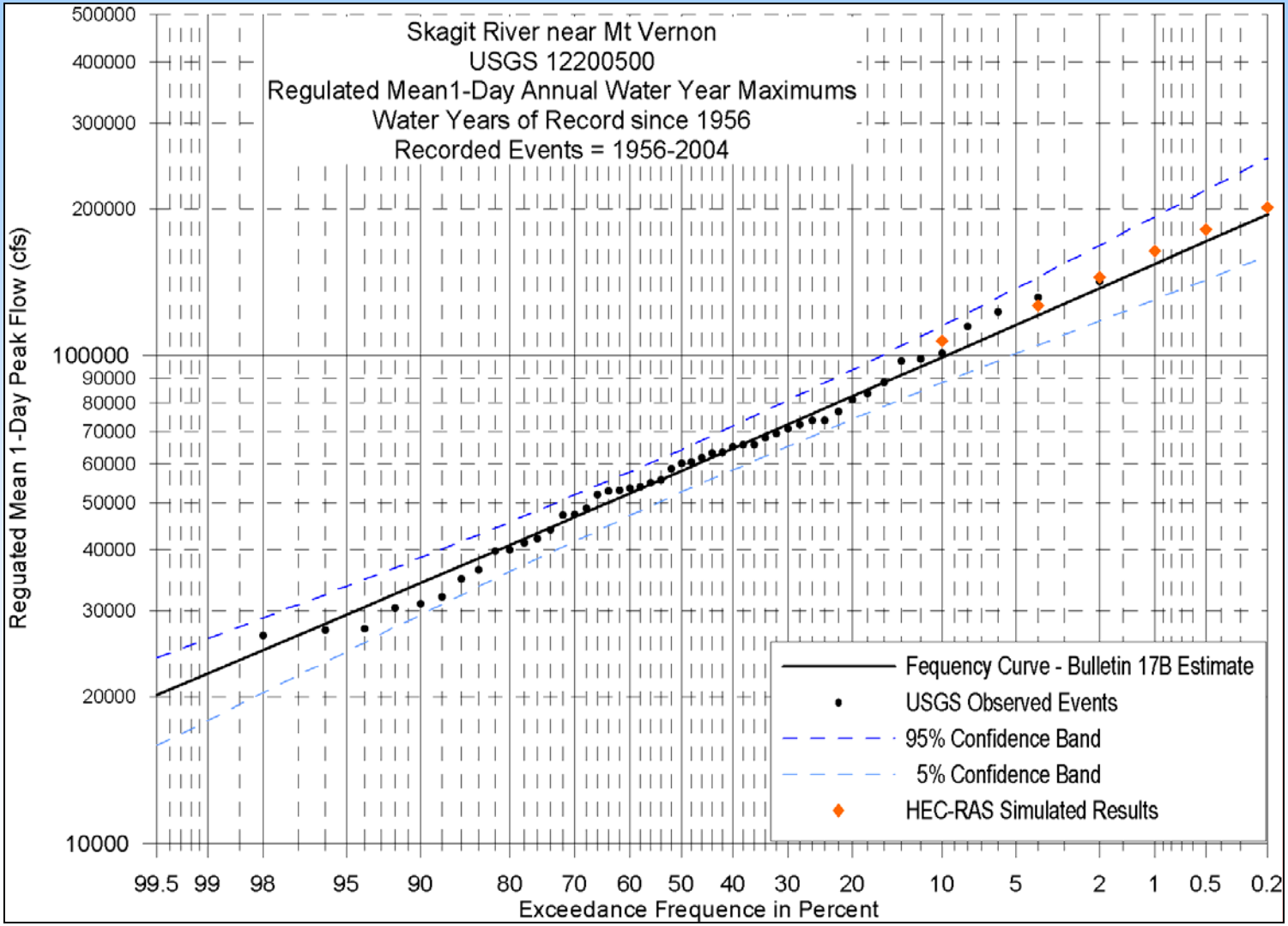
Regression of regulated one-day flows observed by USGS at Concrete and Mount Vernon, compared with the HEC-RAS simulated one-day values for the 10-, 25-, 50-, 100-, 200-, and 500-year synthetic events



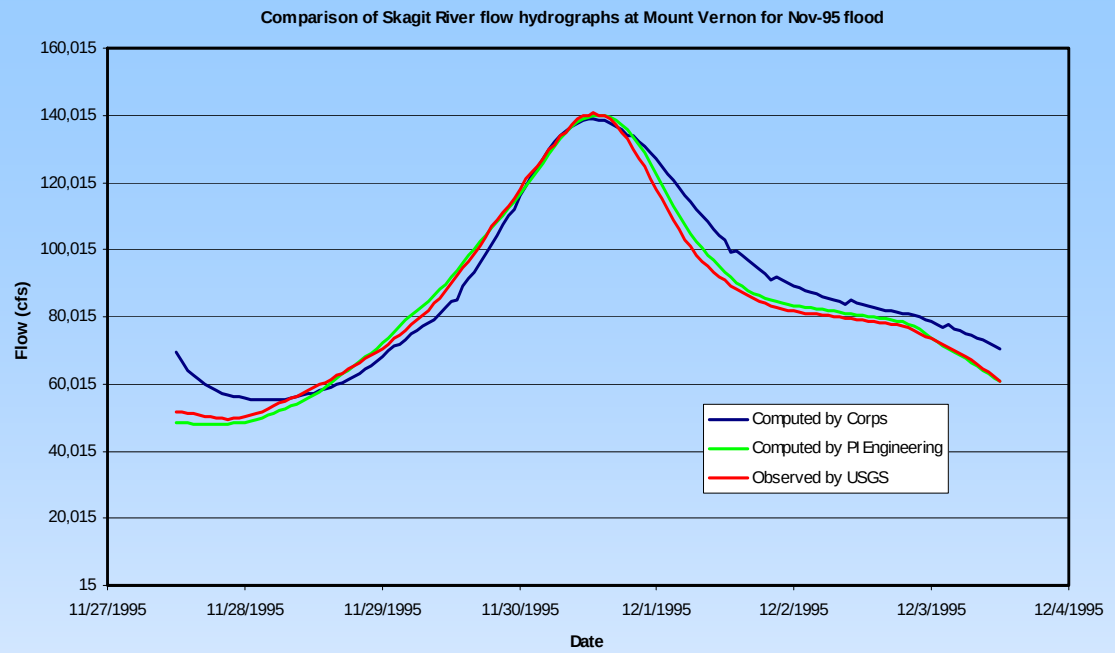
Flood frequency curves for regulated peak discharges observed by USGS at Mount Vernon, compared with the HEC-RAS simulated peak flows at Mount Vernon for the 10-, 25-, 50-, 100-, and 500-year synthetic events

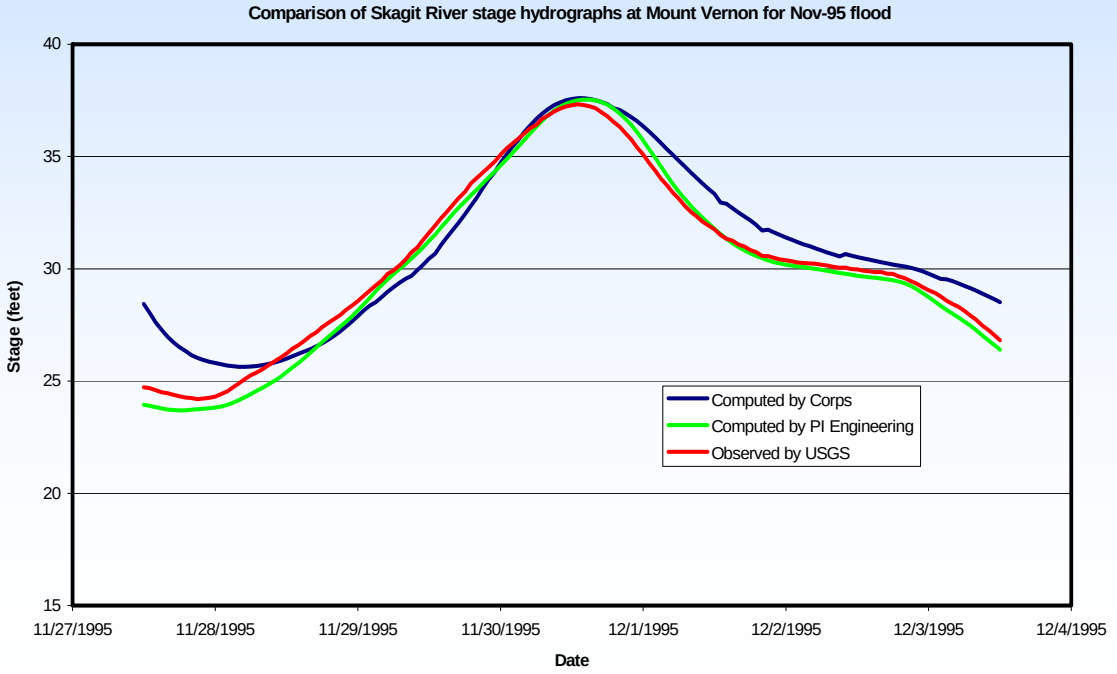


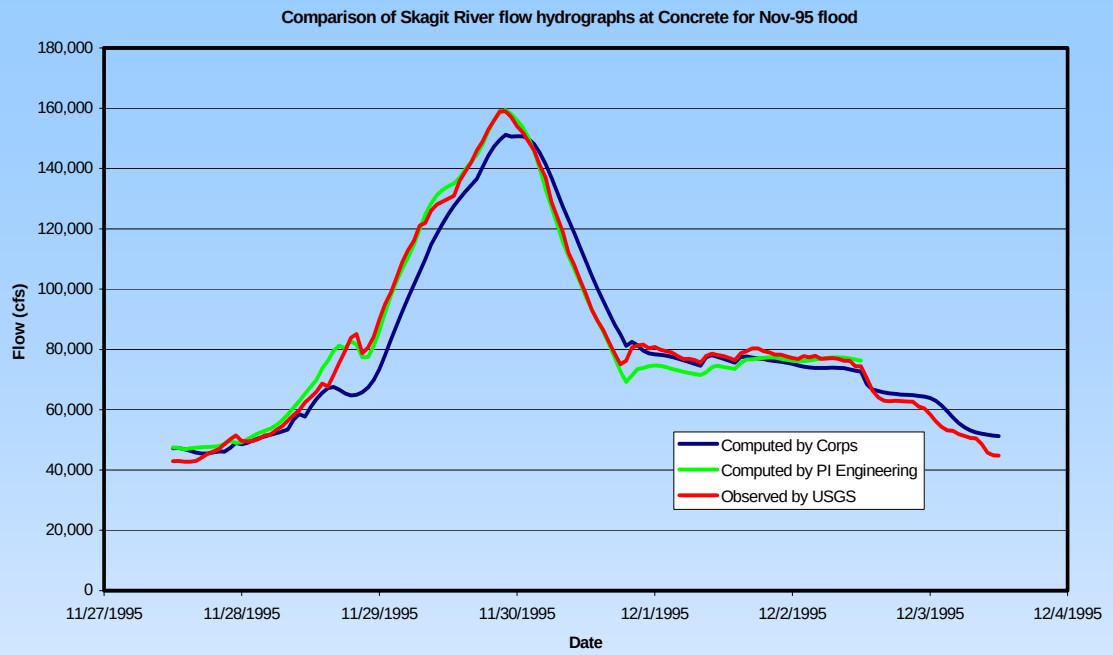
Flood frequency curves for regulated one-day discharges observed by USGS at Mount Vernon, compared with the HEC-RAS simulated one-day flows at Mount Vernon for the 10-, 25-, 50-, 100-, and 500-year synthetic events

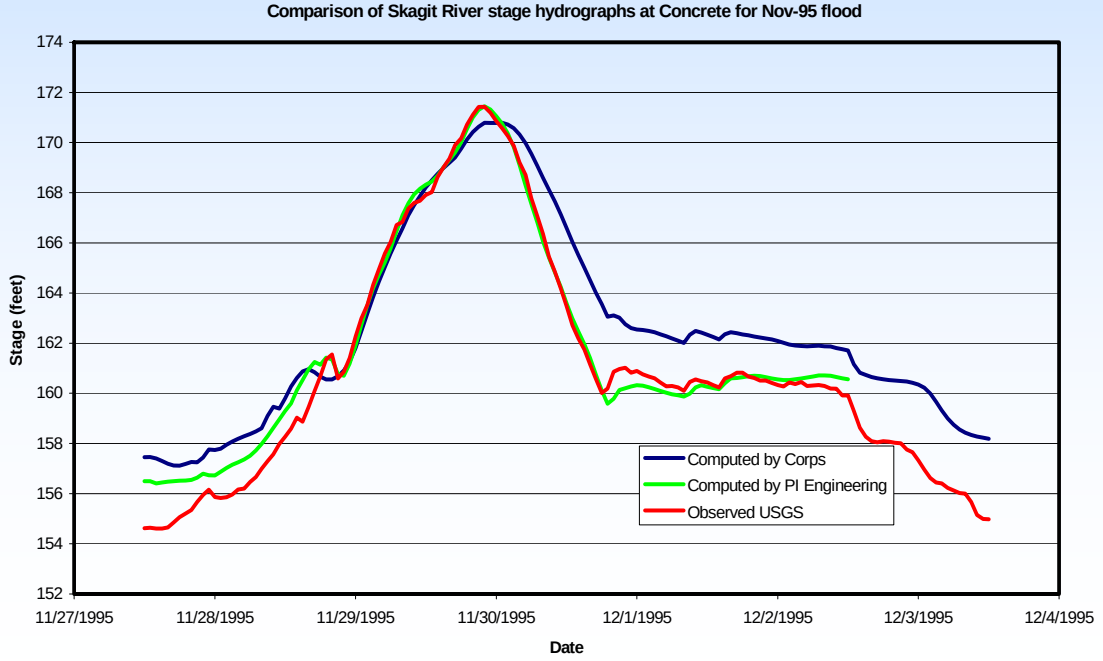


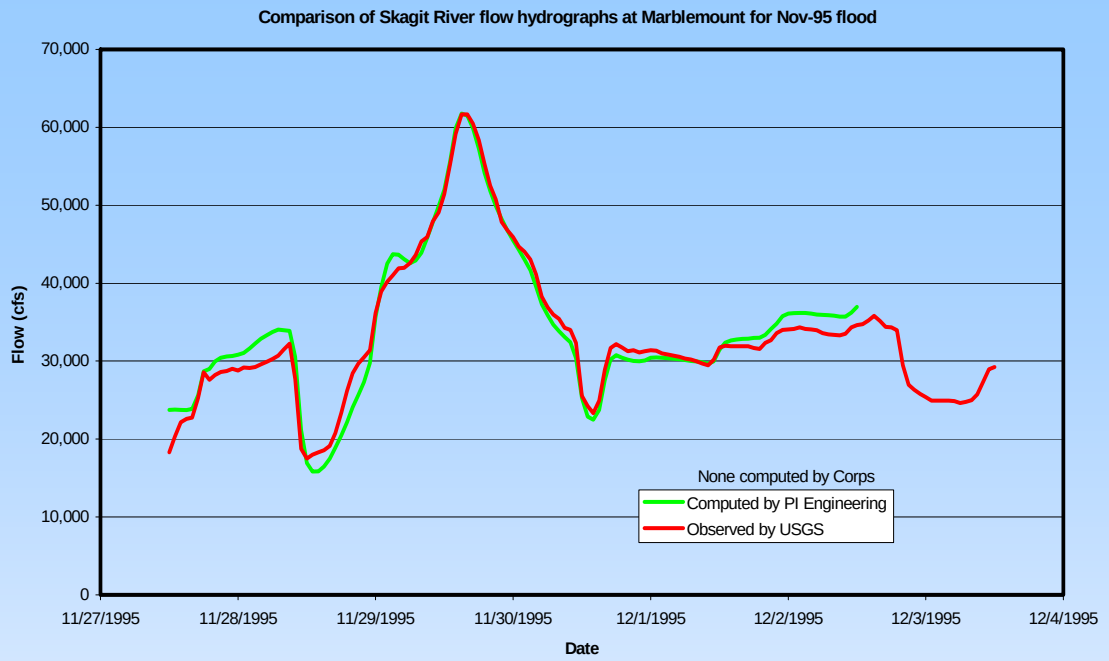
Section II – Army Corps – PIE HH Comparison

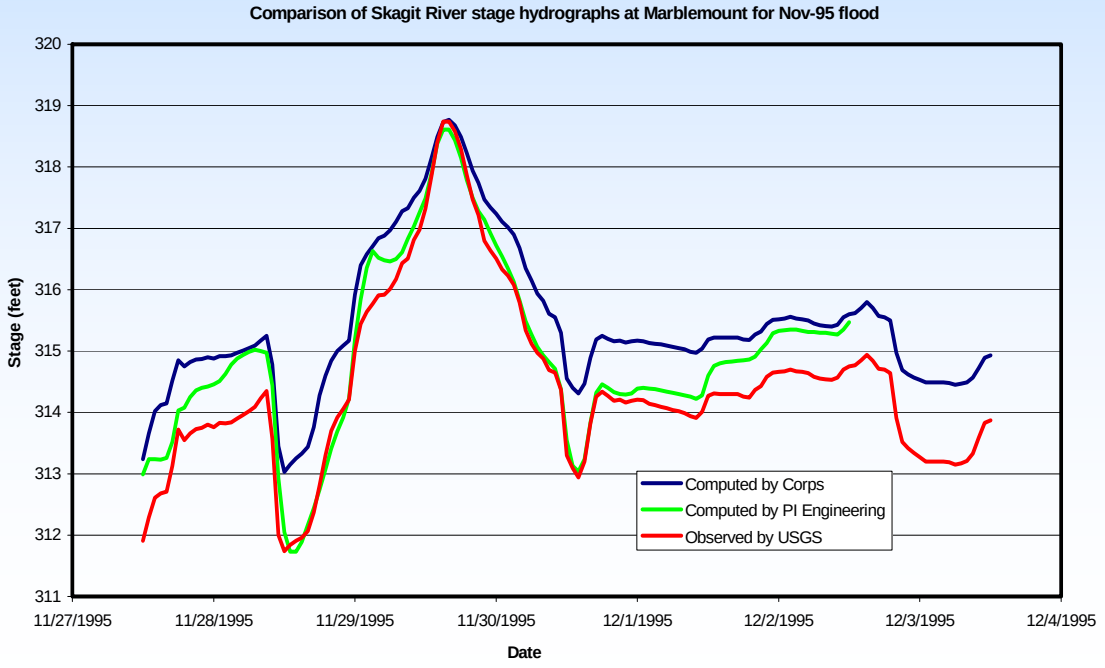

Comparison of Skagit River flow hydrographs at Mount Vernon for Nov-95 flood
160,015
140,015
120,015
100,015
80,015
60,015
40,015
20,015
15
Flow (cfs)
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

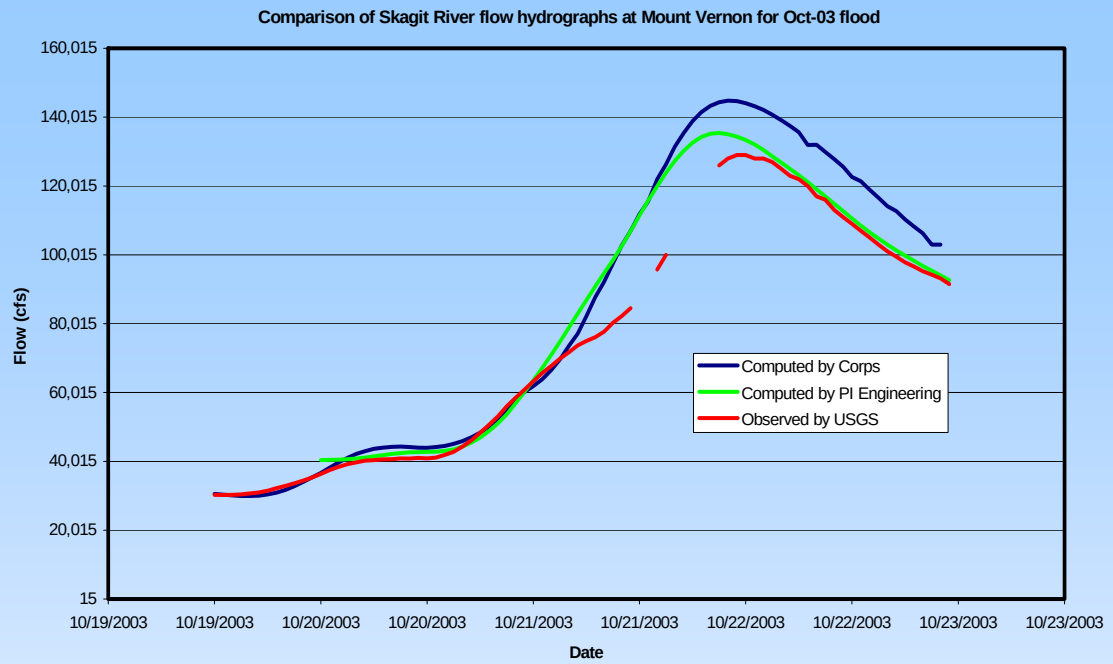

Comparison of Skagit River stage hydrographs at Mount Vernon for Nov-95 flood
40
35
30
25
20
15
Stage (feet)
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

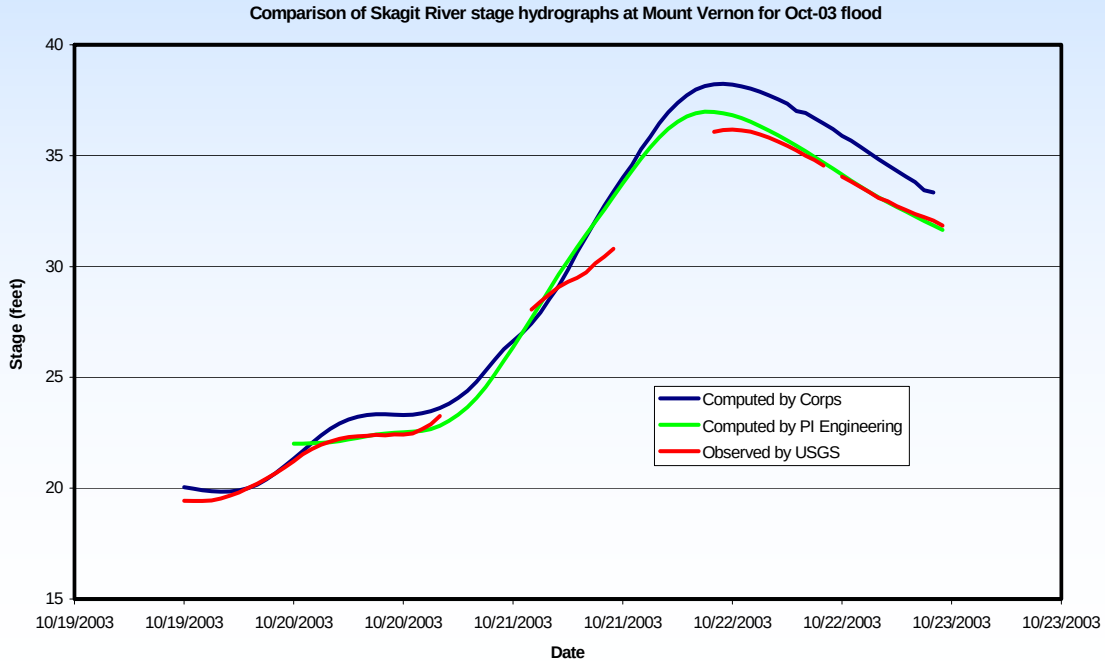

Comparison of Skagit River flow hydrographs at Concrete for Nov-95 flood
Flow (cfs)
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

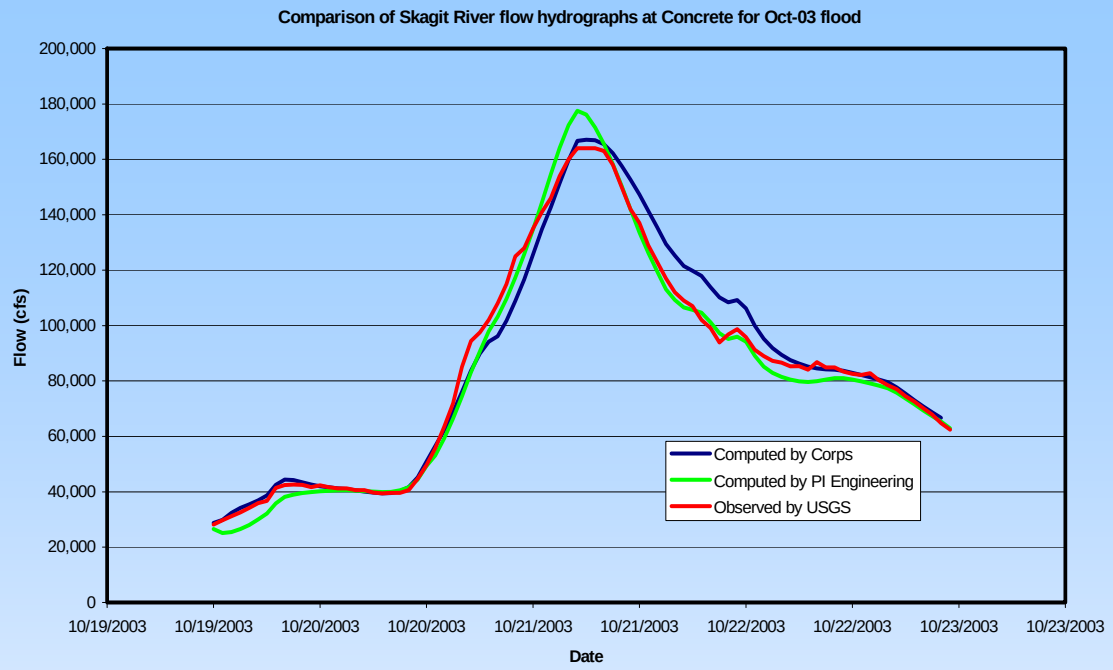

Comparison of Skagit River stage hydrographs at Concrete for Nov-95 flood
Stage (feet)
174
172
170
168
166
164
162
160
158
156
154
152
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date
Computed by Corps
Computed by PI Engineering
Observed USGS

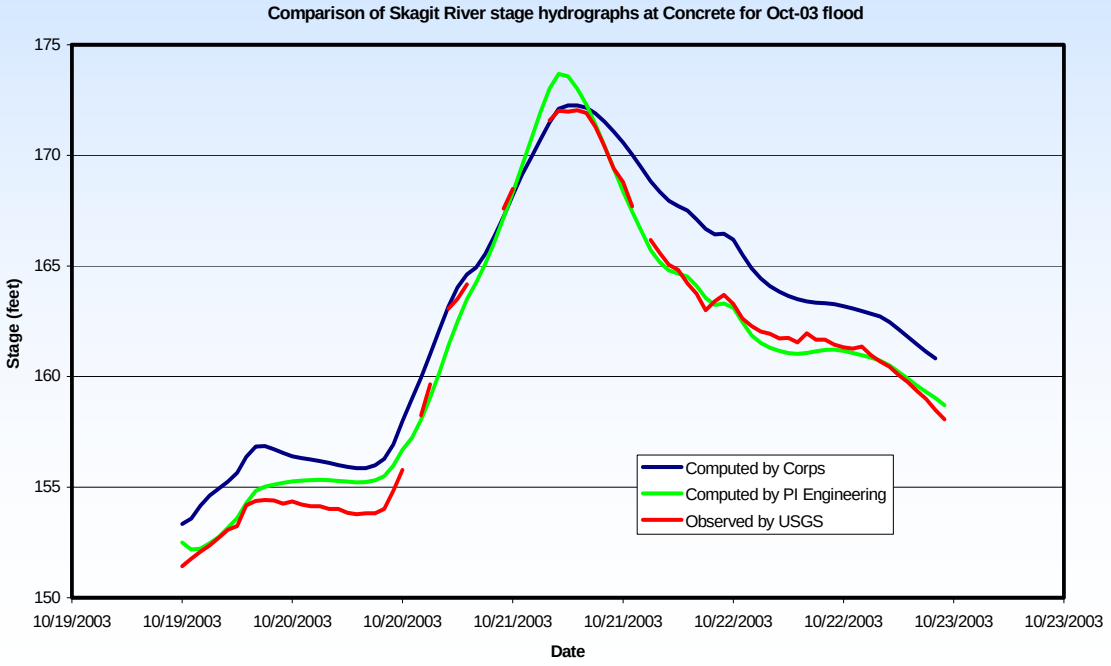

Comparison of Skagit River flow hydrographs at Marblemount for Nov-95 flood
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Flow (cfs)
None computed by Corps
Computed by PI Engineering
Observed by USGS
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date

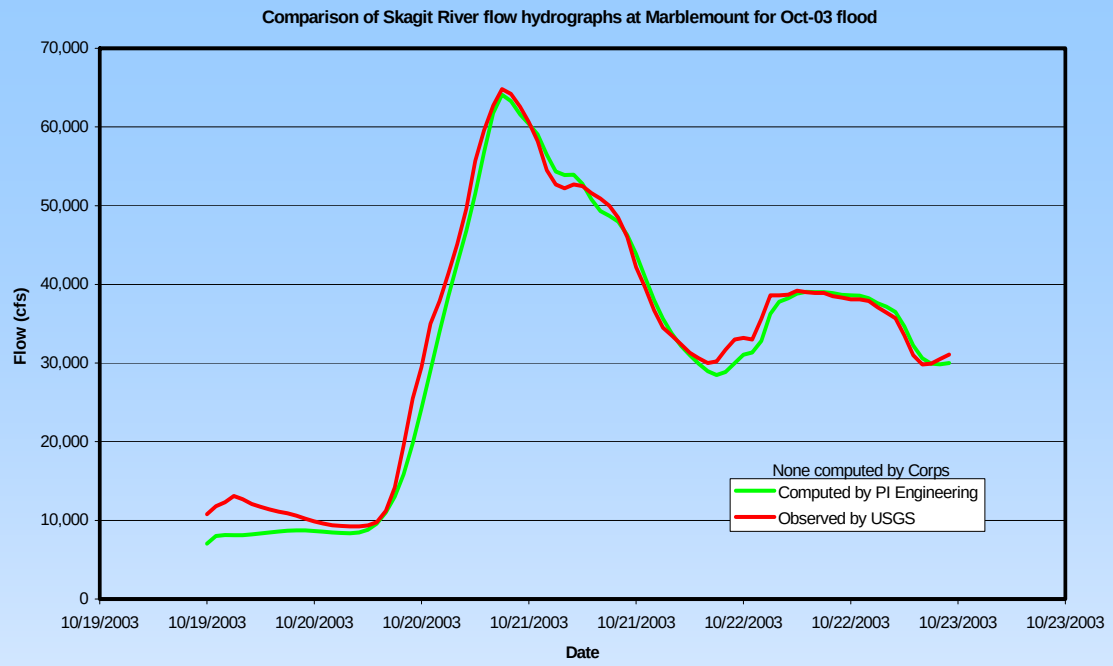

Comparison of Skagit River stage hydrographs at Marblemount for Nov-95 flood
320
319
318
317
316
315
314
313
312
311
Stage (feet)
Computed by Corps
Computed by PI Engineering
Observed by USGS
11/27/1995
11/28/1995
11/29/1995
11/30/1995
12/1/1995
12/2/1995
12/3/1995
12/4/1995
Date

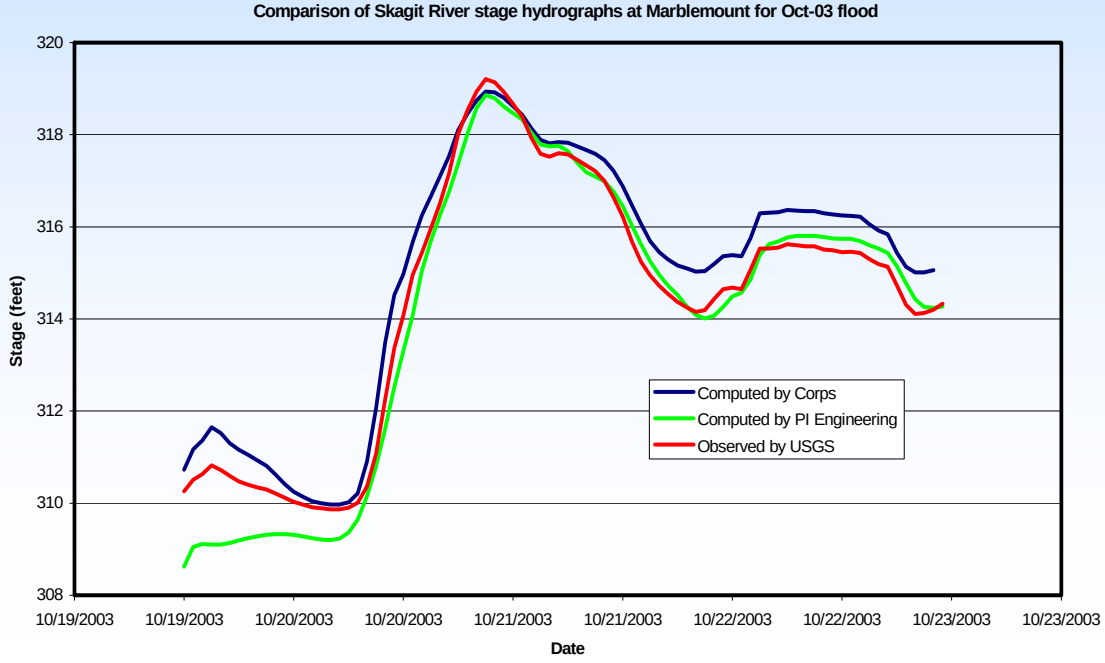

Comparison of Skagit River flow hydrographs at Mount Vernon for Oct-03 flood
160,015
140,015
120,015
100,015
80,015
60,015
40,015
20,015
15
Flow (cfs)
10/19/2003
10/19/2003
10/20/2003
10/20/2003
10/21/2003
10/21/2003
10/22/2003
10/22/2003
10/23/2003
10/23/2003
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

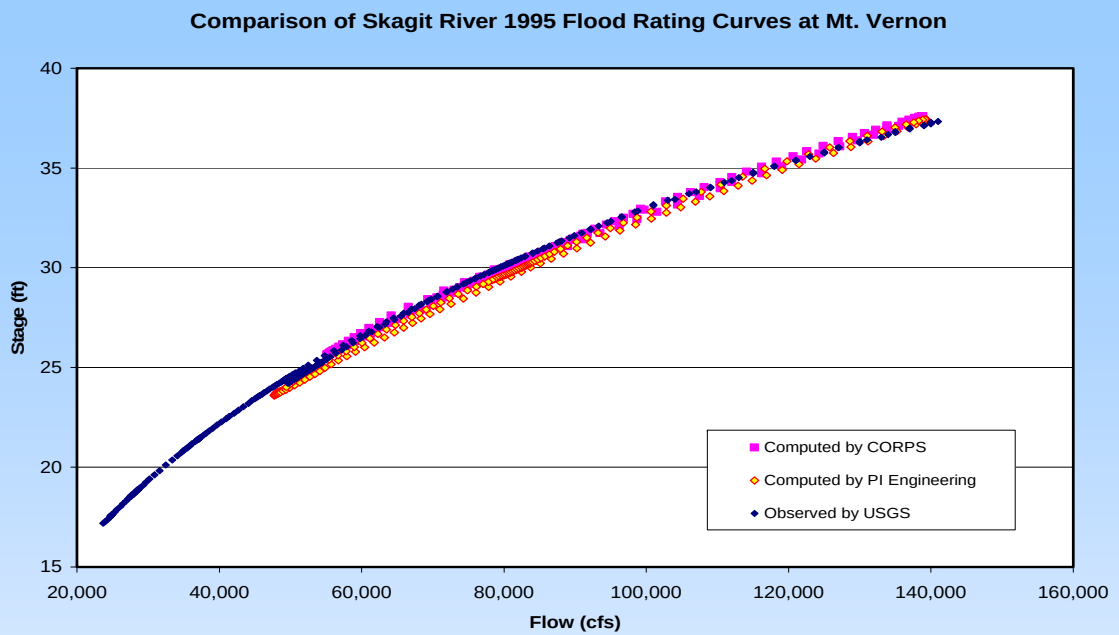

Comparison of Skagit River stage hydrographs at Mount Vernon for Oct-03 flood
40
35
30
25
20
15
Stage (feet)
10/19/2003
10/19/2003
10/20/2003
10/20/2003
10/21/2003
10/21/2003
10/22/2003
10/22/2003
10/23/2003
10/23/2003
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

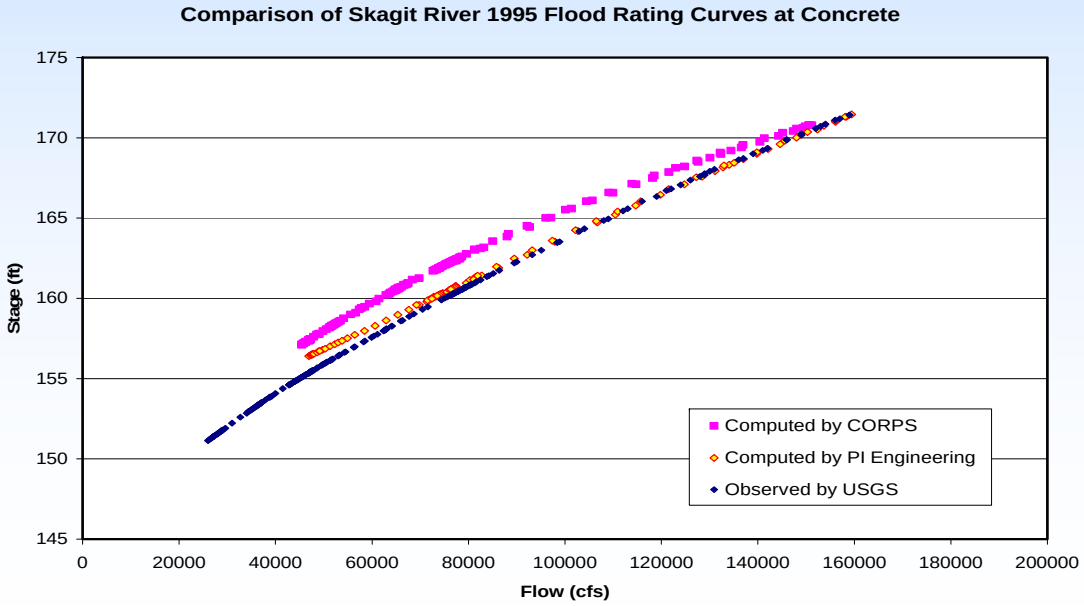

Comparison of Skagit River flow hydrographs at Concrete for Oct-03 flood
Flow (cfs)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
10/19/2003
10/19/2003
10/20/2003
10/20/2003
10/21/2003
10/21/2003
10/22/2003
10/22/2003
10/23/2003
10/23/2003
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

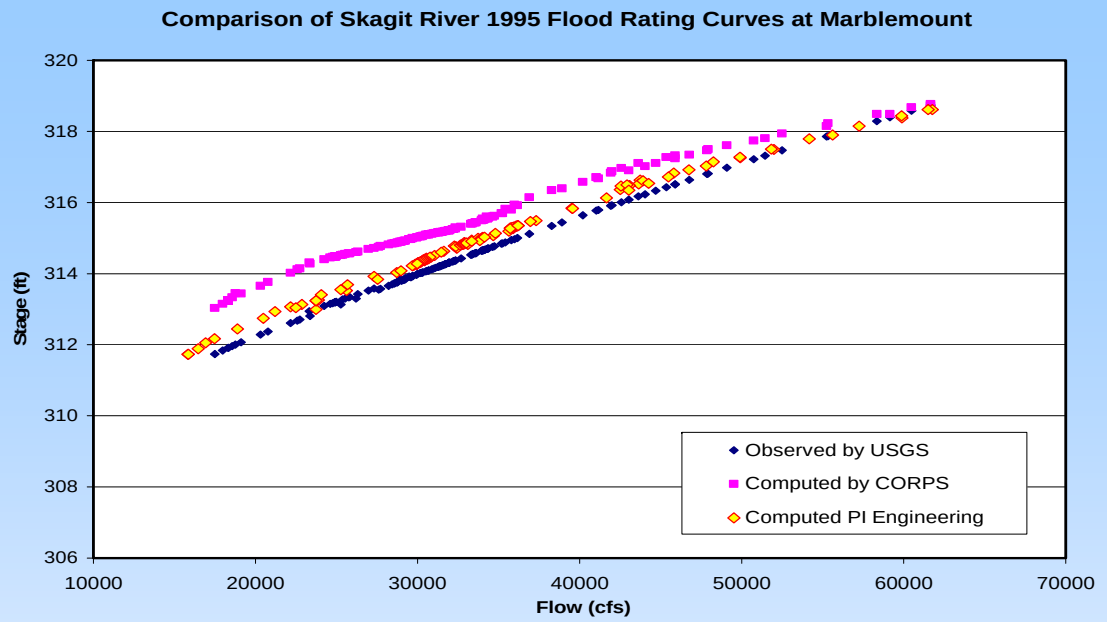

Comparison of Skagit River stage hydrographs at Concrete for Oct-03 flood
Stage (feet)
175
170
165
160
155
150
10/19/2003
10/19/2003
10/20/2003
10/20/2003
10/21/2003
10/21/2003
10/22/2003
10/22/2003
10/23/2003
10/23/2003
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

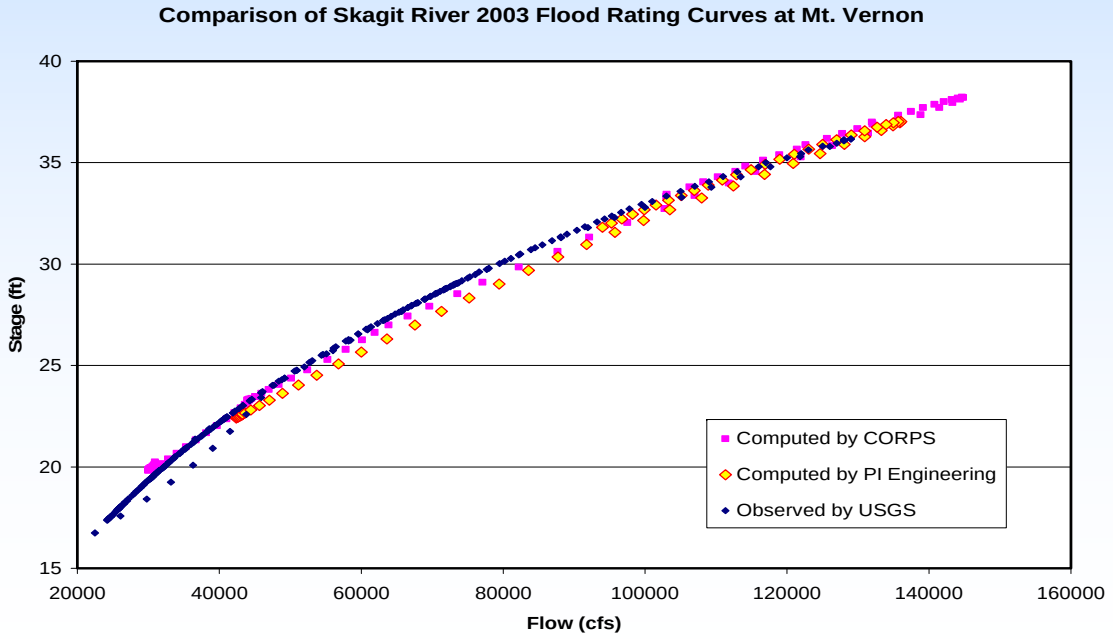

Comparison of Skagit River flow hydrographs at Marblemount for Oct-03 flood
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Flow (cfs)
10/19/2003
10/19/2003
10/20/2003
10/20/2003
10/21/2003
10/21/2003
10/22/2003
10/22/2003
10/23/2003
10/23/2003
Date
None computed by Corps
Computed by PI Engineering
Observed by USGS

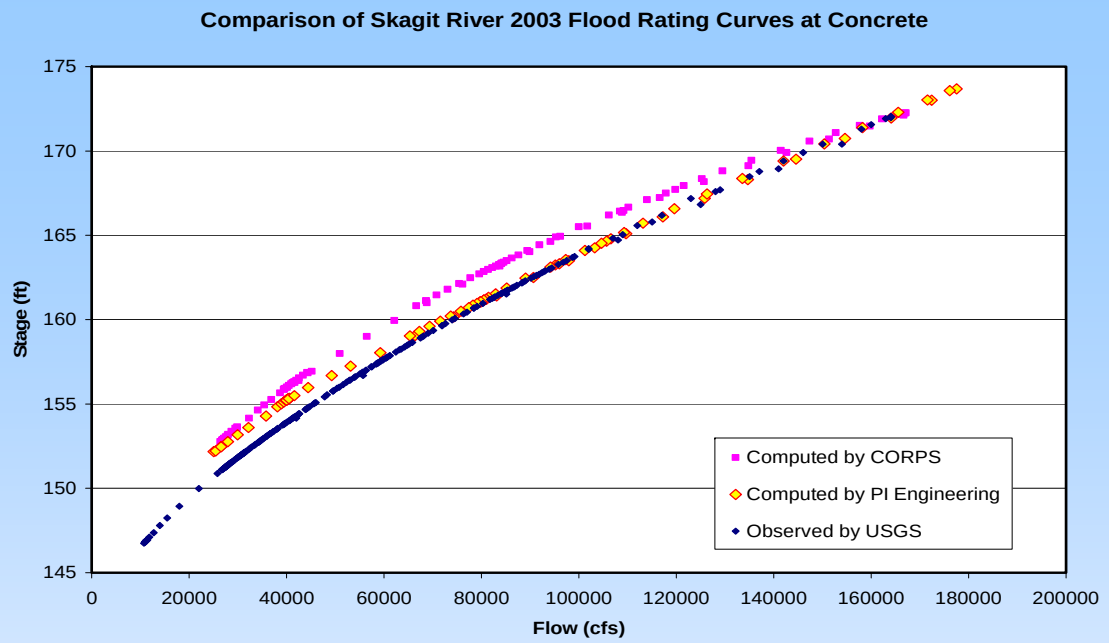

Comparison of Skagit River stage hydrographs at Marblemount for Oct-03 flood
320
318
316
314
312
310
308
Stage (feet)
10/19/2003
10/19/2003
10/20/2003
10/20/2003
10/21/2003
10/21/2003
10/22/2003
10/22/2003
10/23/2003
10/23/2003
Date
Computed by Corps
Computed by PI Engineering
Observed by USGS

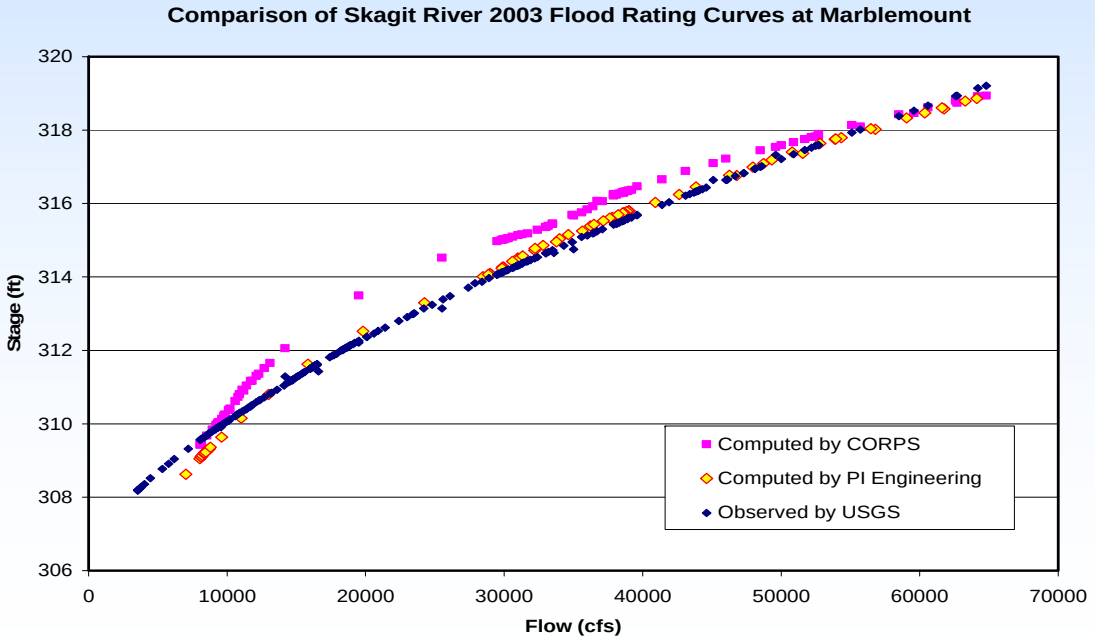

Comparison of Skagit River 1995 Flood Rating Curves at Mt. Vernon
Stage (ft)
40
35
30
25
20
15
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
Flow (cfs)
Computed by CORPS
Computed by PI Engineering
Observed by USGS


Comparison of Skagit River 1995 Flood Rating Curves at Concrete
Stage (ft)
175
170
165
160
155
150
145
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
200000
Flow (cfs)
Computed by CORPS
Computed by PI Engineering
Observed by USGS

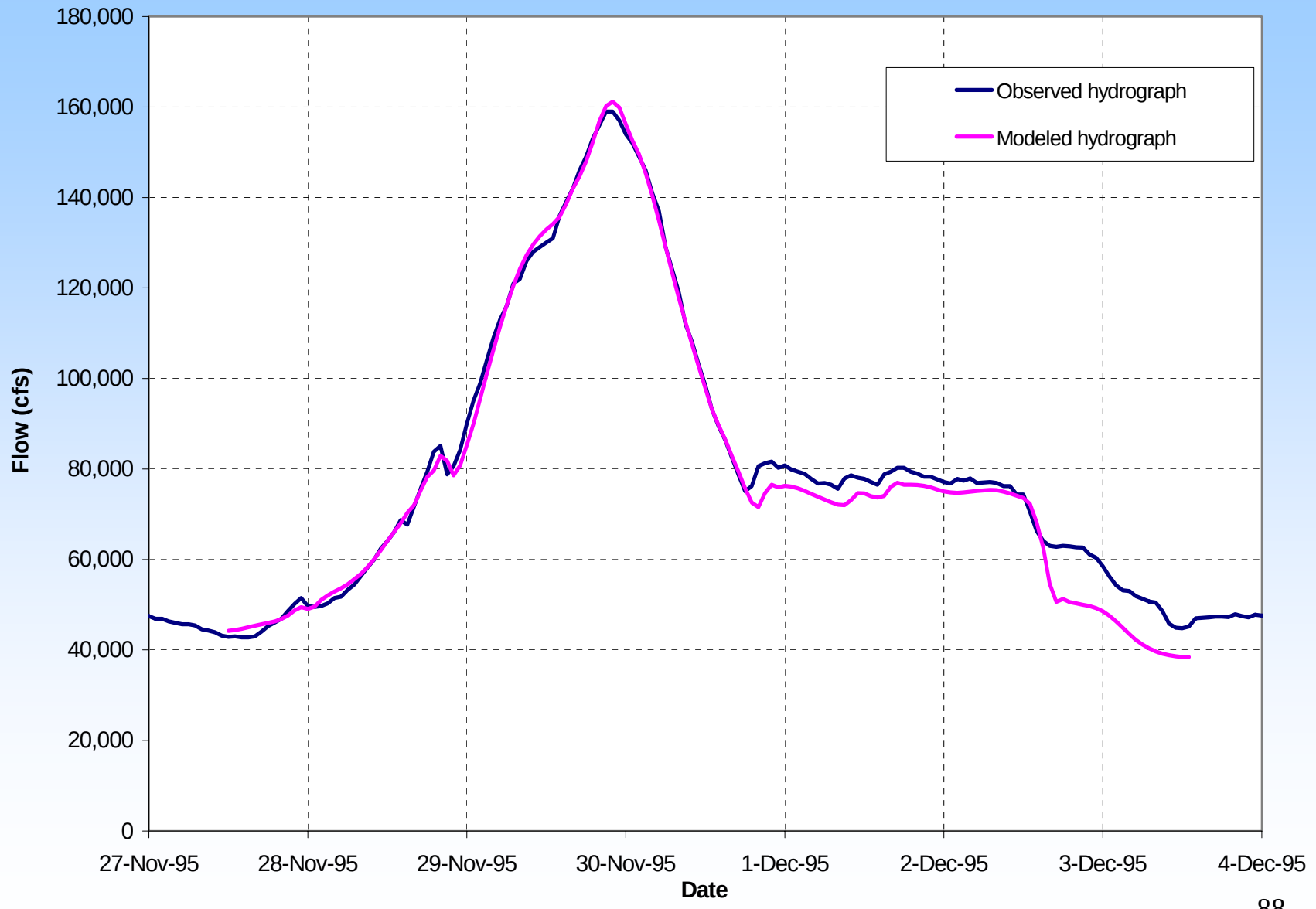

Comparison of Skagit River 1995 Flood Rating Curves at Marblemount
Stage (ft)
320
318
316
314
312
310
308
306
10000
20000
30000
40000
50000
60000
70000
Flow (cfs)
Observed by USGS
Computed by CORPS
Computed PI Engineering

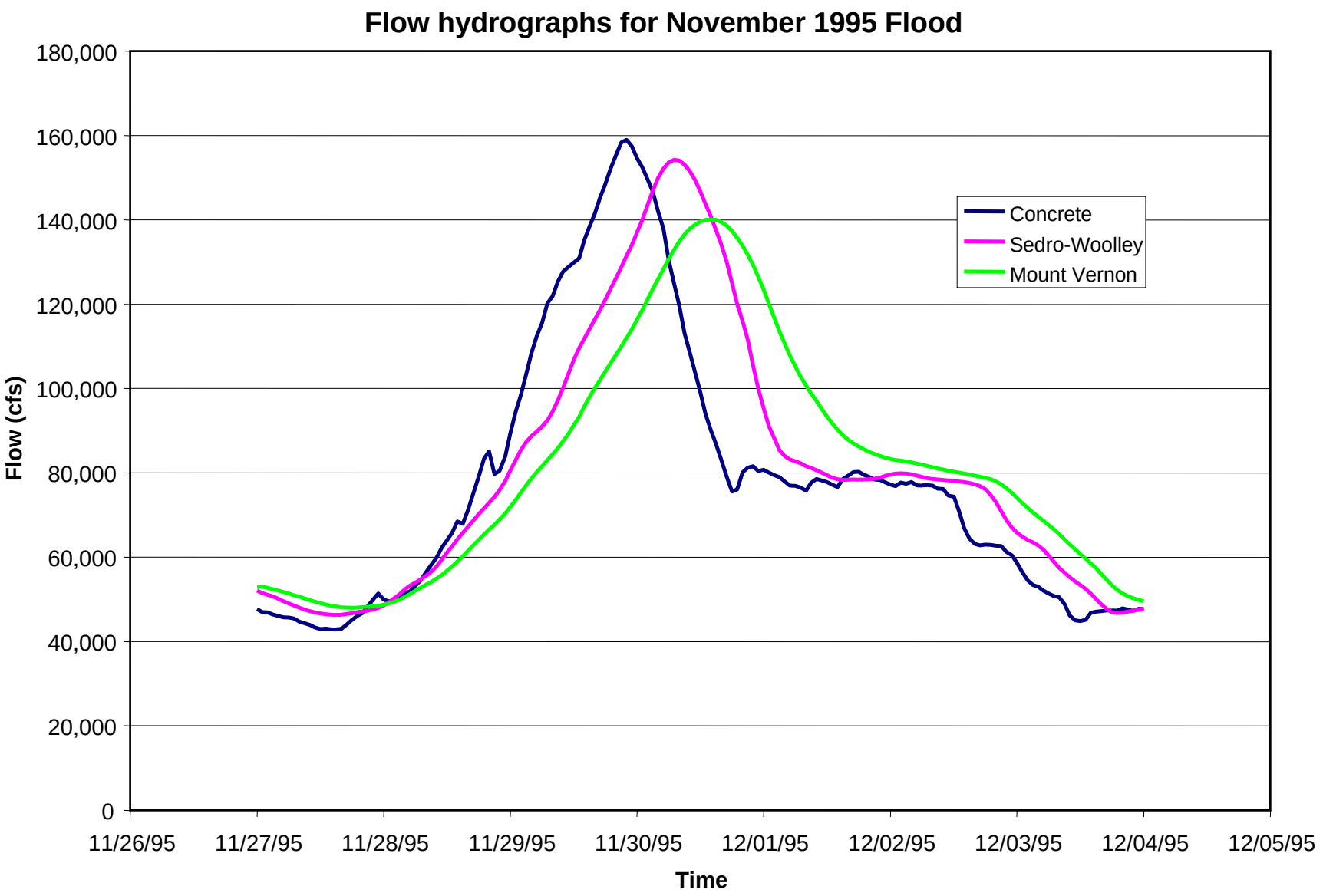

Comparison of Skagit River 2003 Flood Rating Curves at Mt. Vernon
Stage (ft)
40
35
30
25
20
15
20000
40000
60000
80000
100000
120000
140000
160000
Flow (cfs)
Computed by CORPS
Computed by PI Engineering
Observed by USGS

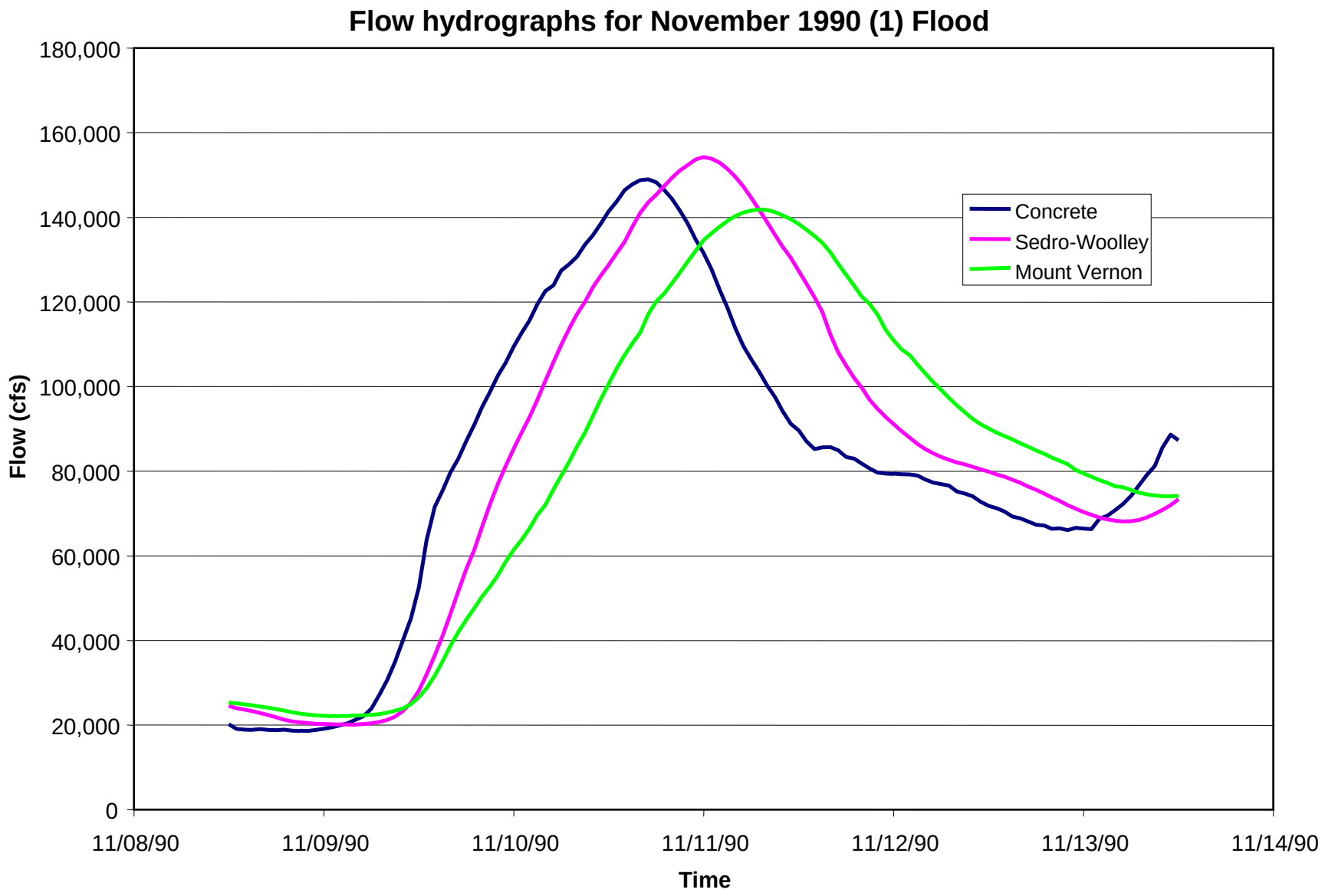

Comparison of Skagit River 2003 Flood Rating Curves at Concrete
Stage (ft)
175
170
165
160
155
150
145
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
200000
Flow (cfs)
Computed by CORPS
Computed by PI Engineering
Observed by USGS

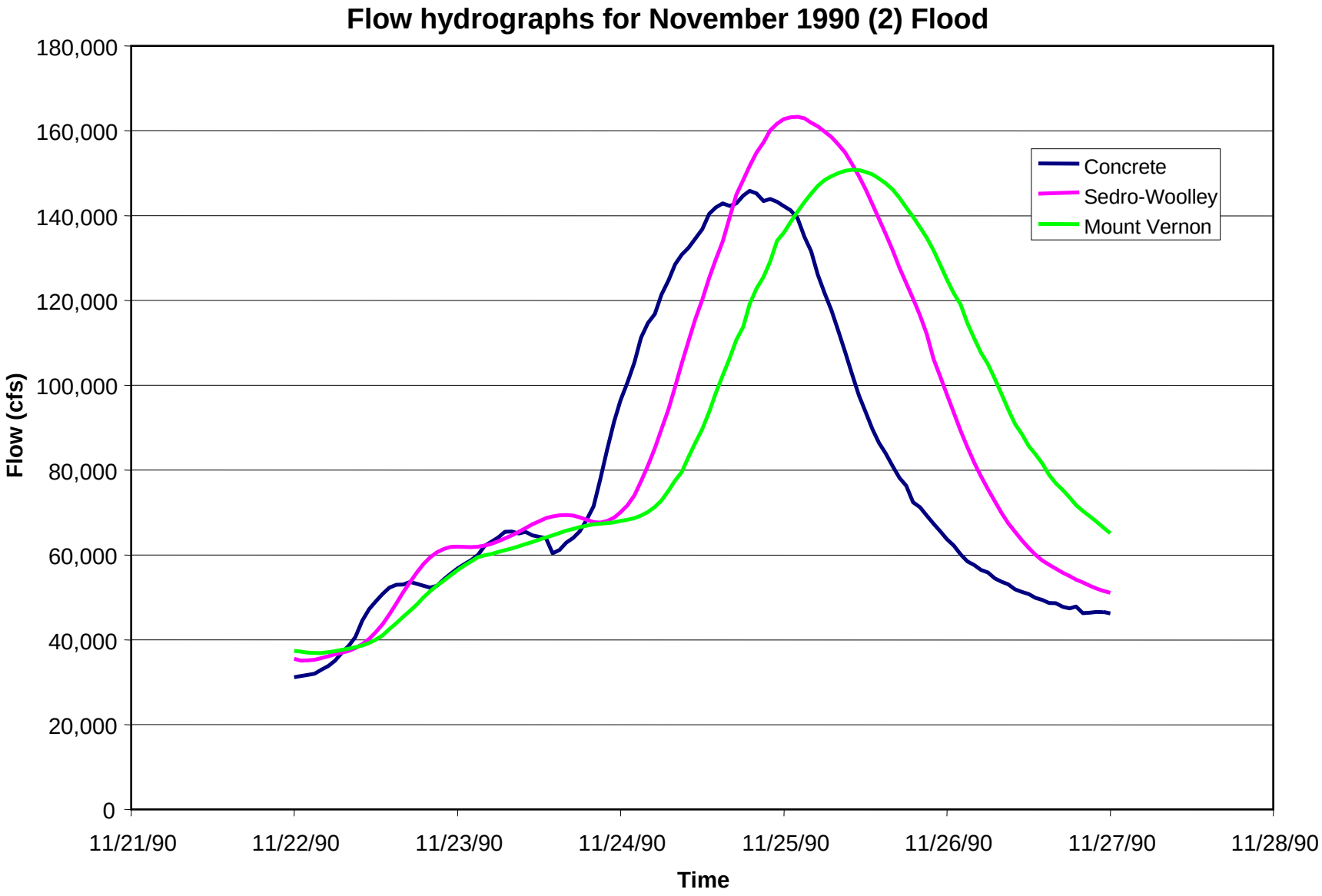

Comparison of Skagit River 2003 Flood Rating Curves at Marblemount
Stage (ft)
320
318
316
314
312
310
308
306
0
10000
20000
30000
40000
50000
60000
70000
Flow (cfs)
Computed by CORPS
Computed by PI Engineering
Observed by USGS

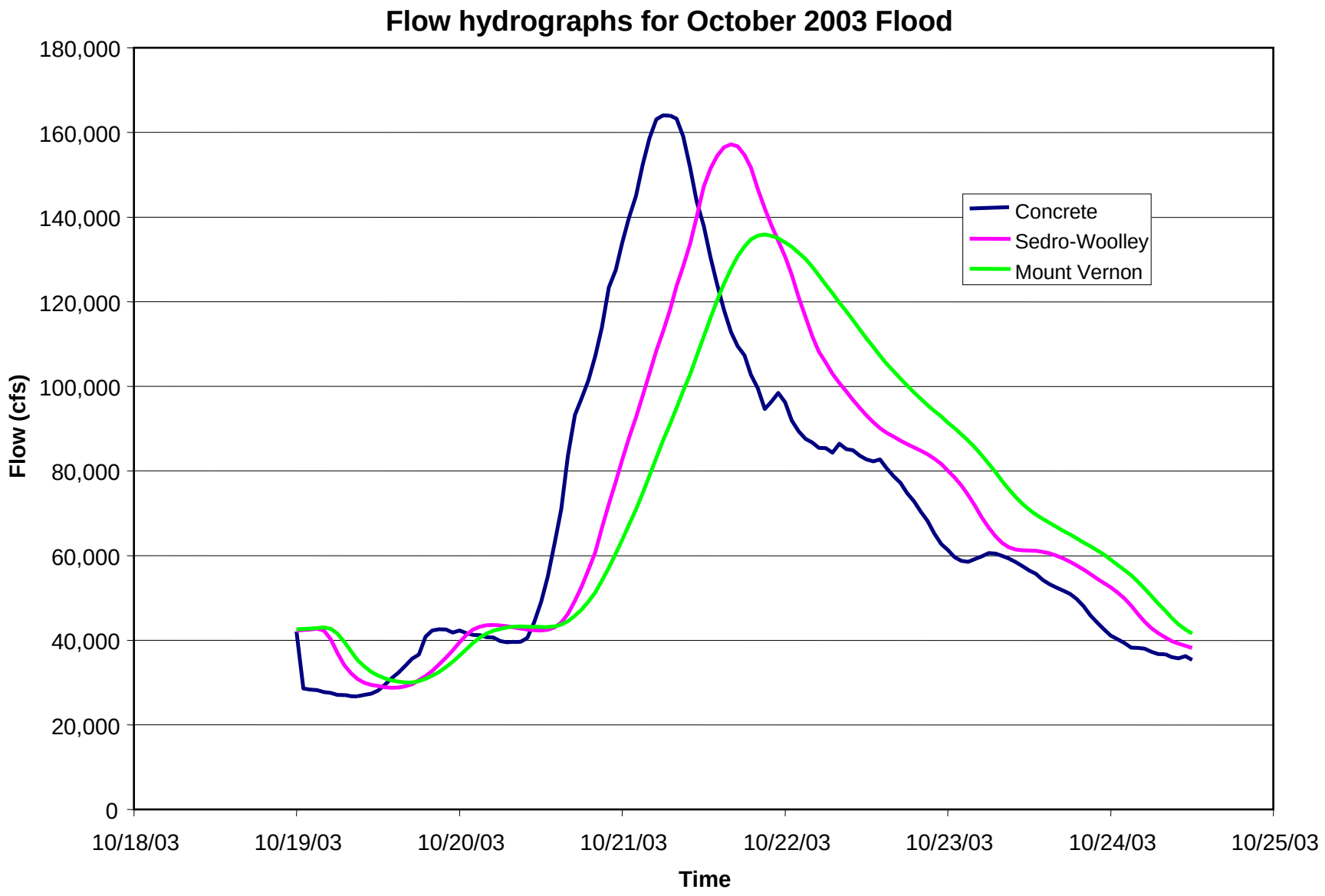
HEC-5 model calibration of 1995 flood hydrograph at Skagit River near Concrete




Flow hydrographs for November 1995 Flood
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
11/26/95
11/27/95
11/28/95
11/29/95
11/30/95
12/01/95
12/02/95
12/03/95
12/04/95
12/05/95
Time
Concrete
Sedro-Woolley
Mount Vernon


Flow hydrographs for November 1990 (1) Flood
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
11/08/90
11/09/90
11/10/90
11/11/90
11/12/90
11/13/90
11/14/90
Time
Concrete
Sedro-Woolley
Mount Vernon


Flow hydrographs for November 1990 (2) Flood
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
11/21/90
11/22/90
11/23/90
11/24/90
11/25/90
11/26/90
11/27/90
11/28/90
Time
Concrete
Sedro-Woolley
Mount Vernon


Flow hydrographs for October 2003 Flood
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
10/18/03
10/19/03
10/20/03
10/21/03
10/22/03
10/23/03
10/24/03
10/25/03
Time
Concrete
Sedro-Woolley
Mount Vernon