SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

April 2014
Board of Consultants Meeting (#4)

Draft PMF Study

ALASKA ENERGY AUTHORITY

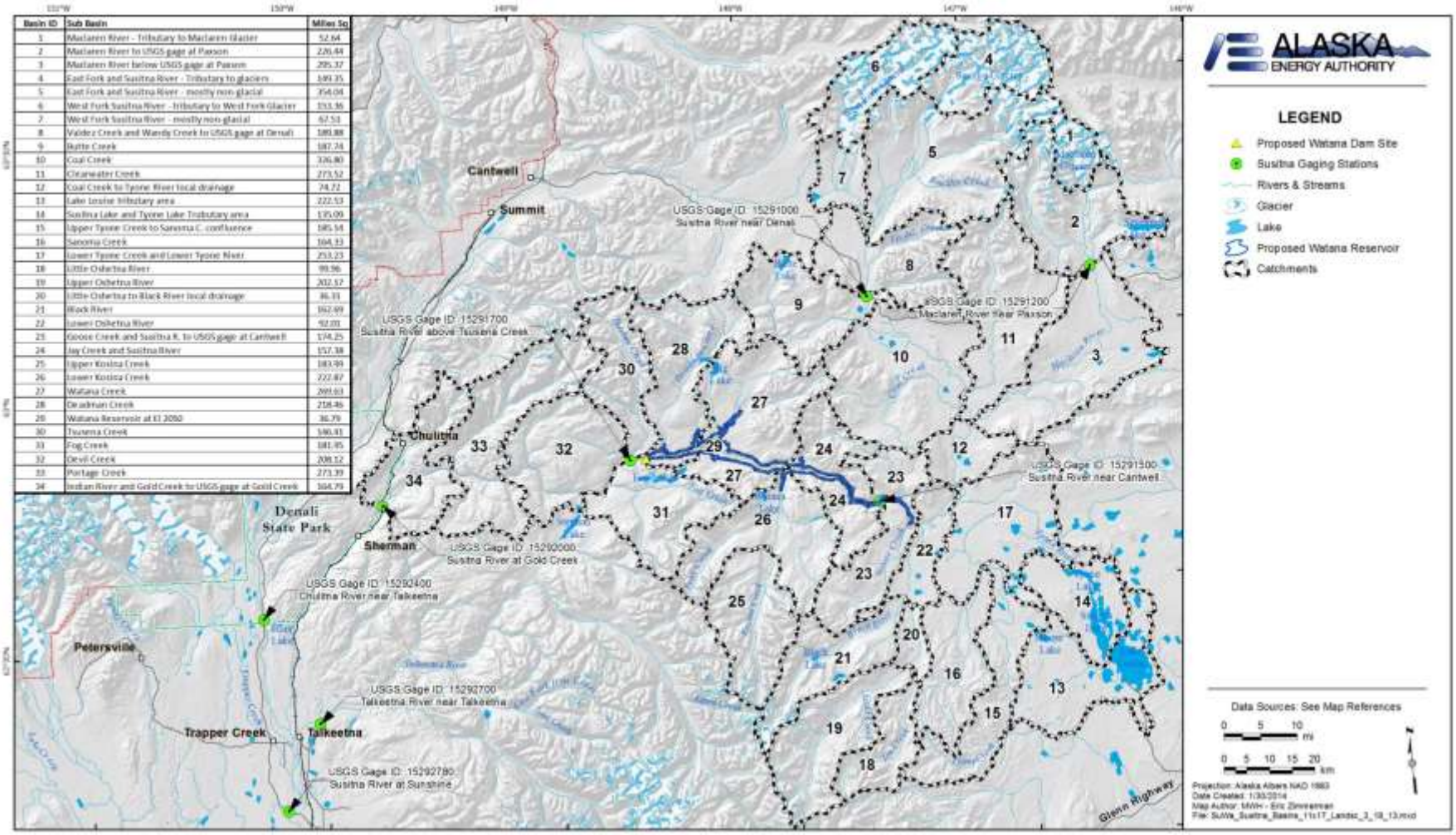
PMF Study Presentation Outline

- Review of previous PMF Study presentations
- Snowpack – 100-year; probable maximum
- Field trip – May-June Flood Analysis
- Calibration and verification
  - Summer floods
  - Spring floods
- Unit hydrograph parameters
- Losses
- PMP summary
- Intermediate flood routing and freeboard
- PMF cases
- Spillway sizing
- Sensitivity analysis
- Comparison to previous studies

Rainfall – Runoff Model Selection

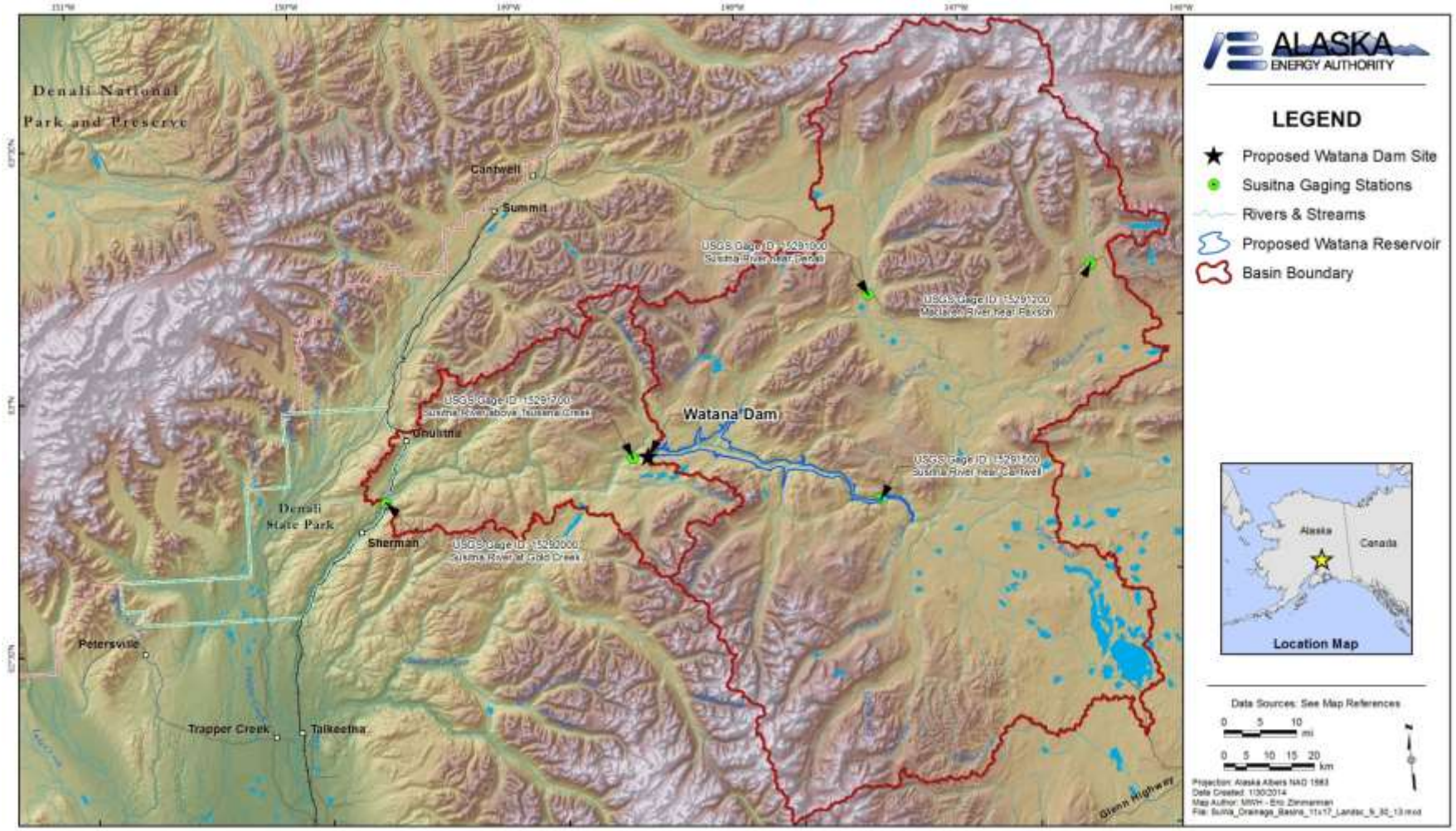
- Considered SSARR – Streamflow Synthesis and Reservoir Routing
  - Used in the 1982 Acres Study
  - No longer supported or in common use
- Considered HEC-HMS Hydrologic Modeling System
  - Windows successor to HEC-1
  - Poorly documented snowmelt methodology
- Selected HEC-1 Flood Hydrograph Package
  - Only model to include the recommended energy budget snowmelt methodology
  - Wealth of experience
  - Used in the 1984 Harza-Ebasco Susitna PMF

Sub-Basin Boundaries

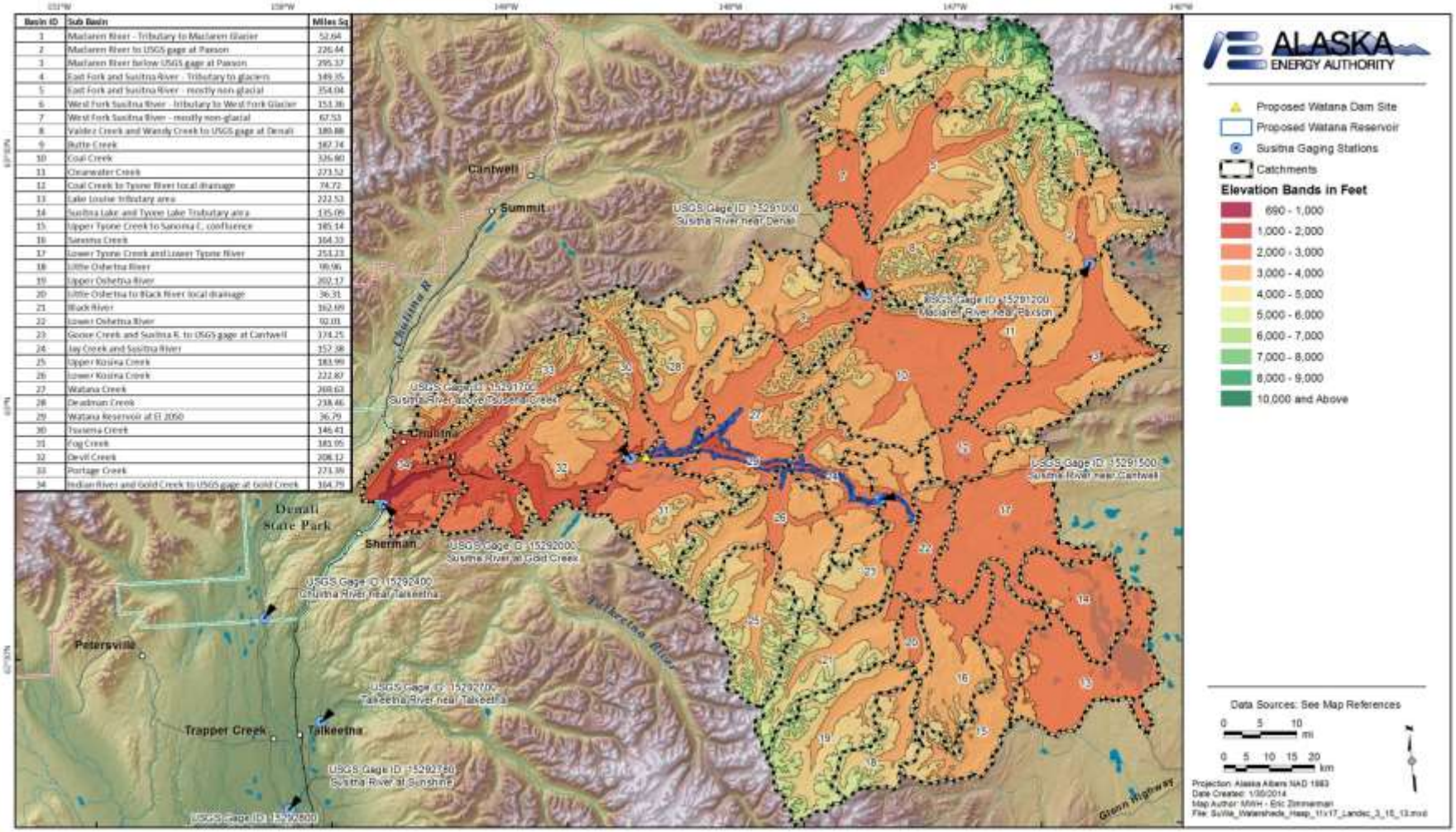


Basin ID	Sub Basin	Miles Sq
1	Maclaren River - Tributary to Maclaren Glacier	52.64
2	Maclaren River to USGS gage at Paxson	226.44
3	Maclaren River below USGS gage at Paxson	295.37
4	East Fork and Susitna River - Tributary to glaciers	349.35
5	East Fork and Susitna River - mostly non-glacial	354.04
6	West Fork Susitna River - tributary to West Fork Glacier	153.36
7	West Fork Susitna River - mostly non-glacial	62.53
8	Valdez Creek and Waverly Creek to USGS gage at Denali	189.88
9	Butte Creek	187.74
10	Coal Creek	326.80
11	Clearwater Creek	273.52
12	Coal Creek to Tyone River local drainage	74.72
13	Lake Louise tributary area	222.53
14	Susitna Lake and Tyone Lake Tributary area	135.09
15	Upper Tyone Creek to Sanoma C. confluence	185.54
16	Sanoma Creek	164.33
17	Lower Tyone Creek and Lower Tyone River	253.23
18	Little Oshetna River	99.96
19	Upper Oshetna River	202.57
20	Little Oshetna to Black River local drainage	86.33
21	Black River	162.99
22	Lower Oshetna River	92.03
23	Goose Creek and Susitna R. to USGS gage at Cantwell	174.25
24	Jay Creek and Susitna River	157.38
25	Upper Kosina Creek	183.99
26	Lower Kosina Creek	222.87
27	Watana Creek	269.63
28	Deadman Creek	258.46
29	Watana Reservoir at El 2050	86.79
30	Tsusena Creek	140.81
31	Fog Creek	181.95
32	Devil Creek	208.12
33	Portage Creek	273.39
34	Indian River and Gold Creek to USGS gage at Gold Creek	164.79

Susitna Watershed – Rivers and USGS Gage Locations



1,000- foot Elevation Bands



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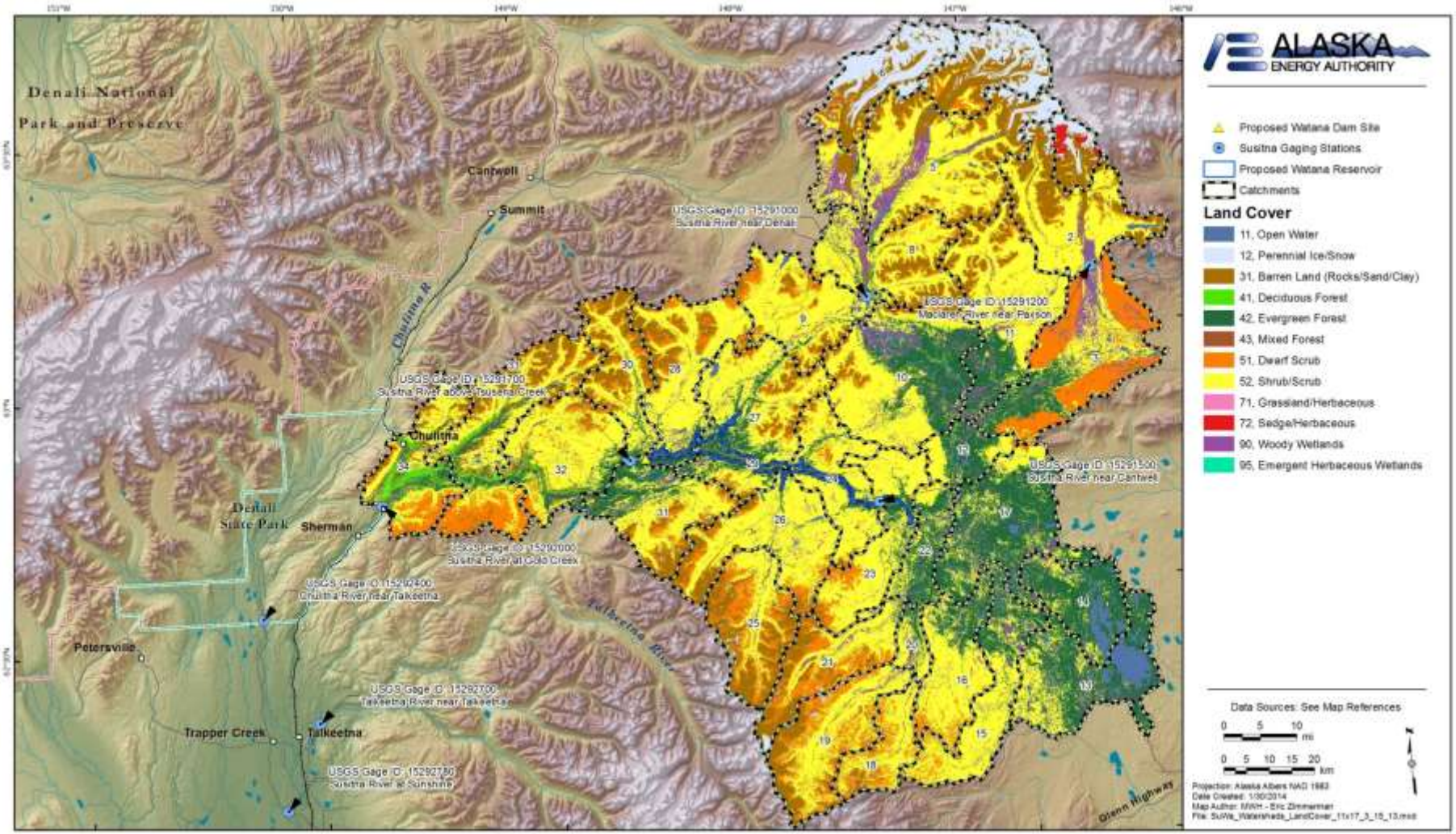
5	East Fork and Susitna River - mostly non-glacial	354.04
6	West Fork Susitna River - Tributary to West Fork Glacier	153.36
7	West Fork Susitna River - mostly non-glacial	67.53
8	Valdez Creek and Wandy Creek to USGS gage at Denali	180.88
9	Butte Creek	182.74
10	Coal Creek	326.90
11	Clearwater Creek	273.52
12	Coal Creek to Tyone River local drainage	74.72
13	Lake Louise tributary area	222.53
14	Susitna Lake and Tyone Lake Tributary area	135.09
15	Upper Tyone Creek to Sanorna C. confluence	185.14
16	Sanorna Creek	164.33
17	Lower Tyone Creek and Lower Tyone River	253.23
18	Little Oshetna River	99.96
19	Upper Oshetna River	202.17
20	Little Oshetna to Black River local drainage	96.31
21	Black River	162.69
22	Lower Oshetna River	92.01
23	Goose Creek and Susitna R. to USGS gage at Cantwell	174.25
24	Jay Creek and Susitna River	152.58
25	Upper Kosina Creek	183.99
26	Lower Kosina Creek	222.87
27	Watana Creek	269.63
28	Deadman Creek	238.46
29	Watana Reservoir at El 2050	36.79
30	Tsusena Creek	146.41
31	Fog Creek	183.05
32	Devil Creek	208.12
33	Portage Creek	273.36
34	Indian River and Gold Creek to USGS gage at Gold Creek	164.79

Area in Elevation Bands to Watana Dam

Basin No.	Area in Elevation Bands (sq.mi.) for Model with Reservoir												% of Total
	1-2000	2-3000	3-4000	4-5000	5-6000	6-7000	7-8000	8-9000	9-10000	10-11000	11-14000	Total	
1	0.0	0.0	8.7	19.7	8.9	11.3	3.9	0.2	0.0	0.0	0.0	52.7	1.02%
2	0.0	16.4	105.6	65.3	32.3	7.0	0.4	0.0	0.0	0.0	0.0	226.9	4.39%
3	0.0	145.7	139.5	9.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	295.2	5.71%
4	0.0	3.5	18.2	28.5	34.4	32.5	17.1	9.2	3.8	1.4	0.8	149.4	2.89%
5	0.0	90.7	93.0	99.8	48.5	18.5	3.6	0.0	0.0	0.0	0.0	354.2	6.85%
6	0.0	3.6	23.1	39.8	37.0	29.8	14.0	3.4	1.5	0.9	0.4	153.4	2.97%
7	0.0	55.2	9.4	2.1	0.8	0.0	0.0	0.0	0.0	0.0	0.0	67.5	1.31%
8	0.0	54.3	60.4	59.5	15.8	0.1	0.0	0.0	0.0	0.0	0.0	190.1	3.68%
9	0.0	38.5	91.3	52.5	5.3	0.0	0.0	0.0	0.0	0.0	0.0	187.6	3.63%
10	0.0	180.0	113.2	28.1	5.5	0.0	0.0	0.0	0.0	0.0	0.0	326.9	6.32%
11	0.0	72.4	130.2	57.0	13.7	0.4	0.0	0.0	0.0	0.0	0.0	273.6	5.29%
12	0.0	48.7	23.7	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.7	1.45%
13	0.0	202.6	20.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	222.6	4.30%
14	0.0	131.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	135.2	2.61%
15	0.0	68.0	87.9	29.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	185.2	3.58%
16	0.0	41.6	100.5	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	164.4	3.18%
17	0.0	223.2	27.3	2.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	253.3	4.90%
18	0.0	0.1	28.7	48.2	21.2	1.8	0.0	0.0	0.0	0.0	0.0	100.0	1.93%
19	0.0	0.6	45.9	77.9	62.9	14.4	0.5	0.0	0.0	0.0	0.0	202.2	3.91%
20	0.0	16.5	19.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.3	0.70%
21	0.0	7.2	48.4	52.3	42.3	11.6	1.0	0.0	0.0	0.0	0.0	162.7	3.15%
22	0.0	76.3	14.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	92.0	1.78%
23	0.0	41.0	88.7	35.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0	168.9	3.27%
24	0.0	51.6	89.5	20.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	162.8	3.15%
25	0.0	5.3	42.0	72.4	54.0	10.2	0.1	0.0	0.0	0.0	0.0	184.0	3.56%
26	0.0	37.1	115.5	51.0	17.2	2.1	0.0	0.0	0.0	0.0	0.0	222.9	4.31%
27	0.0	141.0	92.5	33.3	2.8	0.1	0.0	0.0	0.0	0.0	0.0	269.6	5.21%
28	0.0	62.2	88.5	61.7	8.8	0.0	0.0	0.0	0.0	0.0	0.0	221.1	4.28%
29	0.0	36.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.8	0.71%
Total	0.0	1851.4	1729.1	972.2	417.6	139.8	40.6	12.8	5.3	2.3	1.3	5172.3	100.00%
	0.00%	35.79%	33.43%	18.80%	8.07%	2.70%	0.78%	0.25%	0.10%	0.04%	0.02%	100.00%	

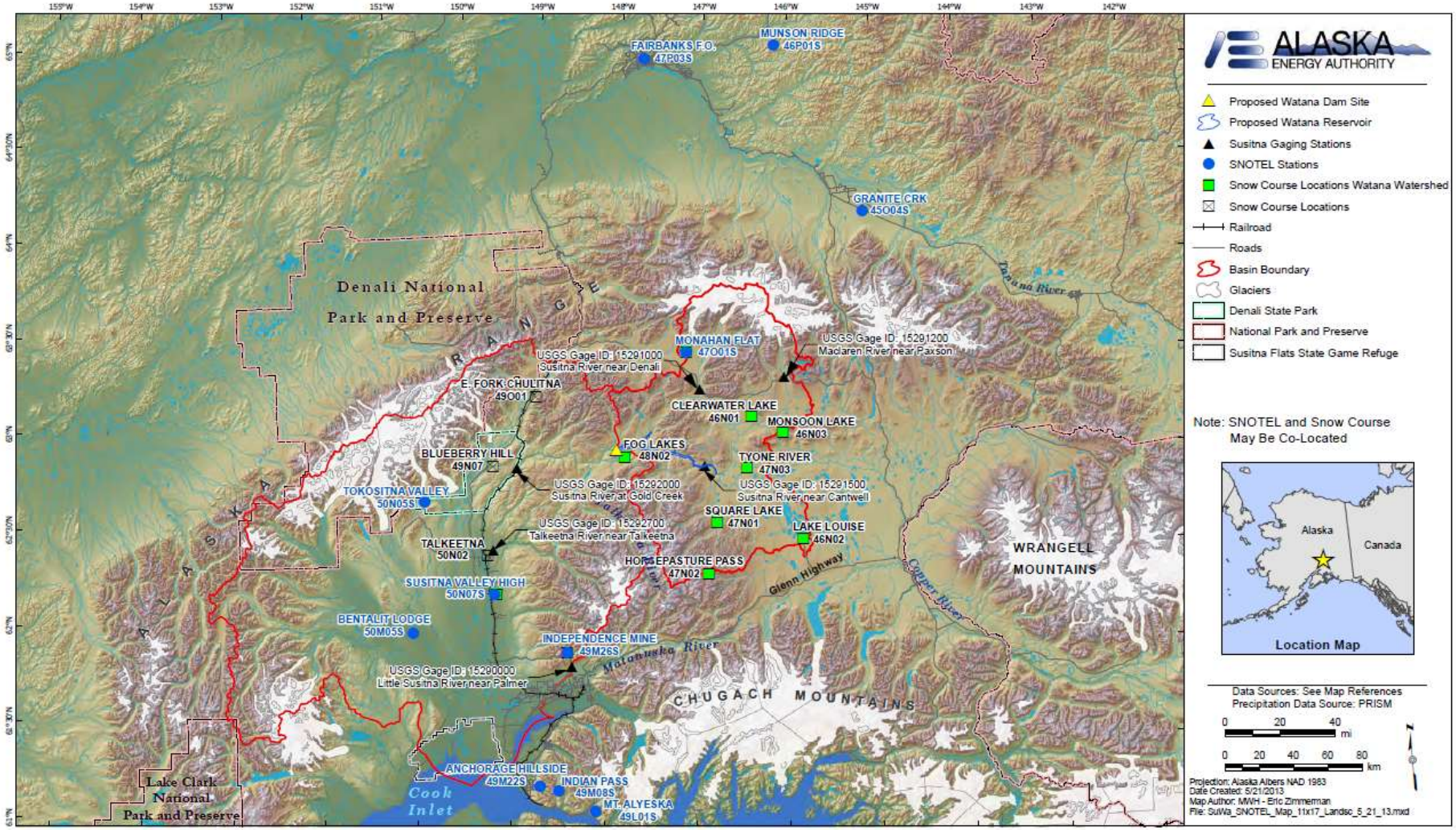
Watershed Cover Map



Watershed Cover Distribution

Code	To Gold Creek without Reservoir Description	Area (sq. mi.)	% of Total
52	Shrub/Scrub	2784.0	45.3%
42	Evergreen Forest	996.4	16.2%
31	Barren Land (Rocks/Sand/Clay)	925.9	15.1%
51	Dwarf Scrub	652.9	10.6%
90	Woody Wetlands	238.9	3.9%
12	Perennial Ice/Snow	234.3	3.8%
11	Open Water	180.3	2.9%
43	Mixed Forest	56.4	0.9%
41	Deciduous Forest	54.2	0.9%
72	Sedge/Herbaceous	14.6	0.2%
95	Emergent Herbaceous Wetlands	2.9	0.0%
22	Developed, Low Intensity	1.7	0.0%
71	Grassland/Herbaceous	1.6	0.0%
21	Developed, Open Space	0.1	0.0%
23	Developed, Medium Intensity	0.01	0.0%
	Total	6144.1	100.0%

Susitna Watershed – Snow Data



Stream Gage, SNOTEL and Snow Course Site Locations

Snowpack Development

100-Year Snowpack Requirements

- Spatial (sub-basin) distribution
- Elevation distribution (1,000-foot elevation bands)
- Seasonal (monthly) distribution

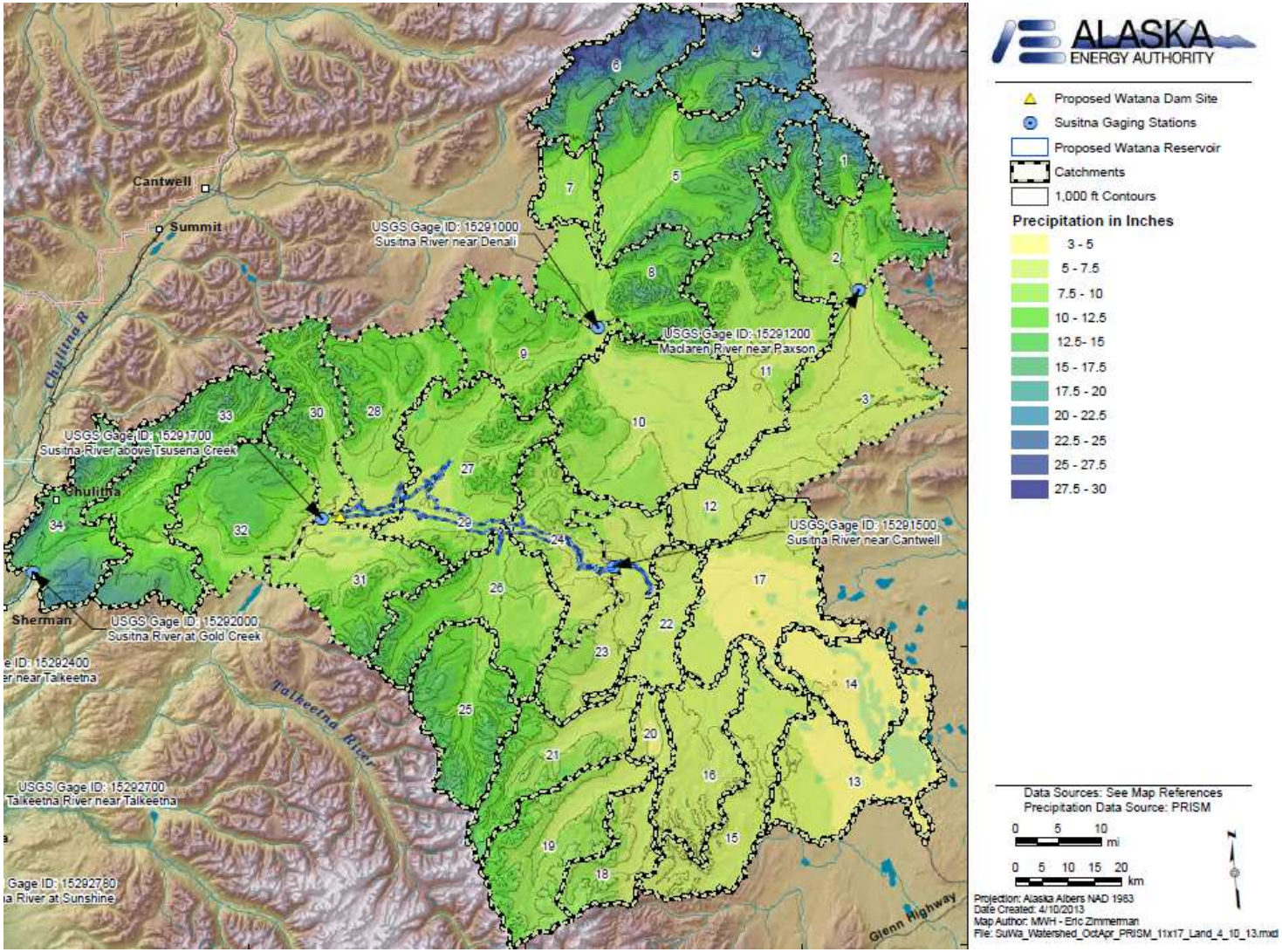
100-Year Snowpack Development

- Use historic snow course and SNOTEL data
- Combine historic SWE data as an index and October-April total precipitation map – similar to HMR 42, PMF for Yukon River
- 100-year is 1.68 times the Oct thru April average precipitation

Probable Maximum Snowpack Development with 100-Year Rain

- Probable maximum snowpack method from HMR 42 – 3.0 times the October-April total precipitation

October - April Average Precipitation



Monthly and Seasonal Precipitation by Sub-Basin

Sub-Basin Number	Basin Area (sq.mi.)	Average Precipitation (inches)														Oct-Apr % of Year
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Oct-Apr	
1	52.6	1.73	2.61	2.07	1.54	1.67	3.46	4.36	5.85	5.61	4.32	2.01	2.64	37.88	16.92	44.7%
2	226.4	1.26	1.79	1.40	1.11	1.34	2.86	3.75	4.60	4.15	3.30	1.44	1.95	28.94	12.24	42.3%
3	295.4	0.81	0.71	0.61	0.59	1.10	2.34	2.93	2.85	2.19	1.92	0.84	1.18	18.08	6.66	36.8%
4	149.3	2.38	2.73	2.49	1.60	1.76	3.72	4.84	6.29	5.83	4.44	2.43	3.14	41.66	19.22	46.1%
5	354.0	1.61	1.97	1.55	1.14	1.37	3.04	4.10	4.73	4.21	3.29	1.62	2.26	30.91	13.45	43.5%
6	153.4	2.67	2.60	2.21	1.65	1.62	3.83	5.39	6.31	5.79	4.68	2.33	3.74	42.84	19.90	46.4%
7	67.5	1.43	1.24	0.92	0.81	1.11	2.93	3.98	3.59	2.78	2.35	1.14	1.65	23.93	9.54	39.9%
8	189.9	1.35	1.67	1.29	1.01	1.28	2.87	3.85	4.35	3.85	2.96	1.41	1.88	27.76	11.57	41.7%
9	187.7	1.42	1.32	1.00	0.97	1.30	3.11	4.20	4.24	3.57	2.75	1.34	1.72	26.93	10.50	39.0%
10	326.8	0.94	0.97	0.72	0.76	1.13	2.35	3.24	3.70	2.94	2.36	0.90	1.31	21.31	7.96	37.3%
11	273.5	1.02	1.06	0.87	0.84	1.17	2.57	3.33	3.71	3.18	2.62	1.07	1.47	22.91	8.95	39.1%
12	74.7	0.69	0.57	0.54	0.51	1.08	2.28	2.86	2.69	2.01	1.61	0.79	1.12	16.76	5.84	34.9%
13	222.5	0.54	0.45	0.44	0.32	1.04	2.31	2.68	1.82	1.55	1.22	0.77	1.05	14.20	4.79	33.7%
14	135.1	0.47	0.41	0.38	0.26	1.06	2.34	2.70	1.75	1.64	1.25	0.66	0.90	13.81	4.32	31.3%
15	185.1	0.61	0.56	0.60	0.44	1.14	2.48	2.94	2.18	1.68	1.32	0.95	1.28	16.17	5.75	35.6%
16	164.3	0.60	0.50	0.58	0.51	1.18	2.53	3.02	2.36	1.85	1.44	0.95	1.30	16.83	5.88	34.9%
17	253.2	0.57	0.47	0.51	0.35	1.05	2.24	2.71	2.17	1.71	1.32	0.79	1.08	14.97	5.09	34.0%
18	100.0	0.69	1.00	0.89	0.75	1.45	3.01	3.57	2.92	2.35	1.75	1.03	1.40	20.81	7.52	36.1%
19	202.2	0.77	1.01	0.91	1.15	1.99	3.30	3.84	3.35	3.19	2.33	1.12	1.55	24.52	8.85	36.1%
20	36.3	0.52	0.46	0.47	0.63	1.26	2.49	3.03	2.72	2.21	1.58	0.76	1.04	17.15	5.45	31.8%
21	162.7	0.79	0.81	0.78	1.29	1.87	2.94	3.84	3.71	4.08	2.70	1.21	1.57	25.59	9.15	35.8%
22	92.0	0.56	0.46	0.49	0.54	1.05	2.24	2.83	2.73	2.05	1.59	0.77	1.08	16.40	5.50	33.6%
23	174.2	0.67	0.58	0.57	0.86	1.39	2.57	3.34	3.57	3.02	2.21	0.90	1.22	20.91	7.02	33.6%
24	157.4	0.86	0.75	0.63	0.85	1.23	2.48	3.45	3.86	3.04	2.46	0.99	1.28	21.89	7.84	35.8%
25	184.0	1.16	1.02	0.80	1.66	1.76	3.50	4.72	5.59	5.76	3.96	1.72	1.92	33.57	12.24	36.5%
26	222.9	1.02	0.92	0.75	1.32	1.40	2.99	4.35	4.72	4.06	3.07	1.46	1.60	27.67	10.14	36.6%
27	269.6	1.08	1.04	0.84	0.94	1.18	2.62	3.66	4.00	3.19	2.28	1.39	1.42	23.63	8.99	38.0%
28	218.5	1.20	1.23	1.03	0.99	1.22	2.89	4.05	4.44	3.71	2.15	1.78	1.66	26.35	10.04	38.1%
29	36.8	0.76	0.73	0.60	0.75	0.99	2.19	2.99	3.25	2.58	1.78	1.03	1.06	18.70	6.71	35.9%
30	146.4	1.32	1.42	1.23	1.20	1.36	2.91	4.22	4.79	4.12	2.19	2.16	1.88	28.78	11.40	39.6%
31	181.9	1.03	1.08	0.87	1.29	1.30	3.05	4.05	4.77	4.14	2.27	1.64	1.37	26.87	9.55	35.6%
32	208.1	1.02	1.48	1.39	1.53	1.52	2.86	3.85	4.69	4.10	1.75	2.59	1.72	28.49	11.47	40.3%
33	273.4	1.57	1.67	1.59	1.49	1.48	2.97	4.13	5.04	4.40	2.16	2.57	2.21	31.29	13.26	42.4%
34	164.8	2.07	1.98	1.87	1.48	1.21	3.04	4.57	6.27	5.45	3.69	2.28	2.69	36.60	16.06	43.9%
To Gold Creek Gage	6,143	1.11	1.17	1.01	0.99	1.32	2.80	3.70	3.97	3.45	2.46	1.40	1.67	25.04	9.80	39.1%
To Watana Dam	5,168	1.05	1.10	0.93	0.91	1.31	2.77	3.61	3.76	3.26	2.48	1.24	1.61	24.03	9.32	38.8%
To Denali Gage	914	1.85	2.08	1.71	1.25	1.44	3.24	4.37	5.09	4.56	3.57	1.79	2.53	33.50	14.79	44.2%
To Maclaren Gage	279	1.35	1.94	1.52	1.19	1.40	2.97	3.86	4.84	4.42	3.49	1.55	2.08	30.62	13.12	42.8%
To Cantwell Gage	4,079	1.05	1.13	0.96	0.85	1.30	2.74	3.51	3.58	3.10	2.42	1.17	1.62	23.44	9.20	39.3%

Note: Precipitation data is also available by 1,000-ft elevation band within each sub-basin

Snowpack Data Summary

Station Name	Station Number	Station Type	In Susitna R. Watershed (1)	Latitude (deg:min)	Longitude (deg:min)	Elevation (feet)	Maximum SWE (2)		Earliest Day (3) with Snowpack	Latest Day (3) with Snowpack	Years of Available Snowpack Data In the Period of Record
							(inches)	Date			
Anchorage Hillside	1070	SNOTEL	No	N 61:07	W 149:40	2,080	18.4	4/12/2012	10/6/2009	5/31/2012	8 years: 2006 - 2013
Bentalit Lodge	1086	SNOTEL	Yes	N 61:56	W 150:59	150	12.1	4/2/2012	10/10/2009	5/8/2008	8 years: 2006 - 2013
Fairbanks F.O.	1174	SNOTEL	No	N 64:51	W 147:48	450	11.2	4/26/1991	9/12/1992	5/20/2013	31 years: 1983 - 2013
Granite Creek	963	SNOTEL	No	N 63:57	W 145:24	1,240	7.7	4/16/1991	9/12/1992	5/14/2013	26 years: 1988 - 2013
Independence Mine	1091	SNOTEL	Border	N 61:48	W 149:17	3,550	23.5	5/17/2001	10/1/2002	6/13/2013	16 years: 1998 - 2013
Indian Pass	946	SNOTEL	No	N 61:04	W 149:29	2,350	40.1	5/13/2001	9/17/1992	6/27/1985	34 years: 1980 - 2013
Monohan Flat (4)	1094	SNOTEL	**Border**	N 63:18	W 147:39	2,710	N/A	N/A	10/4/2008	5/25/2013	6 years: 2008 - 2013
Mt. Alyeska	1103	SNOTEL	No	N 60:58	W 149:05	1,540	69.1	5/13/1998	10/1/1993	7/3/1980	40 years: 1973 - 2013
Munson Ridge	950	SNOTEL	No	N 64:51	W 146:13	3,100	18.4	4/15/1991	9/11/1992	6/2/1982	33 years: 1981 - 2013
Susitna Valley High	967	SNOTEL	Yes	N 62:08	W 150:02	375	18.7	4/1/1990	10/1/1997	5/21/1999	27 years: 1988 - 2013
Tokositna Valley	1089	SNOTEL	Yes	N 62:38	W 150:47	850	20.7	4/27/2008	10/8/2009	6/3/2013	8 years: 2006 - 2013
Blueberry Hill	49N07	Snow Course	Yes	N 62:48	W 149:59	1,200	27.6	3/30/1990	-----	-----	26 years: 1988 - 2013
Clearwater Lake	46N01	Snow Course	**Yes**	N 62:56	W 146:57	2,650	9.4	4/27/1972	-----	-----	47 years: 1964 - 2013
E. Fork Chulitna River	47N02	Snow Course	Yes	N 63:08	W 149:27	1,800	27.7	4/28/2005	-----	-----	26 years: 1988 - 2013
Fog Lakes	48N02	Snow Course	**Yes**	N 62:47	W 148:28	2,120	11.2	3/28/1991	-----	-----	50 years: 1964 - 2013
Horsepasture Pass	47N02	Snow Course	**Border**	N 62:08	W 147:38	4,300	11.8	3/30/2005	-----	-----	46 years: 1968 - 2013
Independence Mine	49M26	Snow Course	Border	N 61:48	W 149:17	3,550	41.0	5/2/1990	-----	-----	25 years: 1989 - 2013
Lake Louise	46N02	Snow Course	**Yes**	N 62:16	W 146:31	2,400	7.6	4/2/1993	-----	-----	50 years: 1964 - 2013
Monohan Flat	47O01	Snow Course	**Border**	N 63:18	W 147:39	2,710	14.8	3/31/2005	-----	-----	49 years: 1964 - 2013
Monsoon Lake	46N03	Snow Course	**Border**	N 62:50	W 146:37	3,100	10.3	3/30/1990	-----	-----	29 years: 1985 - 2013
Square Lake	47N01	Snow Course	**Yes**	N 62:24	W 147:28	2,950	7.2	4/26/1982	-----	-----	50 years: 1964 - 2013
Susitna Valley High	50N07	Snow Course	Yes	N 62:08	W 150:02	375	18.1	3/30/1990	-----	-----	19 years: 1988 - 2012
Talkeetna	50N02	Snow Course	Yes	N 62:19	W 150:05	350	18.3	3/26/1990	-----	-----	47 years: 1967 - 2013
Tyone River	47N03	Snow Course	**Yes**	N 62:40	W 147:08	2,500	6.2	3/29/2000	-----	-----	21 years: 1981 - 2011

Notes:

(1) Items in bold indicate the location is tributary to Watana Dam. Border indicates the station is on or near the watershed border.

(2) SWE is snow water equivalent, the depth of melted snow in a snowpack.

(3) Snow course measurements are infrequent and insufficient to determine the earliest and latest days with a snowpack.

(4) Snow water equivalent data is unavailable for the Monahan Flat SNOTEL site.

100-Year Snowpack at Snow Course Stations

Station Name	Is Station Area Tributary to Watana Dam (1)	Elevation (feet)	100-Year Snow Water Equivalent				Oct-Apr Avg. Total Precip. (inches)	Ratio May 1 100-Year / Oct-Apr (2)
			Feb. 1 (inches)	Mar. 1 (inches)	Apr. 1 (inches)	May 1 (inches)		
Blueberry Hill	No	1,200	24.0	32.8	36.5	33.8	16.9	2.01
Clearwater Lake	Yes	2,650	8.1	8.2	9.8	11.6	6.0	1.94
E. Fork Chulitna River	No	1,800	23.6	28.8	31.5	34.3	11.8	2.90
Fog Lakes	Yes	2,120	11.6	12.1	12.9	11.9	6.7	1.78
Horsepasture Pass	Yes/Border	4,300	9.4	11.8	12.5	12.8	7.0	1.82
Independence Mine	No	3,550	39.6	48.1	50.1	50.1	24.5	2.05
Lake Louise	Yes	2,400	6.7	7.1	8.2	7.2	4.4	1.63
Monohan Flat	Yes/Border	2,710	12.7	13.8	14.7	12.0	8.5	1.40
Monsoon Lake	Yes/Border	3,100	8.3	9.6	10.8	-----	6.0	1.79
Square Lake	Yes	2,950	6.0	6.5	7.4	7.2	4.8	1.51
Susitna Valley High	No	375	13.6	15.5	16.5	19.0	13.3	1.43
Talkeetna	No	350	11.3	15.9	18.4	16.7	12.0	1.39
Tyone River	Yes	2,500	5.7	6.2	7.3	-----	4.8	1.53
						Average of non-red values		1.68

Notes:

(1) Border indicates that the stations are on or near the watershed boundary.

(2) Where May 1 data is missing, April 1 data was used.

Values in the red boxes were not used to determine the 100-year snowpack.

Conclusion: Use 1.68 times the Oct thru April precipitation to develop the 100-year snowpack

100-Year Snow Water Equivalent (SWE) by Sub-Basin

Sub-Basin Number	Basin Area (sq.mi.)	Annual Precip. (inches)	Oct-Apr Precip. (inches)	100-Year SWE (inches)
1	52.6	37.9	16.9	28.4
2	226.4	28.9	12.2	20.6
3	295.4	18.1	6.7	11.2
4	149.3	41.7	19.2	32.3
5	354.0	30.9	13.5	22.6
6	153.4	42.8	19.9	33.4
7	67.5	23.9	9.5	16.0
8	189.9	27.8	11.6	19.4
9	187.7	26.9	10.5	17.6
10	326.8	21.3	8.0	13.4
11	273.5	22.9	9.0	15.0
12	74.7	16.8	5.8	9.8
13	222.5	14.2	4.8	8.0
14	135.1	13.8	4.3	7.3
15	185.1	16.2	5.8	9.7
16	164.3	16.8	5.9	9.9
17	253.2	15.0	5.1	8.5
18	100.0	20.8	7.5	12.6
19	202.2	24.5	8.8	14.9
20	36.3	17.1	5.4	9.2
21	162.7	25.6	9.2	15.4
22	92.0	16.4	5.5	9.2
23	174.2	20.9	7.0	11.8
24	157.4	21.9	7.8	13.2
25	184.0	33.6	12.2	20.6
26	222.9	27.7	10.1	17.0
27	269.6	23.6	9.0	15.1
28	218.5	26.3	10.0	16.9
29	36.8	18.7	6.7	11.3
To Watana Dam	5,168	24.0	9.3	15.7
To Denali Gage	914	33.5	14.8	24.9
To Maclaren Gage	279	30.6	13.1	22.0
To Cantwell Gage	4,079	23.4	9.2	15.5

Probable Maximum Snow Water Equivalent by Sub-Basin

Sub-Basin Number	Basin Area (sq.mi.)	Annual Precip. (inches)	Oct-Apr Precip. (inches)	PMS SWE (inches)
1	52.6	37.9	16.9	50.8
2	226.4	28.9	12.2	36.7
3	295.4	18.1	6.7	20.0
4	149.3	41.7	19.2	57.7
5	354.0	30.9	13.5	40.4
6	153.4	42.8	19.9	59.7
7	67.5	23.9	9.5	28.6
8	189.9	27.8	11.6	34.7
9	187.7	26.9	10.5	31.5
10	326.8	21.3	8.0	23.9
11	273.5	22.9	9.0	26.9
12	74.7	16.8	5.8	17.5
13	222.5	14.2	4.8	14.4
14	135.1	13.8	4.3	13.0
15	185.1	16.2	5.8	17.3
16	164.3	16.8	5.9	17.6
17	253.2	15.0	5.1	15.3
18	100.0	20.8	7.5	22.6
19	202.2	24.5	8.8	26.5
20	36.3	17.1	5.4	16.3
21	162.7	25.6	9.2	27.5
22	92.0	16.4	5.5	16.5
23	174.2	20.9	7.0	21.1
24	157.4	21.9	7.8	23.5
25	184.0	33.6	12.2	36.7
26	222.9	27.7	10.1	30.4
27	269.6	23.6	9.0	27.0
28	218.5	26.3	10.0	30.1
29	36.8	18.7	6.7	20.1
To Watana Dam	5,168	24.0	9.3	27.9
To Denali Gage	914	33.5	14.8	44.4
To Maclaren Gage	279	30.6	13.1	39.4
To Cantwell Gage	4,079	23.4	9.2	27.6

The probable maximum SWE is equal to 3.0 times the Oct-Apr average precipitation

Flood Seasonality

Month	Gold Creek Gage		Cantwell Gage		Denali Gage		Maclaren Gage		Total of All Gages	
	Annual Peaks	% of Total	Annual Peaks	% of Total	Annual Peaks	% of Total	Annual Peaks	% of Total	Annual Peaks	% of Total
January	0	0%	0	0%	0	0%	0	0%	0	0%
February	0	0%	0	0%	0	0%	0	0%	0	0%
March	0	0%	0	0%	0	0%	0	0%	0	0%
April	0	0%	0	0%	0	0%	0	0%	0	0%
May	8	14%	1	6%	0	0%	1	4%	10	7%
June	28	47%	8	44%	3	10%	12	43%	51	38%
July	9	15%	5	28%	12	41%	6	21%	32	24%
August	10	17%	4	22%	12	41%	7	25%	33	25%
September	4	7%	0	0%	2	7%	2	7%	8	6%
October	0	0%	0	0%	0	0%	0	0%	0	0%
November	0	0%	0	0%	0	0%	0	0%	0	0%
December	0	0%	0	0%	0	0%	0	0%	0	0%
Total	59	100%	18	100%	29	100%	28	100%	134	100%

Gold Creek USGS Gage Maximum Daily Flow (cfs)	
January	2,900
February	3,700
March	2,400
April	24,000
May	55,500
June	85,900
July	60,800
August	77,700
September	70,800
October	36,200
November	8,940
December	4,400

Flood Frequency

Gold Creek

Return Period (Years)	Flow (cfs)
2	44,700
5	58,600
10	68,700
25	82,700
50	93,800
100	106,000
200	118,000
500	135,000
1,000	149,000
10,000	195,000

Watana Dam

Return Period (Years)	Flow (cfs)
2	38,500
5	50,500
10	59,200
20	68,300
25	71,300
50	80,800
100	91,300
500	116,300
1,000	128,400
10,000	168,000

Evaluation Criteria for Selecting Calibration/Verification Floods

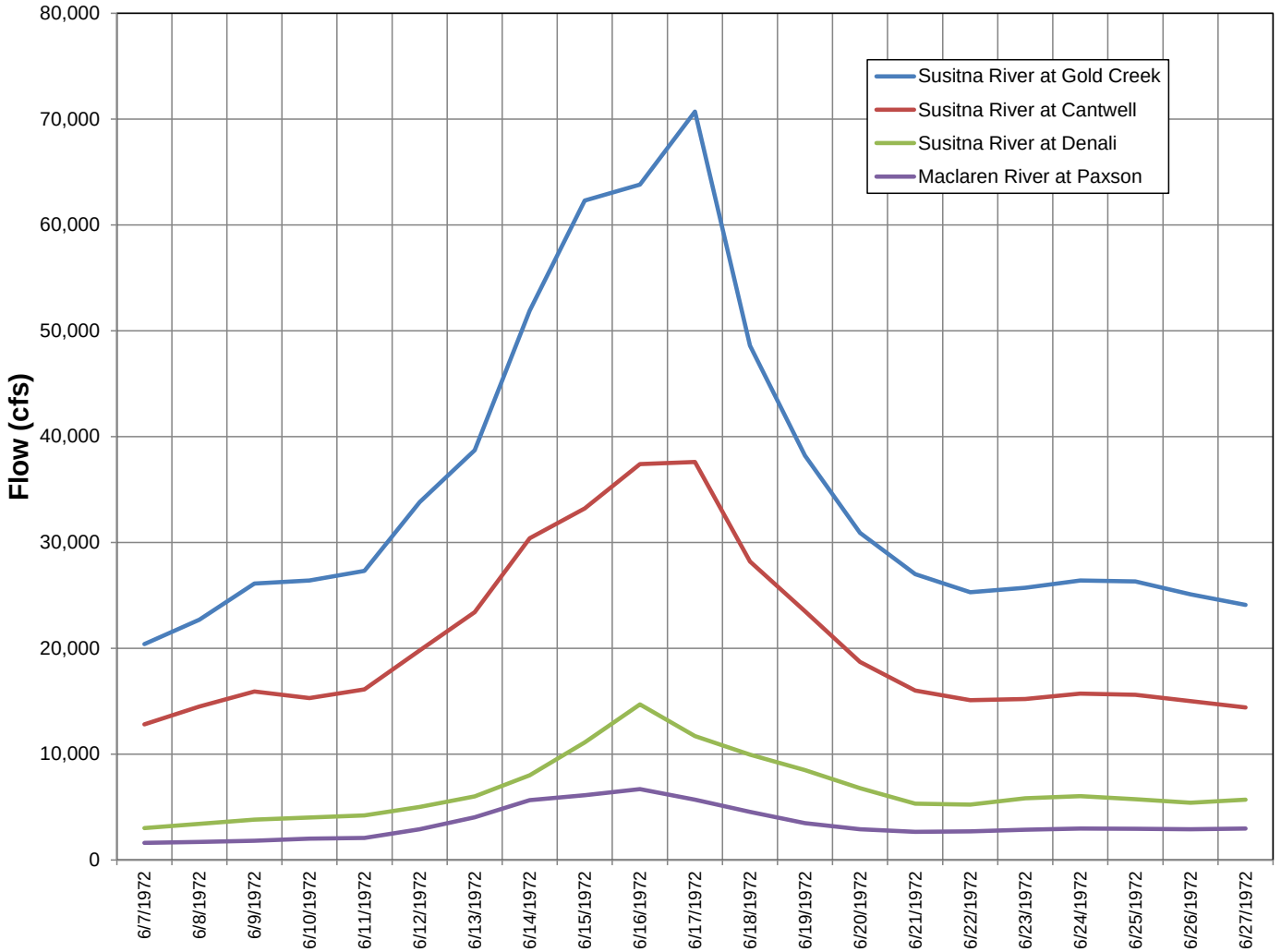
- Start with 11 storm/flood period candidates
- Largest annual peak flows
- Largest partial duration series daily flows
- Data availability at the most USGS gages
- Storm periods used by AWA for PMP
- Floods used for calibration and verification during the 1982 PMF study
- Quality of USGS flow data
- Distribution of floods in the May through October potential flood season (snowmelt/rain)

Summary of Evaluated Floods for Calibration/Verification

(Selected / Not Selected)

1. July 1958
2. August 1959
3. June 1982
4. June 1964
5. August 1967
6. June 1971
7. August 1971
8. June 1972
9. July 1980
10. October 1986
11. September 2012

Example USGS Flow Records – June 1972



Field Trip – May 29, 2013

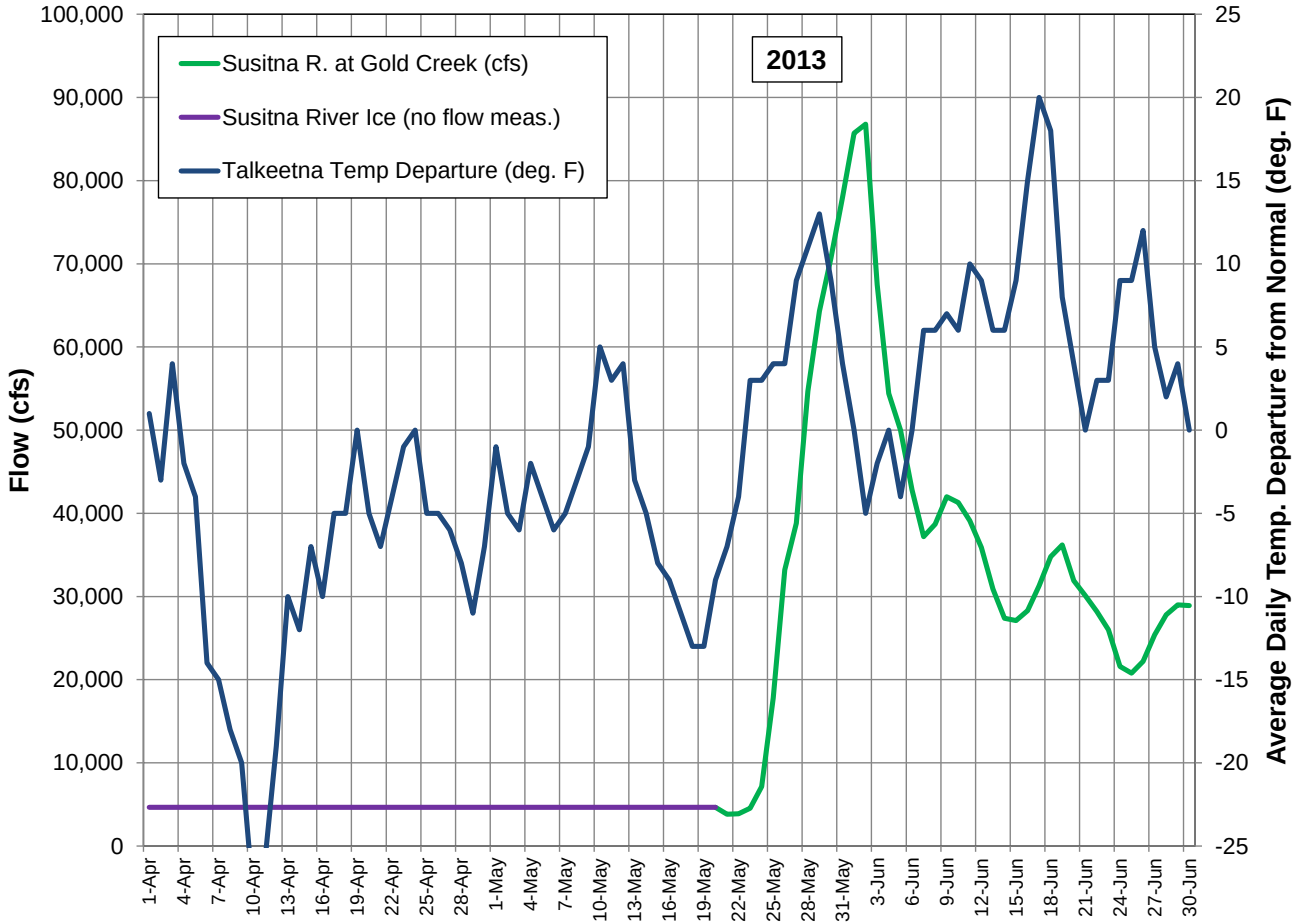
Susitna River near Deadman Creek

Susitna River near Denali Highway crossing

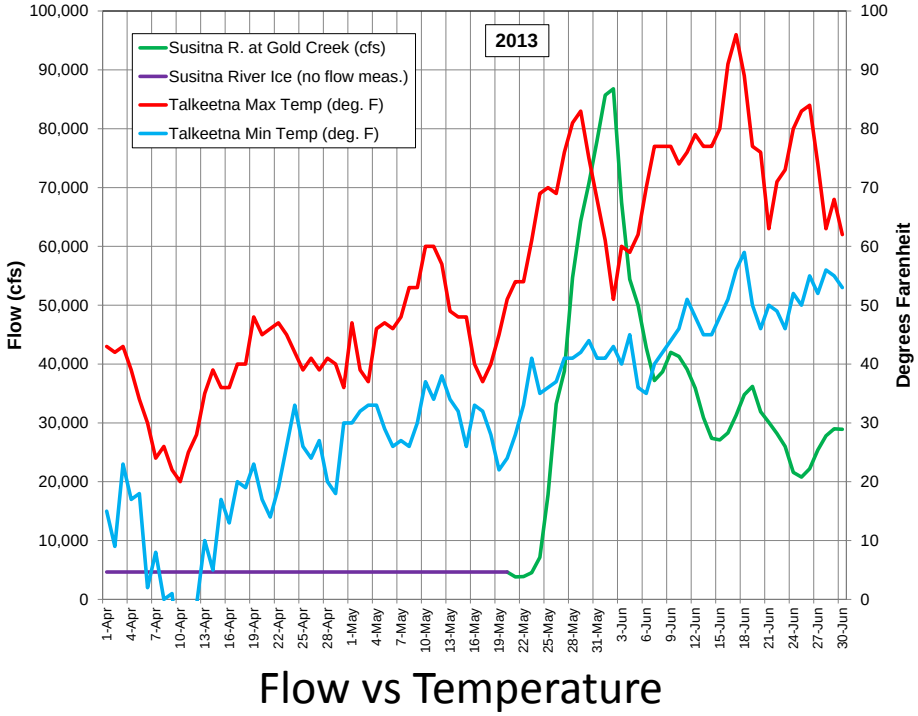
Initiation of Spring Breakup During Historic Large Floods

Flood Peak Rank	Flood Peak Date	Peak Flow (cfs)	Date of Initial 5,000 cfs Flow	Rank Order of Initial 5,000 cfs Flow (of 60 years)
1 (tie)	June 7, 1964	90,700	May 27	1 - Latest
1 (tie)	June 2, 2013	90,700	May 24	3 (tie)
3	August 10, 1971	87,400	May 24	3 (tie)
4	June 17, 1972	82,600	May 5	35
5	June 15, 1962	80,600	May 16	12

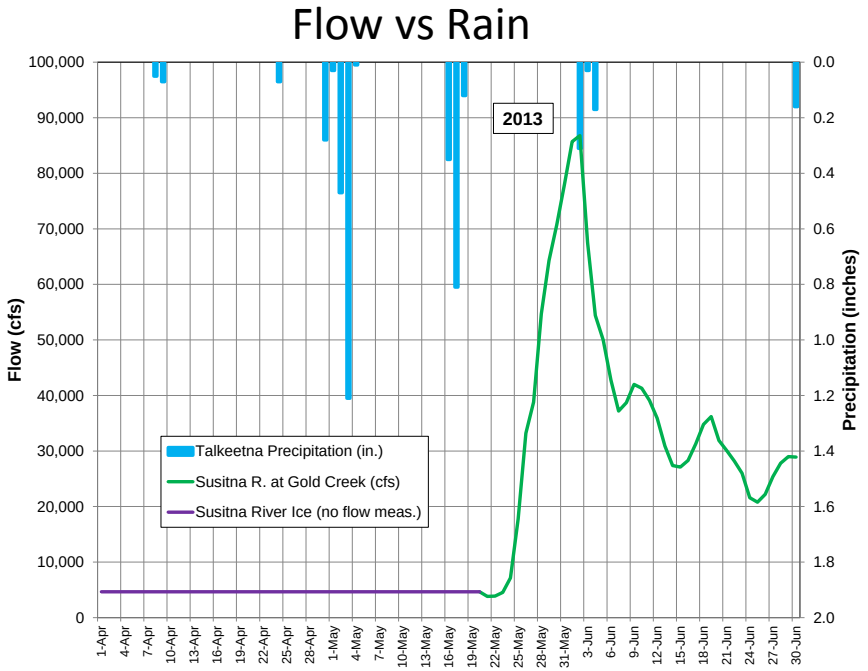
April – June 2013 Flow and Temperature Departure from Normal



April – June 2013 Flow, Temperature and Rain



Flow vs Temperature



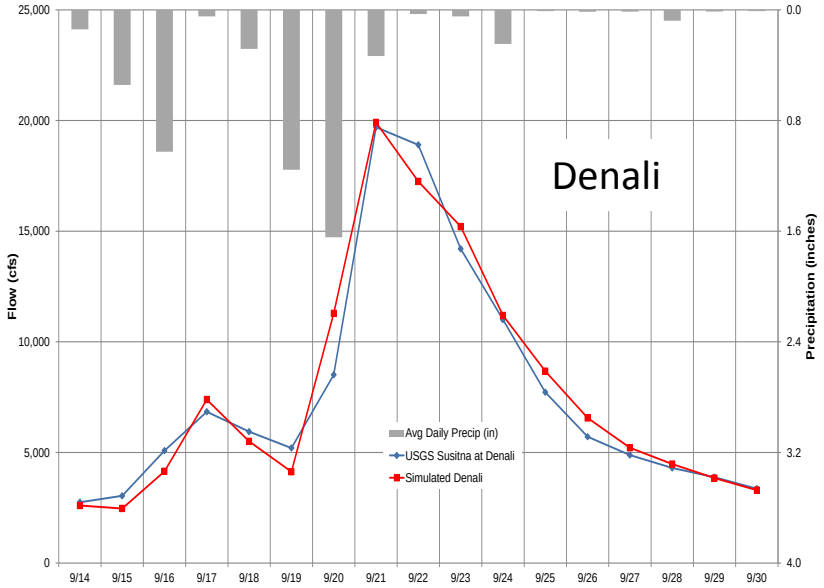
Unit Hydrograph Calibration and Verification

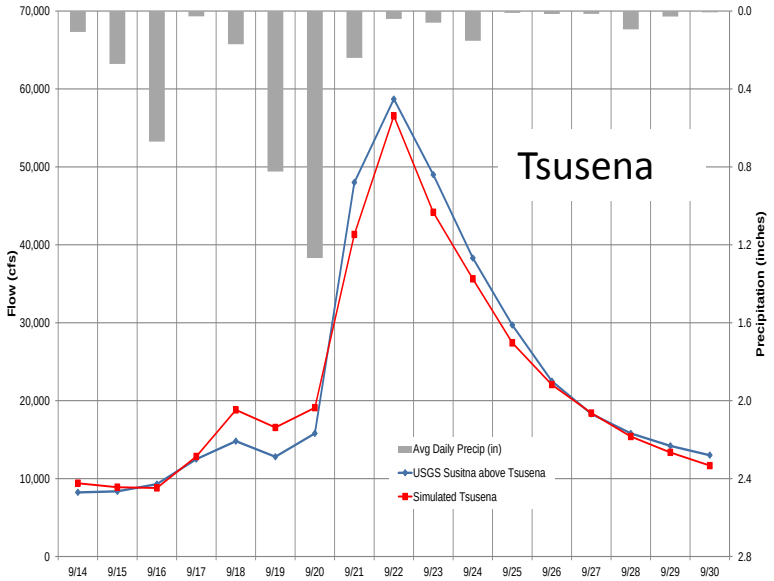
- Calibrate/verify 3 summer and 3 spring floods
- Clark method unit hydrograph
- Time of concentration (lag time)
- Clark storage coefficient (attenuation)
- Losses
- Hydrograph volume and peak flow are key calibration parameters
- Snowpack, and meteorological factors are also subject to adjustment for volume

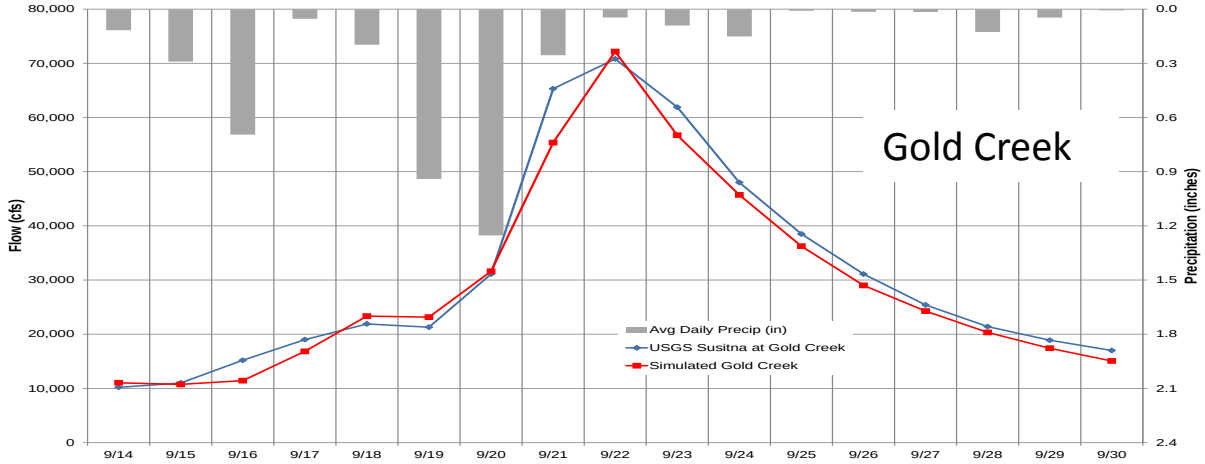
Reconstruction of Previous PMFs

- Determine the relative contribution of snowmelt and rainfall runoff with HEC-1
- Develop initial values for at least some HEC-1 parameters
- Have a working HEC-1 model at the start of historic flood calibration
- Capability to determine what are the major changes between 1980s and current PMF

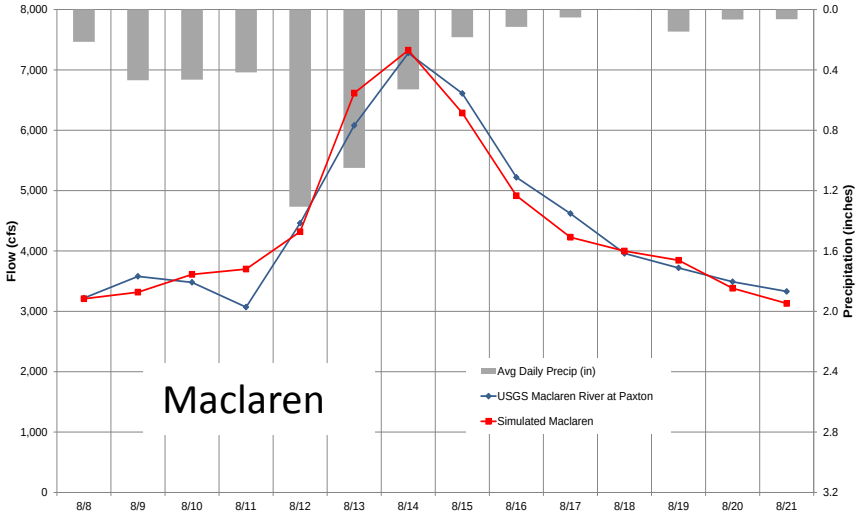
September 2012 Flood Calibration

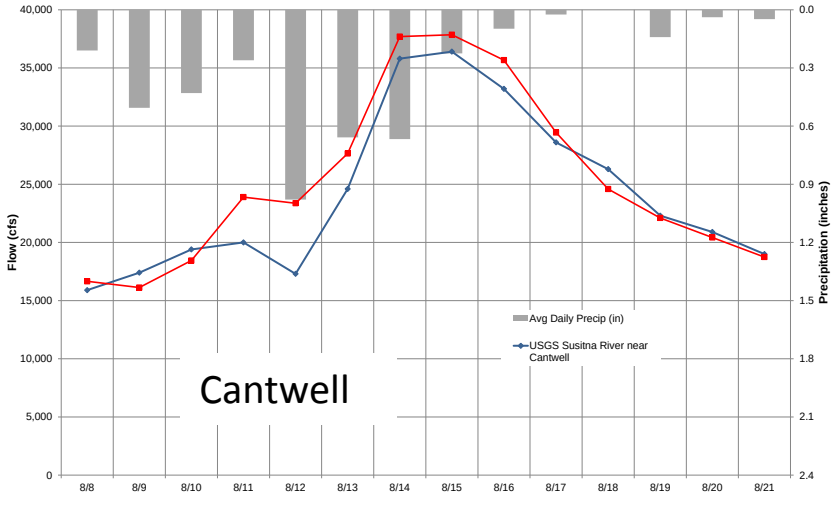


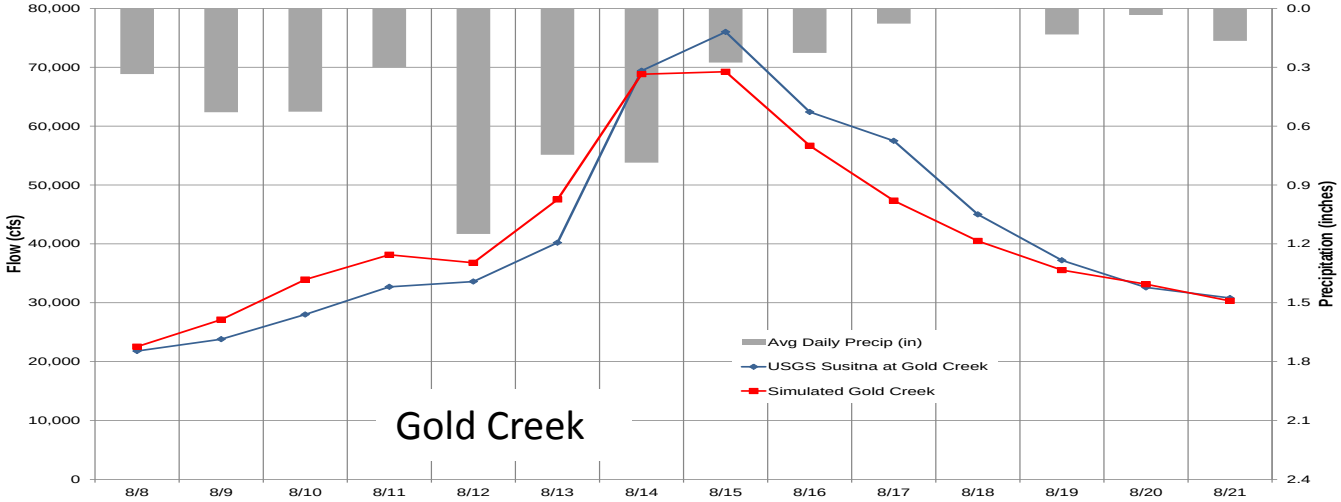




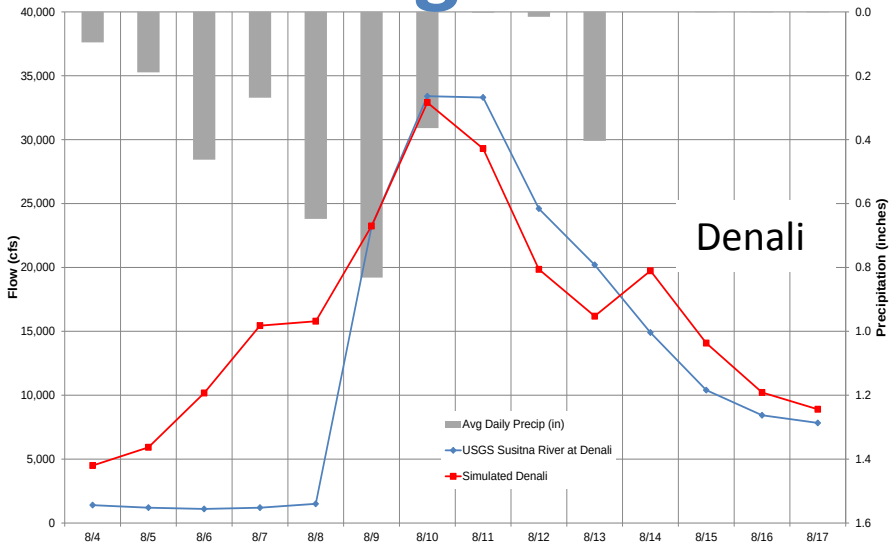
August 1967 Flood Calibration

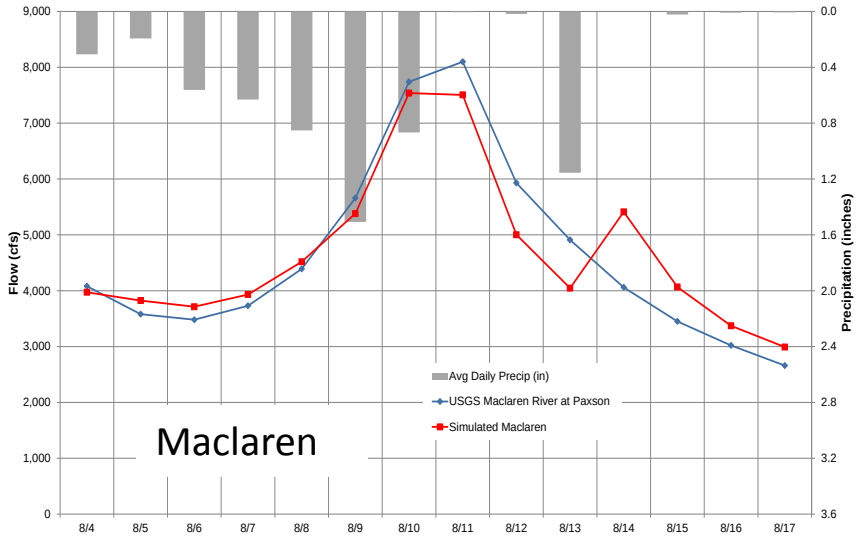


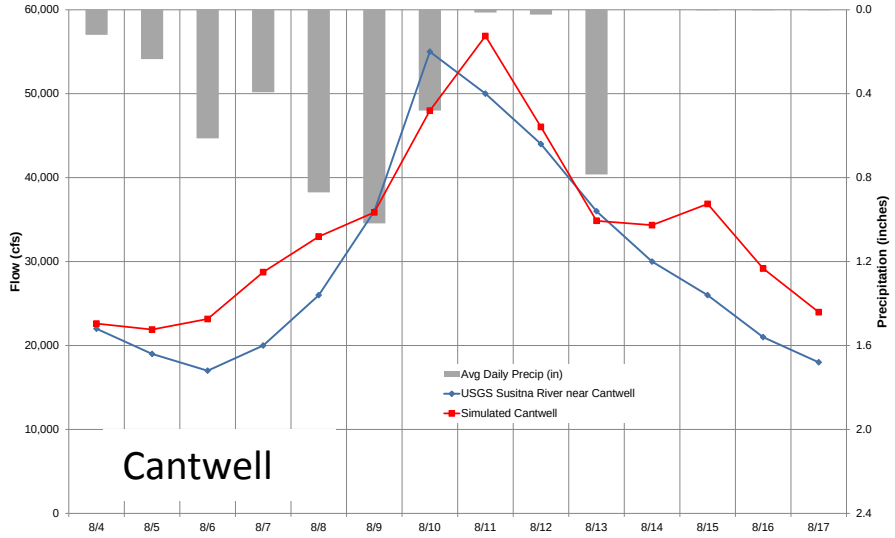


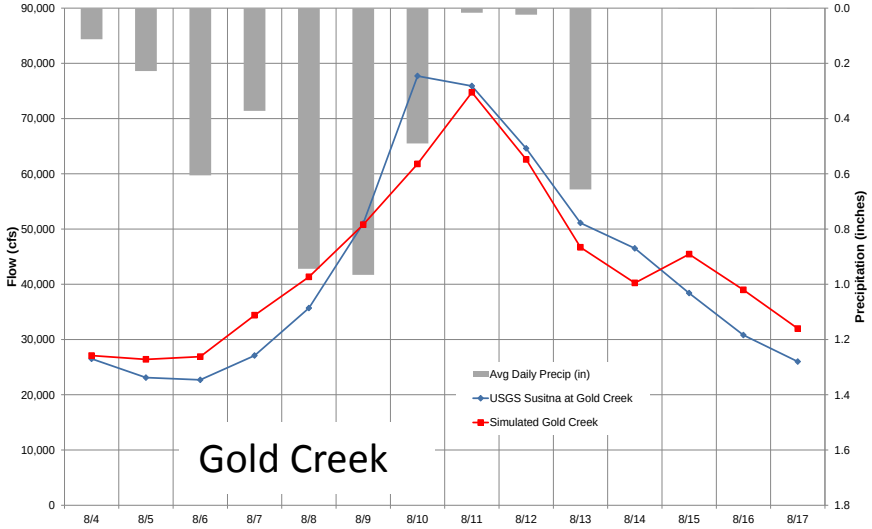


August 1971 Flood Verification

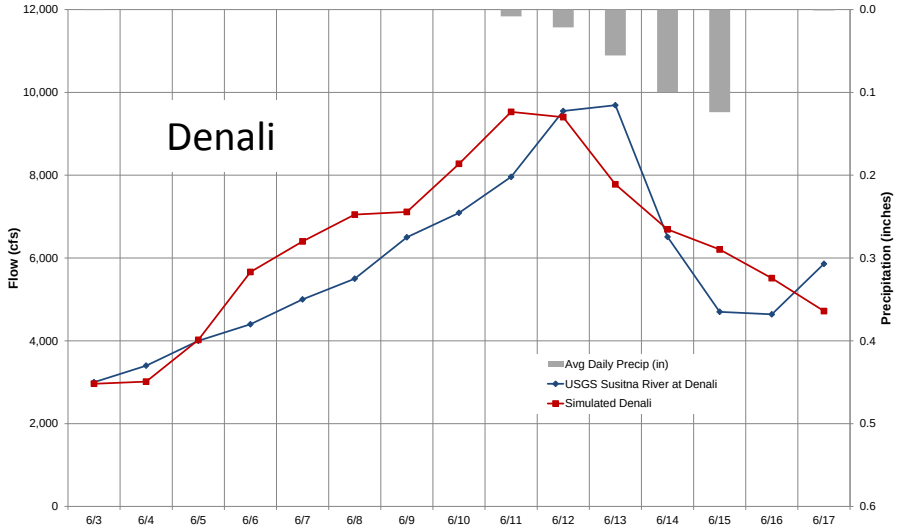


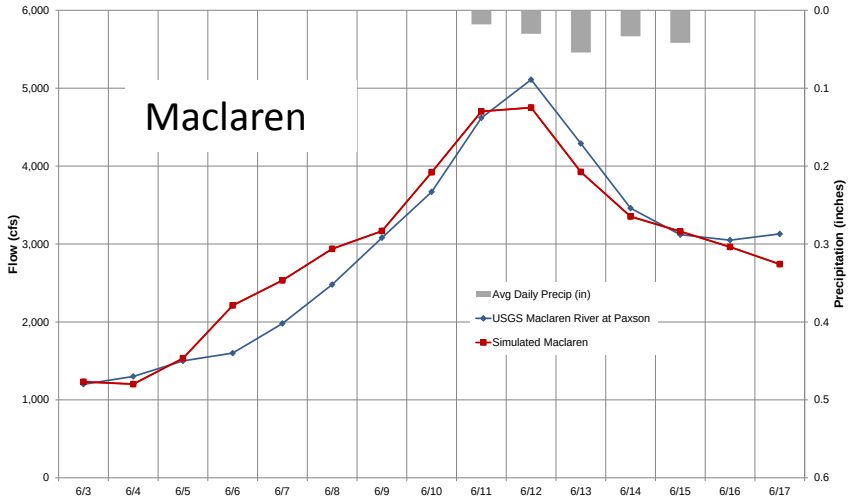


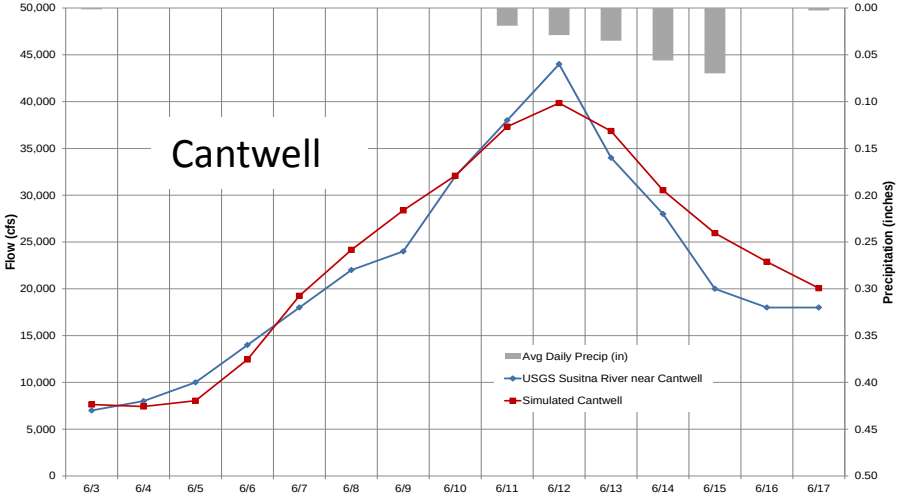


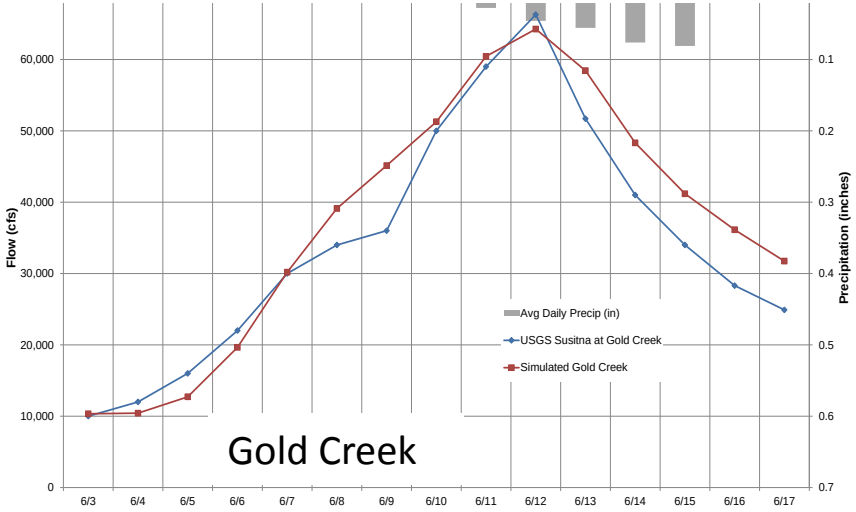


June 1971 Flood Calibration

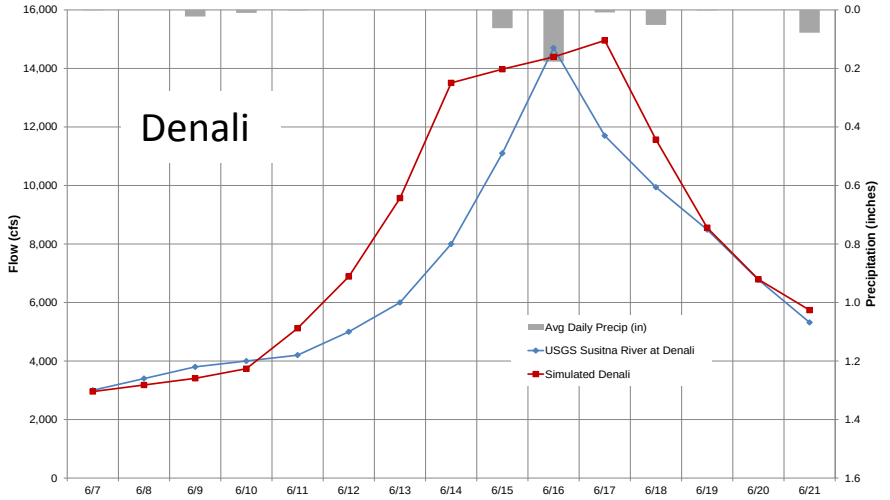


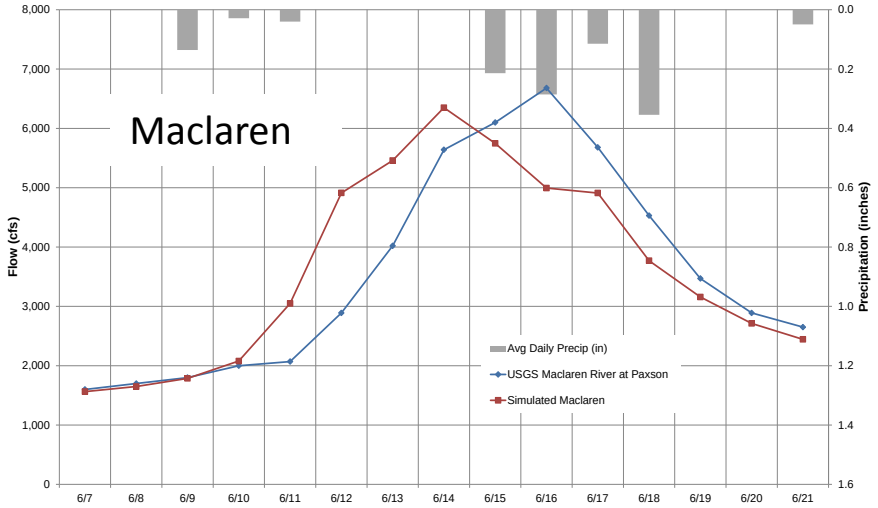


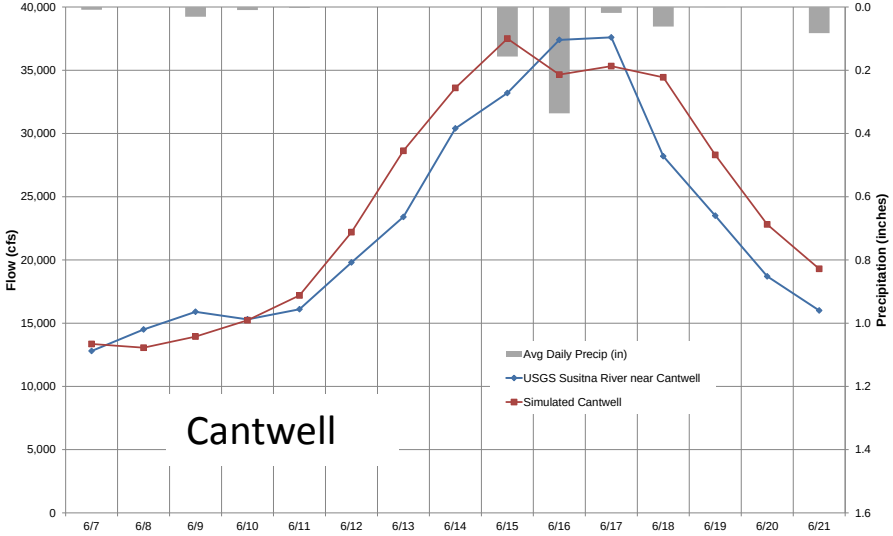


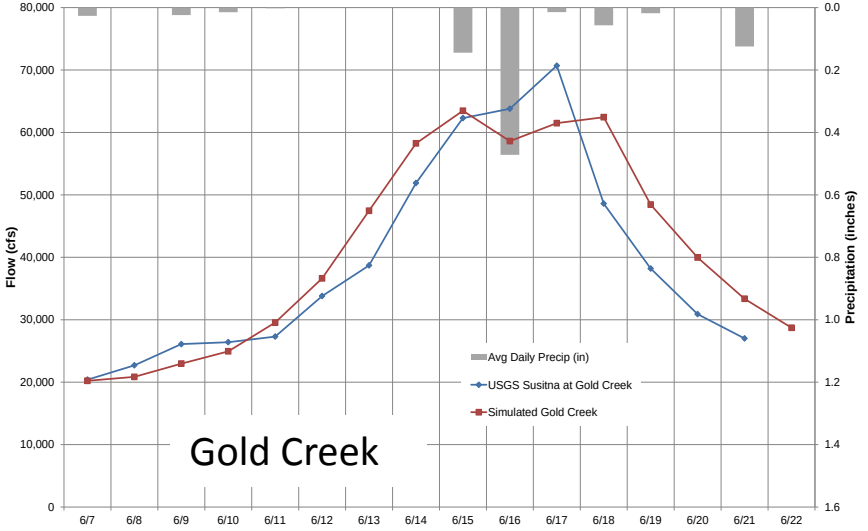


June 1972 Flood Calibration

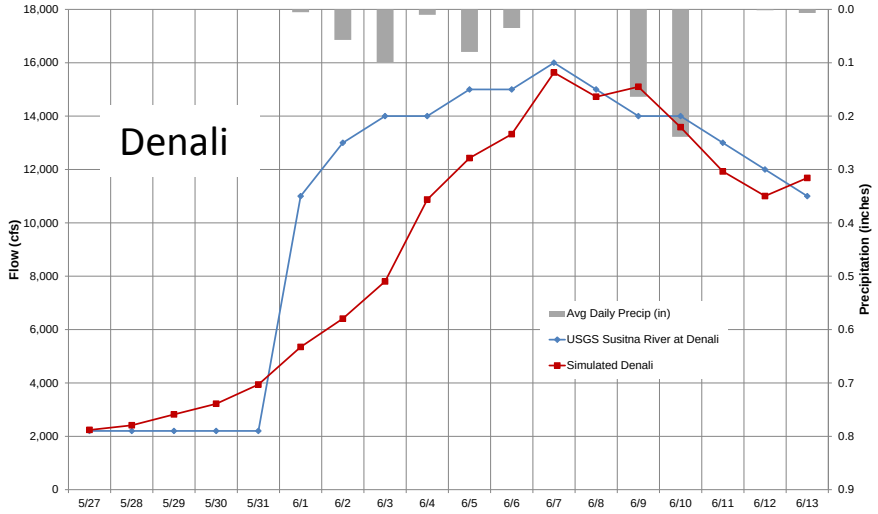


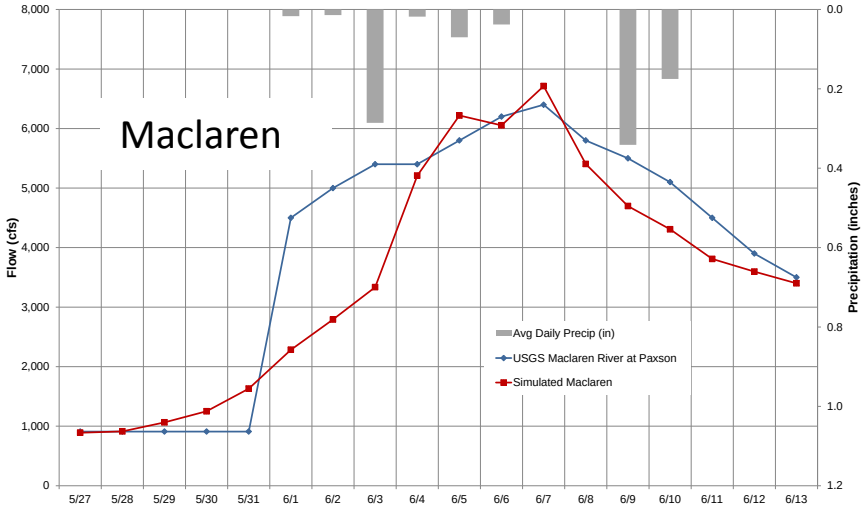


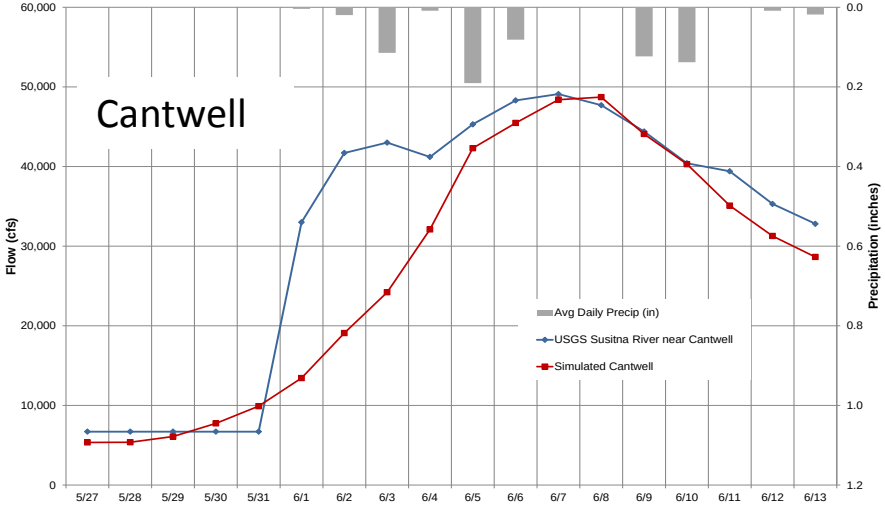


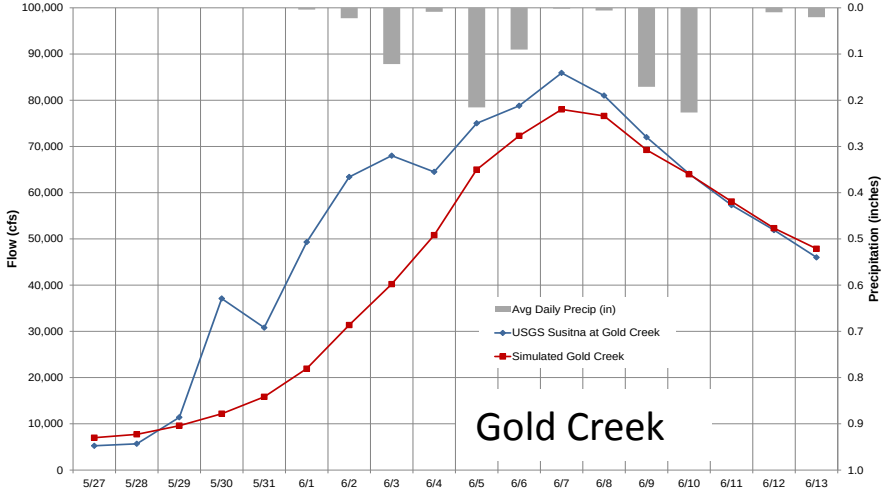


June 1964 Flood Verification









Unit Hydrograph Parameters

Sub-Basin	Tc	R	R/(Tc + R)
1	25.6	31	0.55
2	25.6	31	0.55
3	38.6	41	0.52
4	16.0	39	0.71
5	16.0	39	0.71
6	16.0	39	0.71
7	22.0	53	0.71
8	10.0	24	0.71
9	62.9	44	0.41
10	62.9	44	0.41
11	83.9	35	0.29
12	64.0	54	0.46
13	72.3	61	0.46
14	72.3	61	0.46
15	64.0	68	0.52
16	64.0	68	0.52
17	72.3	61	0.46
18	43.8	37	0.46
19	43.8	37	0.46
20	43.8	37	0.46
21	43.8	37	0.46
22	43.8	37	0.46
23	87.5	46	0.34
24	35.0	29	0.45
25	27.7	23	0.45
26	35.0	29	0.45
27	35.0	29	0.45
28	35.0	29	0.45
29	26.2	22	0.46
30	39.0	21	0.35
31	39.0	21	0.35
32	39.0	21	0.35
33	30.8	17	0.36
34	30.8	17	0.36

Losses

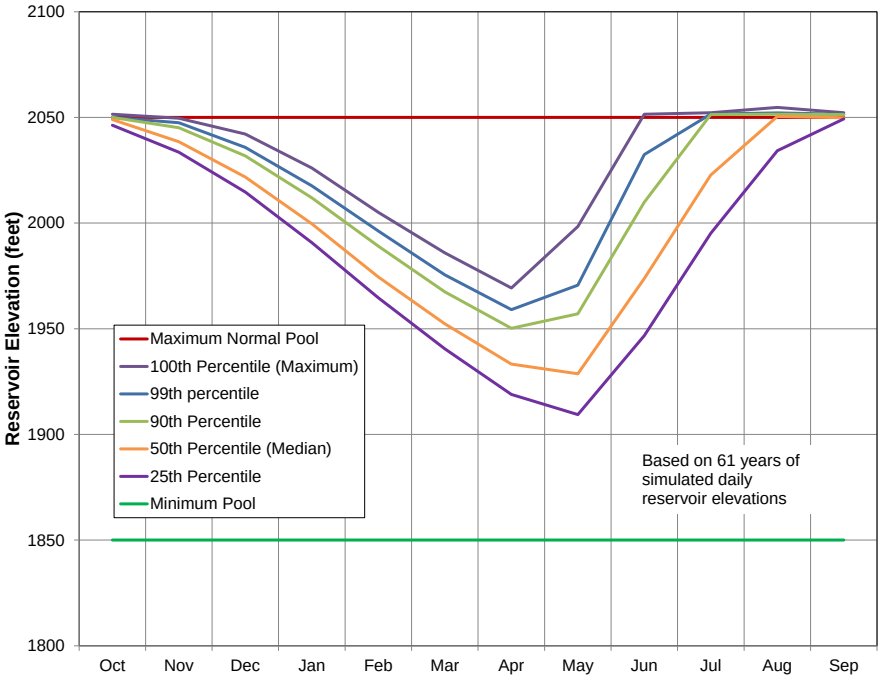
Summer losses

- Initial and constant loss rate method
- Initial losses were 0.06 to 0.08 inch, with glacier areas at 0.09 inch
- Constant losses were 0.02 to 0.04 inch/hour

Spring losses

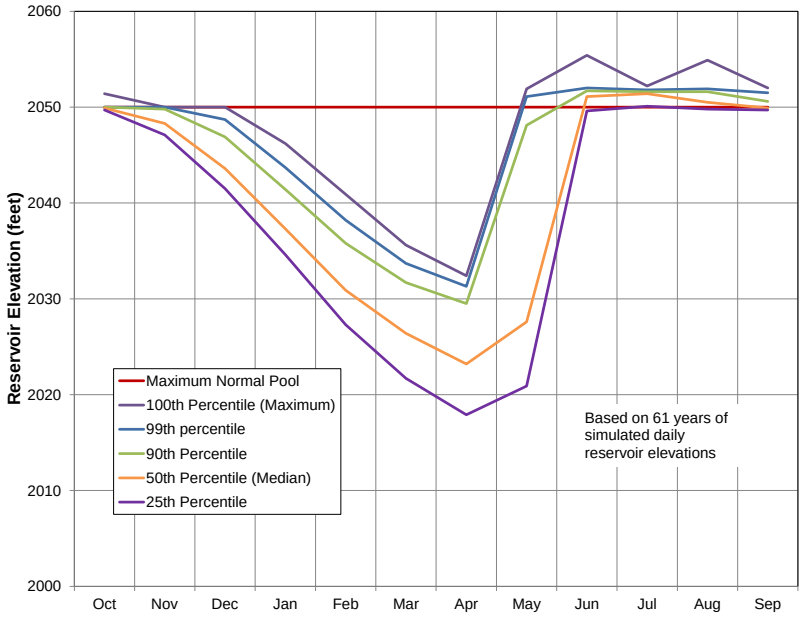
- Exponential loss rate method
- For the entire 216 hour June 1 PMP storm period, total losses (rainfall losses plus snowmelt losses) averaged 0.032 inch/hour
- For the most intense 72-hour period of the June 1 PMP, total losses averaged 0.060 inch/hour

Reservoir Elevation Frequency for Initial Reservoir Level



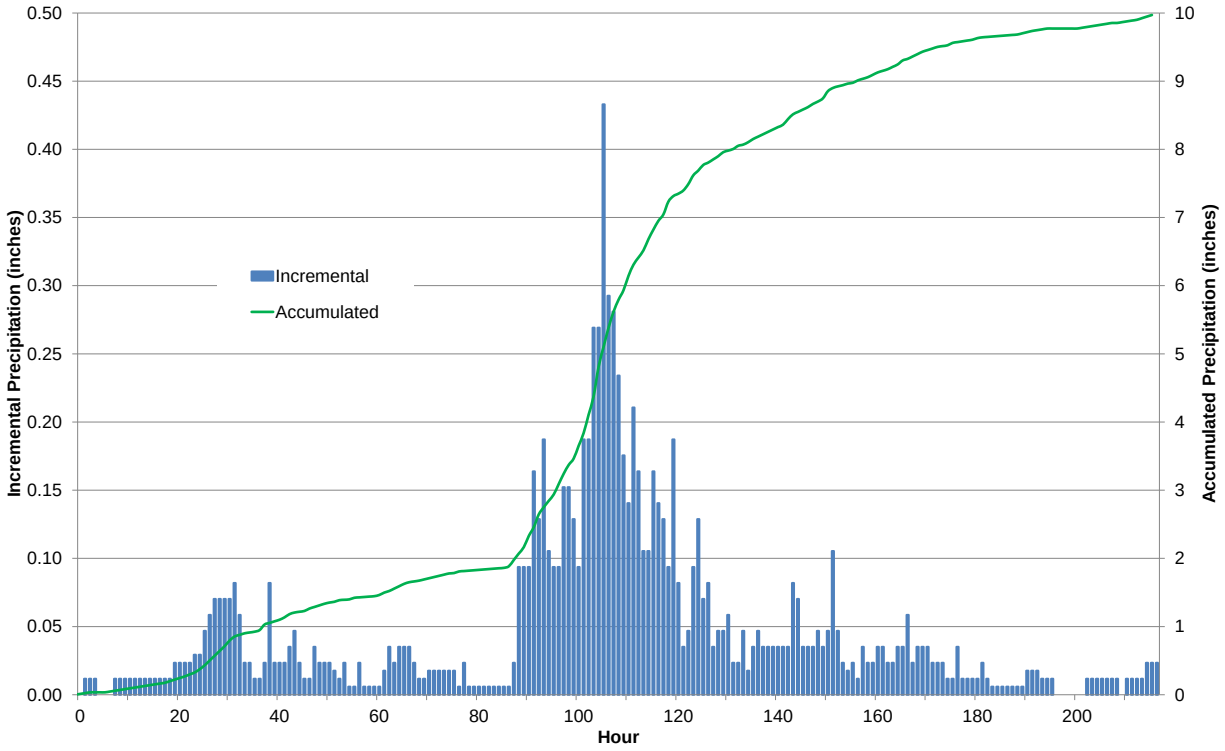
Maximum Load Conditions

50% Load Conditions



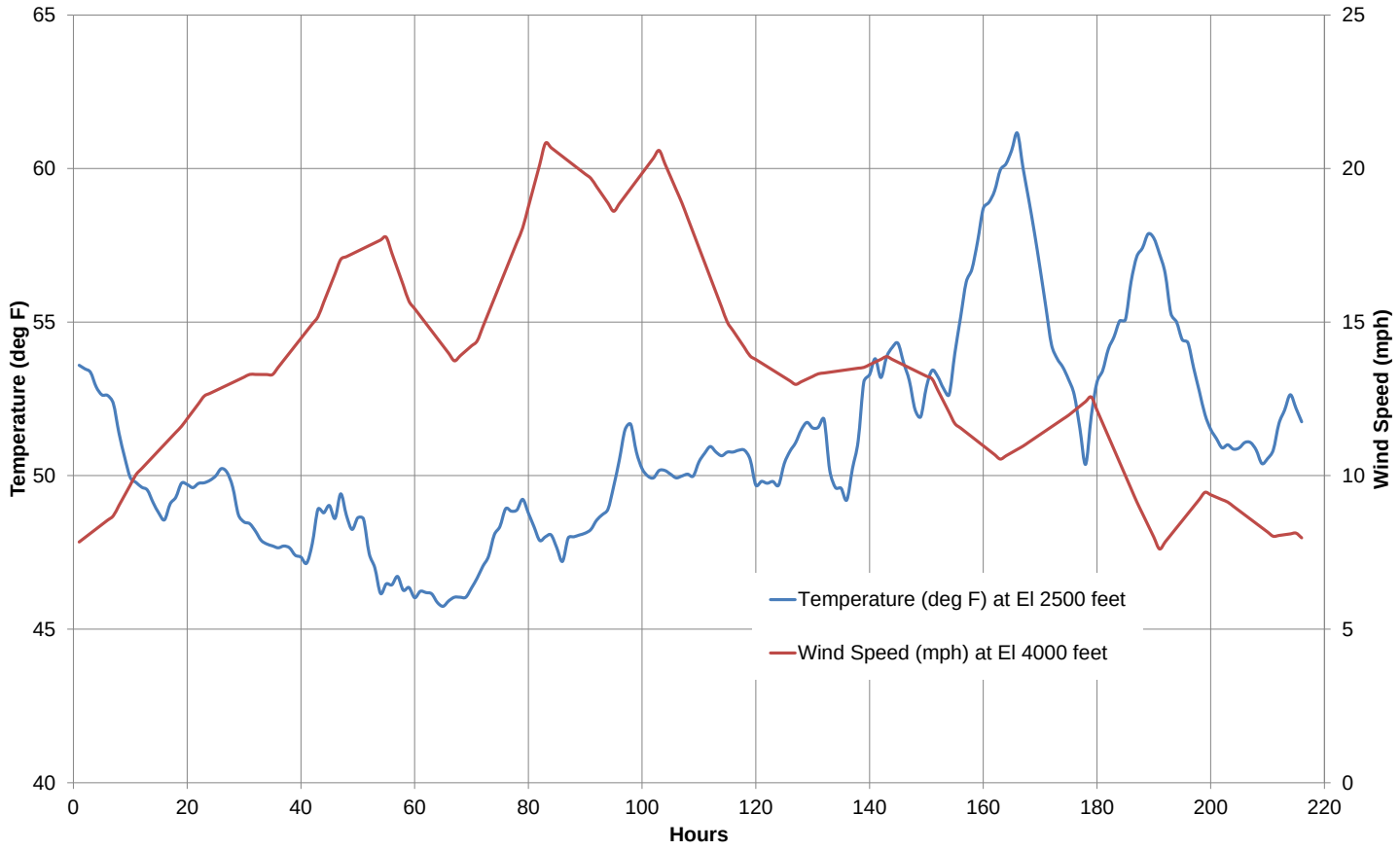
PMP Temporal Distributions

Based on Storm	All Season 1-hr PMP (inches)	All Season 6-hr PMP (inches)	All Season 24-hr PMP (inches)	All Season 72-hr PMP (inches)	All Season 216-hr PMP (inches)
Aug 1967	0.43	1.78	4.40	7.19	10.00
Aug 1955	0.43	1.40	2.77	5.53	10.00
Sep 2012	0.43	1.29	2.72	4.63	10.00



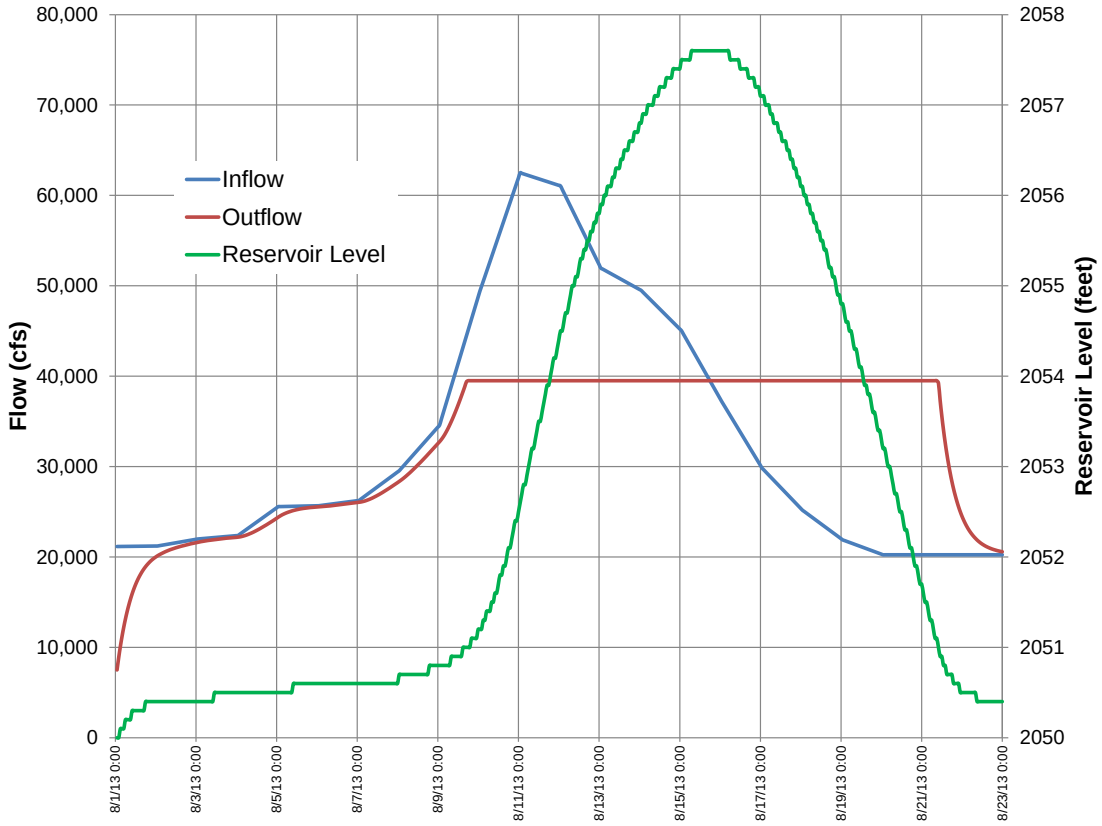
Based on August 1967 Storm

PMP Temperature and Wind



Applied to all PMP temporal distributions

Intermediate Flood Routing



- 50-year seasonal flood
- 8 valves @ 4,000 cfs – 32,000 cfs total
- 7,500 cfs powerhouse flow
- Spillway gates begin to open at El 2057.6

Freeboard

Parameter	Wind Speed (mph)		
	40	50	100
Significant wave height (feet)	2.8	3.7	8.7
Wave period (seconds)	3.0	3.3	4.3
Wave length (feet)	45.2	54.2	95.1
Wave runup (feet)	3.08	4.06	9.52
Wind setup (feet)	0.01	0.01	0.03
Wave runup + wind setup (feet)	3.09	4.07	9.55

Normal freeboard – at least 15 feet above El 2050
Minimum freeboard – at least 3.5 feet

USBR ACER TM No. 2 indicates that the 3.5-ft high solid parapet entirely above the dam crest provides for minimum freeboard in the event of the PMF.

PMF Run Plan

Date	PMP Ratio	Temp. and Dew Point Ratio	Wind Speed Ratio	Snowpack	Comment
January	-----	-----	-----	-----	Eliminated by lack of historic floods, low temperatures, etc.
February	-----	-----	-----	-----	
1-Mar	-----	-----	-----	-----	
15-Mar	0.300	-----	1.450	-----	
1-Apr	0.450	0.39	1.350	-----	Eliminated by lack of historic floods, low antecedent reservoir levels, low PMP, and low temperatures.
15-Apr	0.600	0.55	1.250	-----	
1-May	0.715	0.69	1.155	100-year	Run only if May 15 appears be controlling
15-May	0.830	0.80	1.060	100-year	Case M1
1-Jun	0.885	0.90	0.965	100-year	Case M2
15-Jun	0.940	0.95	0.870	Reduced	Eliminated - snowpack reduced compared to June 1
1-Jul	0.970	1.00	0.895	Glacier only	Eliminated - no snowpack, less than All-Season PMP
15-Jul	1.000	1.00	0.920	Glacier only	Eliminated - August 15 is more critical due to wind speed
1-Aug	1.000	1.00	0.960	Glacier only	Eliminated - August 15 is more critical due to wind speed
15-Aug	1.000	1.00	1.000	Glacier only	Case M3
1-Sep	0.960	0.94	1.075	Glacier only	Case M4
15-Sep	0.920	0.86	1.150	Glacier only	Case M5
1-Oct	0.860	0.77	1.200	Glacier only	Eliminated - lack of snowpack
15-Oct	0.800	0.64	1.250	Avg. Oct Precip.	Case M6
1-Nov	0.725	0.51	1.265	Avg. Oct Precip.	Eliminated - less critical than October 15.
15-Nov	0.650	-----	1.280	-----	Eliminated by low temperatures and low PMP.
December	-----	-----	-----	-----	Eliminated by lack of historic floods, low temperatures, etc.

Interpolated

Additional cases: (1) Test three alternative temporal PMP distributions in spring and summer to determine which is critical.
(2) Probable maximum snowpack with 100-year precipitation.

Results – PMP Temporal Distribution Cases

Case Number	Season	Based on Storm	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Reservoir W.S. Elev. (feet)
T1	Spring	Aug-67	196,000	195,000	2059.3
T2	Spring	Aug-55	180,000	179,000	2059.1
T3	Spring	Sep-12	158,000	157,000	2058.9
T4	Summer	Aug-67	222,000	218,000	2059.6
T5	Summer	Aug-55	159,000	157,000	2058.9
T6	Summer	Sep-12	130,000	126,000	2058.6

Conclusion: The August 1967 temporal distribution is critical for both spring and summer PMF runs.

Results – Seasonal PMF Cases

Case Number	Starting Date (1)	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Reservoir W.S. Elev. (feet)
M1	15-May	96,000	96,000	2058.2
M2	1-Jun	196,000	195,000	2059.3
M3	15-Aug	222,000	218,000	2059.6
M4	1-Sep	206,000	201,000	2059.4
M5	15-Sep	163,000	158,000	2058.9
M6	15-Oct	25,000	24,000	2050.5
M7	1-Jun (2)	136,000	134,000	2058.6

Notes

(1) See Table 9.1 for the elimation of some months.

(2) Probable maximum snowpack with 100-year rain.

Results – PMF Sensitivity Runs

Case Number	Modification (if any) to June 1 PMF	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Reservoir W.S. Elev. (feet)
S1	No modification to June 1 PMF	196,000	195,000	2059.3
S2	June 1 PMF with summer loss rates	241,000	239,000	2059.8
S3	June 1 PMF with constant 0.02 in/hr loss rates	310,000	281,000	2064.4
S4	June 1 PMF with +10 mph winds	232,000	231,000	2059.7
S5	June 1 PMF with +3 degree F temperatures	235,000	234,000	2059.8
S6	June 1 PMF with Harza-Ebasco temp and wind	312,000	277,000	2063.7
S7	June 1 PMF with initial reservoir level at El 2030	196,000	191,000	2059.3

Potential for additional review of loss rates is noted.

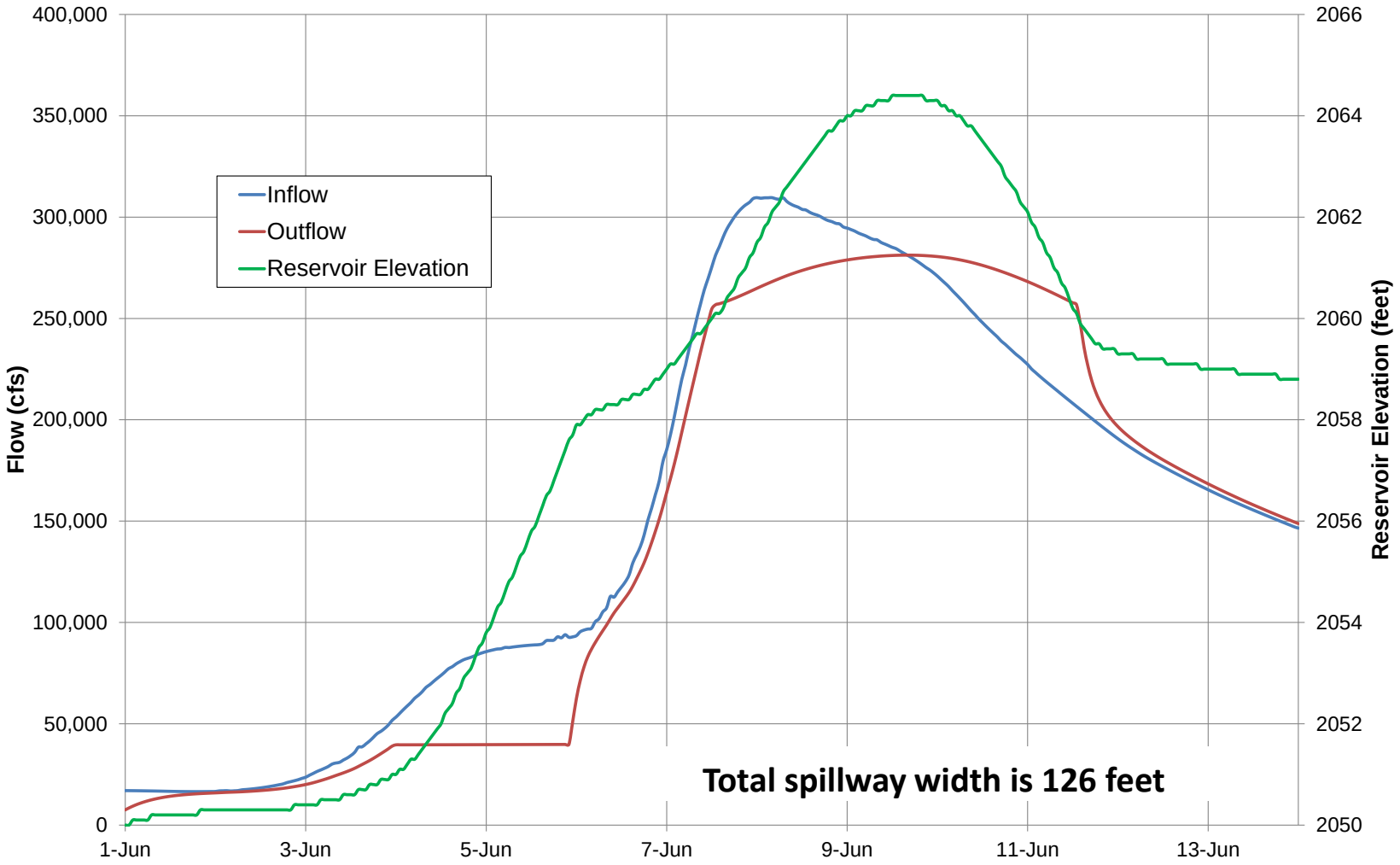
PMF Selection Background

- The PMF is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin under study.
- The PMP is defined as theoretically, the greatest depth of precipitation for a given duration that is physically possible for a given size storm area at a particular geographic location at a certain time of year.
- The maximum possible flood presupposes the simultaneous occurrence in one area of every possible natural factor in such a manner as to create the theoretically maximum possible flood. Use of the maximum possible flood is not currently acceptable practice.
- Much of the conservatism of the PMF is typically embodied in the PMP. In many cases, the PMP can overwhelm the sensitivity to other parameters, but this is not really the case for Susitna-Watana.
- Use of the PMF as the design flood is an inherently conservative design criterion, but it should not become excessively conservative.

Selected PMF and Spillway Sizing

- June 1 PMF sensitivity run – 310,000 cfs inflow
- Ogee-crested spillway – 3 gates
- Spillway crest at El 2000
- Spillway gates begin to open at El 2057.6
- Zero turbine flow at water levels above El 2057.6
- 8 valves @4,000 cfs operate during PMF
- Maximum PMF water level is at El 2064.4
- Total spillway crest length is 126 feet

PMF Inflow, Outflow, and Reservoir Elevation



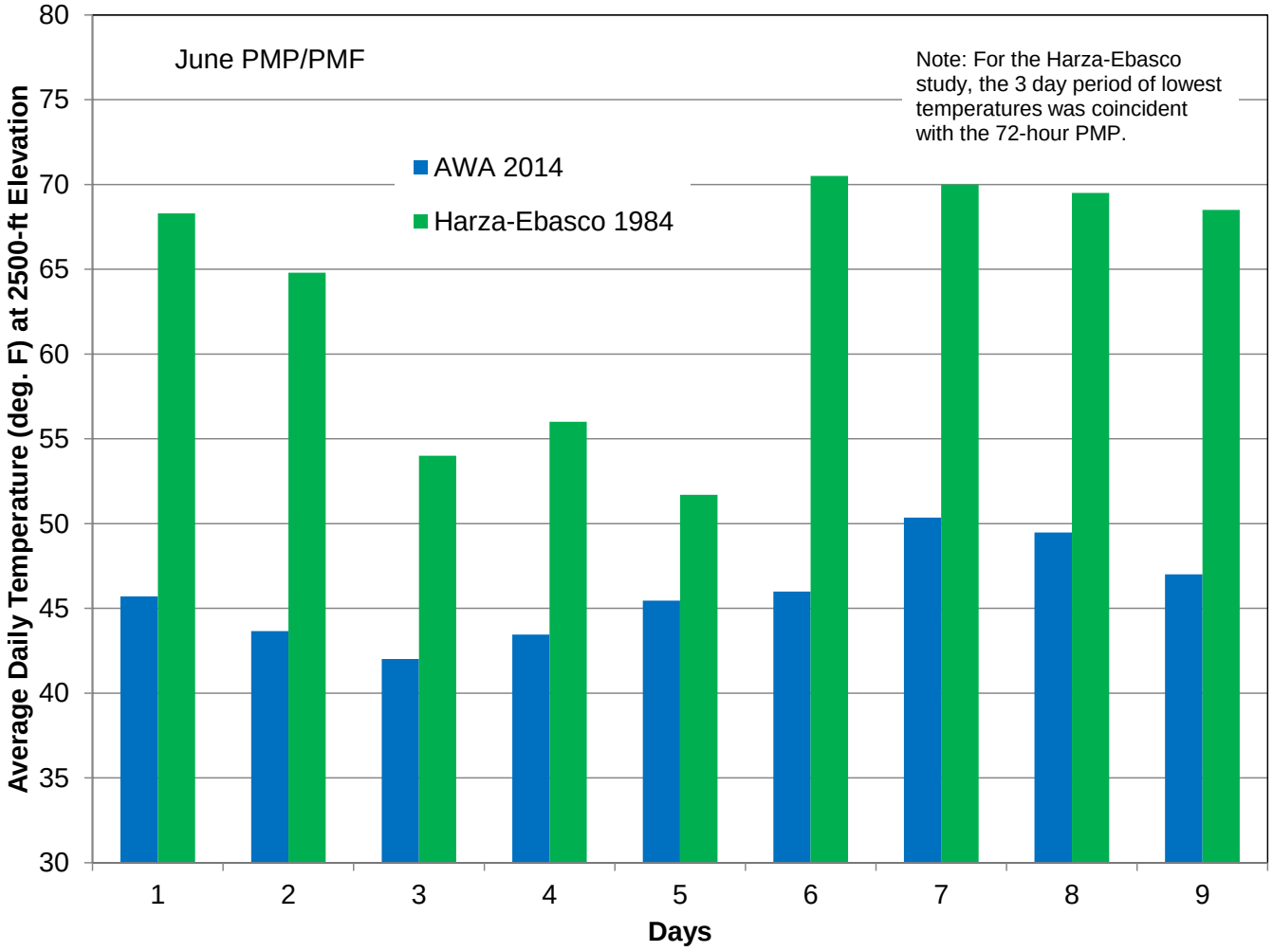
PMF Study Comparison – PMP and SWE

PMP Duration	All-Season PMP (inches)			June PMP (inches)		
	Acres 1982	H-E 1984	AWA 2014	Acres 1982	H-E 1984	AWA 2014
24 hours	3.07	4.10	4.40	2.15	3.80	4.14
72 hours	6.59	6.80	7.19	4.61	6.30	6.76
PMP total (days)	12.5 (10 days)	N/A	10.00 (9 days)	8.7 (10 days)	N/A	9.4 (9 days)

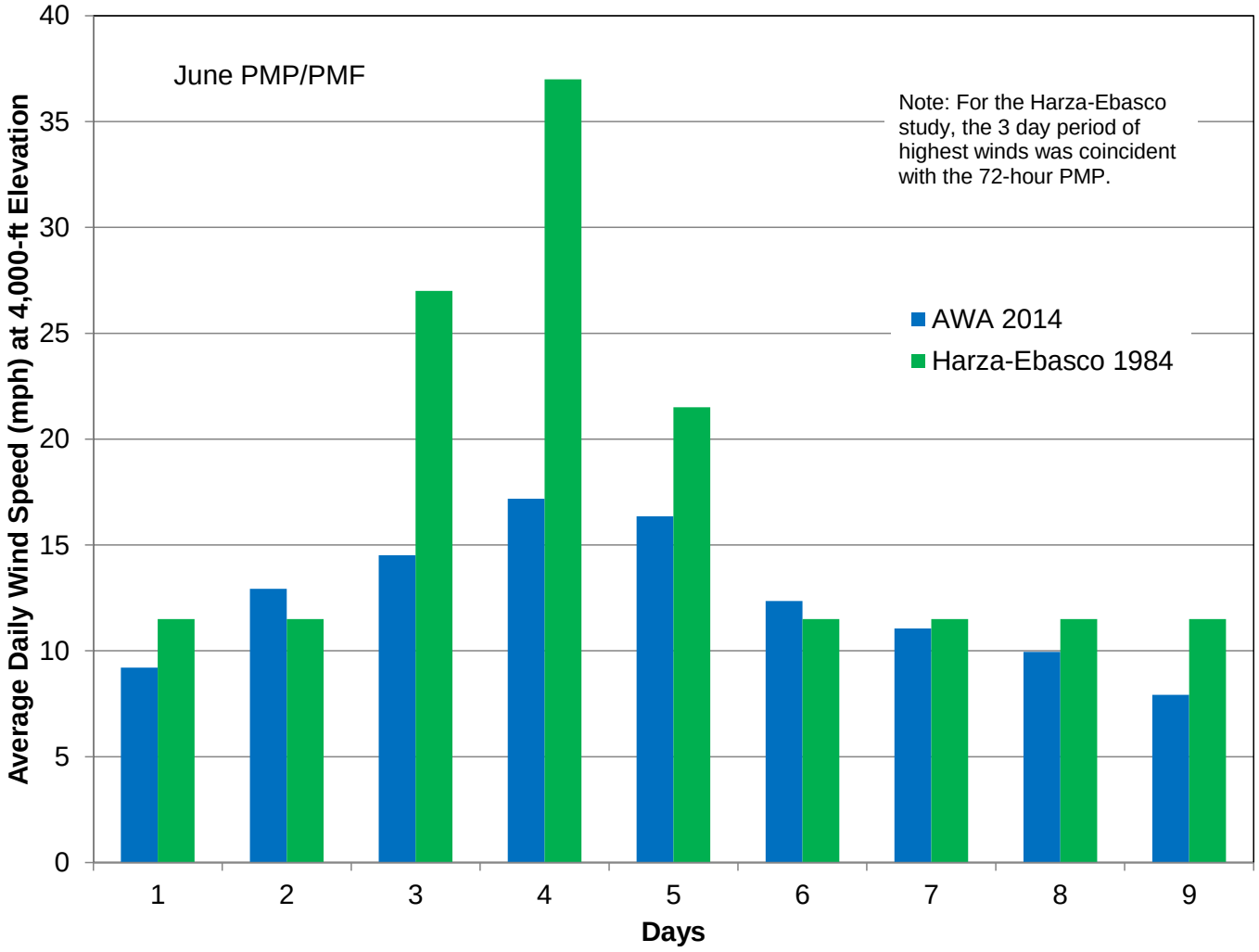
Snowpack SWE Coincident with PMP	
Acres 1982	49 inches
Harza-Ebasco 1984	16.8 inches
MWH current	15.7 inches

Probable Maximum Snowpack	
Acres 1982	N/A
Harza-Ebasco 1984	N/A
MWH current	27.9 inches

PMF Study Comparison – Temperature



PMF Study Comparison – Wind



PMF Study Comparison – PMF Inflow and Outflow

Parameter	1982 Acres PMF	1984 Harza-Ebasco PMF	2014 MWH PMF
PMF peak inflow (cfs)	326,000	309,000	310,000
PMF peak outflow (cfs)	302,400	N/A	281,000
13-Day Maximum Inflow Volume (acre-feet)	6,480,000	3,980,000	3,980,000
Fixed-cone valves total capacity (cfs)	24,000	N/A	32,000
Spillway capacity at PMF surcharge (cfs)	278,400	N/A	249,000

Previous Study Comparison – Freeboard

Parameter	1985 (1) Watana Stage I	1985 (1) Watana Stage III	2014 Watana AEA
Maximum normal pool elevation (feet)	2000.0	2185.0	2050.0
50-year flood peak reservoir elevation (feet)	2011.0	2191.5	2057.6
Elevation that spillway begins to operate (feet)	2014.0	2193.0	2057.6
PMF peak reservoir elevation (feet)	2017.1	2199.3	2064.5
Total flood control storage (feet)	17.1	14.3	14.5
Normal freeboard (feet)	25.0	25.0	> 15
Minimum freeboard for PMF (feet)	7.9	10.7	> 3.5

Note: (1) Data from 1985 FERC License Application

PMP / PMF Study Summary

- All-season PMP: 4.40 in 24 hrs; 7.19 in 72 hrs; 10.00 in 216 hours (Watana basin averages)
- Controlling case – June 1 sensitivity run with low loss rates
- Includes 8 outlet valves @4,000 cfs = 32,000 cfs
- Includes ogee-crested spillway with three 42-ft wide gates and crest level at El 2000 ft.
- Peak PMF inflow – 310,000 cfs
- Peak PMF outflow – 281,000 cfs
- Peak PMF reservoir elevation – 2064.4 feet