

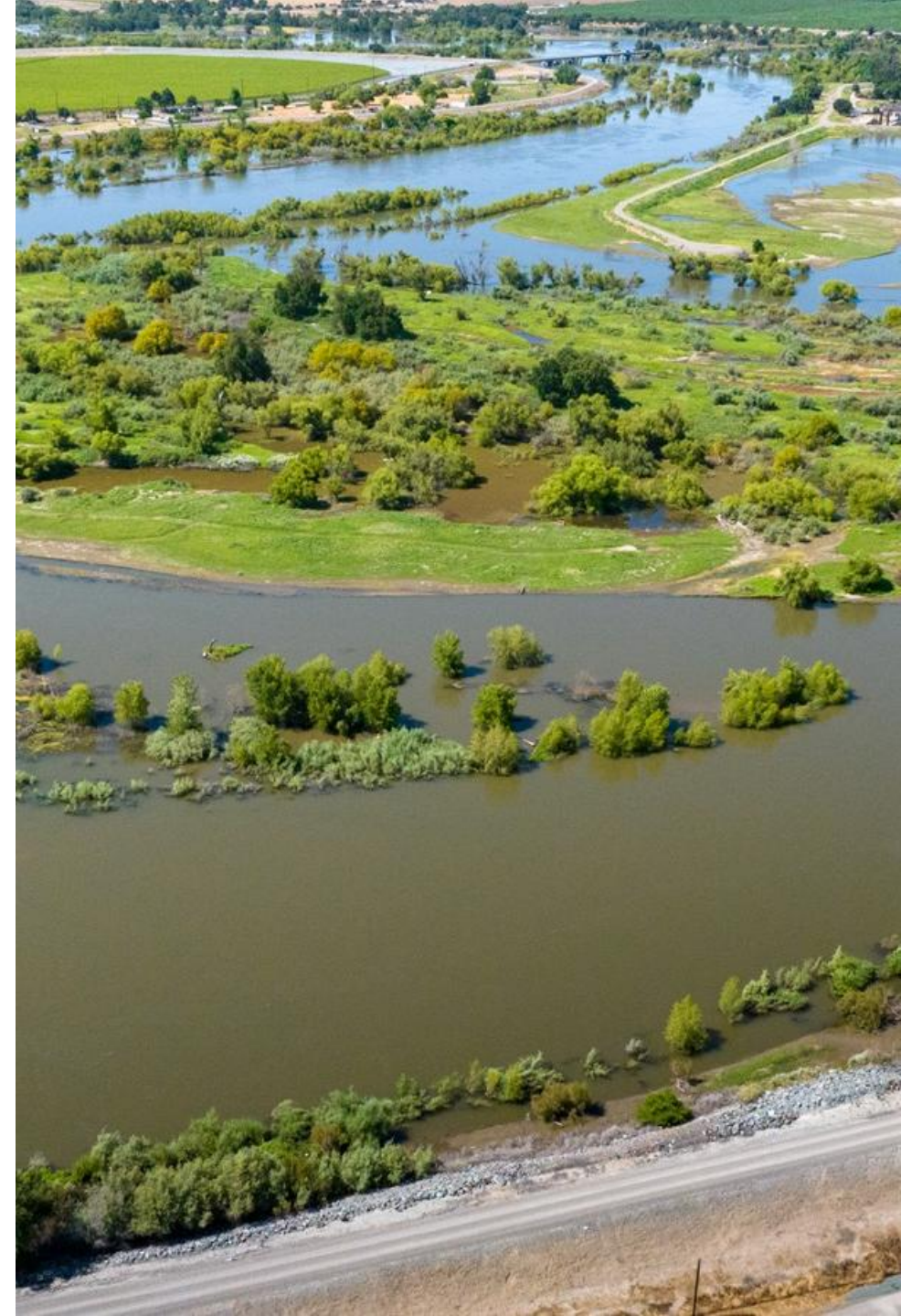
Analyzing Climate Modeling in the Central Valley: Nexus of Statistics and Data Analysis Tools

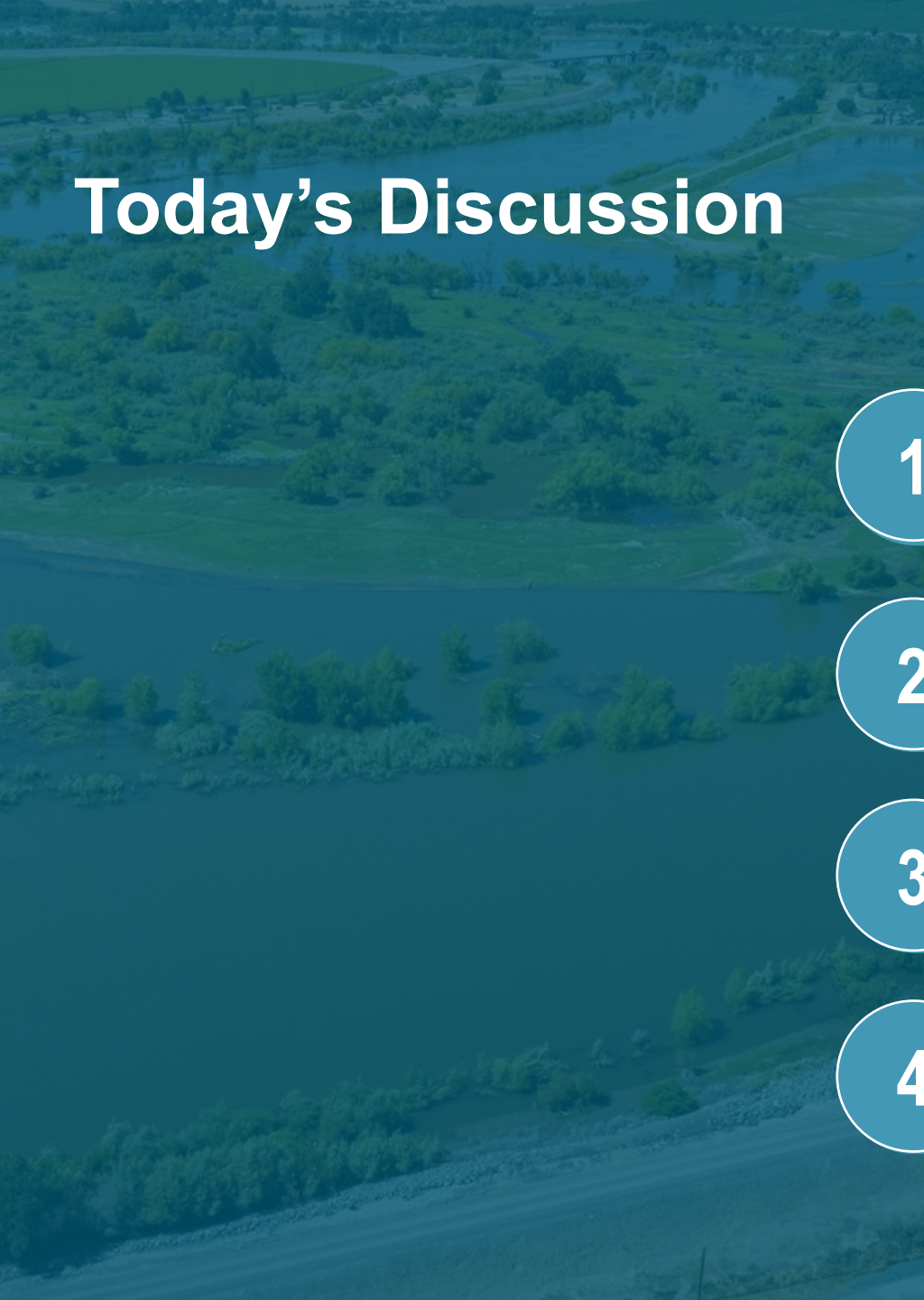
California Water and Environmental Modeling Forum
April 21, 2026

Chakri Malakpet, PE, BC. WRE
Asphota Wasti, PhD

Collaborators:

Chong Vang, PE (DWR)
Michael Konieczki, PE, BC. WRE



An aerial photograph of a river winding through a lush green forest. The river is dark blue, and the surrounding land is covered in dense green trees and vegetation. The image is partially obscured by a dark blue overlay on the left side, which serves as a background for the text.

Today's Discussion

1 CVFPP Climate Analysis Overview

2 Flow Frequency Analysis Methods

3 Consistency Checks

4 Key Takeaways

01 CVFPP Climate Analysis Overview

What is the CVFPP?

The Central Valley Flood Protection Plan (CVFPP) is a critical document to guide California's participation (and influence federal and local participation) in managing flood risk along the Sacramento River and San Joaquin River systems.

The CVFPP proposes a systemwide investment approach for sustainable, integrated flood management in areas currently protected by facilities of the State Plan of Flood Control (SPFC). The CVFPP will be updated every five years, with each update providing support for subsequent policy, program, and project implementation.

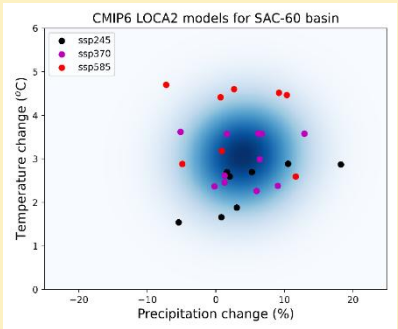


CVFPP Inland Climate Change Approach

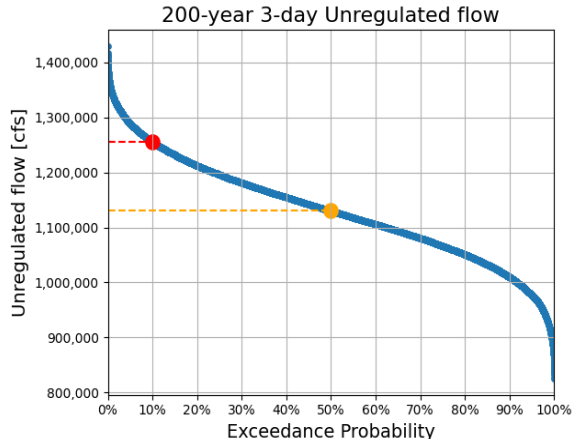
General Circulation Models (GCMs)
(CMIP6 LOCA2 Downscaled)



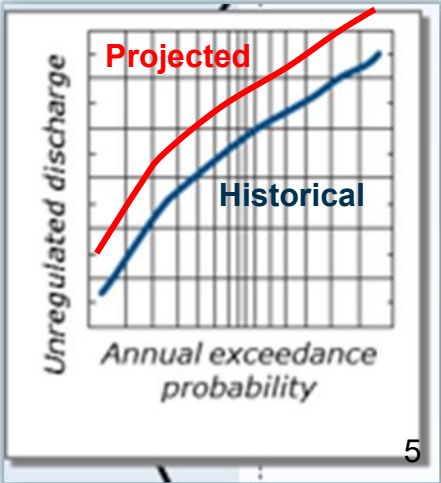
Future Climates



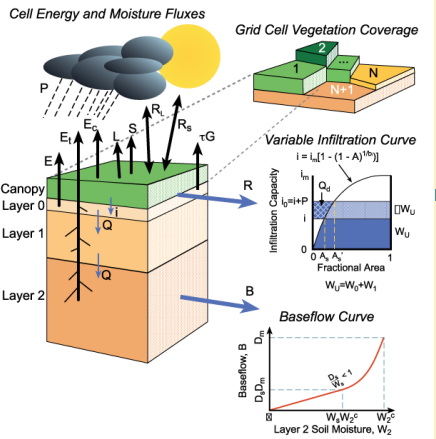
Quantify Future Flood Risk
(Risk Tolerance Level)



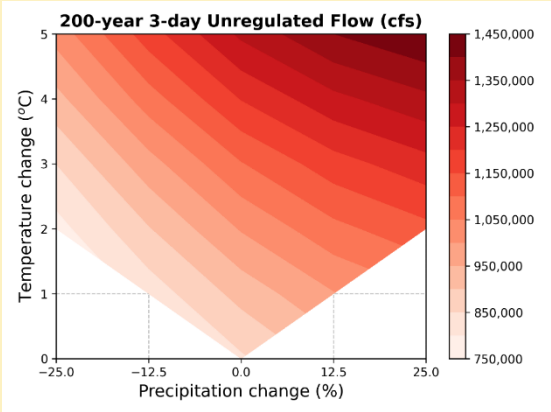
Adjusted Unregulated Flow
Frequency Curve



Climate Scenarios
Weather Generator (WGEN)



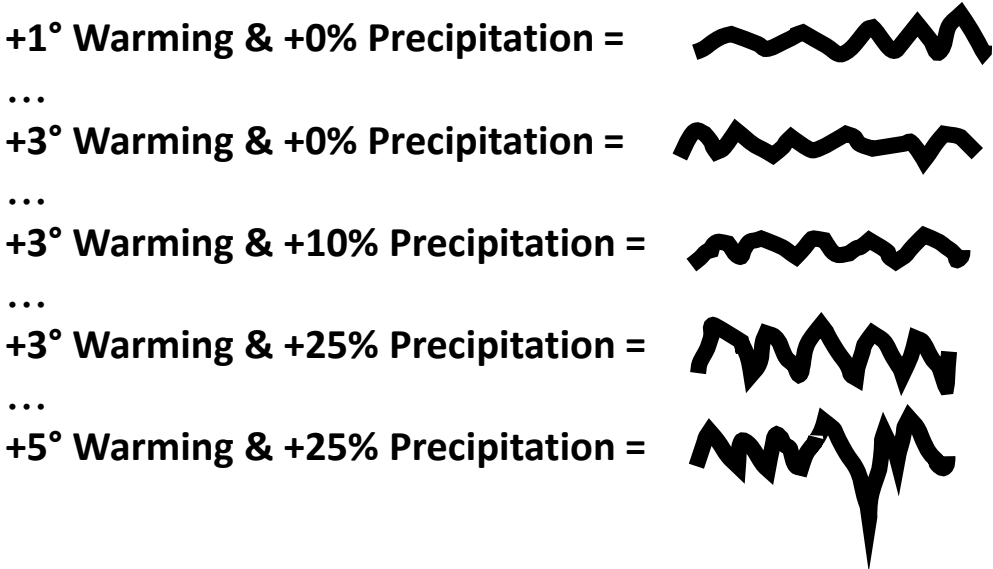
Hydrologic Model



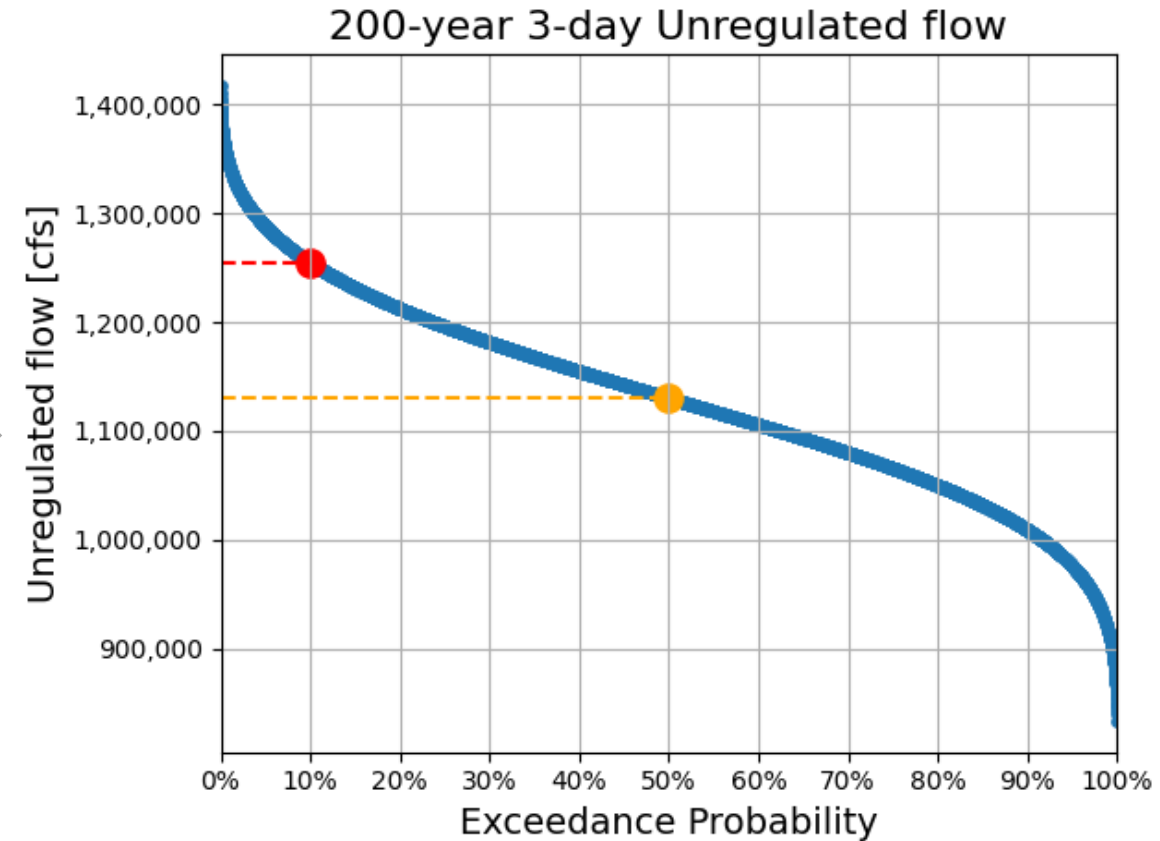
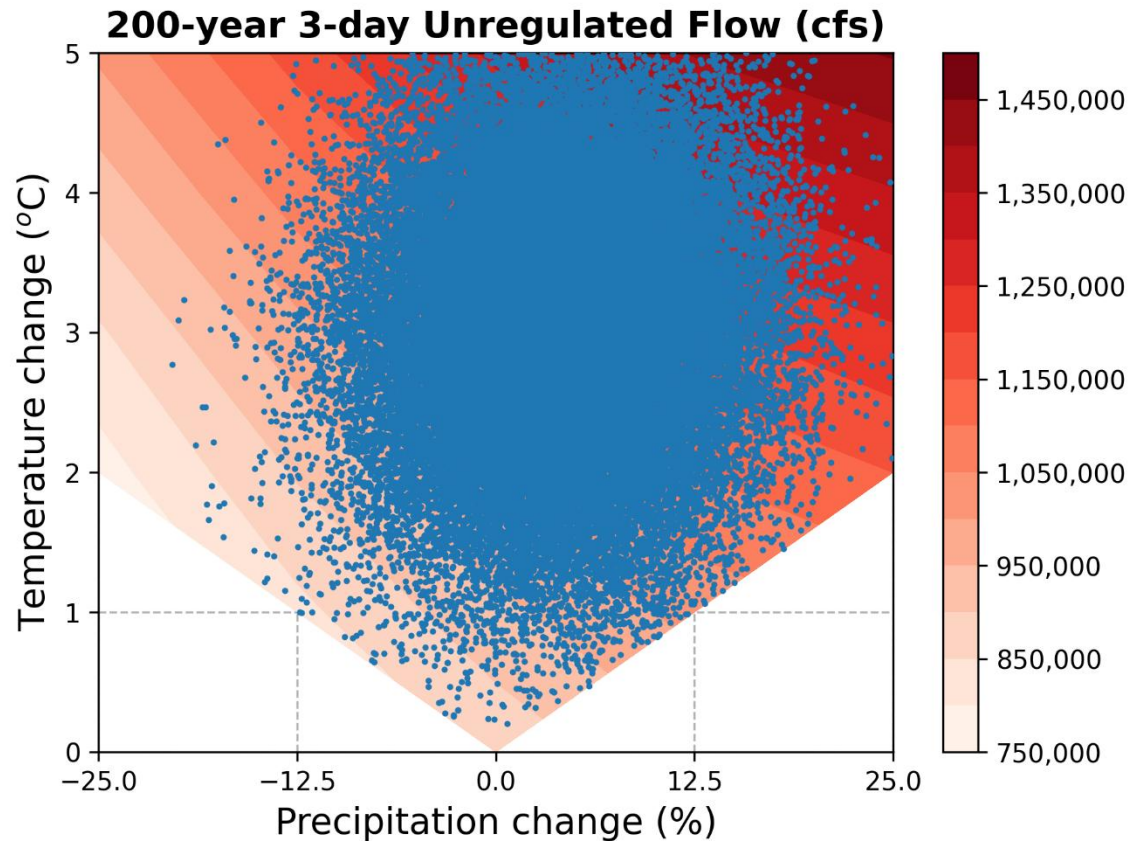
System Stress Test

Weather Generator: Climate Scenario

The weather generator allows us to adjust combinations of changes in temperature and precipitation to identify how large our floods may get.



Response Surface and Future Flows



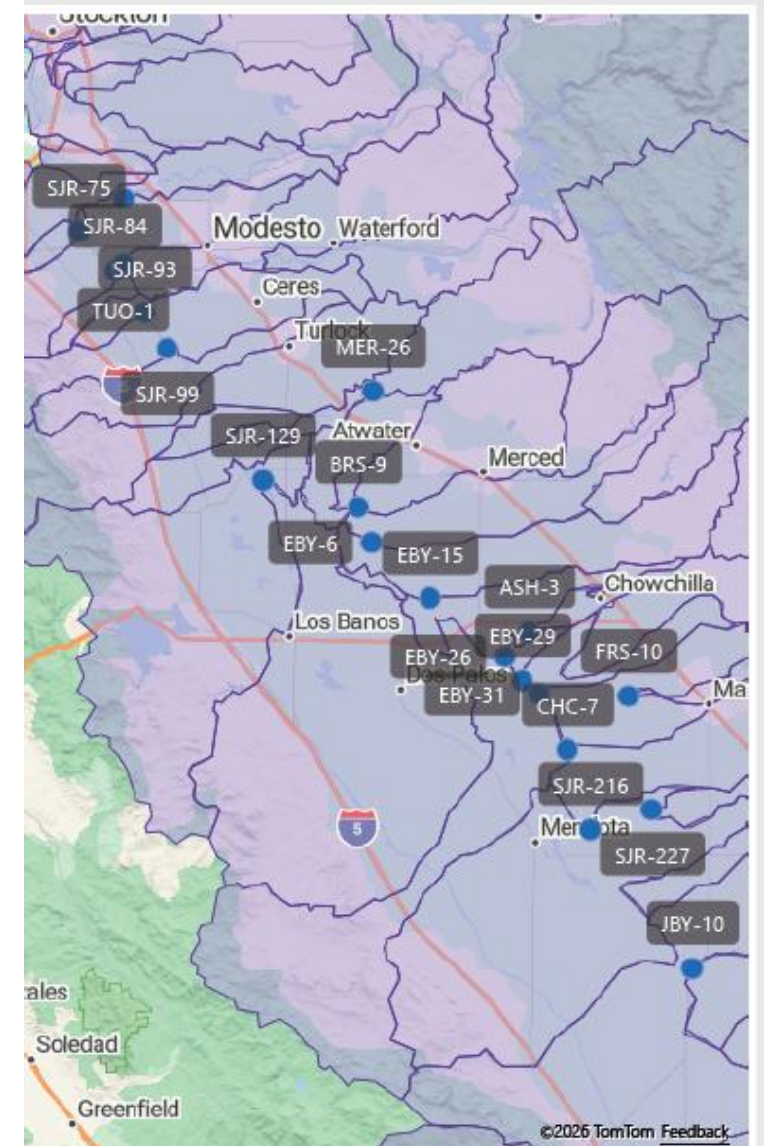
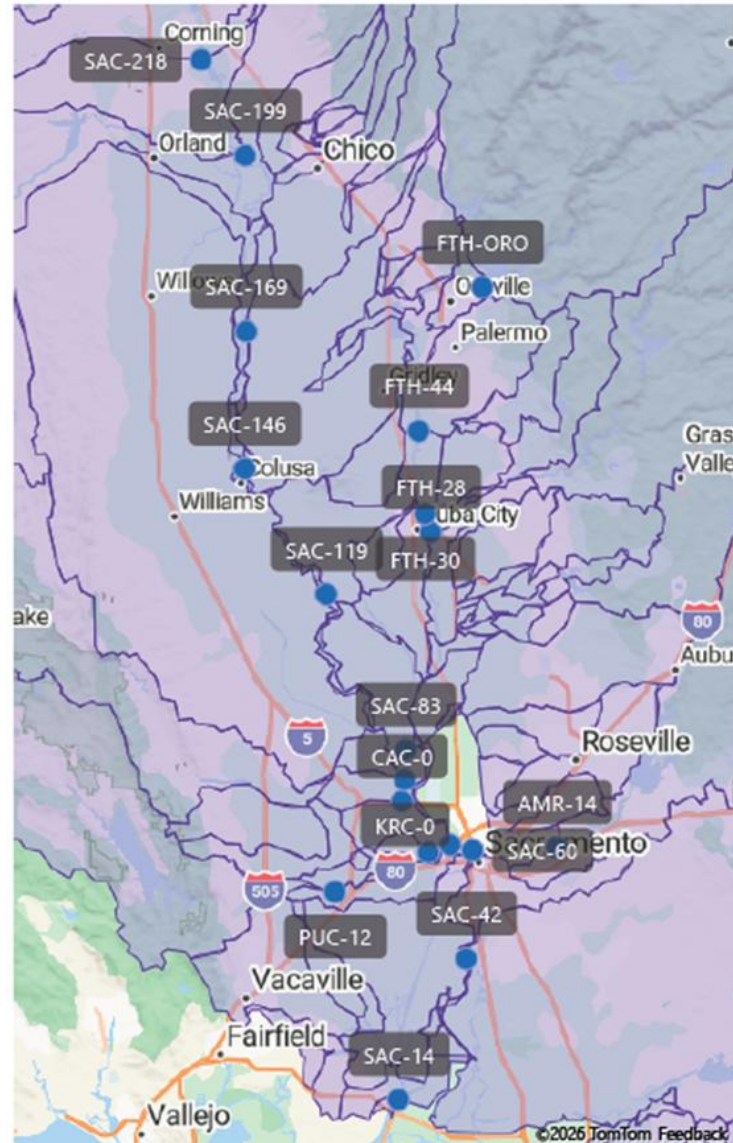
Response Surface derived from WGEN + VIC model & **Climate Samples** (blue dots) from GCM+LOCA2 in Year 2077 at Sacramento River below American River.

Flows in Year 2077 at **10%** and **50%** Risk Tolerance Levels

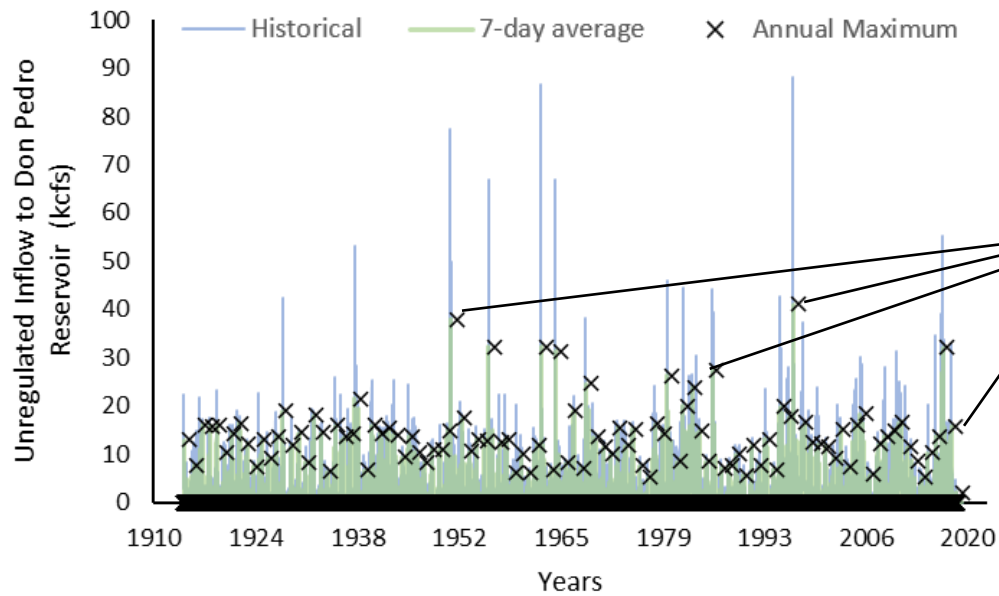
02 Flow Frequency Analysis

CVFPP Study Area

- Flow frequency information is developed at 204 Analysis Points in the Central Valley



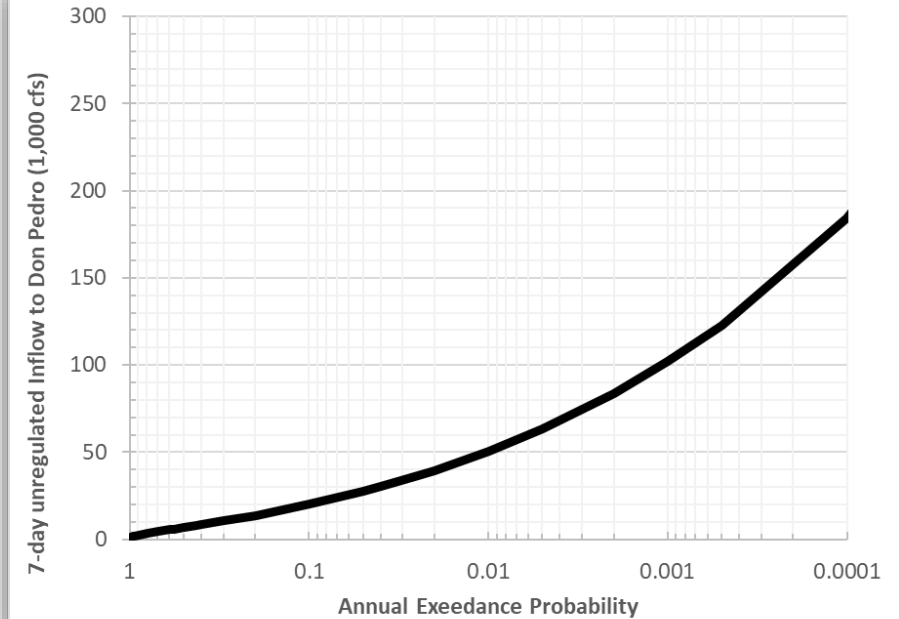
Unregulated Flow Frequency Analysis



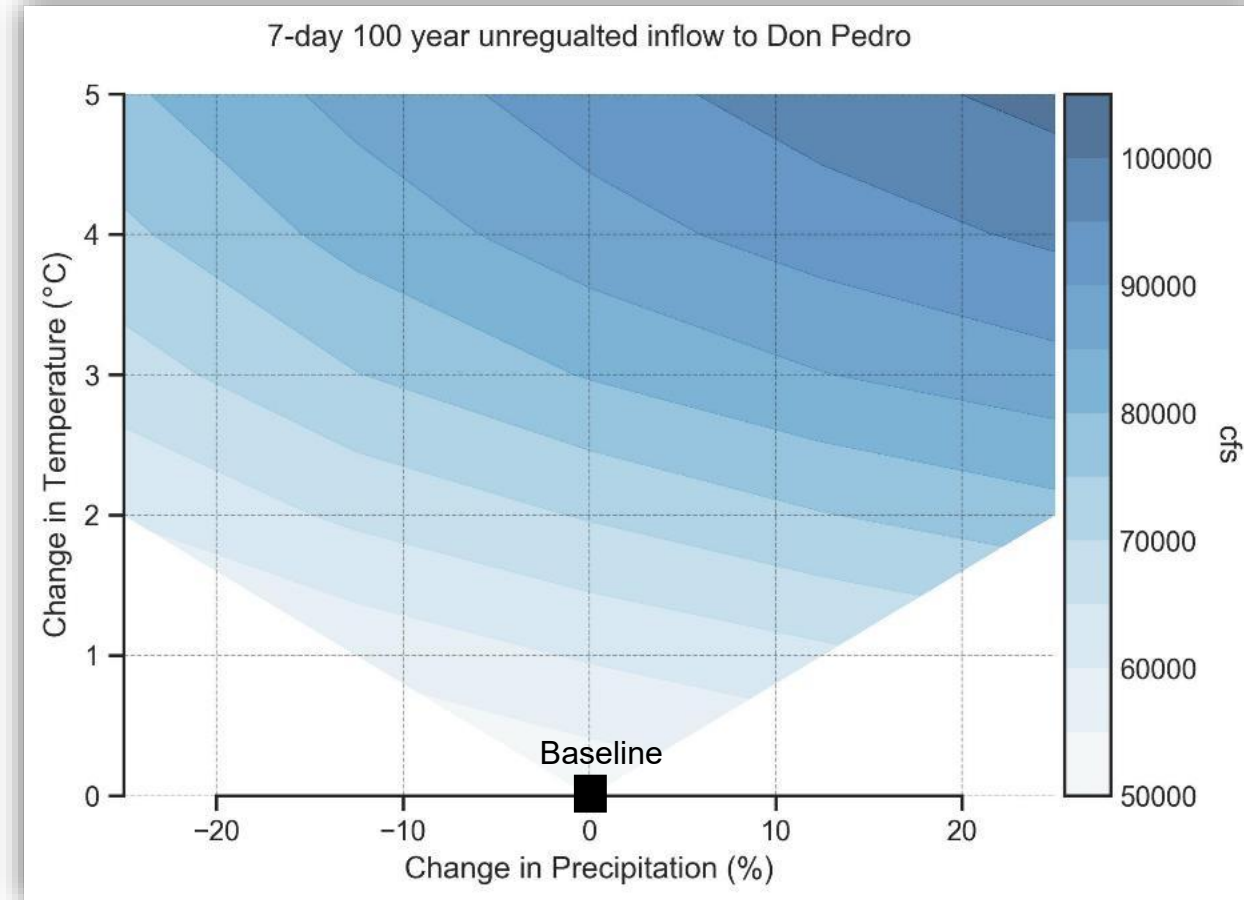
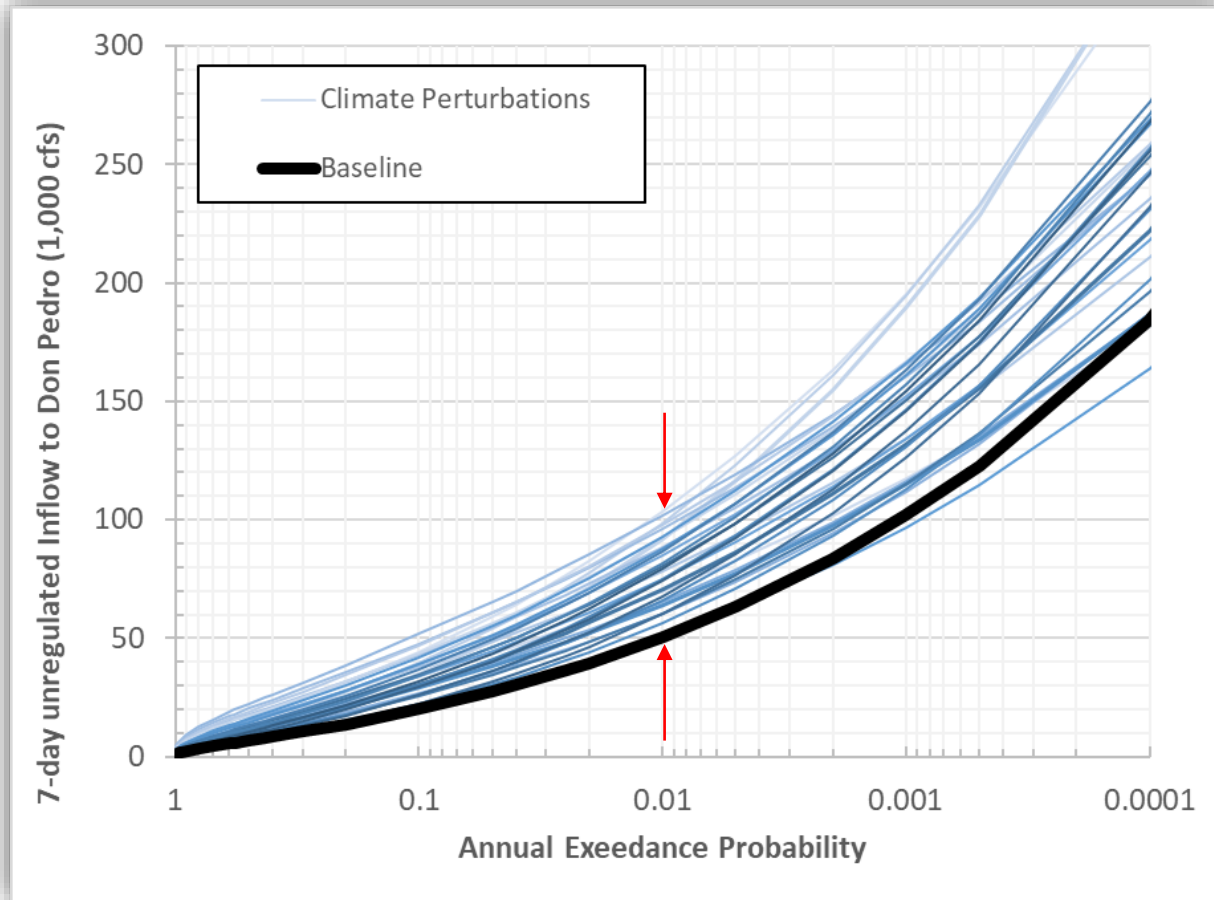
IPAST

Log- Pearson Type III (LP3)

*Bulletin 17C
EM 1110-2-1415*



Extract Flow Quantiles for Response Surface



03 Consistency Checks

HDR's Task

- Conduct External Review of the Climate and Watershed Analysis
- Analyze Results of:
 - VIC Streamflow Simulations
 - Unregulated Flow Frequency Analysis
 - Climate Change Factors
- Confirm Results are Consistent with the Relevant Guidance
- Provide Recommendations

Consistency Check #1

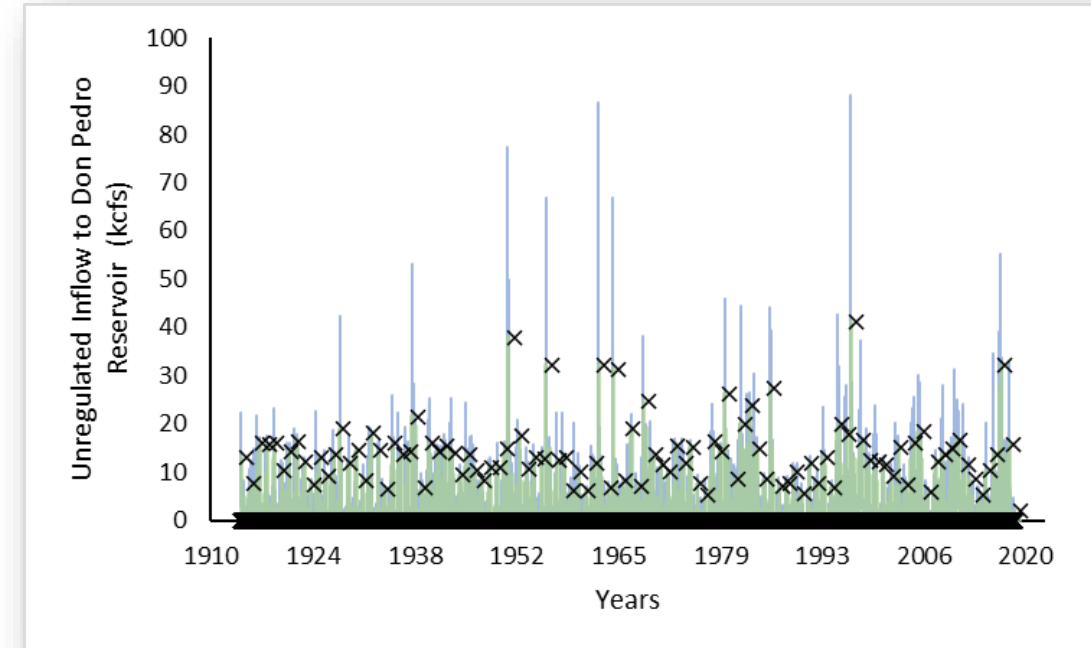
Annual Maxima Series (AMS) Extraction Windows

Question

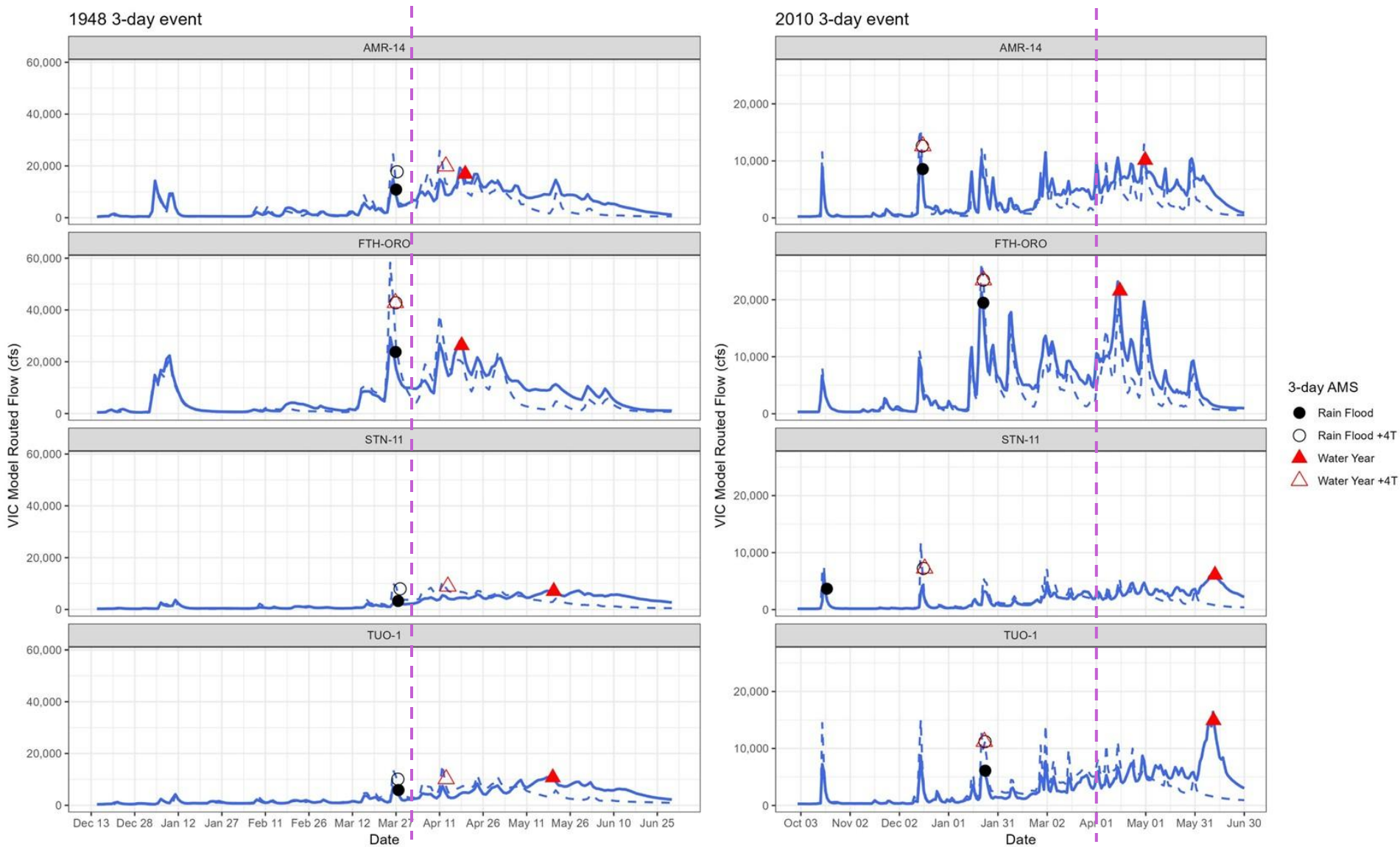
- How Sensitive are Annual Maxima Series to Extraction Time Windows?

Analysis

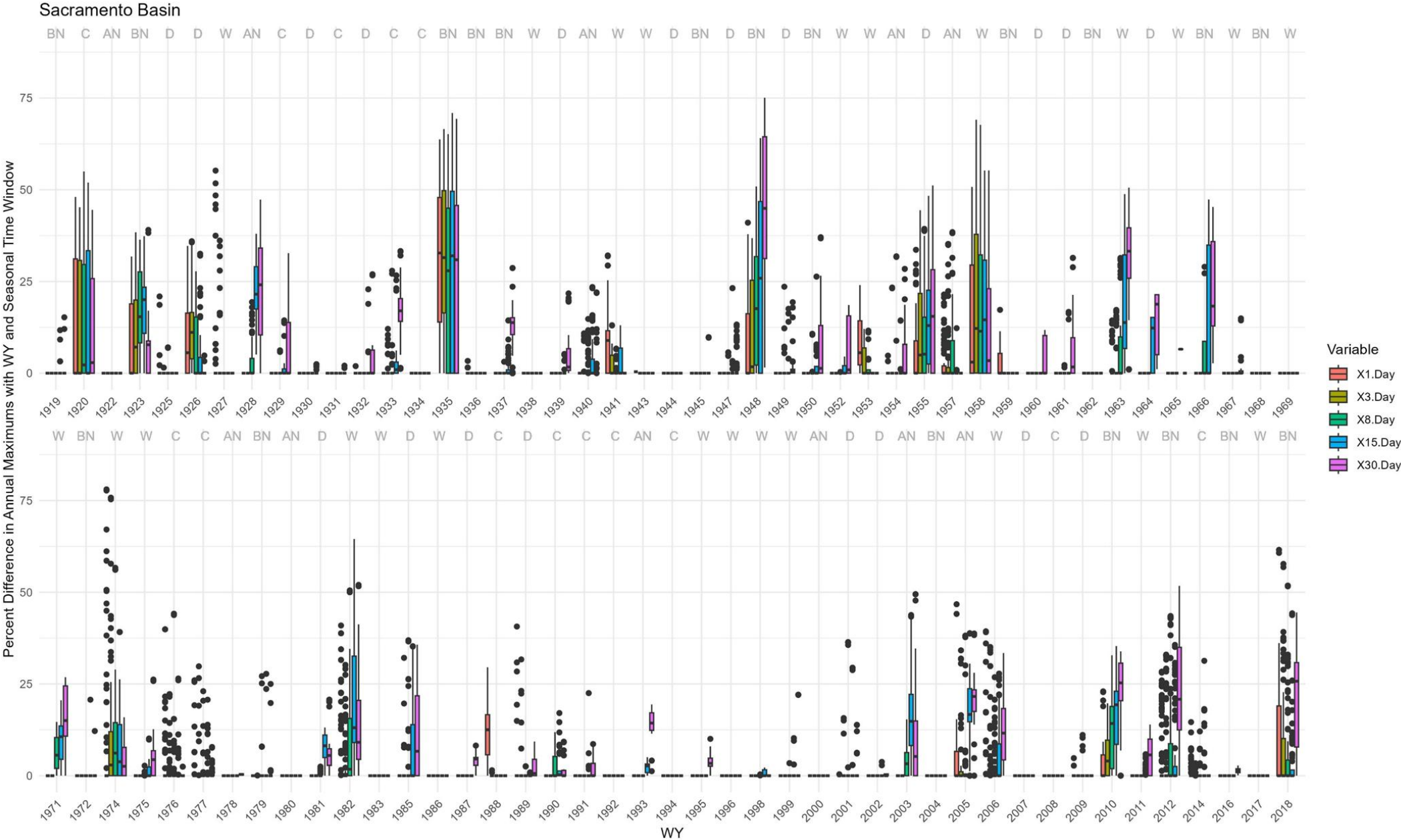
- Water Year (WY) Window (Oct 1 to Sep 30)
- Rain Flood (RF) Window (Oct 1 to Mar 31)



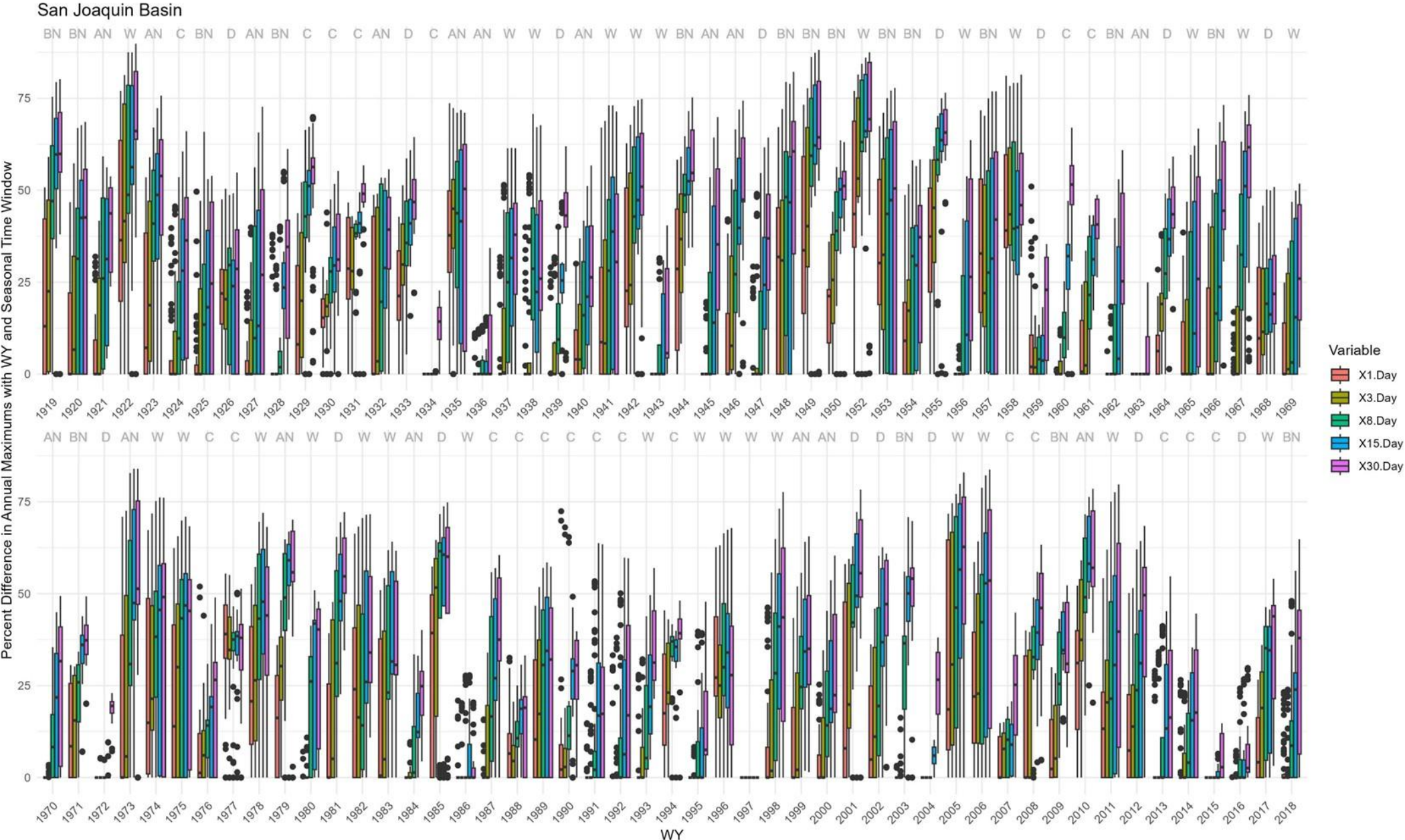
Hydrographs and Annual Maxima Comparison



Sacramento Basin AMS % Differences



San Joaquin Basin AMS % Differences



Consistency Check #1

Annual Maxima Series (AMS) Extraction Windows

Findings

- There are differences in the extracted AMS using WY and the RF windows, with higher differences in San Joaquin Basin compared to Sacramento Basin.
- Using WY window has the potential to include both rain-driven and snowmelt driven flood events in the AMS resulting in mixed population of annual maxima.

Consistency Check #2

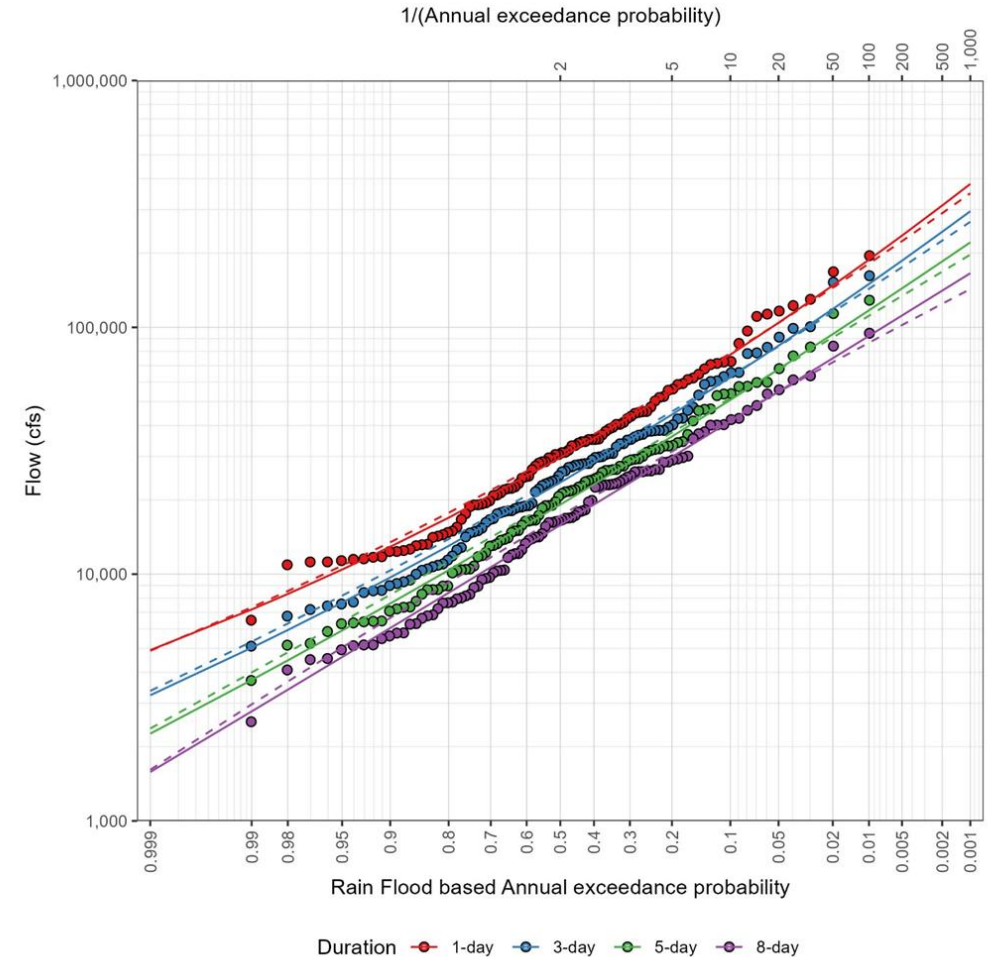
Annual Maxima Series (AMS) Extraction Windows

Question

- How Sensitive are flow frequency curves to Extraction Time Windows?

Analysis

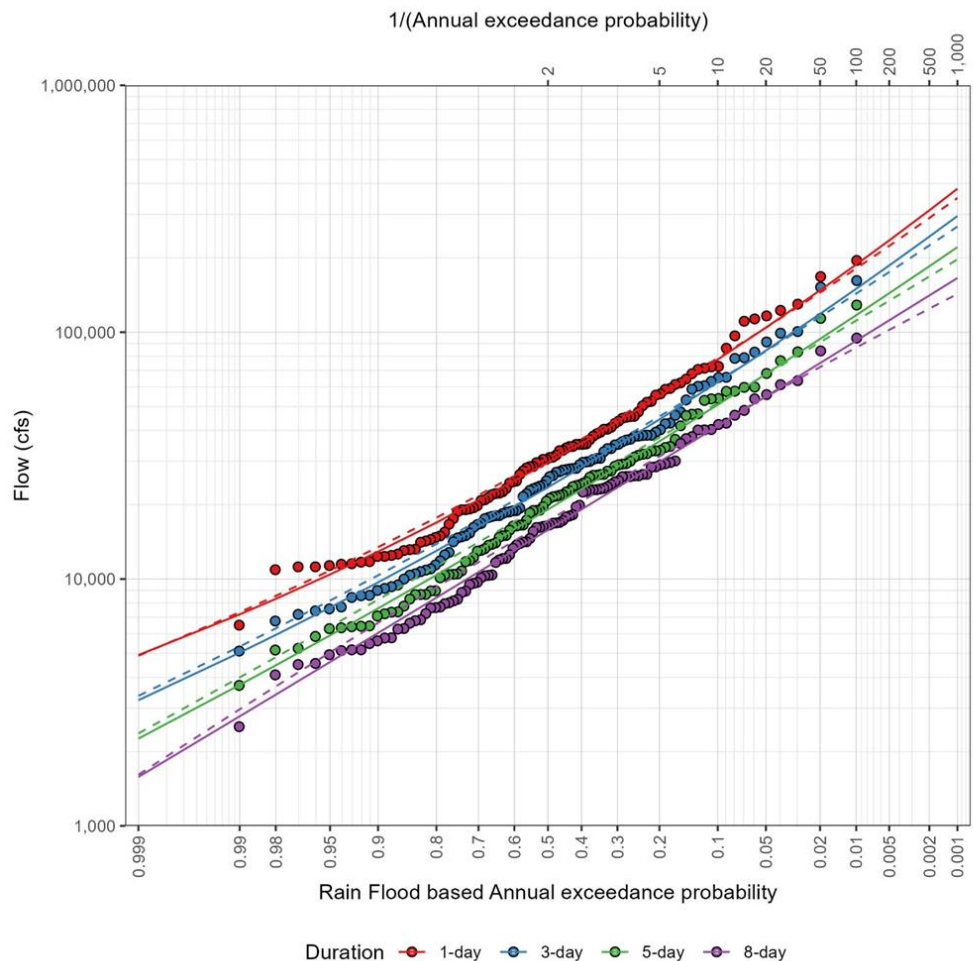
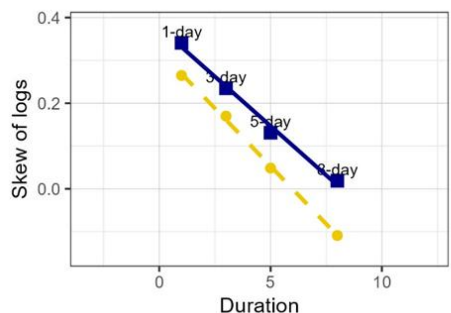
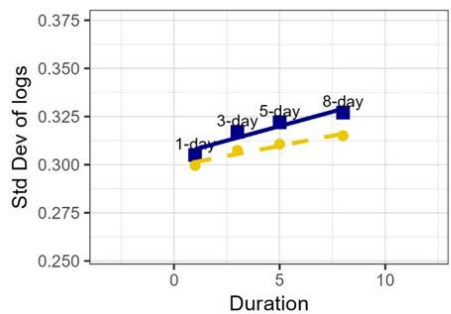
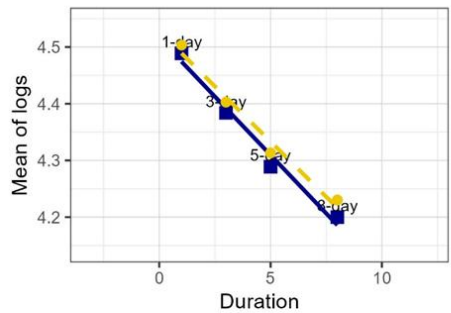
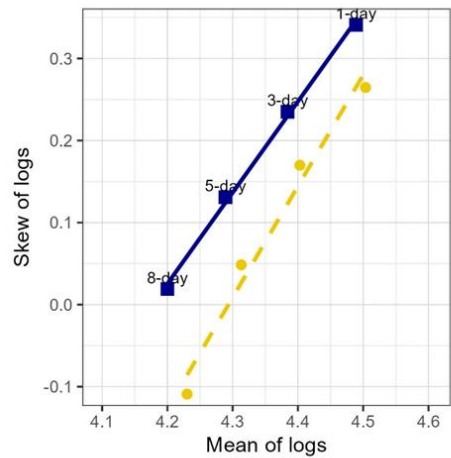
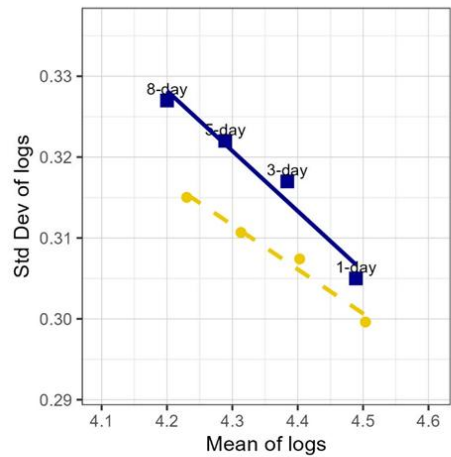
- Water Year (WY) Window (Oct 1 to Sep 30)
- Rain Flood (RF) Window (Oct 1 to Mar 31)
- Fit Log Pearson Type III (LP3) Distributions



Flow Frequency Curves and Parameters

AP name: AMR-14

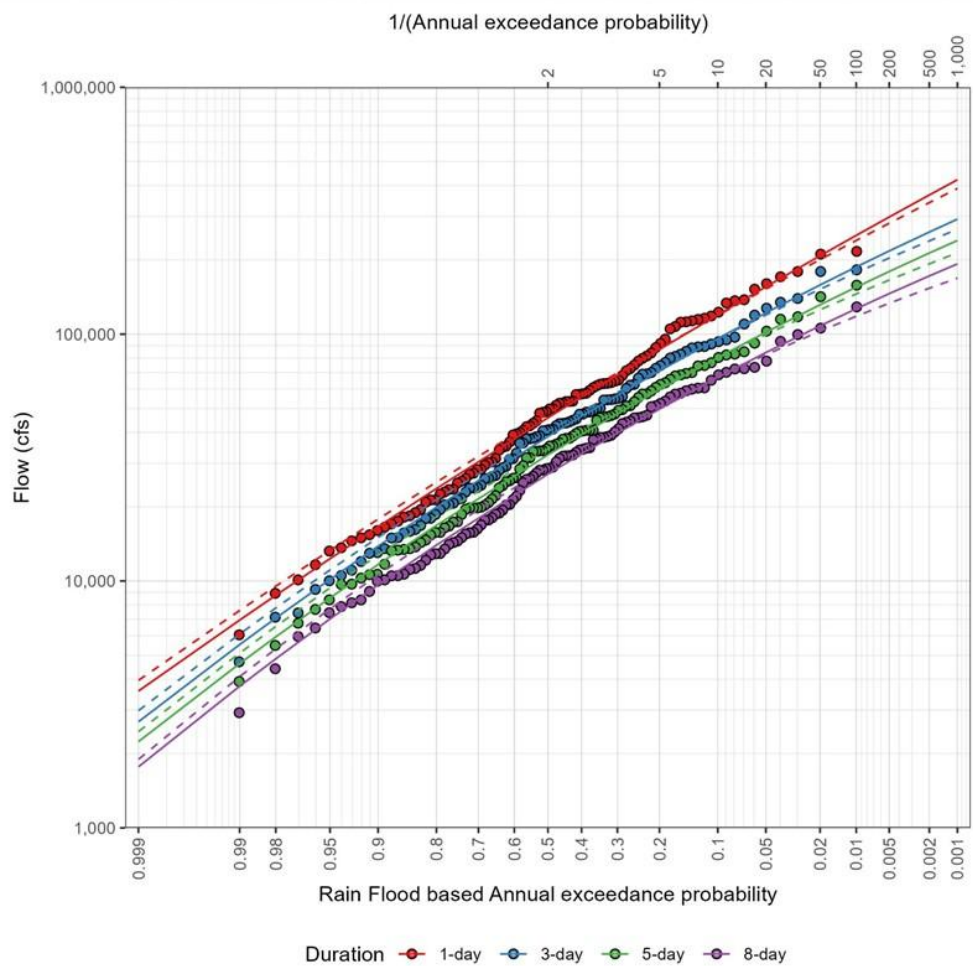
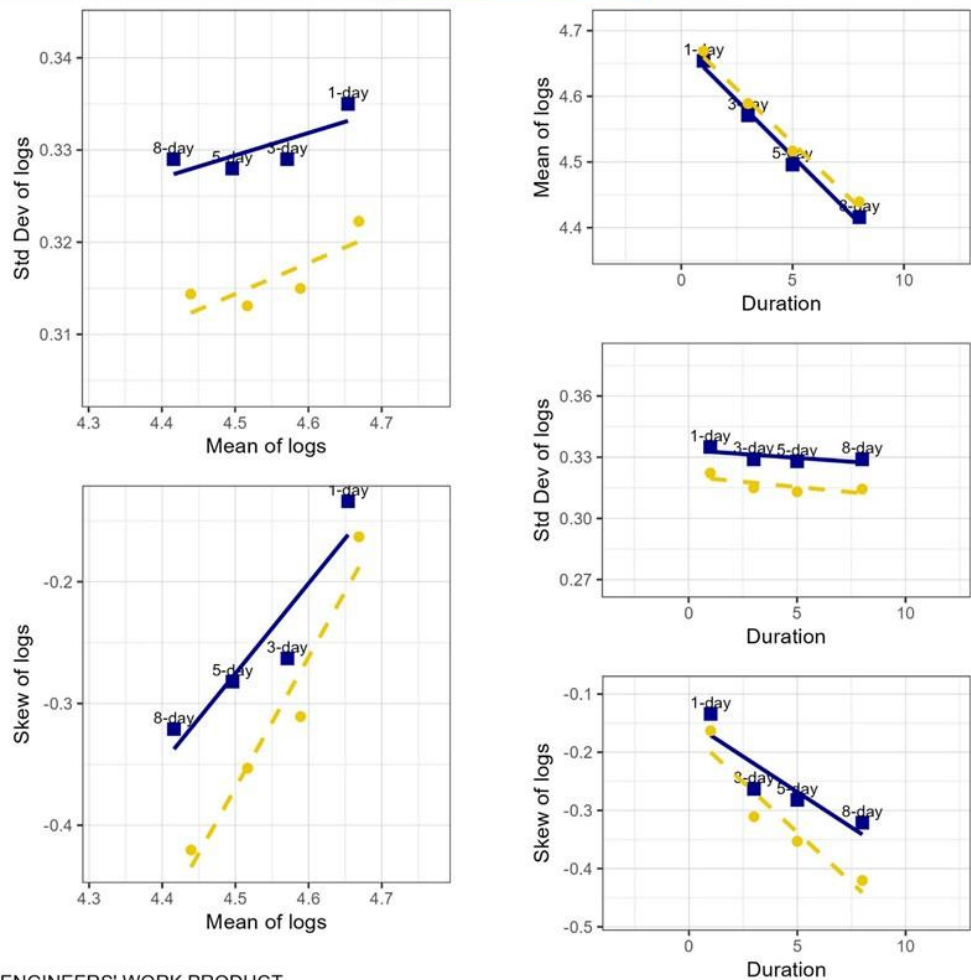
Duration (days)	Rain Flood Mean	Rain Flood Std Dev	Rain Flood Skew	Rain Flood LO	Water Year Mean	Water Year Std Dev	Water Year Skew	Water Year LO	AEP	1/AEP	Rain Flood 1-day	Rain Flood 3-day	Rain Flood 5-day	Rain Flood 8-day	Water Year 1-day	Water Year 3-day	Water Year 5-day	Water Year 8-day	Diff 1-day	Diff 3-day	Diff 5-day	Diff 8-day
1	4.489	0.305	0.341	0	4.503630	0.2996085	0.26466846	0	0.001	1,000	381,200	295,500	221,000	165,700	349,400	267,800	197,100	142,900	-31,800	-27,700	-23,900	-22,800
3	4.384	0.317	0.235	0	4.403034	0.3074092	0.16988530	0	0.002	500	311,600	243,800	185,000	140,800	290,100	224,600	168,100	124,500	-21,500	-19,200	-16,900	-16,300
5	4.289	0.322	0.131	0	4.313148	0.3106820	0.04850916	0	0.005	200	235,400	186,300	143,900	111,700	223,700	175,300	134,100	102,200	-11,700	-11,000	-9,800	-9,500
8	4.200	0.327	0.019	0	4.230199	0.3150231	-0.10899649	0	0.010	100	187,900	149,900	117,200	92,300	181,300	143,300	111,400	86,600	-6,600	-6,600	-5,800	-5,700
									0.020	50	147,800	118,600	93,900	75,000	144,700	115,300	91,000	72,200	-3,100	-3,300	-2,900	-2,800
									0.050	20	104,300	84,300	67,700	54,900	104,200	83,800	67,400	54,800	-100	-500	-300	-100
									0.100	10	77,500	62,700	50,800	41,700	78,500	63,400	51,600	42,700	1,000	700	800	1,000
									0.200	5	54,900	44,300	36,100	29,800	56,400	45,600	37,500	31,400	1,500	1,300	1,400	1,600



Flow Frequency Curves and Parameters

AP name: FTH-ORO

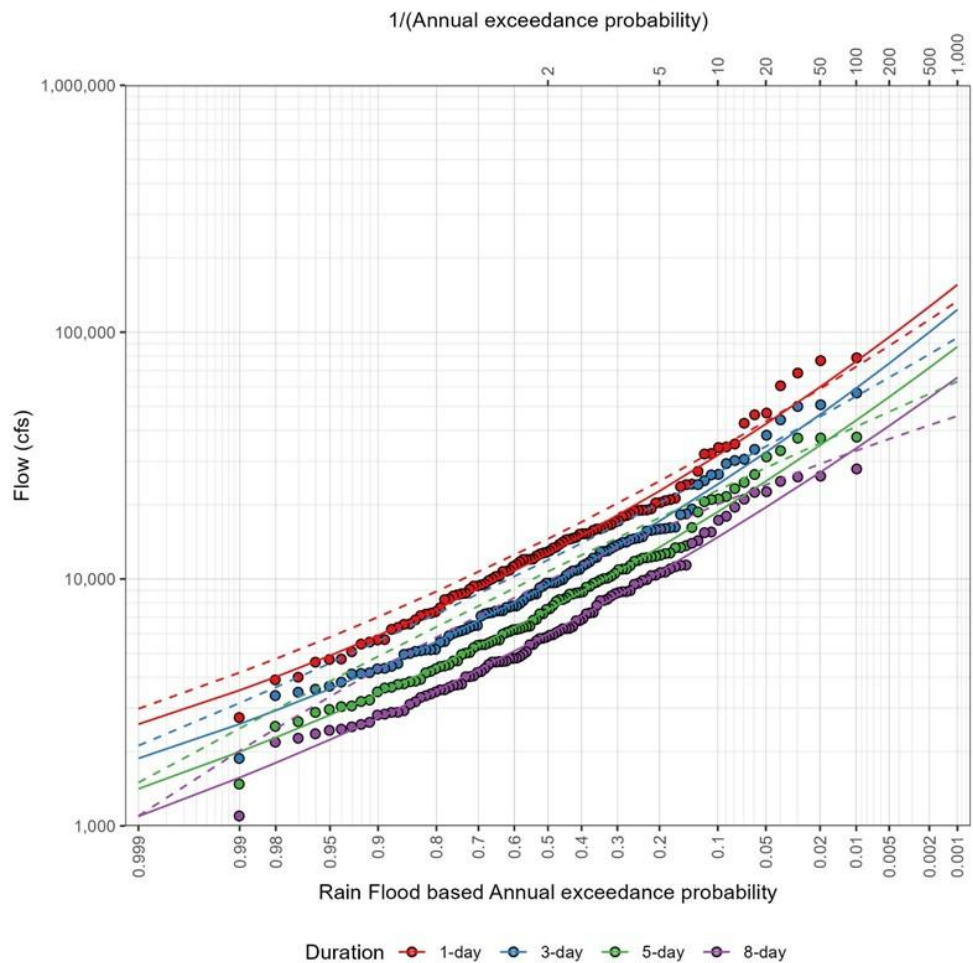
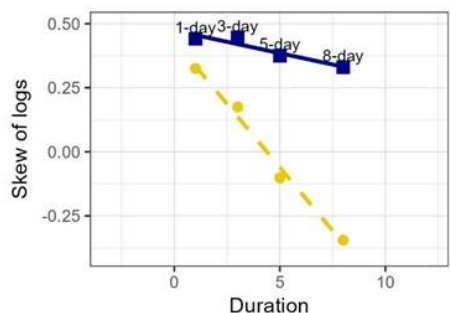
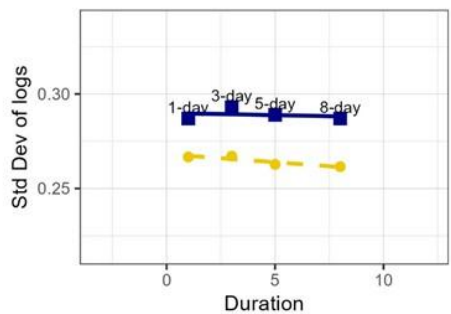
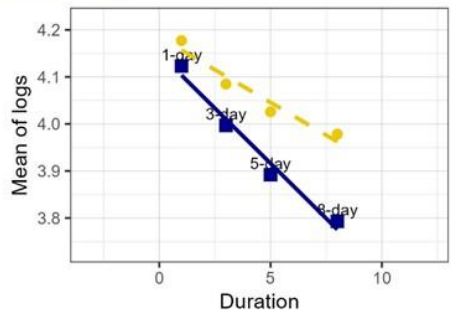
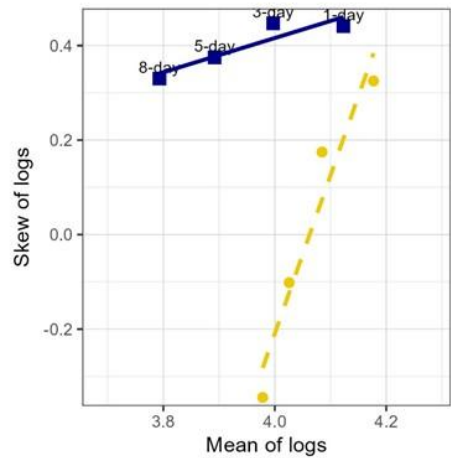
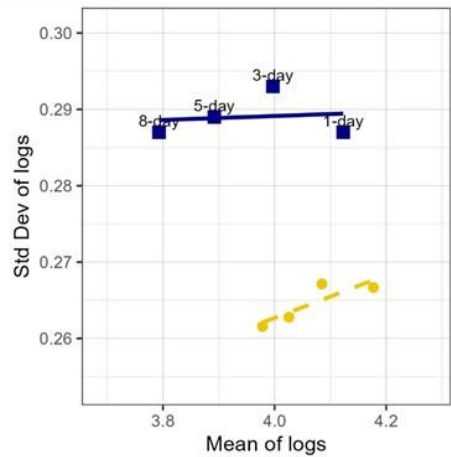
Duration (days)	Rain Flood Mean	Rain Flood Std Dev	Rain Flood Skew	Rain Flood LO	Water Year Mean	Water Year Std Dev	Water Year Skew	Water Year LO	AEP	1/AEP	Rain Flood 1-day	Rain Flood 3-day	Rain Flood 5-day	Rain Flood 8-day	Water Year 1-day	Water Year 3-day	Water Year 5-day	Water Year 8-day	Diff 1-day	Diff 3-day	Diff 5-day	Diff 8-day
1	4.654	0.335	-0.134	0	4.668865	0.3222537	-0.1631043	0	0.001	1,000	422,300	292,400	239,700	192,600	389,400	266,100	213,600	168,600	-32,900	-26,300	-26,100	-24,000
3	4.571	0.329	-0.263	0	4.589045	0.3149794	-0.3107768	0	0.002	500	366,300	259,200	213,200	172,200	341,100	238,800	192,800	153,500	-25,200	-20,400	-20,400	-18,700
5	4.496	0.328	-0.282	0	4.516678	0.3130959	-0.3530792	0	0.005	200	298,400	217,400	179,500	146,000	281,500	203,500	165,800	133,500	-16,900	-13,900	-13,700	-12,500
8	4.416	0.329	-0.321	0	4.439394	0.3143723	-0.4203251	0	0.010	100	251,300	187,200	155,100	126,800	239,700	177,500	145,600	118,200	-11,600	-9,700	-9,500	-8,600
									0.020	50	207,800	158,300	131,500	108,100	200,500	152,200	125,600	102,900	-7,300	-6,100	-5,900	-5,200
									0.050	20	155,600	122,000	101,900	84,200	152,600	119,600	99,600	82,500	-3,000	-2,400	-2,300	-1,700
									0.100	10	119,700	96,000	80,400	66,800	119,100	95,700	80,200	66,900	-600	-300	-200	100
									0.200	5	86,700	71,000	59,600	49,700	87,600	72,100	60,800	51,100	900	1,100	1,200	1,400



Flow Frequency Curves and Parameters

AP name: TUO-1

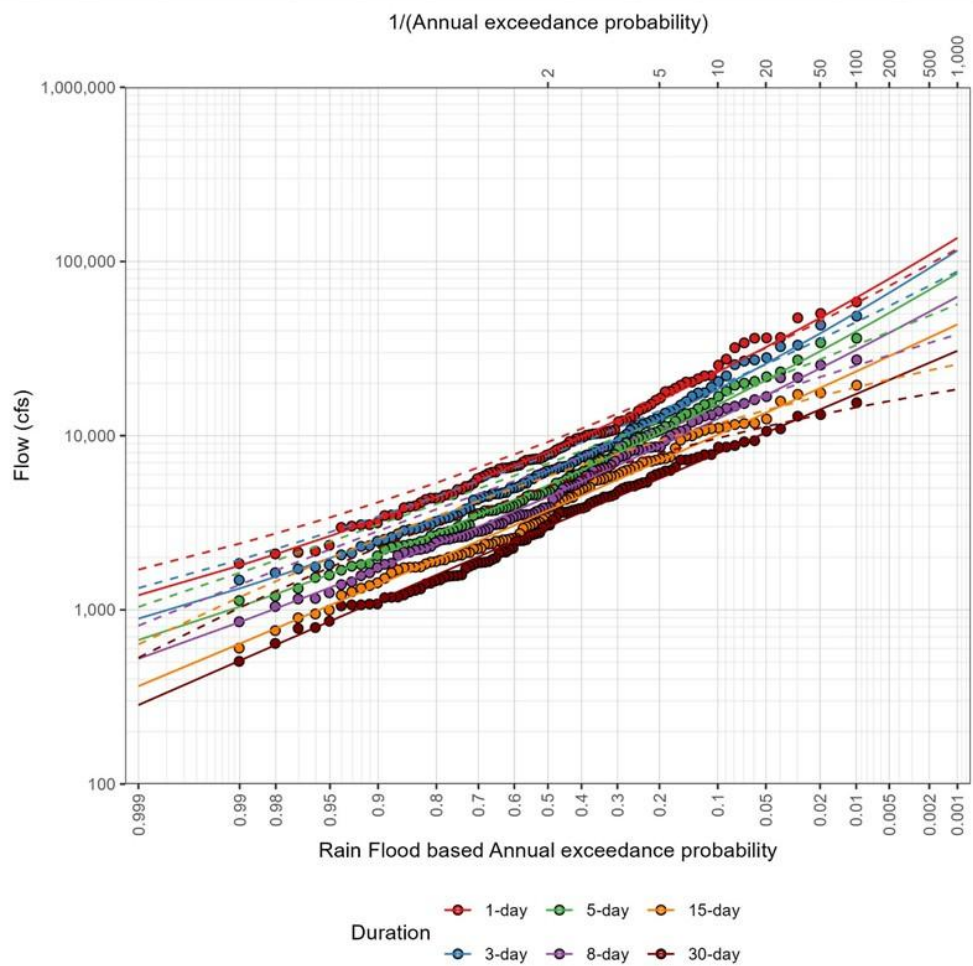
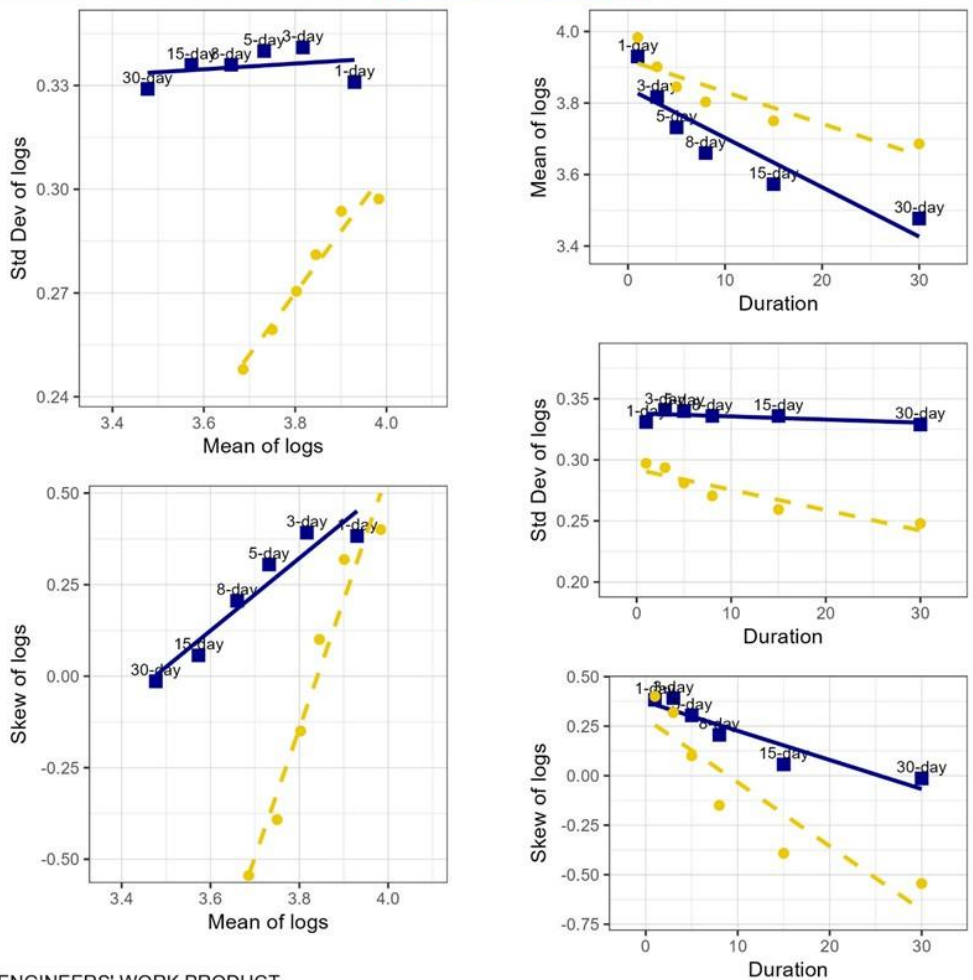
Duration (days)	Rain Flood Mean	Rain Flood Std Dev	Rain Flood Skew	Rain Flood LO	Water Year Mean	Water Year Std Dev	Water Year Skew	Water Year LO	AEP	1/AEP	Rain Flood 1-day	Rain Flood 3-day	Rain Flood 5-day	Rain Flood 8-day	Water Year 1-day	Water Year 3-day	Water Year 5-day	Water Year 8-day	Diff 1-day	Diff 3-day	Diff 5-day	Diff 8-day
1	4.123	0.287	0.441	0	4.177141	0.2666709	0.3250718	0	0.001	1,000	155,700	123,300	87,300	65,500	133,600	94,900	63,100	45,800	-22,100	-28,400	-24,200	-19,700
3	3.997	0.293	0.447	0	4.084877	0.2671512	0.1747547	0	0.002	500	126,800	100,000	71,800	54,300	112,300	81,400	56,200	42,000	-14,500	-18,600	-15,600	-12,300
5	3.892	0.289	0.375	0	4.025837	0.2627789	-0.1016006	0	0.005	200	95,500	74,800	54,600	41,800	88,100	65,600	47,600	36,900	-7,400	-9,200	-7,000	-4,900
8	3.793	0.287	0.330	0	3.978331	0.2615755	-0.3446629	0	0.010	100	76,200	59,300	43,900	33,800	72,500	55,000	41,400	33,100	-3,700	-4,300	-2,500	-700
									0.020	50	60,000	46,400	34,800	27,000	58,900	45,500	35,600	29,200	-1,100	-900	800	2,200
									0.050	20	42,500	32,600	24,900	19,500	43,600	34,400	28,200	24,100	1,100	1,800	3,300	4,600
									0.100	10	31,700	24,200	18,700	14,800	33,600	27,000	22,900	20,100	1,900	2,800	4,200	5,300
									0.200	5	22,700	17,200	13,400	10,700	24,900	20,300	17,700	15,900	2,200	3,100	4,300	5,200



Flow Frequency Curves and Parameters

AP name: STN-11

Duration (days)	Rain Flood Mean	Rain Flood Std Dev	Rain Flood Skew	Rain Flood LO	Water Year Mean	Water Year Std Dev	Water Year Skew	Water Year LO	AEP	1/AEP	Rain Flood 1-day	Rain Flood 3-day	Rain Flood 5-day	Rain Flood 8-day	Rain Flood 15-day	Rain Flood 30-day	Water Year 1-day	Water Year 3-day	Water Year 5-day	Water Year 8-day	Water Year 15-day	Water Year 30-day	Diff 1-day	Diff 3-day	Diff 5-day	Diff 8-day	Diff 15-day	Diff 30-day
1	3.930	0.331	0.383	0	3.983261	0.2971809	0.4004955	0	0.001	1,000	136,600	115,700	85,500	62,700	43,500	30,700	118,300	87,700	56,800	38,200	25,700	18,500	-18,300	-28,000	-28,700	-24,500	-17,800	-12,200
3	3.817	0.341	0.392	0	3.901171	0.2936404	0.3187875	0	0.002	500	108,900	91,500	68,700	51,400	36,600	26,200	96,300	72,500	48,800	34,100	23,700	17,400	-12,600	-19,000	-19,900	-17,300	-12,900	-8,800
5	3.732	0.340	0.305	0	3.845358	0.2810693	0.1004220	0	0.005	200	79,600	66,100	50,700	38,900	28,600	20,900	72,400	55,600	39,400	29,000	21,000	15,800	-7,200	-10,500	-11,300	-9,900	-7,600	-5,100
8	3.660	0.336	0.206	0	3.802972	0.2704927	-0.1497193	0	0.010	100	61,900	50,900	39,700	31,100	23,400	17,300	57,600	44,900	33,100	25,300	19,000	14,500	-4,300	-6,000	-6,600	-5,800	-4,400	-2,800
15	3.573	0.336	0.057	0	3.749950	0.2593951	-0.3918429	0	0.020	50	47,400	38,600	30,500	24,400	18,800	14,100	45,200	35,700	27,400	21,700	16,900	13,200	-2,200	-2,900	-3,100	-2,700	-1,900	-900
30	3.477	0.329	-0.014	0	3.686037	0.2479140	-0.5445301	0	0.050	20	32,200	25,900	20,900	17,000	13,500	10,400	31,900	25,700	20,700	17,200	14,000	11,300	-300	-200	-200	200	500	900
									0.100	10	23,200	18,400	15,000	12,500	10,100	7,900	23,700	19,300	16,200	14,000	11,700	9,700	500	900	1,200	1,500	1,600	1,800
									0.200	5	15,900	12,500	10,300	8,700	7,200	5,700	16,800	13,900	12,000	10,800	9,400	7,900	900	1,400	1,700	2,100	2,200	2,200



Consistency Check #2

Annual Maxima Series (AMS) Extraction Windows

Findings

- Flow frequency curves show larger estimates for rarer events and lower estimates for more common events when the RF time window is used instead of the entire WY.
- For the four analysis points selected, the 1% AEP estimates using the RF AMS are higher than those generated using the WY AMS

1% AEP Flow Estimates Comparison

Analysis Point	1DAY	3DAY	5DAY	8DAY	15DAY	30DAY
AMR-14	4%	5%	5%	6%		
FTH-ORO	5%	5%	6%	13%		
TUO-1	5%	7%	6%	2%		
STN-11	7%	14%	20%	17%	17%	20%

Consistency Check #3

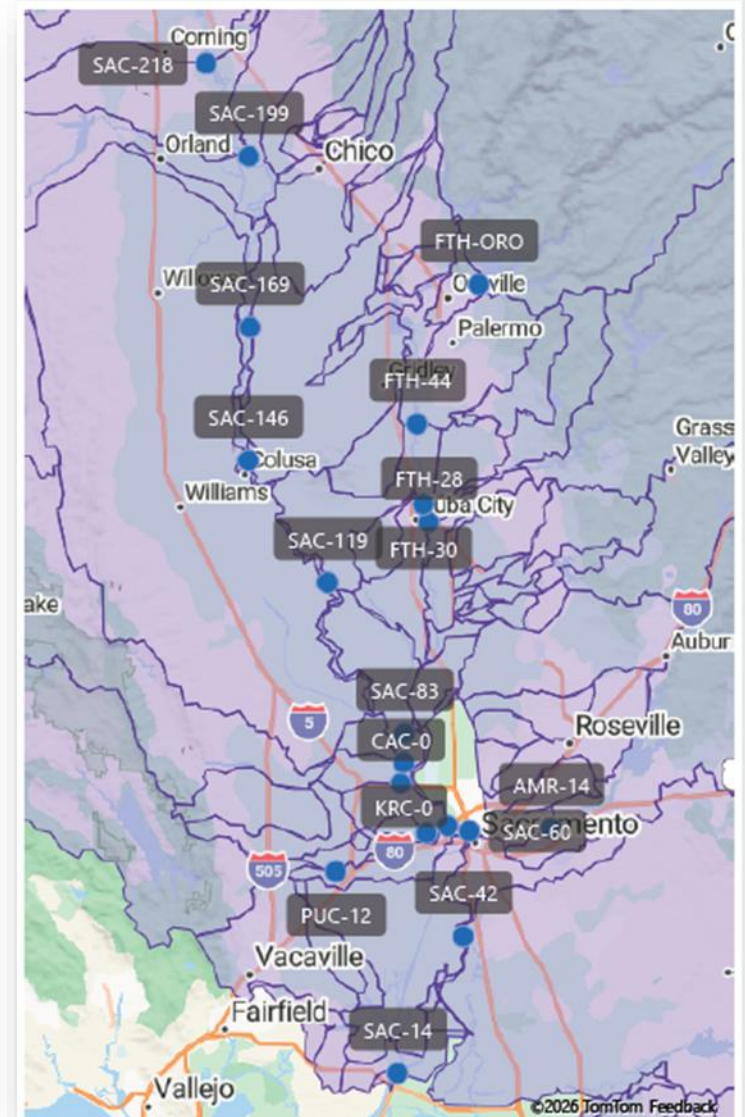
Spatial Consistency Check

Question

- Are the flow frequency curves spatially consistent for various durations?

Analysis

- Compare flow frequency curves for groups of analysis points
- Compare differences in estimated flows for standard AEPs

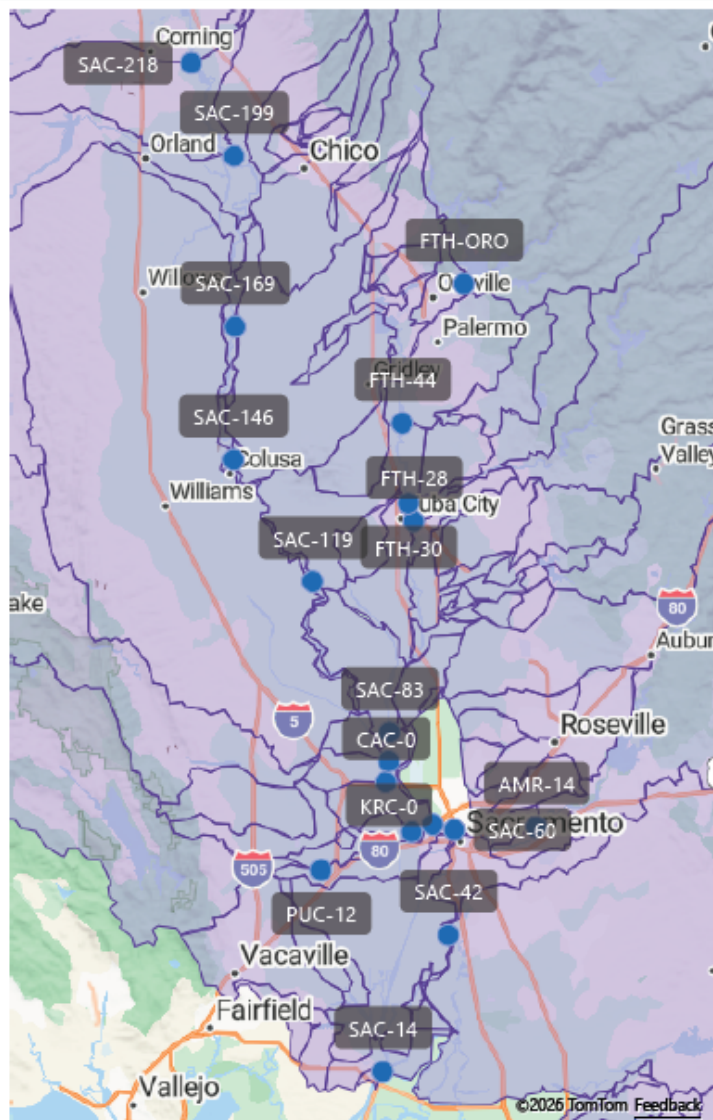


CVFPP 2027 Analysis Dashboard | Spatial Consistency Check

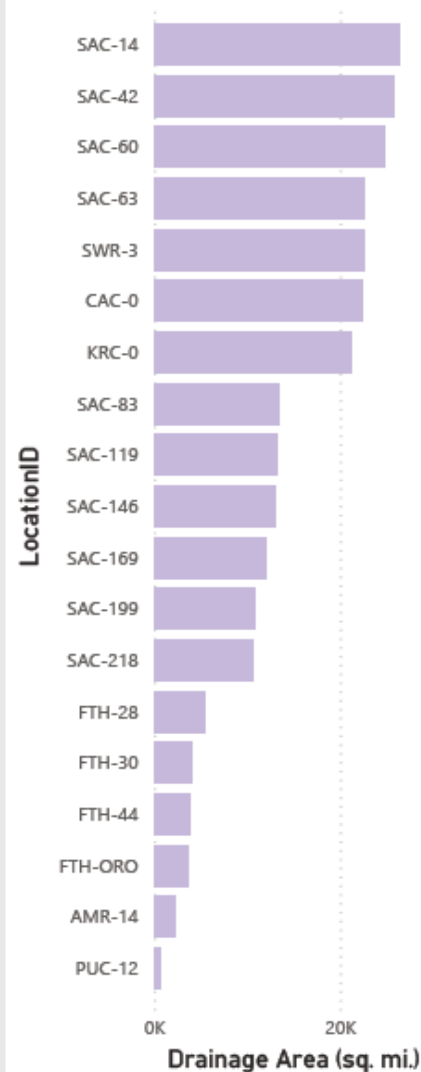
Basin
SAC

Analysis Point
All

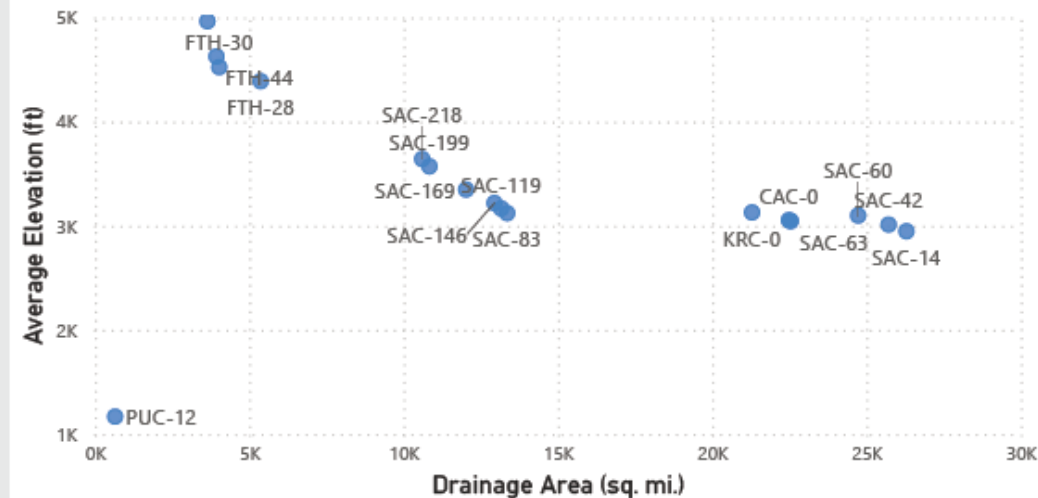
Duration
1DAY



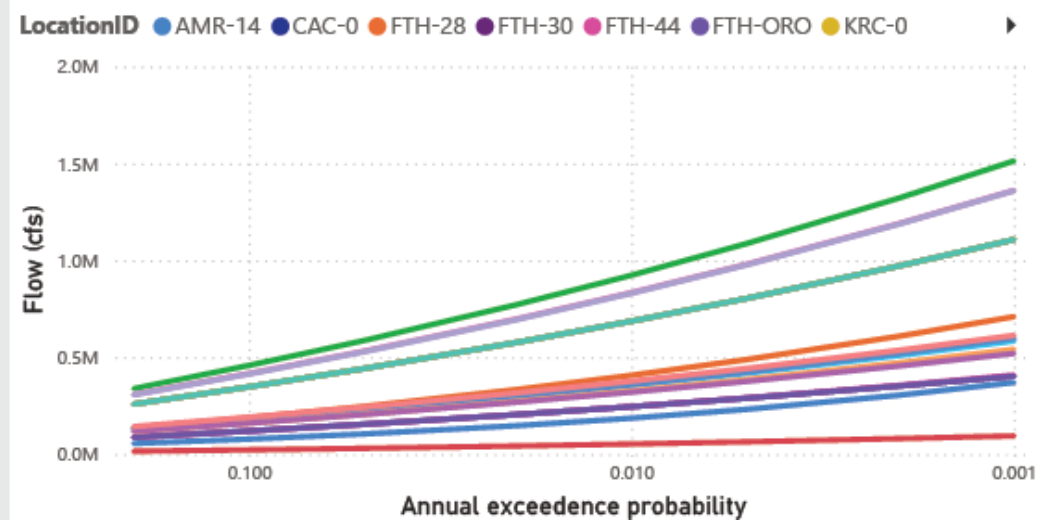
Drainage Area by LocationID



Average Elevation by Drainage Area



VIC Unregulated Flow Frequency Curves



CVFPP 2027 Analysis Dashboard | Spatial Consistency Check

Basin

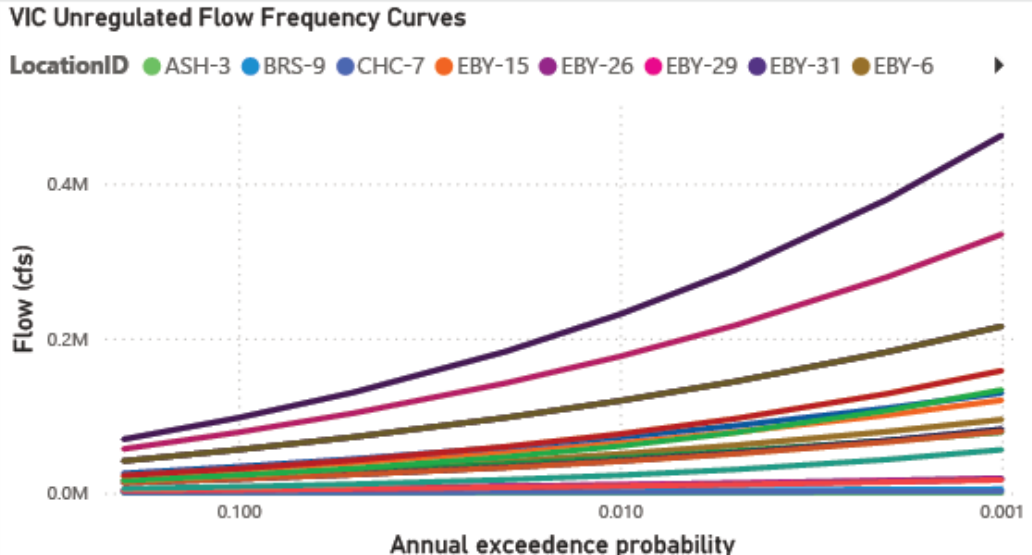
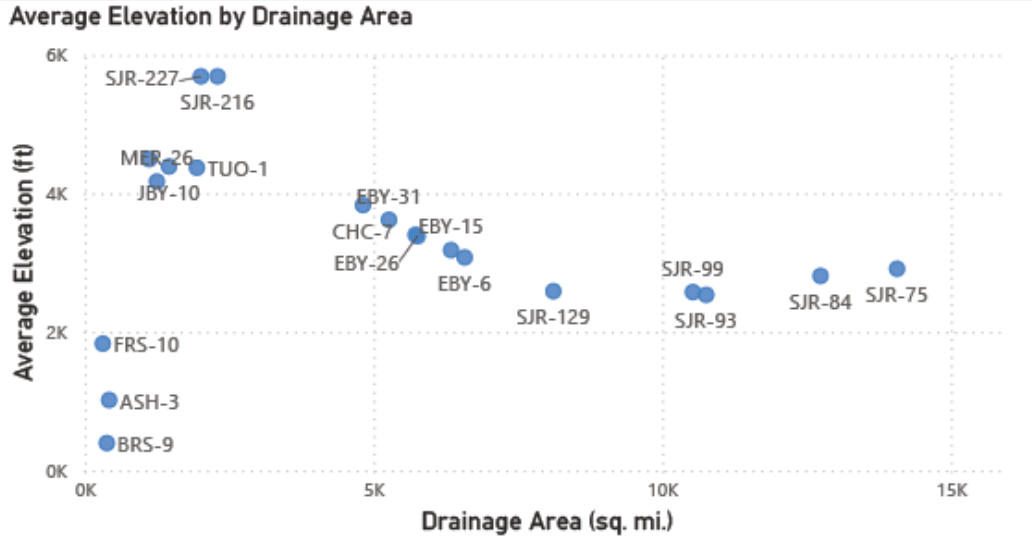
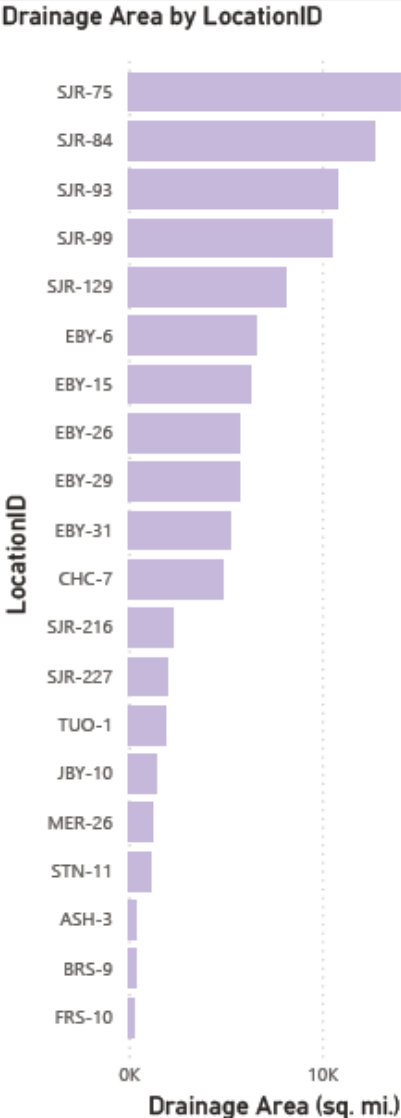
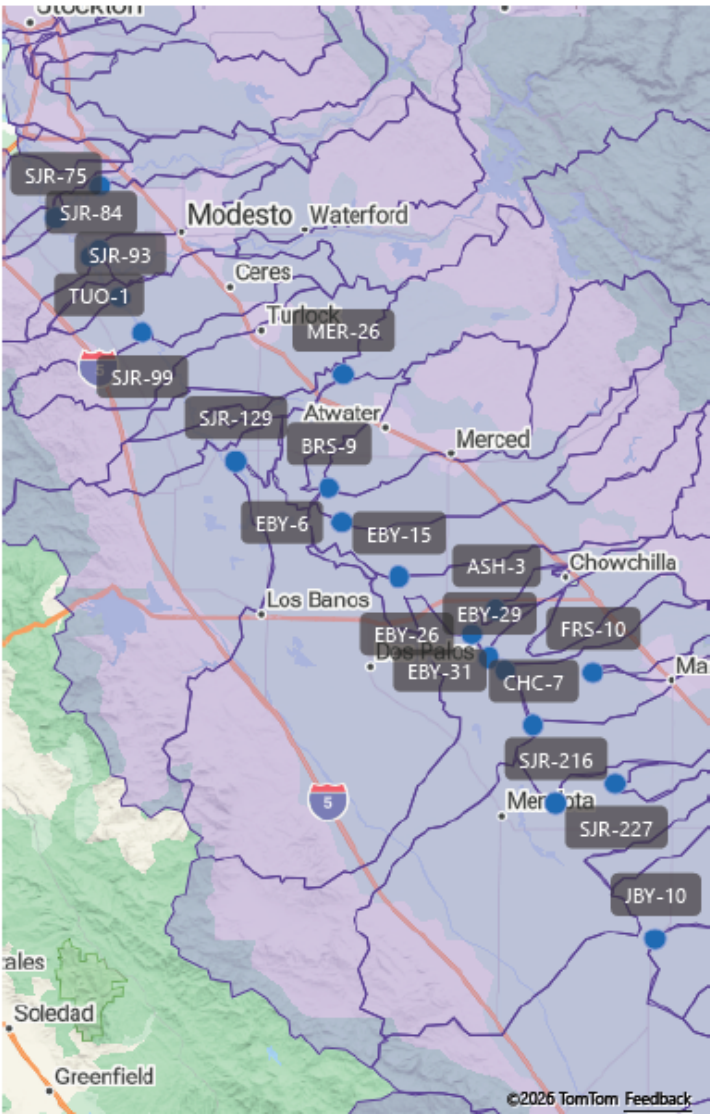
SJR

Analysis Point

All

Duration

1DAY



CVFPP 2027 Analysis Dashboard | Spatial Consistency Check

Basin

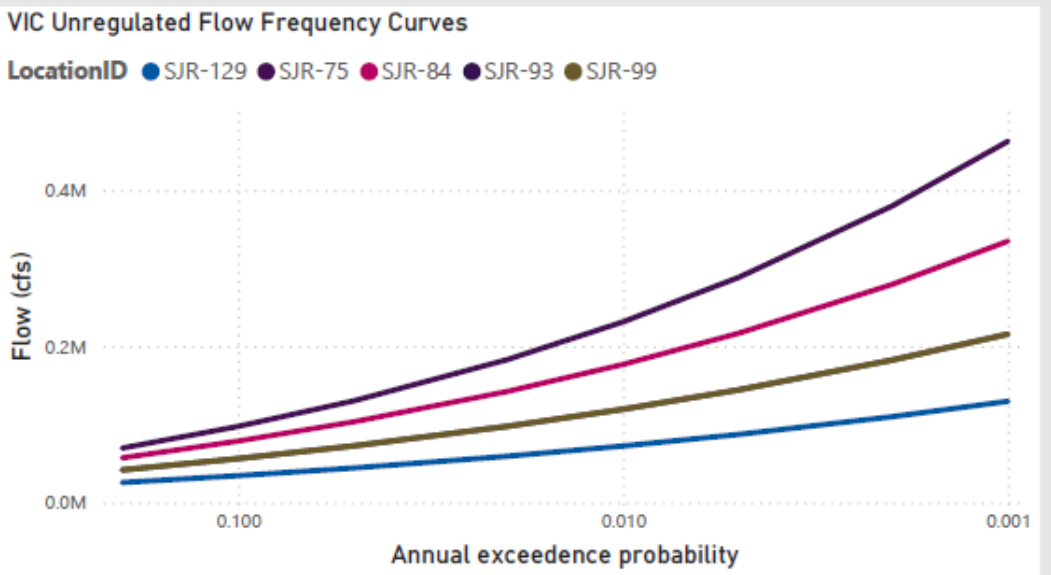
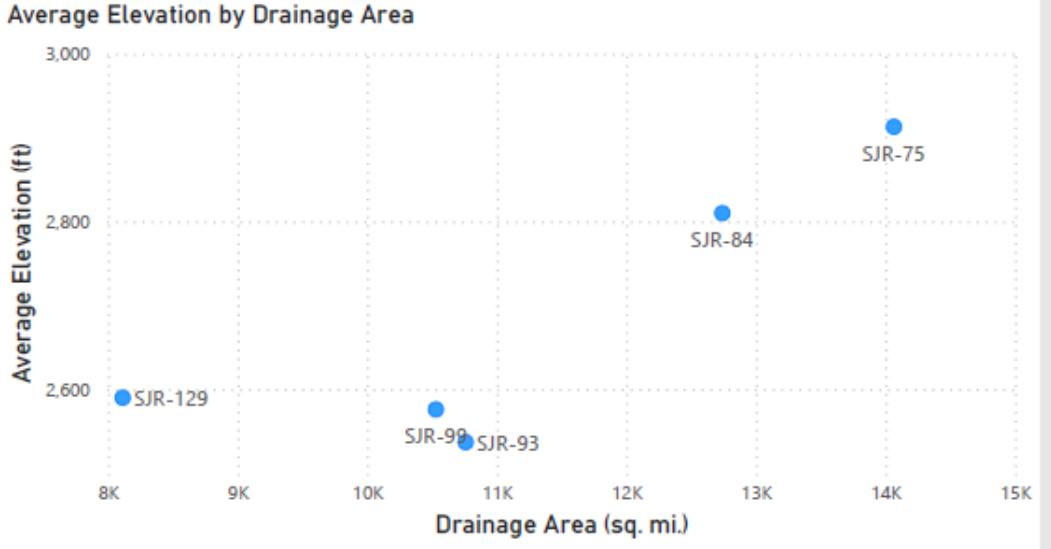
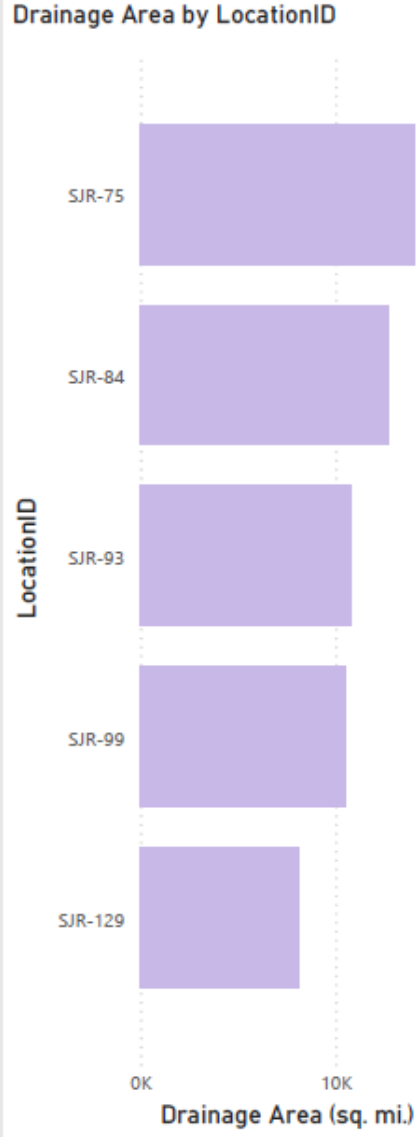
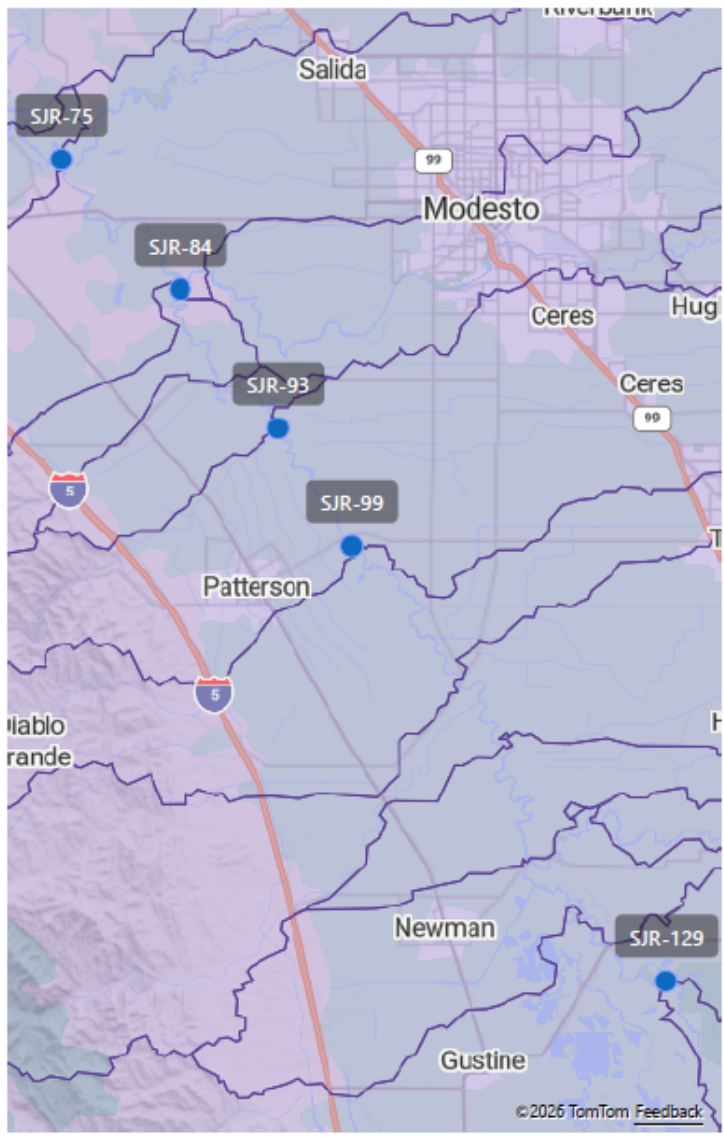
SJR

Analysis Point

Multiple selecti...

Duration

1DAY



Consistency Check #3

Spatial Consistency Check

Findings

- The flow frequency curves (1-day duration) for the groups of analysis points compared did not cross each other and the flow magnitude increased with the cumulative drainage area.

Consistency Check #4

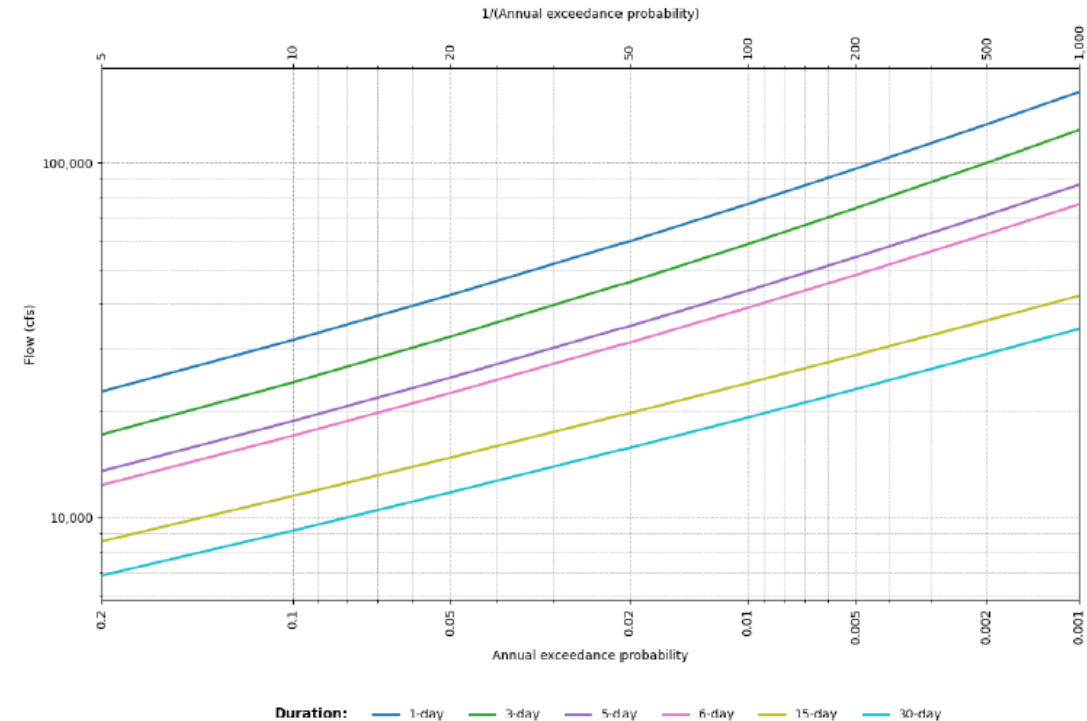
At-Site Consistency Check

Question

- Are the flow frequency curves consistent at-site for various durations?

Analysis

- Compare flow frequency curves for various durations
- Compare differences in estimated flows for standard AEPs





FTH-ORO VIC Unregulated Flow Frequency Curves

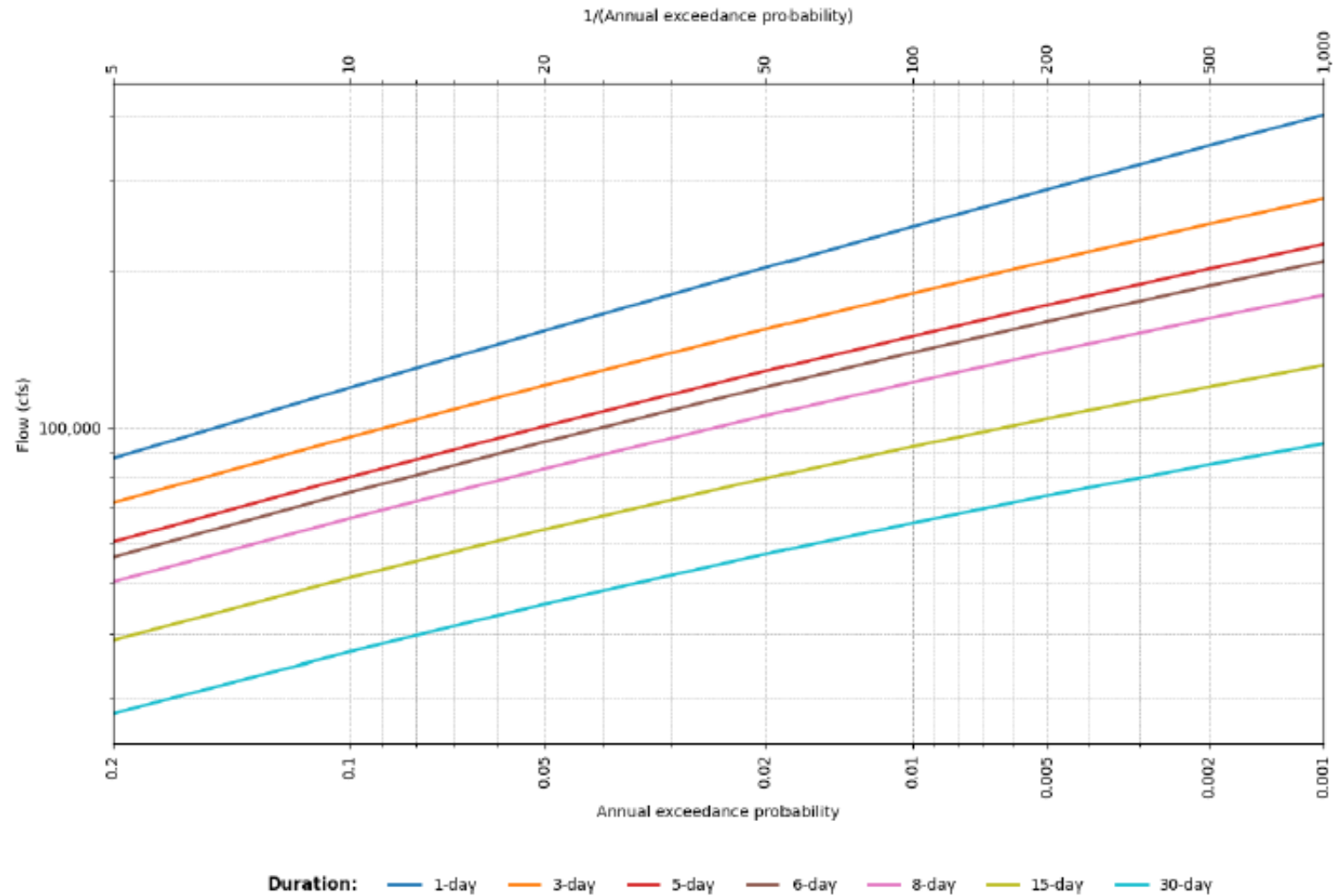
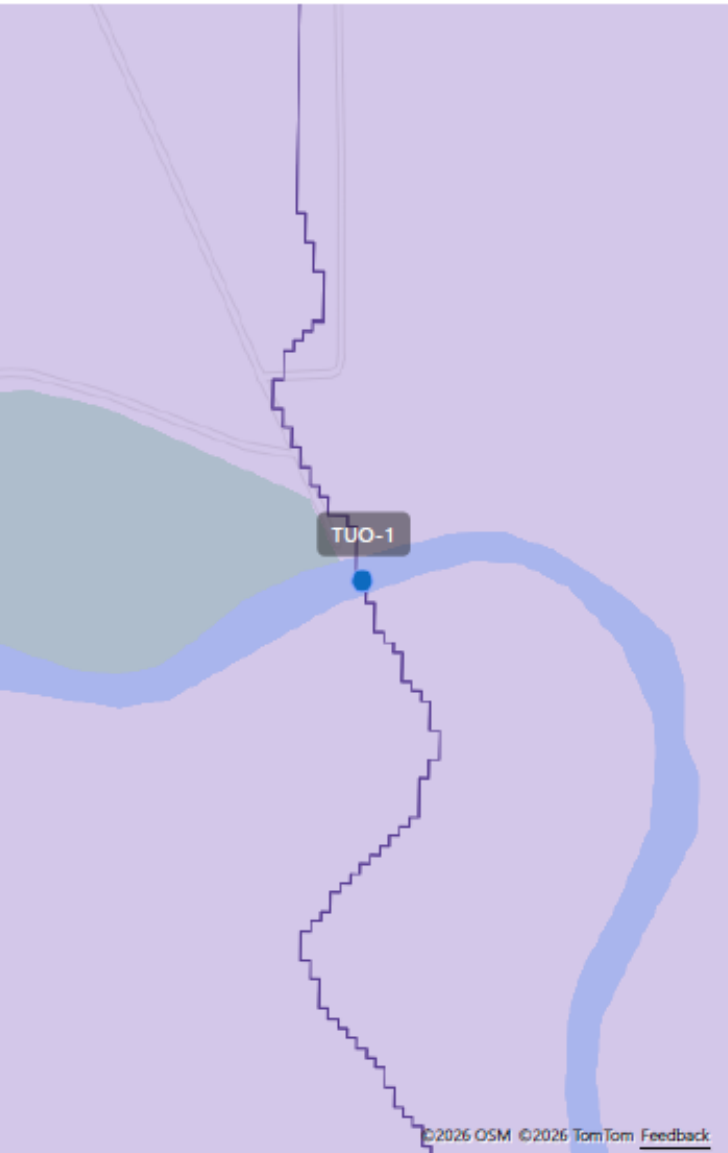


Figure C-13: Unregulated Flow Frequency Curve at Analysis Point FTH-ORO



TUO-1 VIC Unregulated Flow Frequency Curves

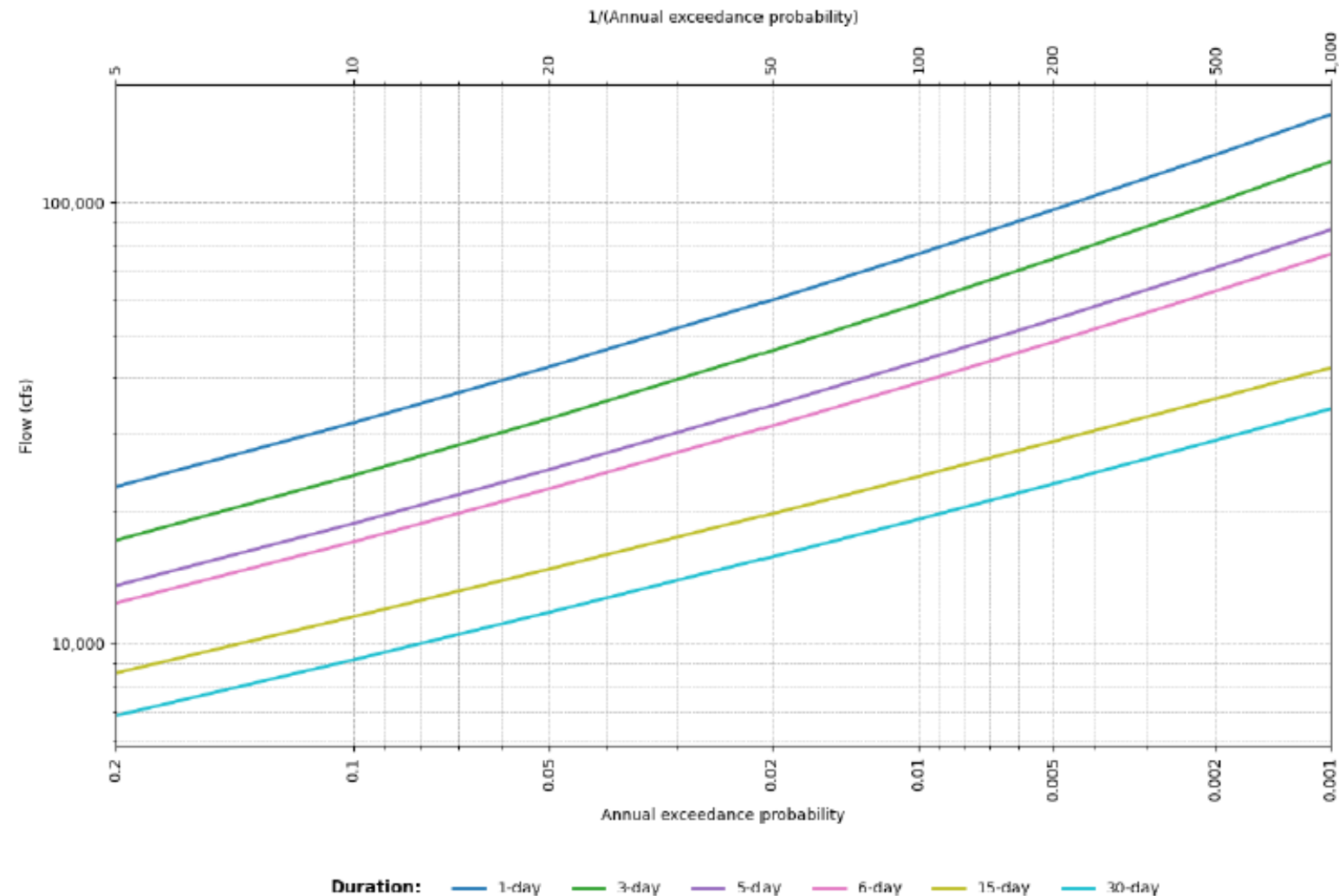


Figure C-15: Unregulated Flow Frequency Curve at Analysis Point TUO-1

Consistency Check #4

At-Site Consistency Check

Findings

- The flow frequency curves for all the durations did not cross each other, indicating that the curves are consistent for that location (at-site consistency).
- At all analysis points, flows increase with decrease in duration (e.g., 1-day flows are higher than 2-day flows) and with decrease in frequency (e.g., $p=0.005$ AEP flows are greater than $p=0.01$ AEP flows)

04 Key Takeaways

Key Takeaways

- Accounting for rain-snow separation in extracting AMS is important for California region, and is consistent with the guidance:
 - Guidelines for Determining Flood Flow Frequency – Bulletin 17C (England et. al, 2018).
 - Engineer Manual (EM) No. 1110-2-1415. Engineering and Design. Hydrologic Frequency Analysis (USACE, 1993).
- The Water Control Manuals for the flood control reservoirs in the Central Valley establish operation rules with dedicated flood storage and release schedules for the rain flood season. Any increase in inflows due to climate change is critical for rain flood season operations.
- Use of data analytics tools can gain insights into checking spatial and at-site consistencies of the flow frequency information

Questions?

