Real-time Allocation of an Environmental Flow Budget

The Functional Flow Adaptive Implementation Model

Lindsay Murdoch, Sarah Yarnell, Francisco Bellido-Leiva, Cameron Carpenter, Leonard Calvo, and Jay Lund

Center for Watershed Sciences, University of California, Davis

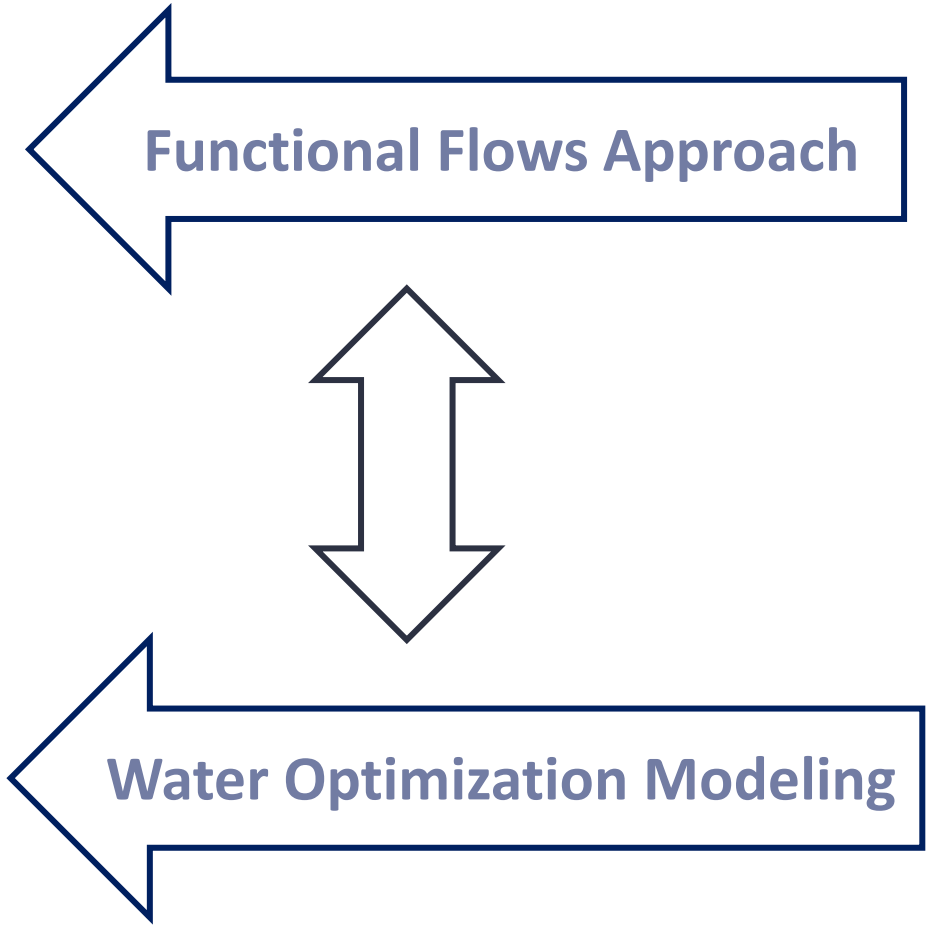
A Question

Can an environmental flow budget (40% of February-June unimpaired flows) be allocated throughout the year, while adaptively managing for changing hydrologic conditions as the operating year develops?

KNOWN	UNKNOWN
• Information on runoff to date • Probabilistic forecasts of future runoff, updated monthly • Natural functional flow metrics based on unimpaired flows	• Total flow volume available for the eflow budget • How to design an eflow regime that continuously scales with evolution of the eflow budget

Study Objectives

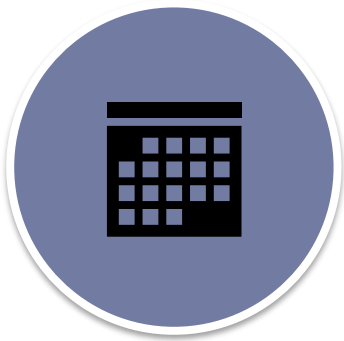
1. Identify a basis for *shaping* and *shifting* allocated flows
2. Adapt this approach to a variable flow budget
3. Illustrate operation in an implementation setting (using forecasts)



Functional Flows as a Basis for Shaping and Shifting Flows

Considerations for e-flow design

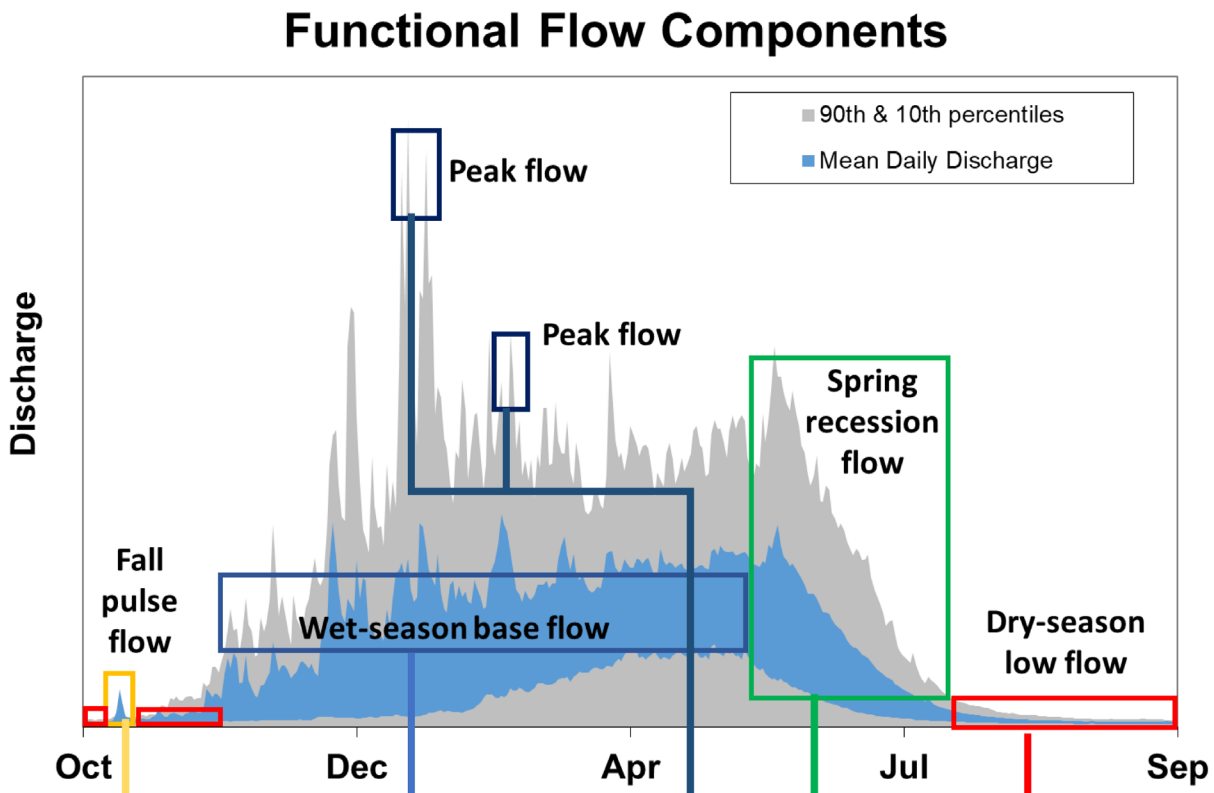
1. How to shape flows within a year?



2. How to vary flows from year-to-year?

Seasonality + **Interannual Variability**

Quantifying Flows



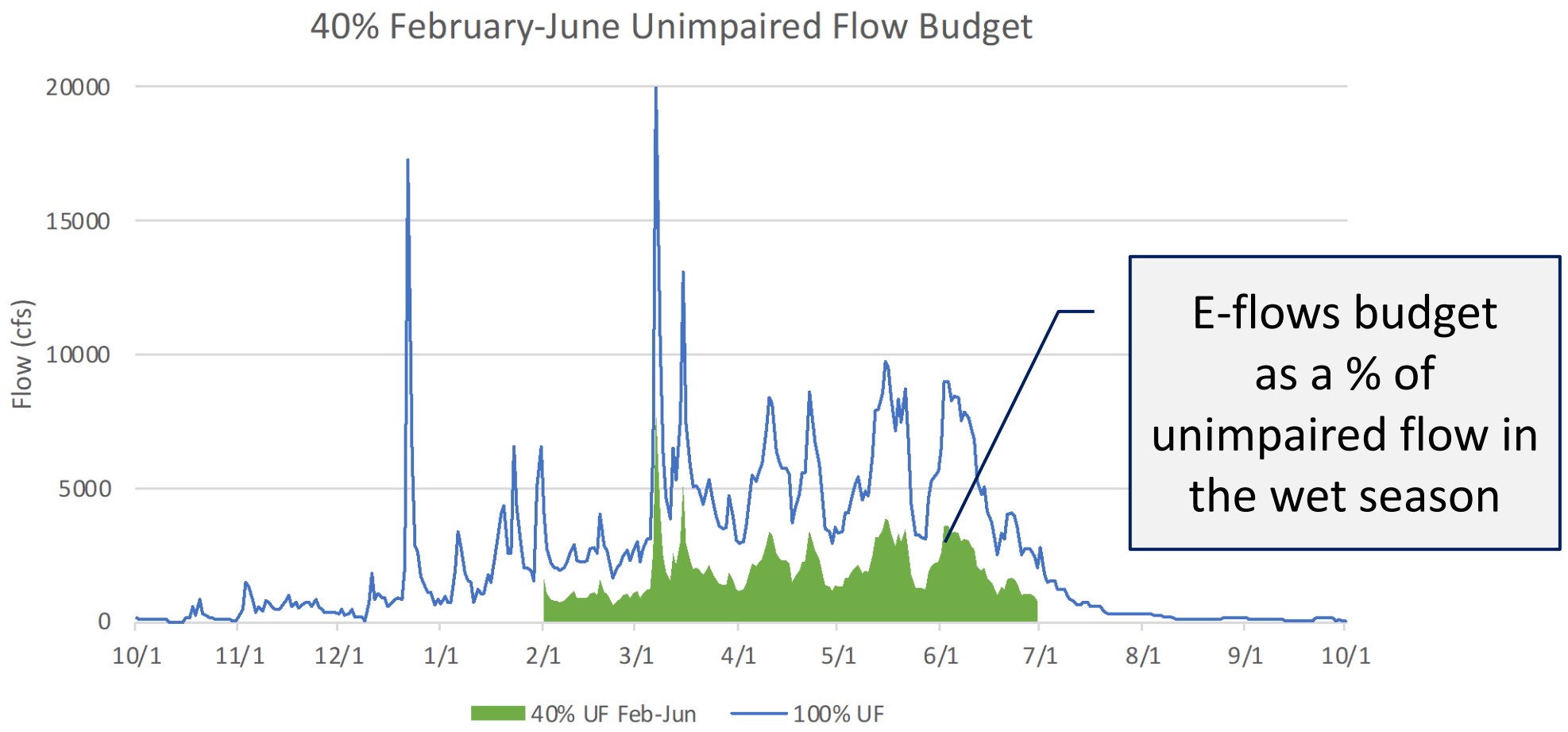
Flow Characteristics	Functional Flow Components: Fall Pulse	Wet Baseflow	Peak Flow	Spring Recession	Dry Low Flow
Magnitude	X	X	X	X	X
Timing	X	X	X	X	X
Duration		X	X	X	X
Frequency			X		
Rate of Change				X	X

Functional Flow metrics vary seasonally and from year to year…

In wetter years, magnitudes increase, the wet season lasts longer, rain events are more frequent…

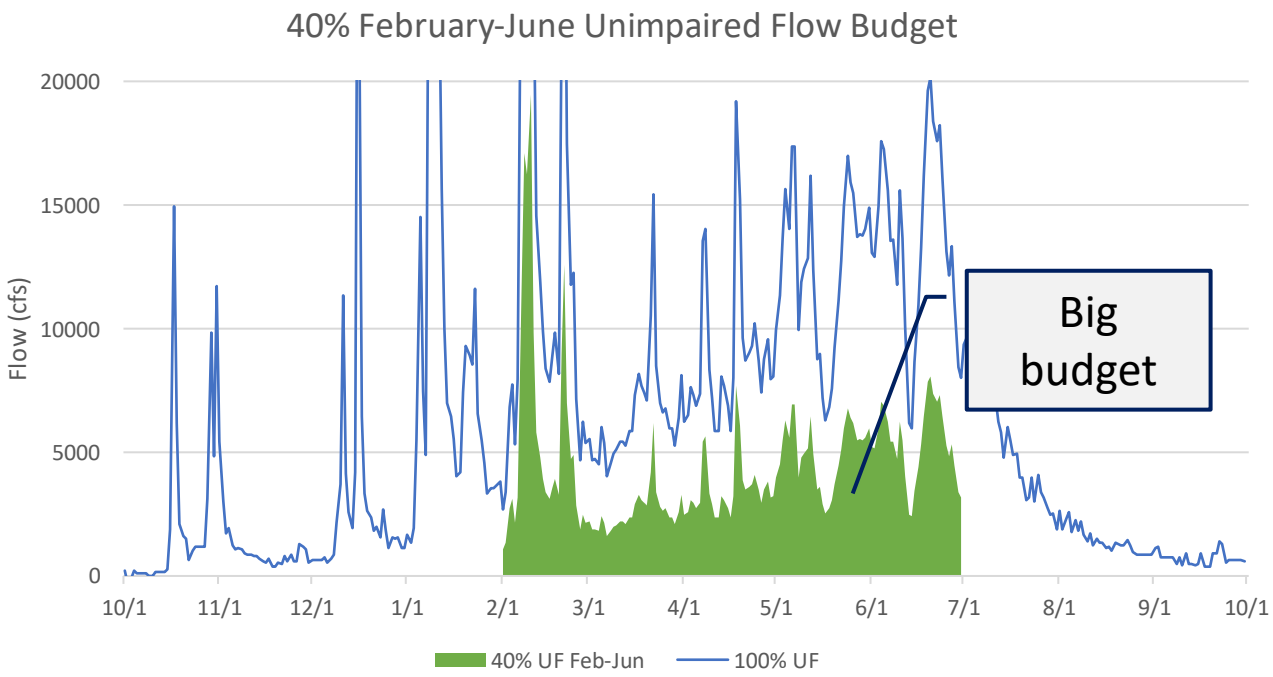
Environmental Flow Budget

Scaled by unimpaired flow availability



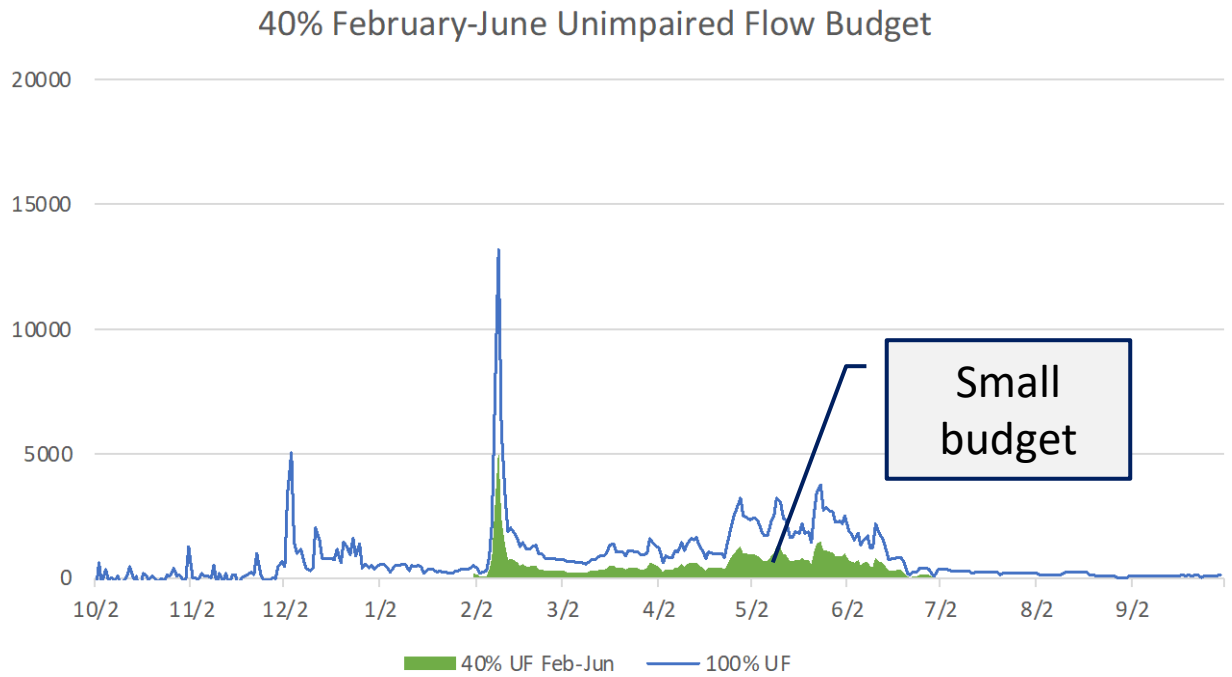
Environmental Flow Budget

Scaled by unimpaired flow availability



2017 – Wettest year by volume

Flow budget: 1332 TAF

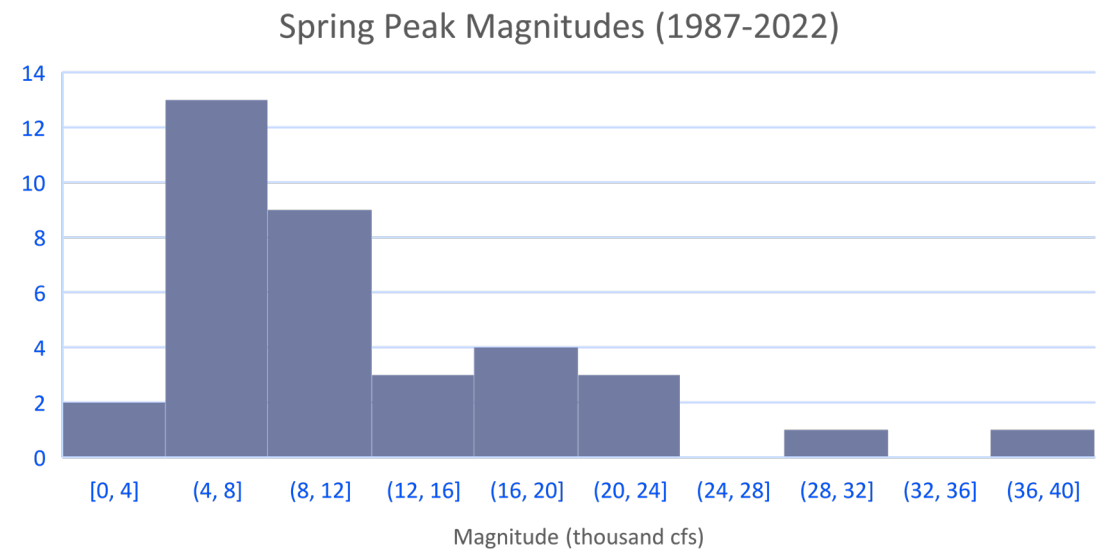


2015 – 2nd driest year by volume

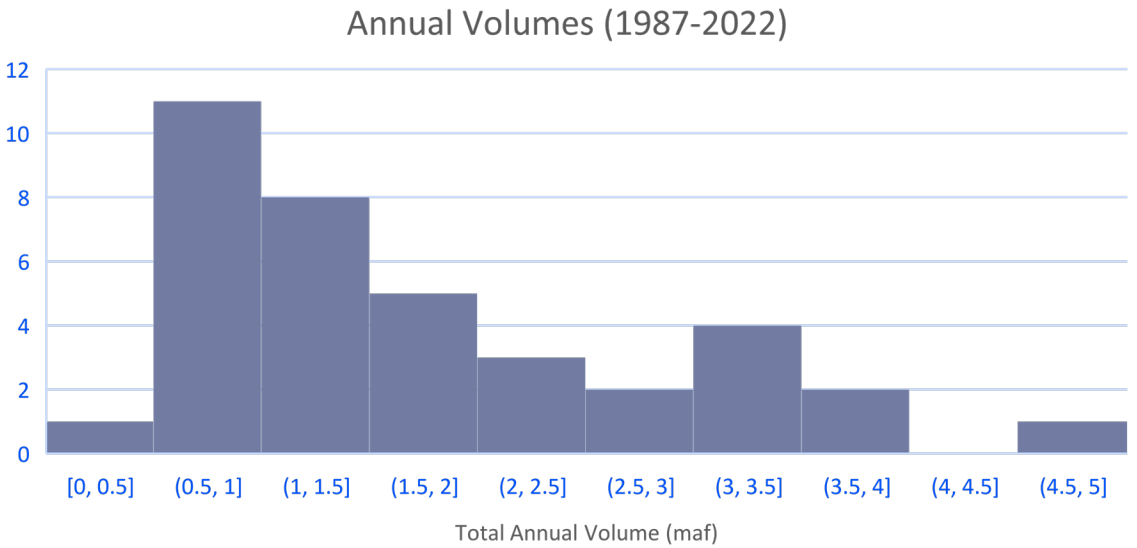
Flow budget: 185 TAF

Identify functional flow metrics that correlate to annual flow volume

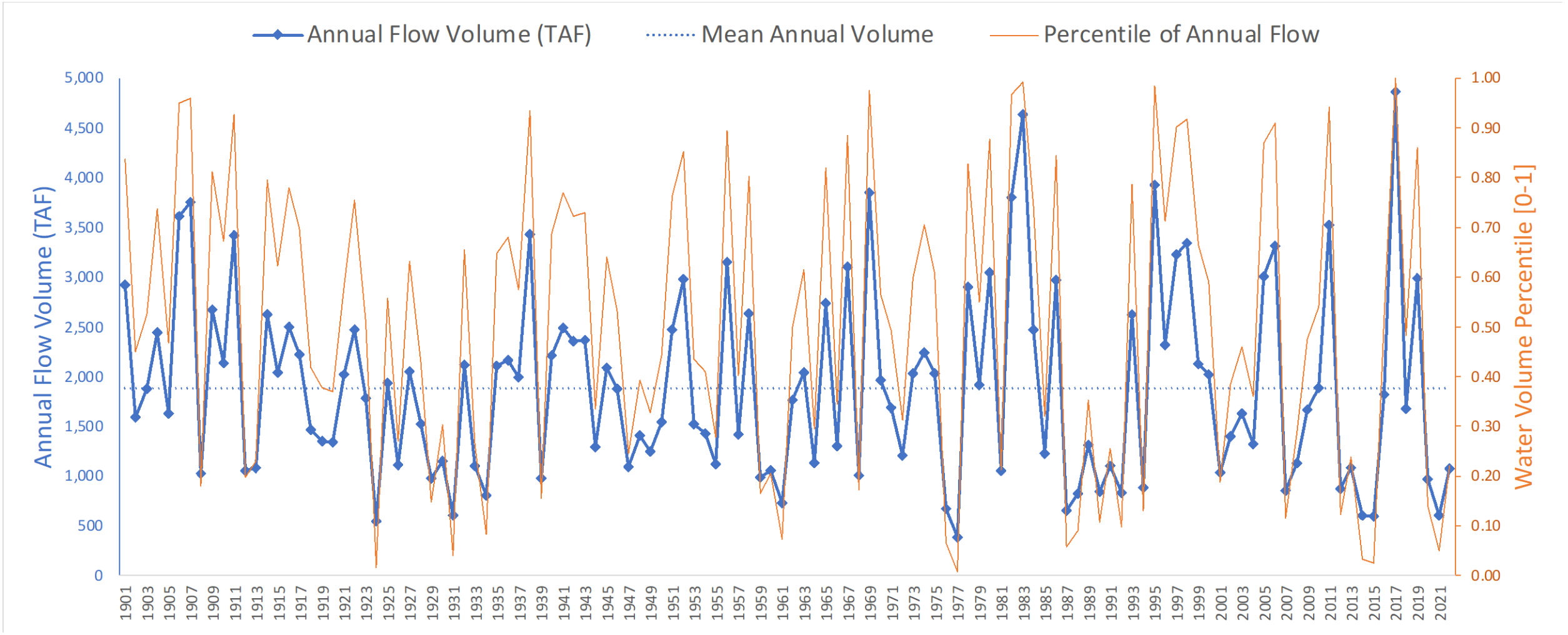
Functional Flows Metric
(peak magnitude of spring pulse)



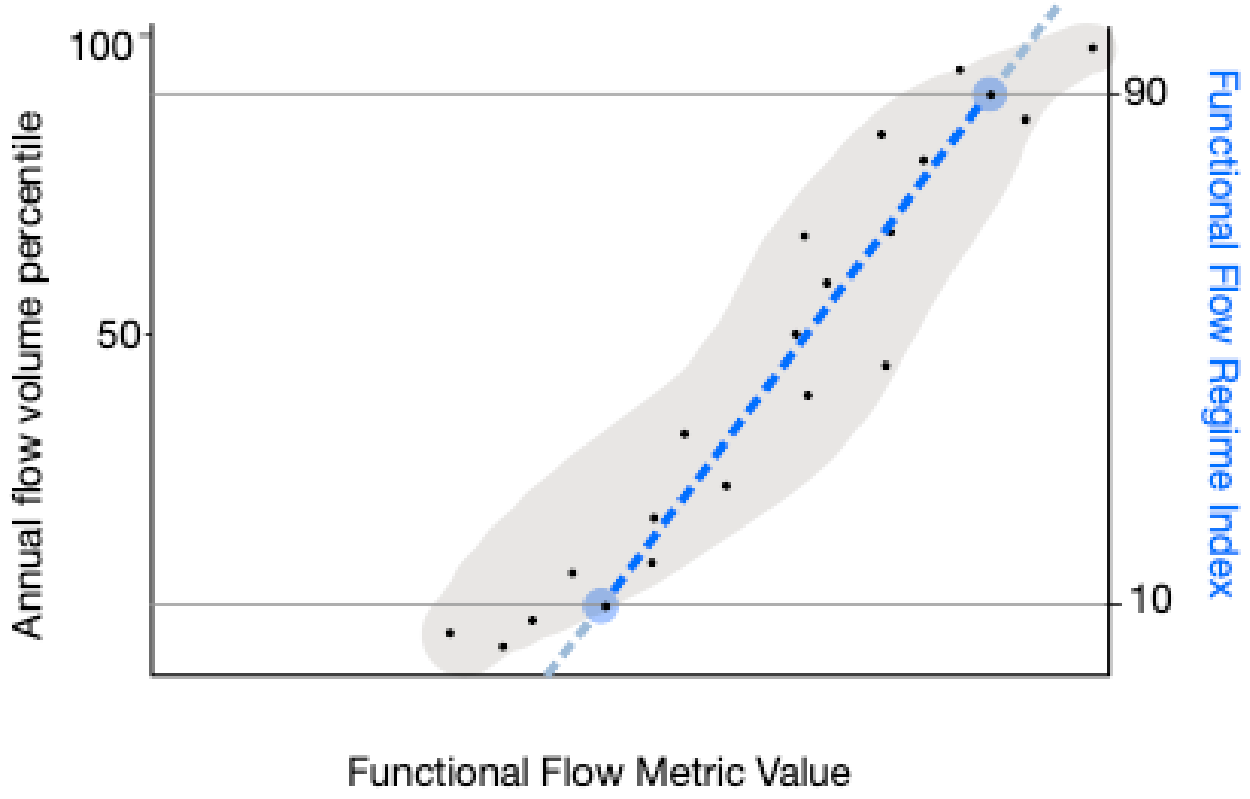
How wet a year was
(Annual flow volume)



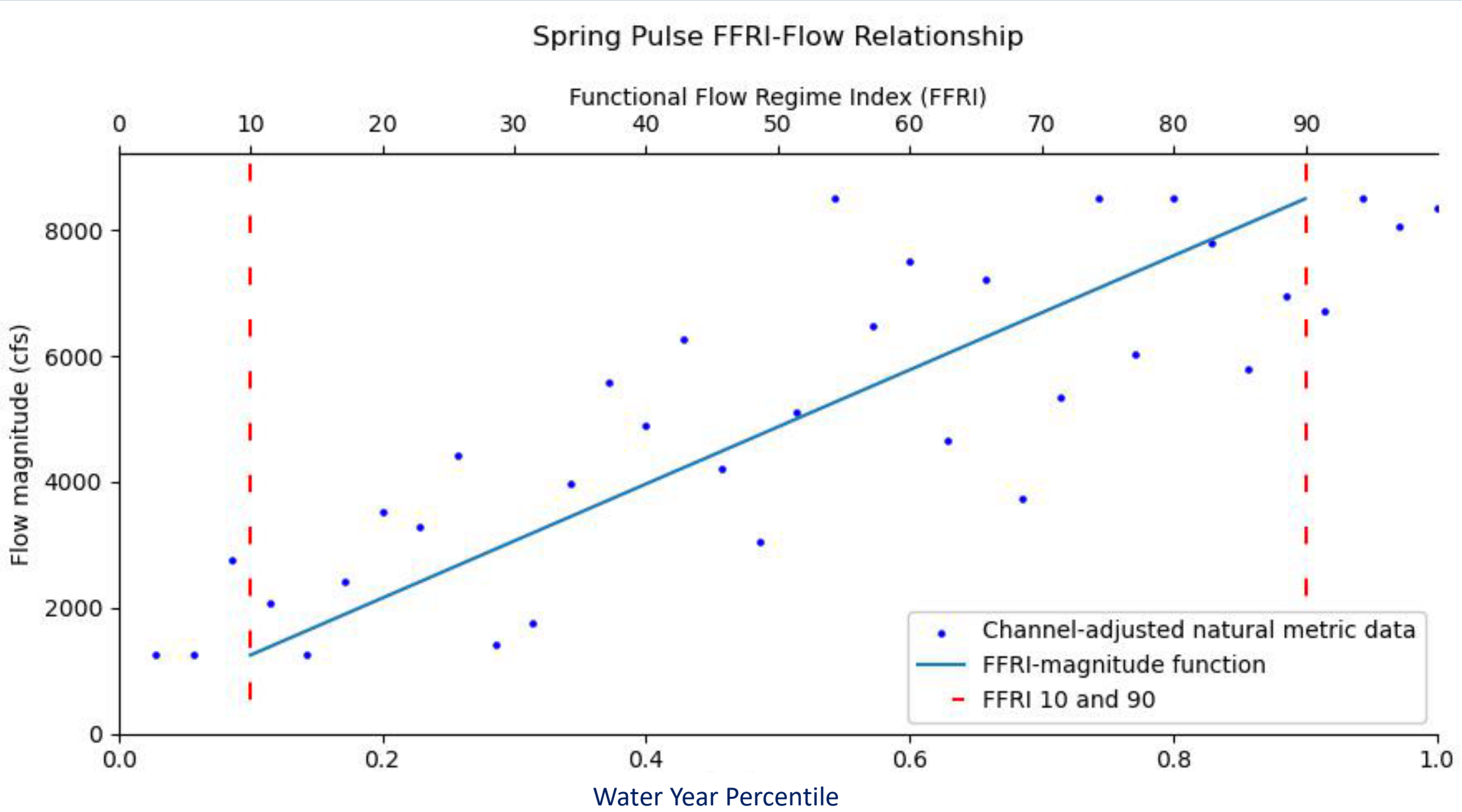
Use percentiles to normalize flow volumes



Associate Functional Flow Metrics with Annual Flow Volumes



- Method for continuously scaling functional flows that represents historical return intervals and provides more comprehensive interannual variability
- Good fits for magnitudes and timings

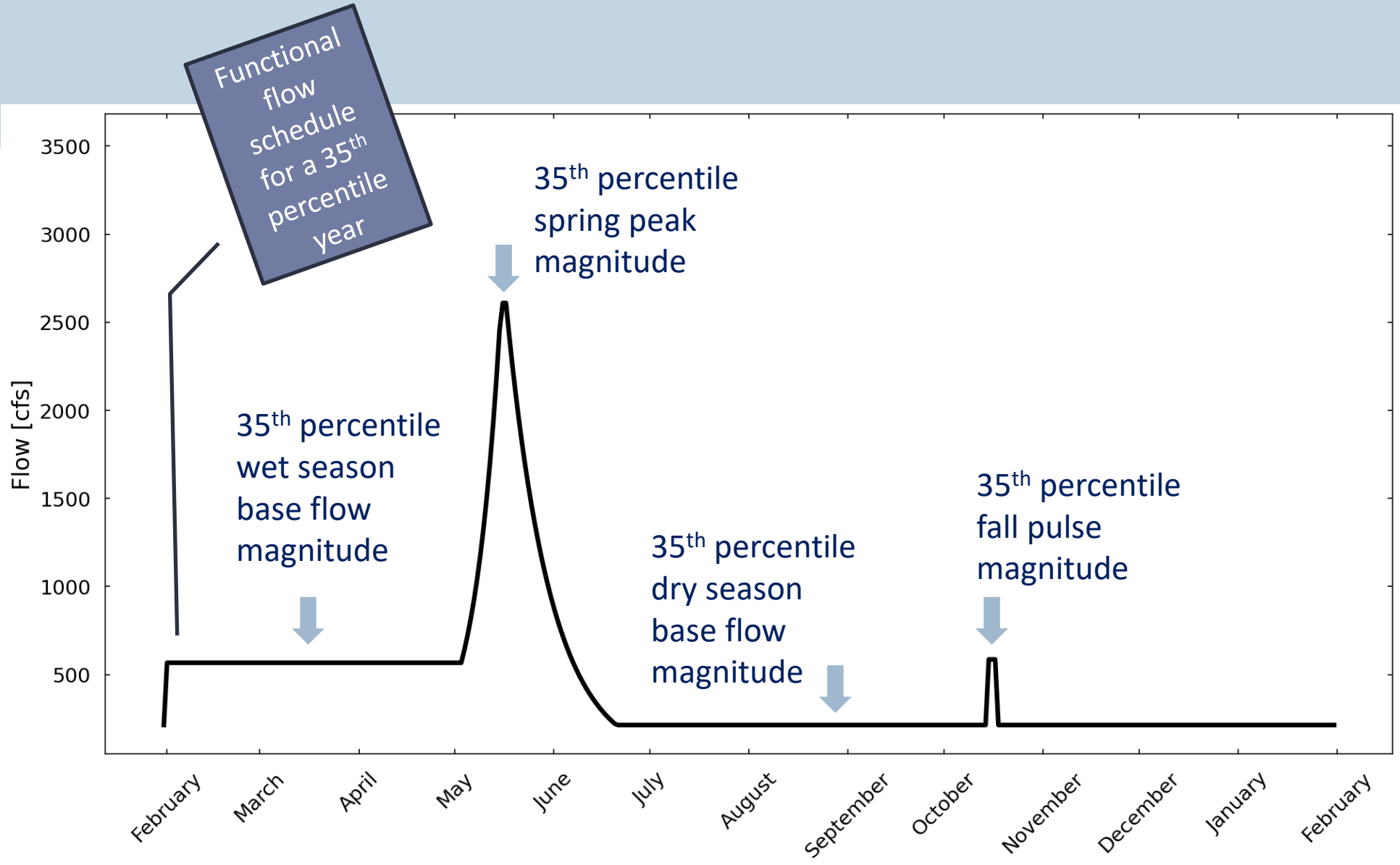


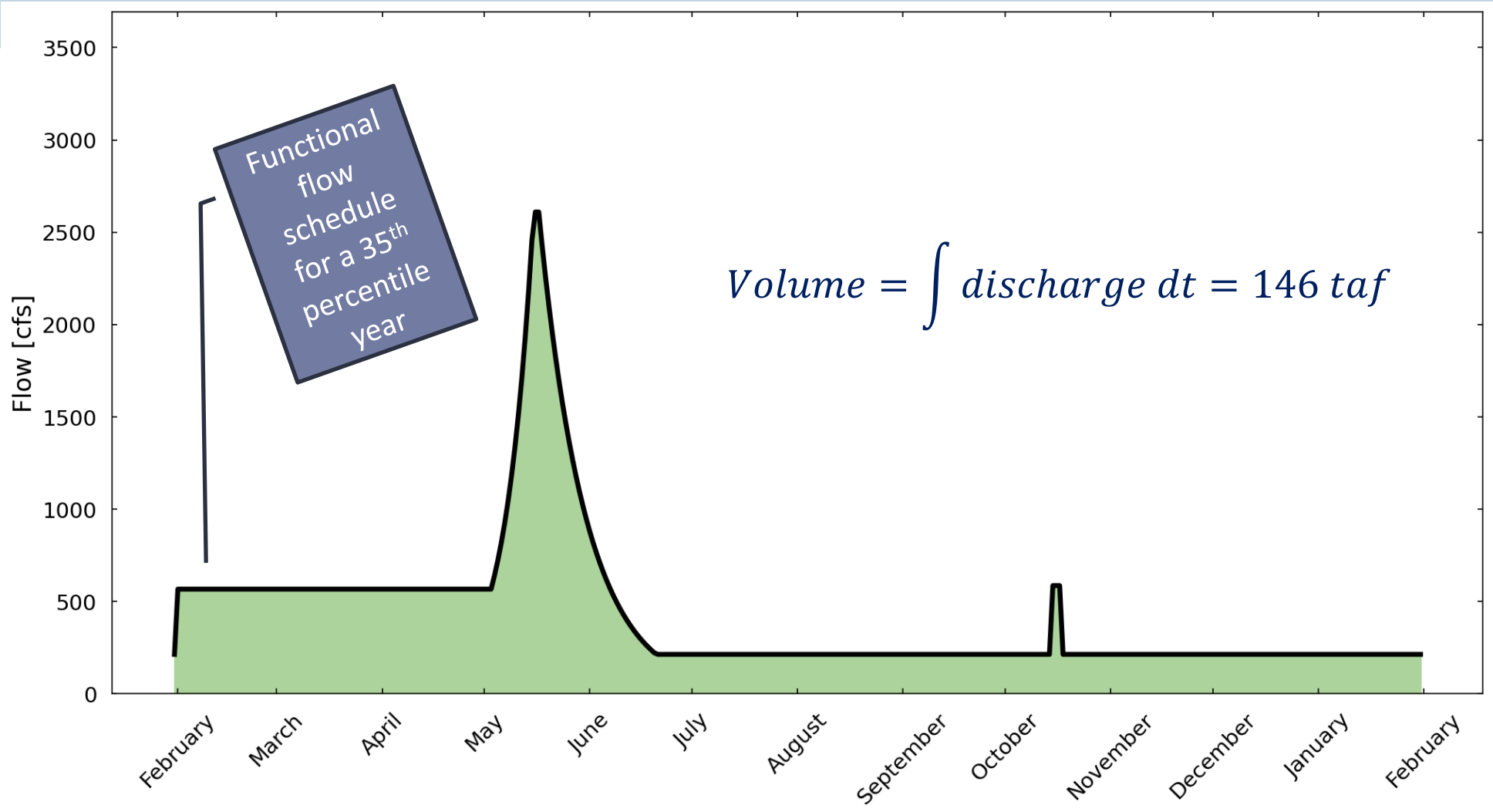
Functional Flow Metric

Annual Flow Volume

Relationship between Functional Flow metric values and Annual Flow Volume to determine flow schedules

Flow component	Metric	Relation-type	Description
Spring peak/recession	Magnitude (at peak and start of recession)	Scaled with annual flow volume (FFRI)	Varies within adjusted range, following patterns identified in the natural flow regime
	Timing (at start of recession)	Manual input (or scaled with annual flow volume (FFRI))	May 4 (or variable April-June)
	Duration	Calculated from timing and rate of change metrics	Until start of Dry Season
	Rate of Change	Manual input	13% per day up-ramp 7% per day down-ramp


Functional flow schedule for a 35th percentile year
35th percentile spring peak magnitude
35th percentile wet season base flow magnitude
35th percentile dry season base flow magnitude
35th percentile fall pulse magnitude
Flow [cfs]
3500
3000
2500
2000
1500
1000
500
February
March
April
May
June
July
August
September
October
November
December
January
February


Functional flow schedule for a 35th percentile year
$Volume = \int discharge\ dt = 146\ taf$
Flow [cfs]
3500
3000
2500
2000
1500
1000
500
0
February
March
April
May
June
July
August
September
October
November
December
January
February

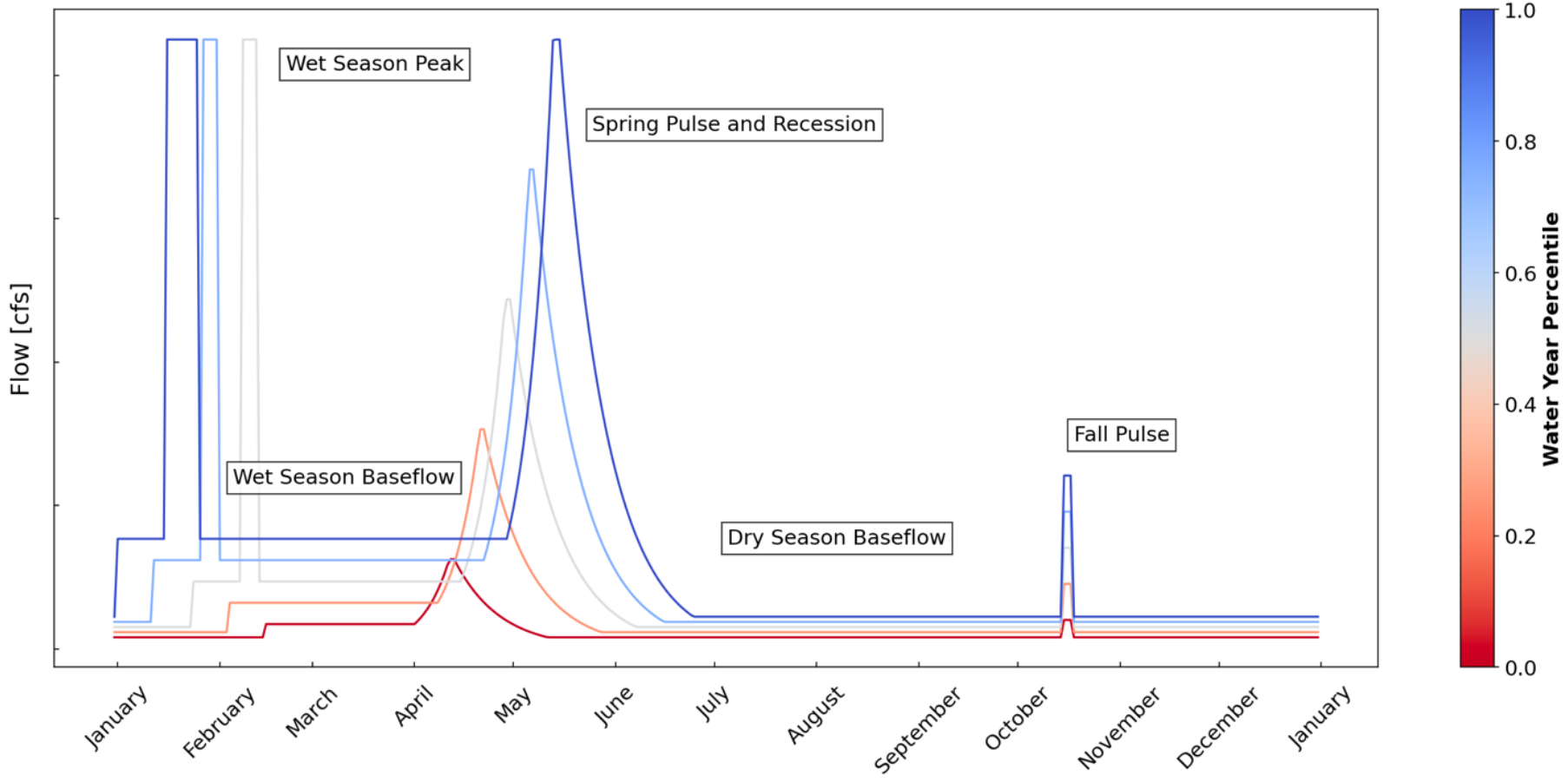
A plan for any volume flow budget…

As a result, we have a range of recommended functional flows for any year type.

For any budget, we can identify an appropriate schedule.

The index value gives us a sense of how wet or dry that flow schedule is.

Functional Flow Regime



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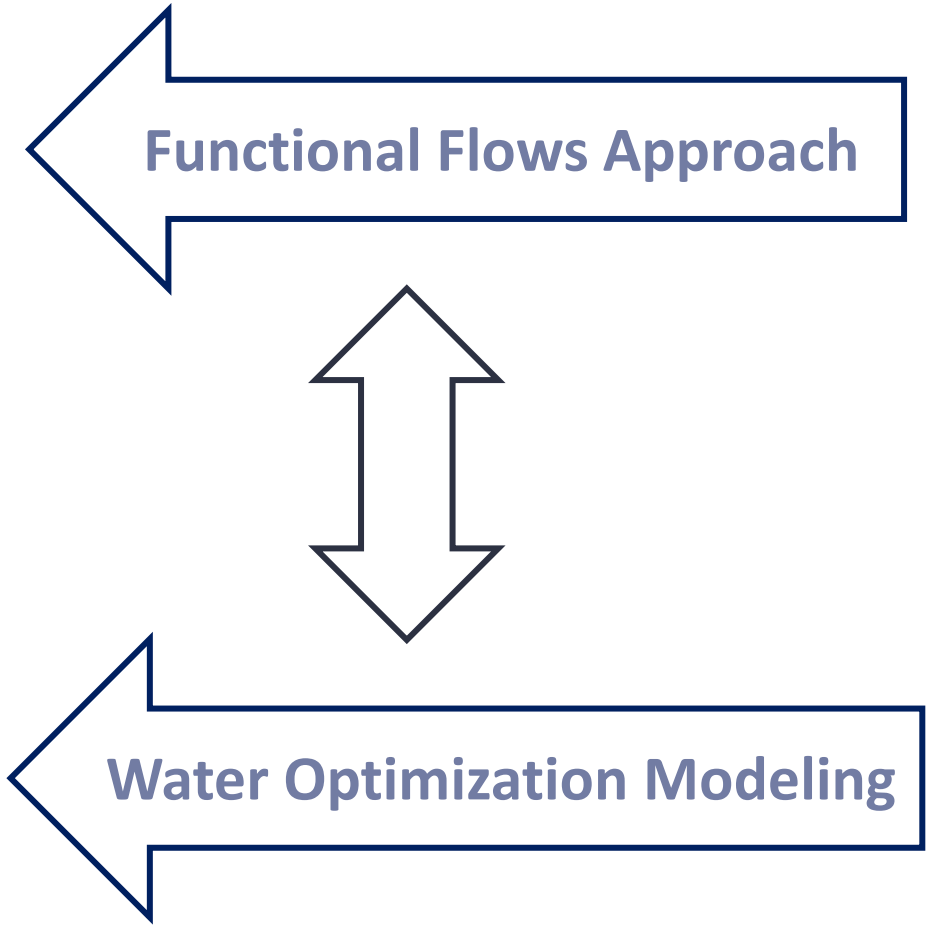
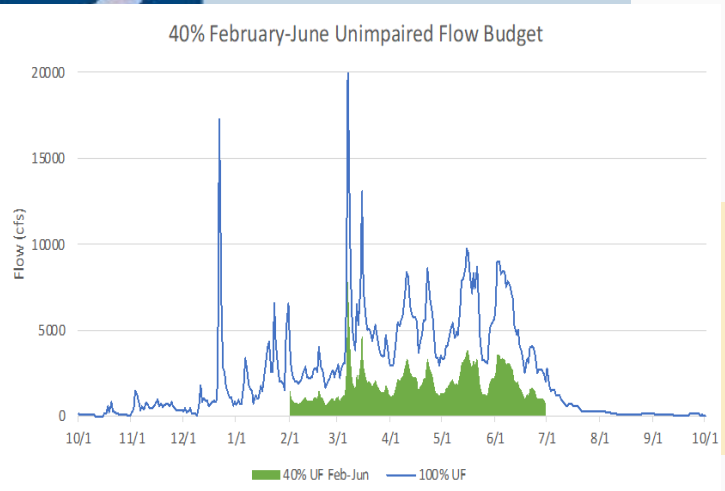




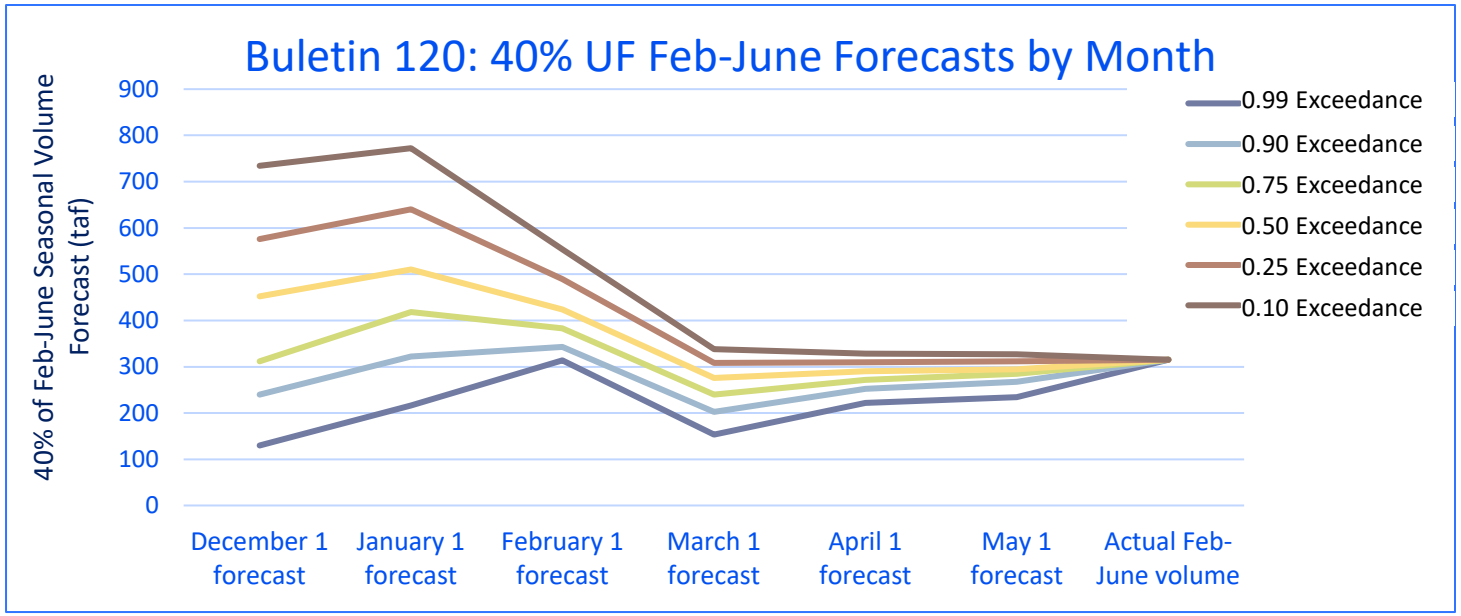
2021 SAN JOAQUIN RIVER WATER YEAR FORECAST BREAKDOWN

December 1, 2020

Stanislaus River below Goodwin Reservoir Unimpaired Flow [taf]

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	WY	Apr-Jul	WY % of avg
99%	8	7	5	8	12	22	38	42	17	3	1	2	165	100	
90%	8	7	11	16	25	46	80	88	35	7	3	4	330	210	
75%	8	7	19	30	46	75	110	140	75	20	5	5	540	345	
50%	8	7	32	53	70	101	140	195	110	30	8	6	760	475	66%
25%	8	7	65	101	108	144	180	275	185	65	14	8	1,160	705	
10%	8	7	93	156	154	197	220	350	260	100	24	10	1,580	930	
1966-2015 avg													1,149	682	

Bulletin 120: Anticipated flow budget changes over time



Introducing FFAIM

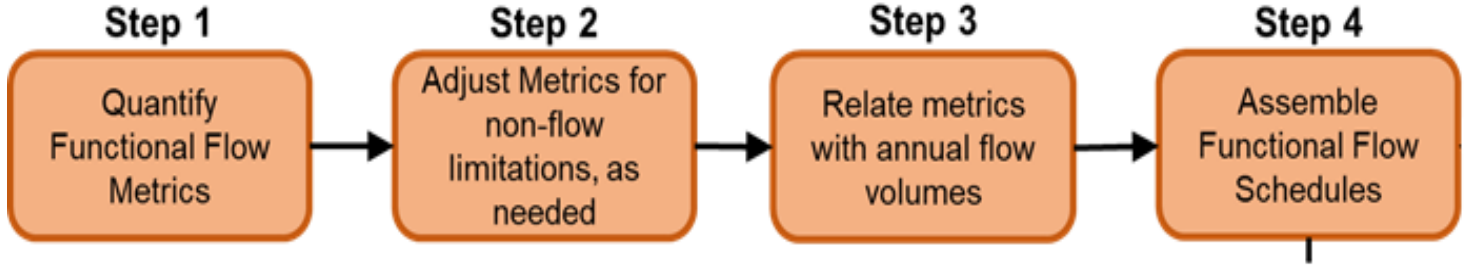
- Functional
- Flows
- Adaptive
- Implementation
- Model

What should operators do now?
What environmental flow schedule should we follow this month to make sure there is water for the rest of the year?

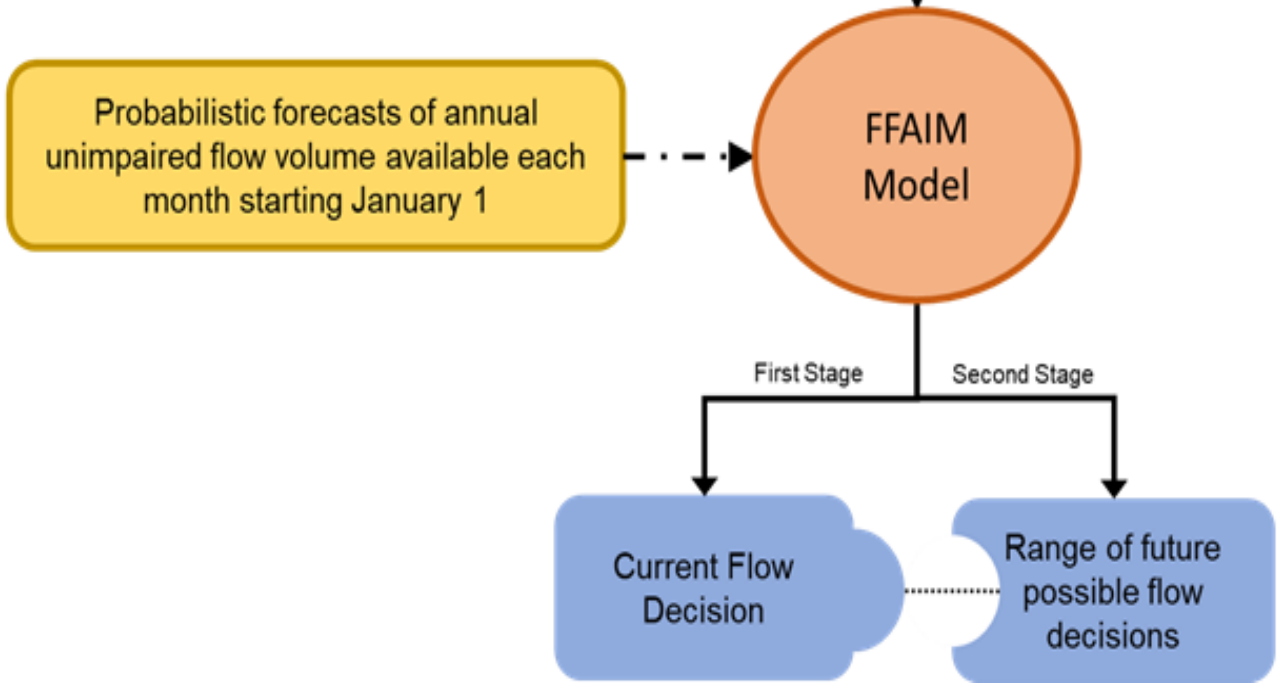
What should operators expect after?
What possible flow schedules remain for the rest of the operating year, given a range of possible flow-budgets?

FFAIM Process

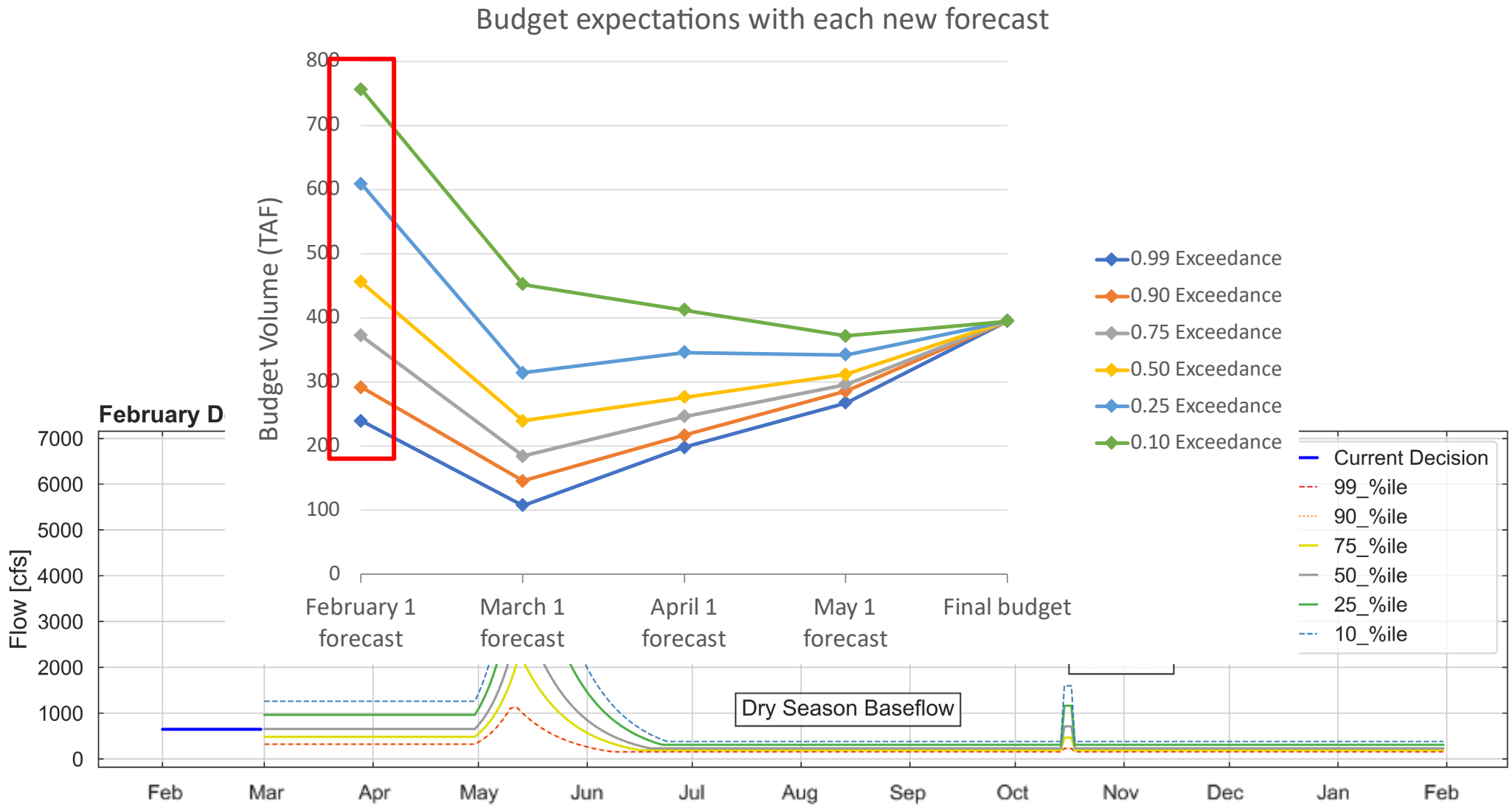
Designing flow schedules from Functional Flow metrics



Using probabilistic optimization to suggest immediate and longer-term decisions



Walk through an operating year: February 1



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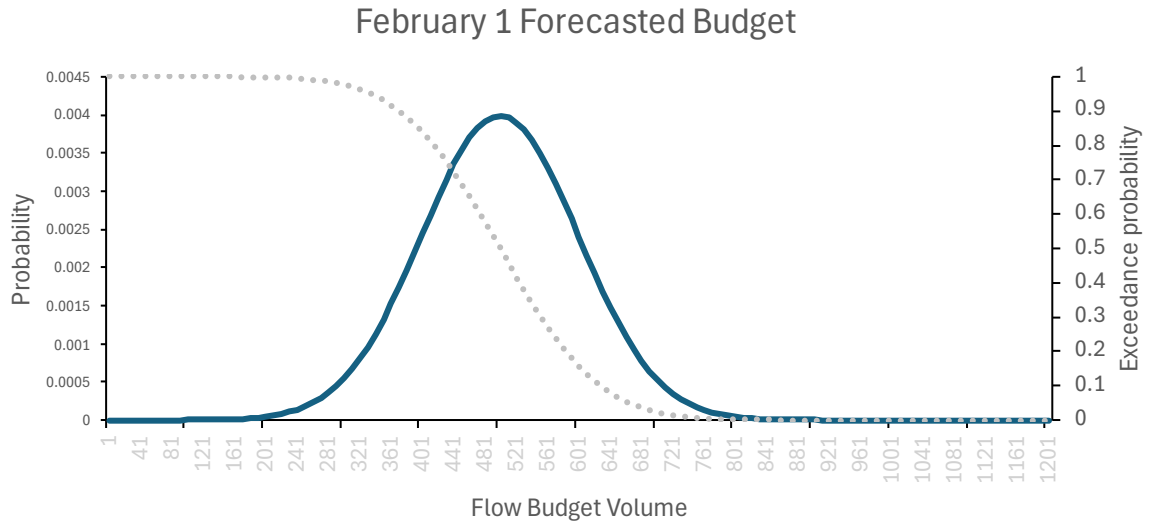
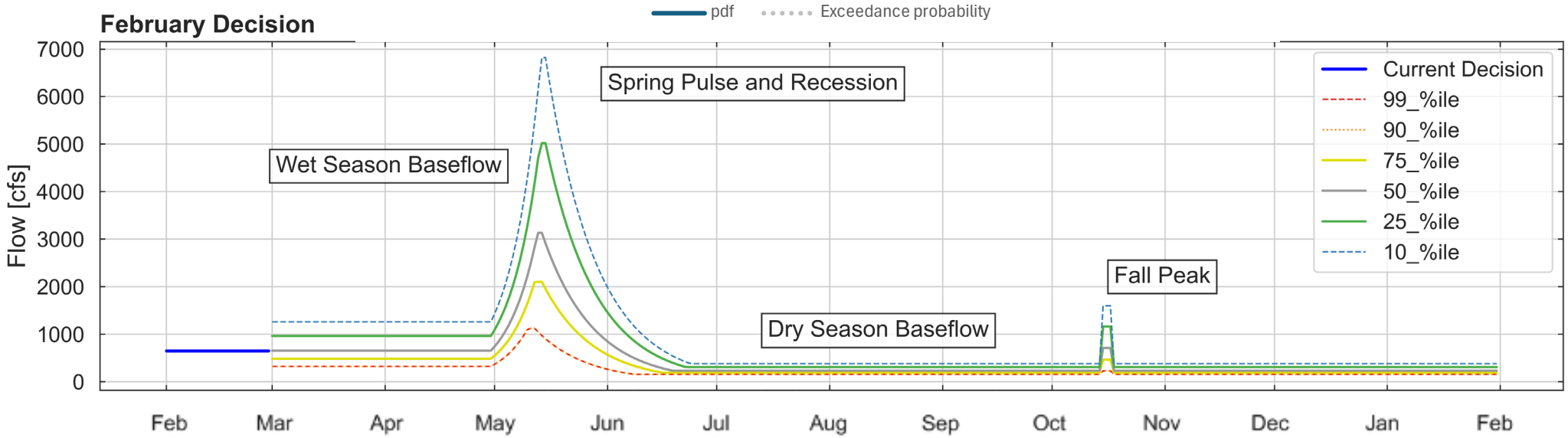
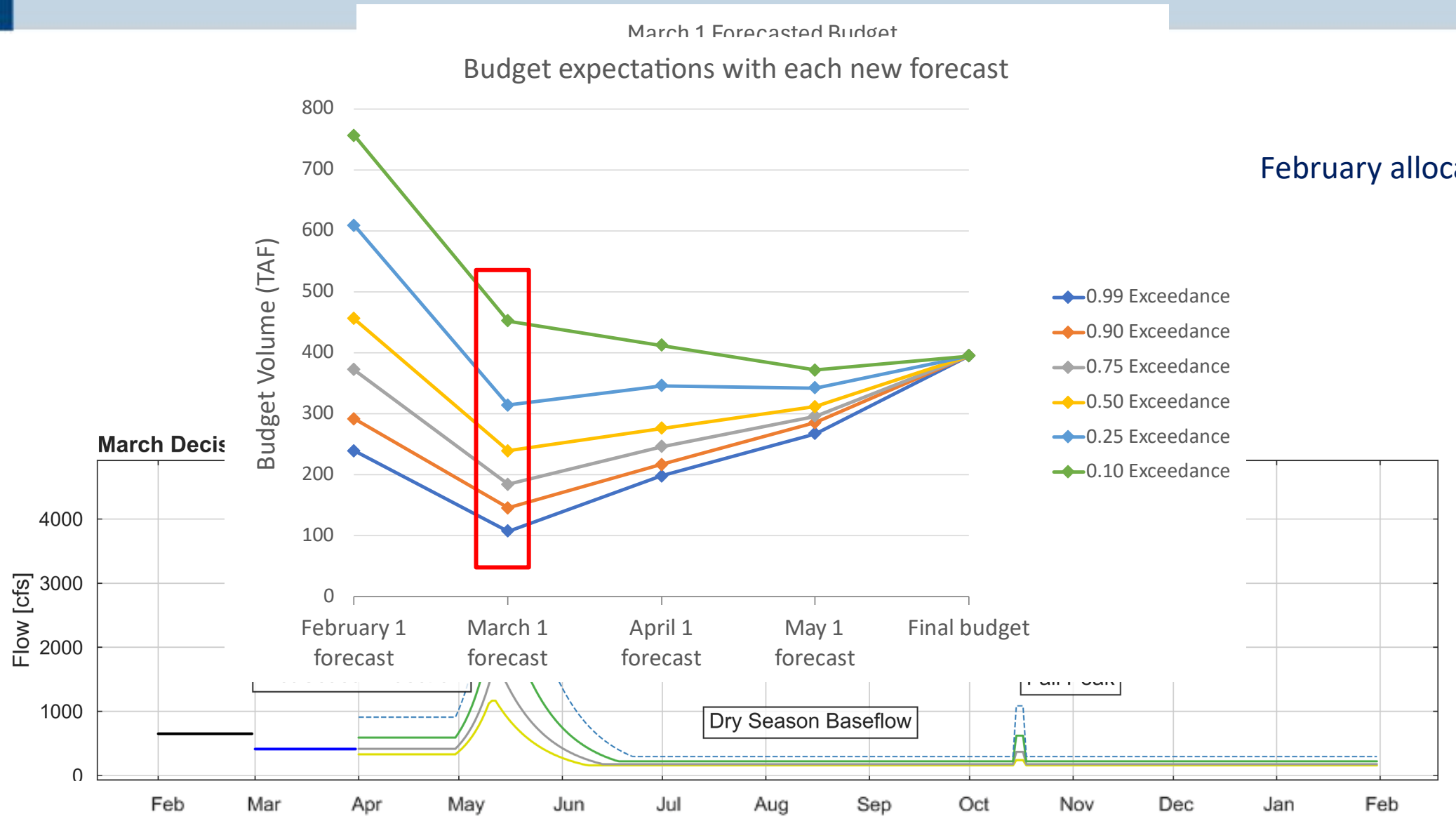


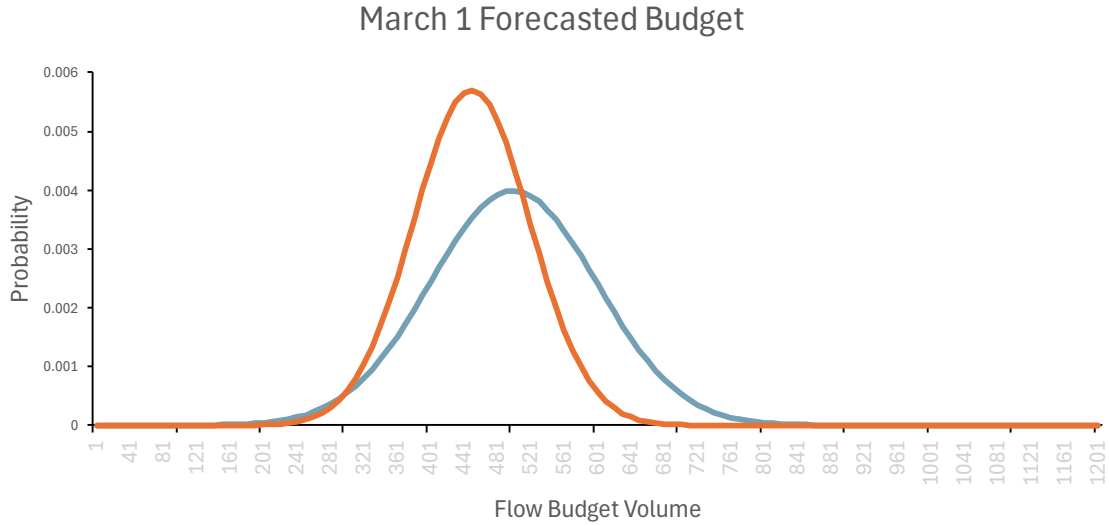


Walk through an operating year: March 1

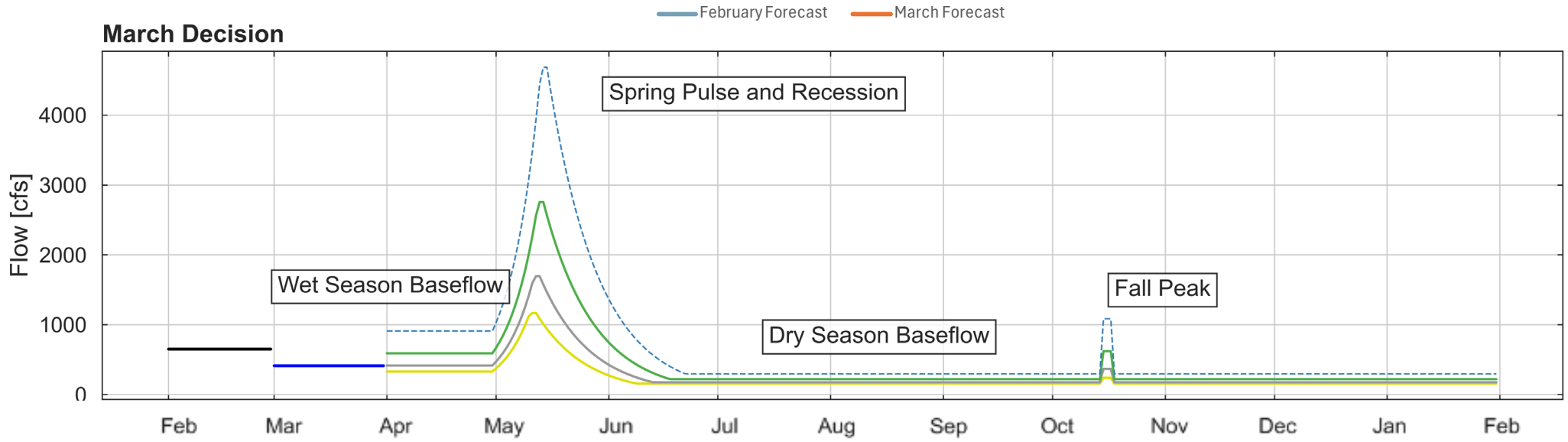


February allocation

Walk through an operating year: March 1

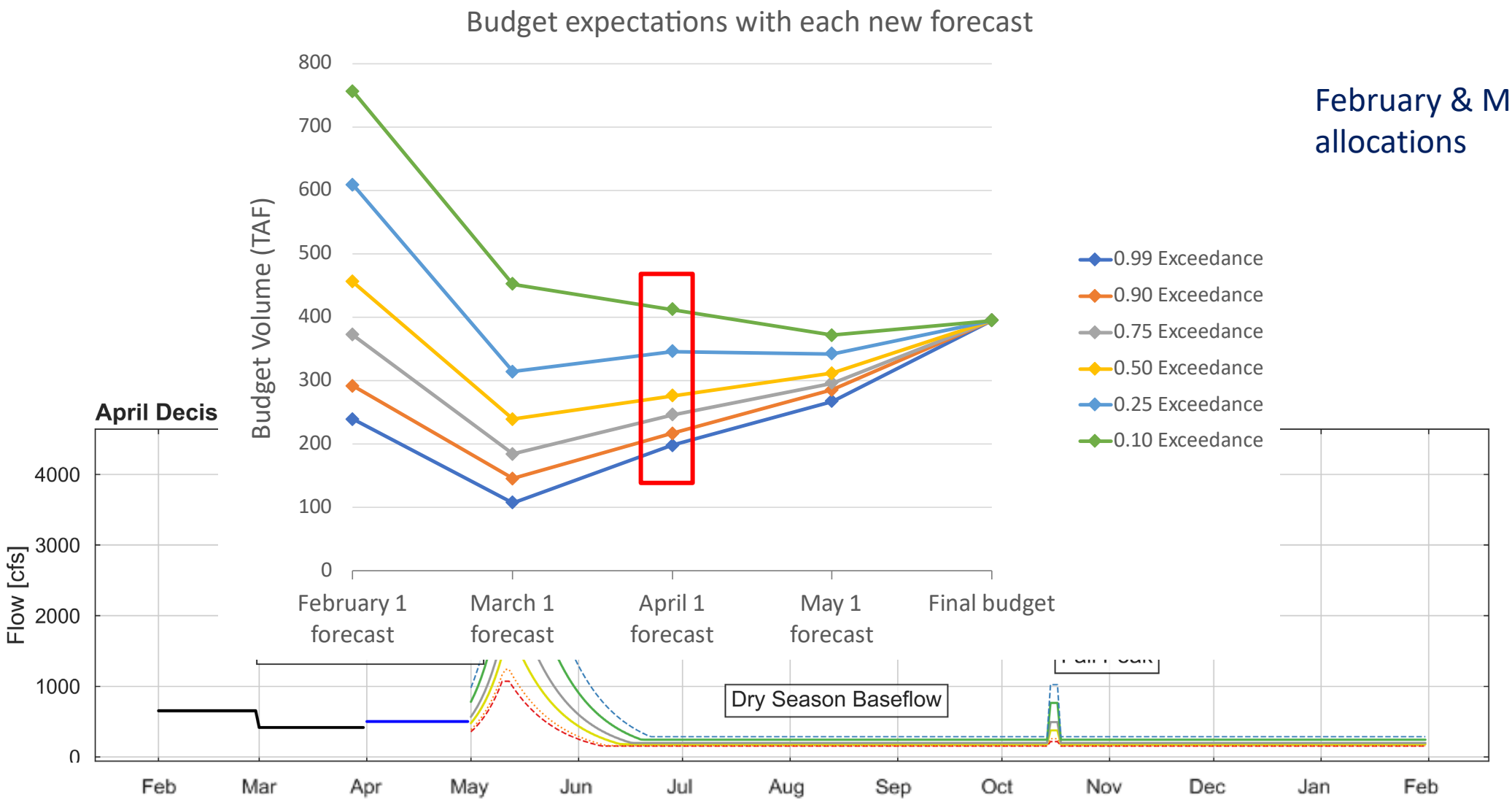


February allocation



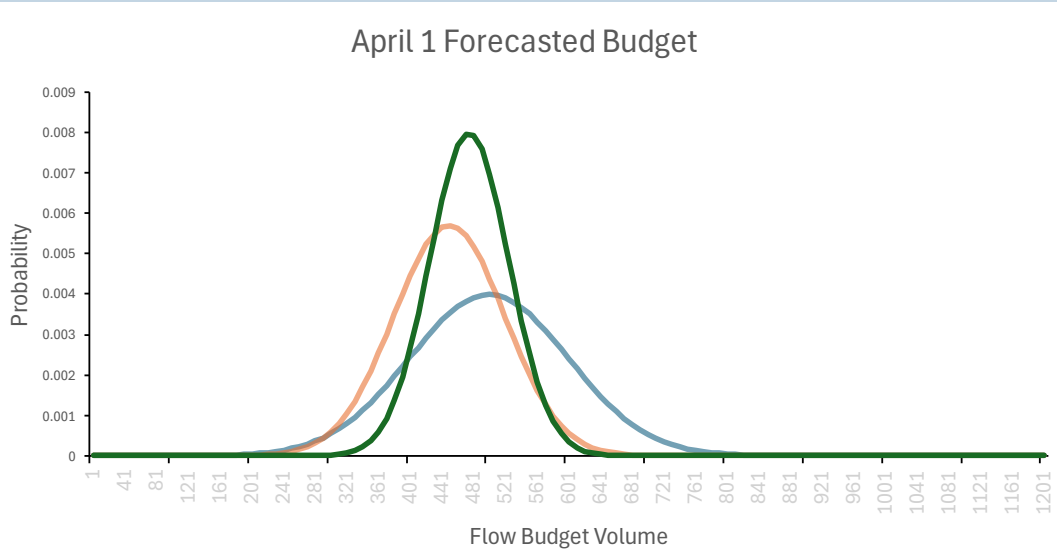
Walk through an operating year: April 1

April 1 Forecasted Budget

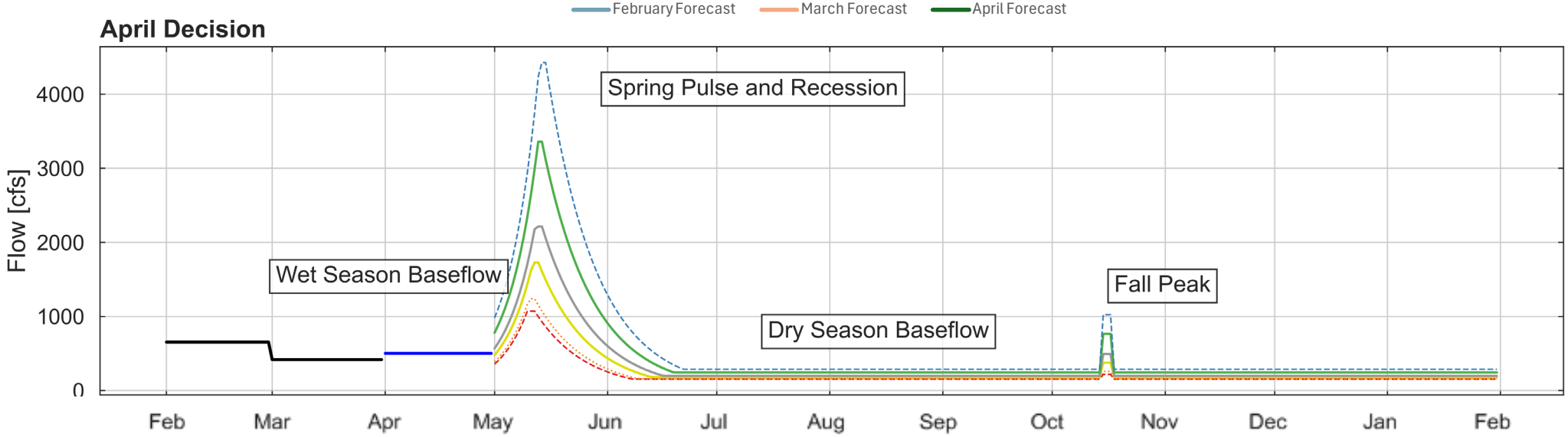


February & March allocations

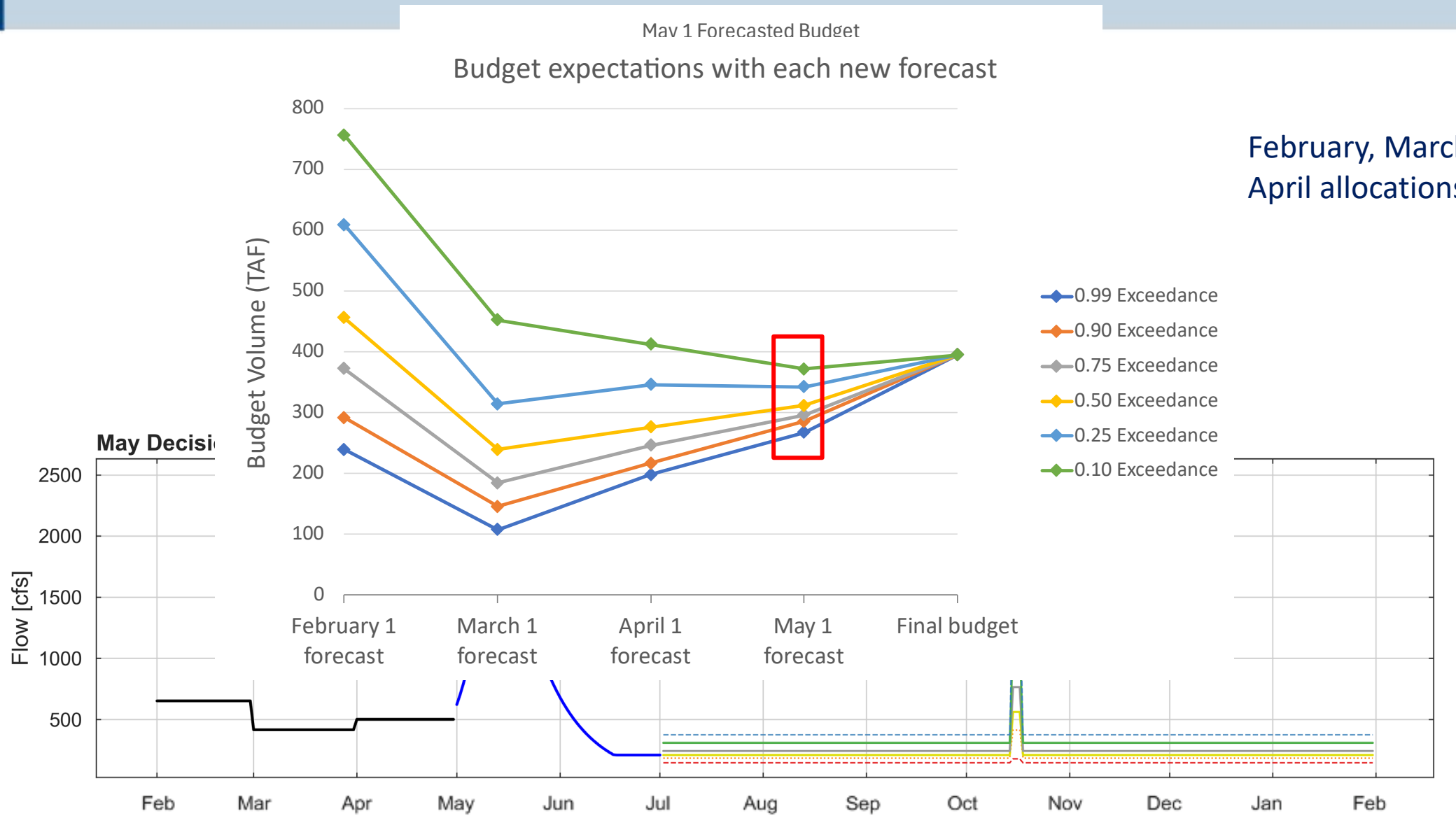
Walk through an operating year: April 1



February & March allocations

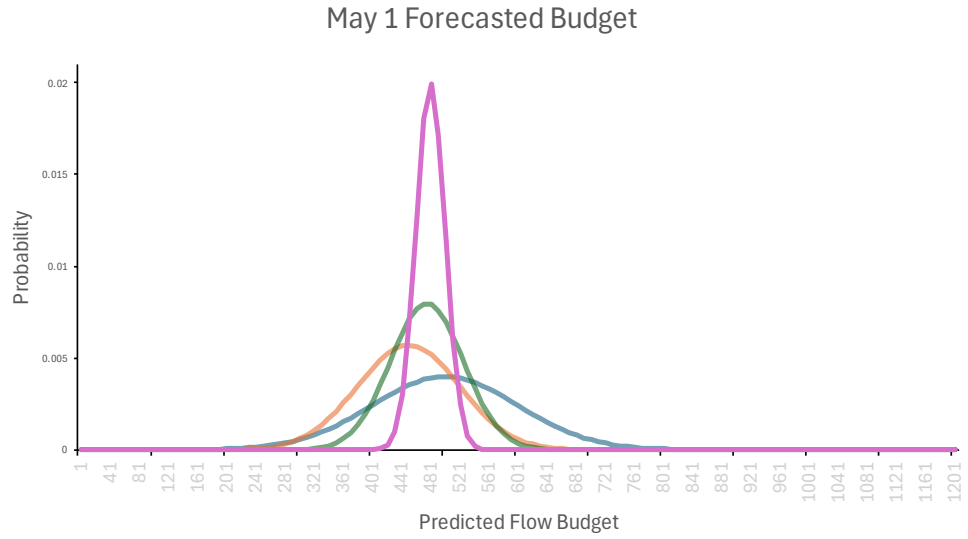


Walk through an operating year: May 1

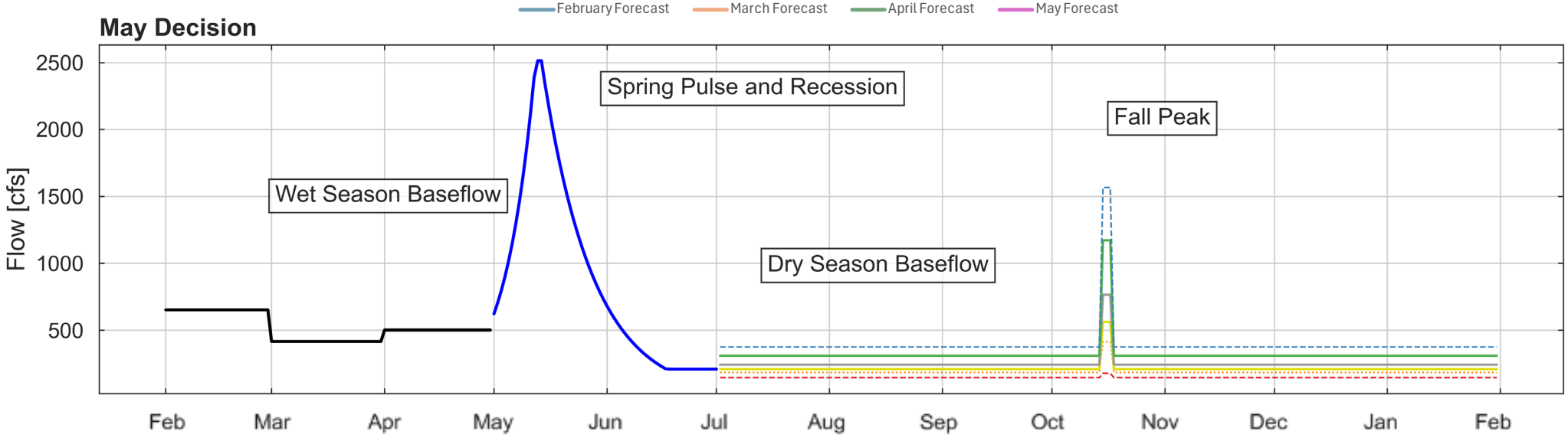


February, March, & April allocations

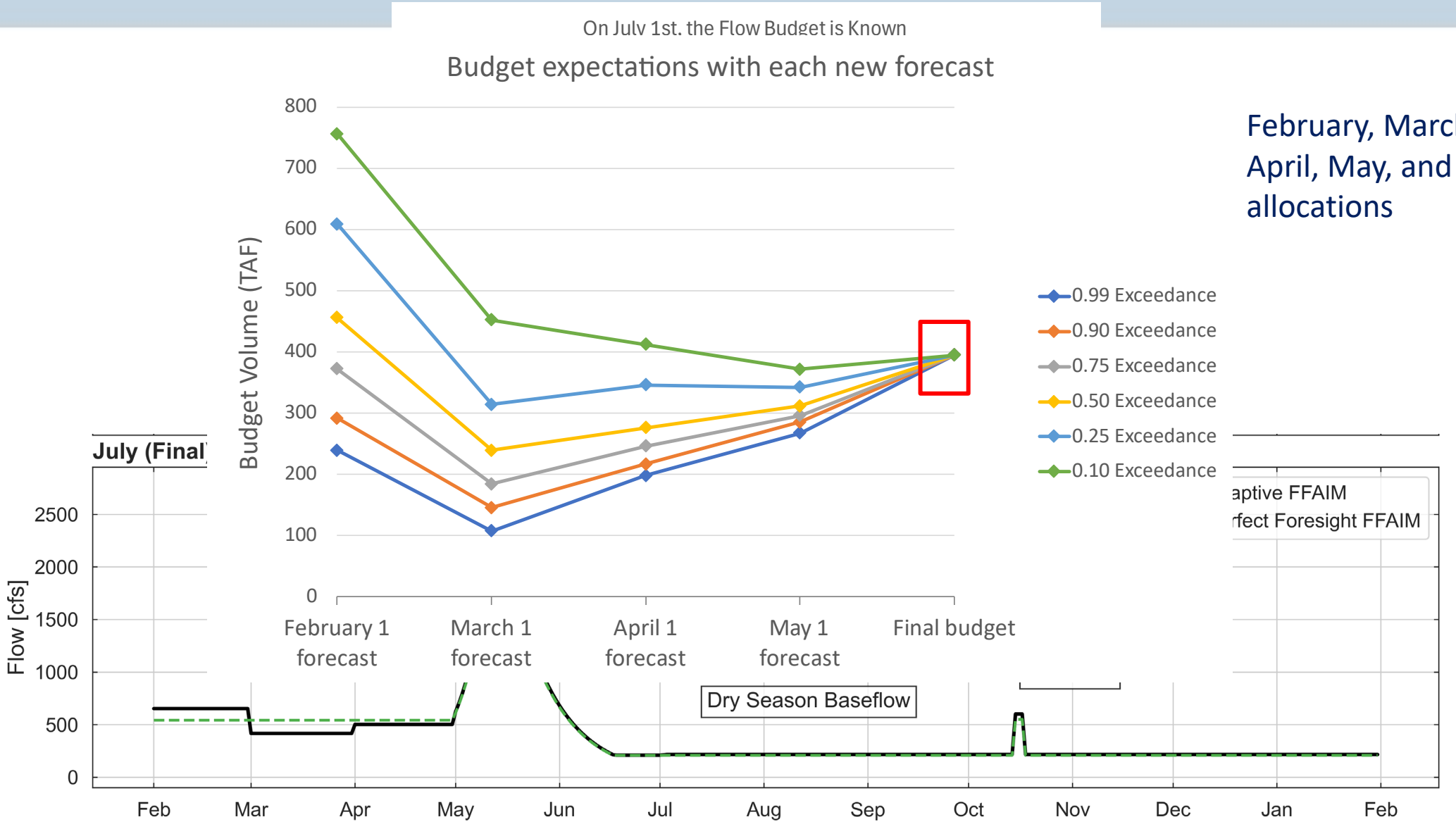
Walk through an operating year: May 1



February, March, & April allocations

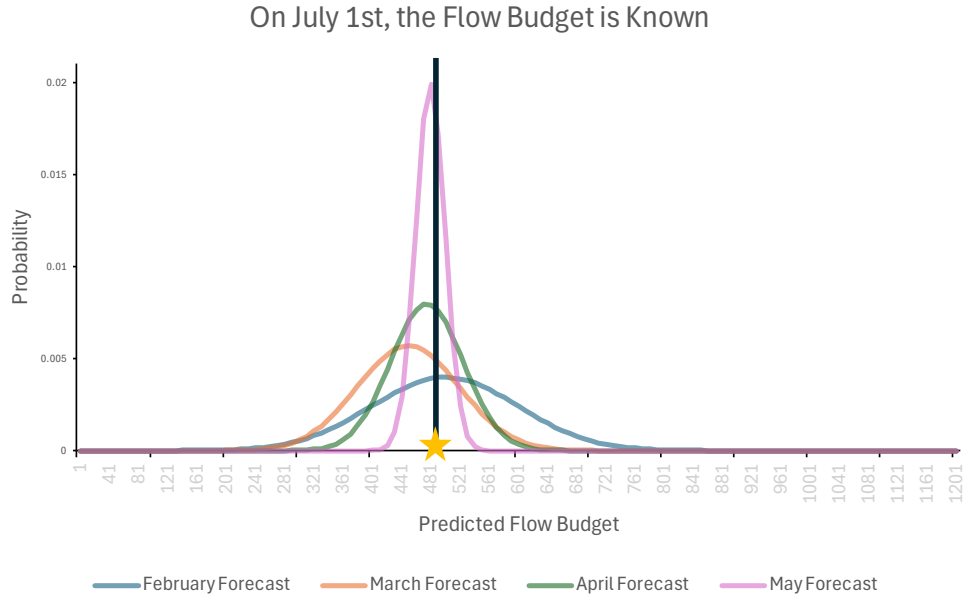


Walk through an operating year: July 1

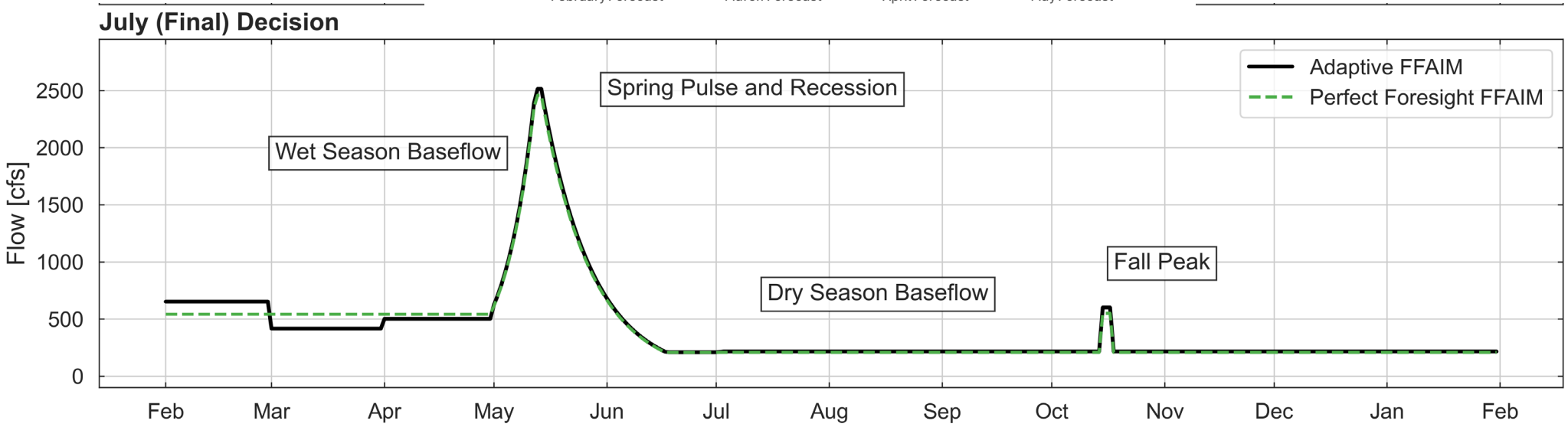


February, March, April, May, and June allocations

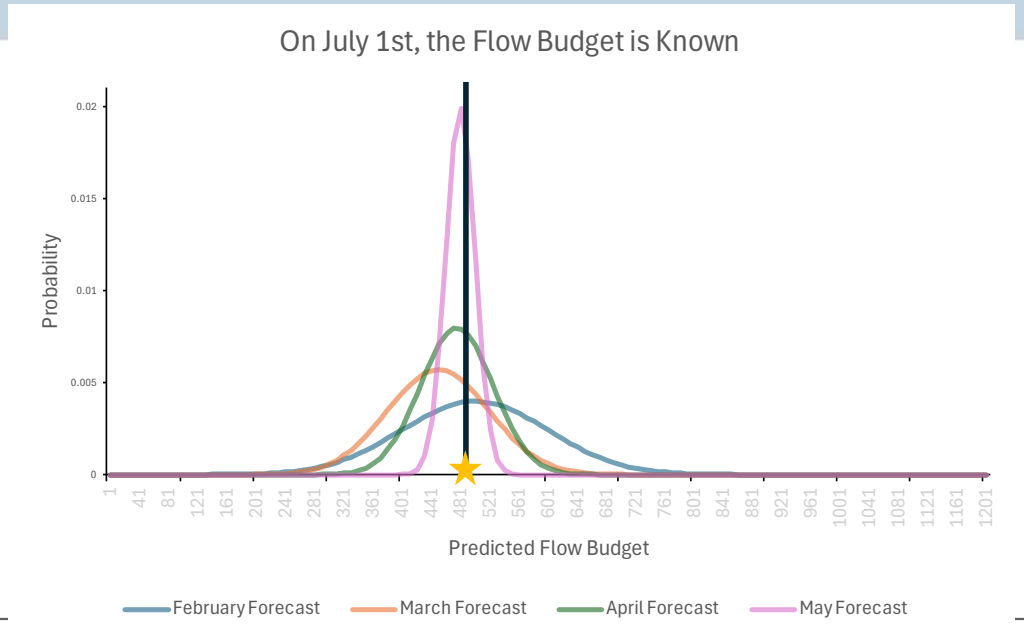
Walk through an operating year: July 1

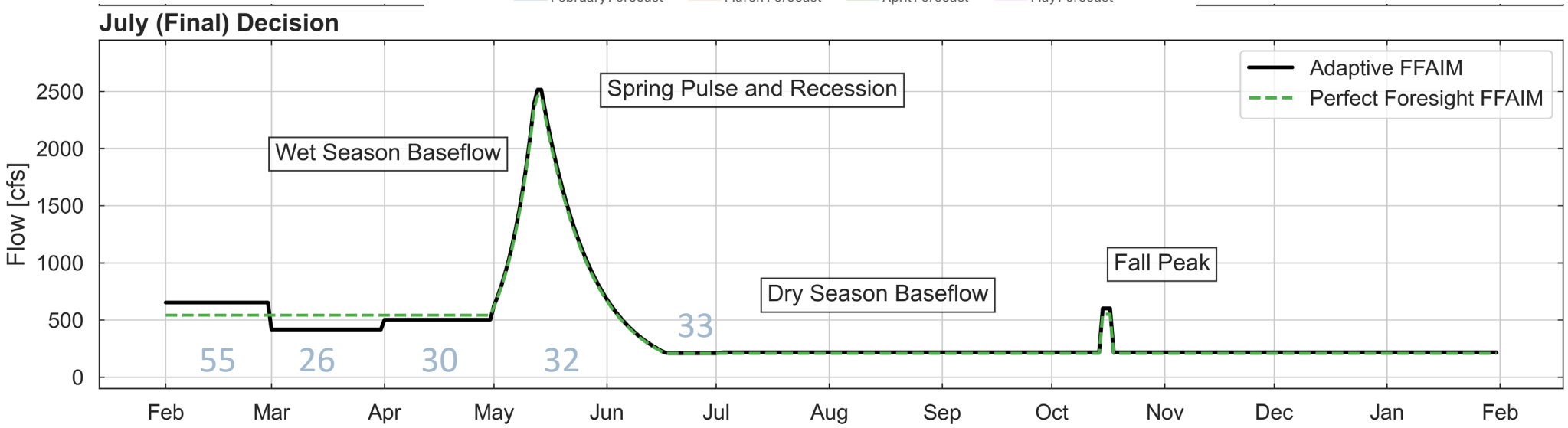


February, March, April, May, and June allocations

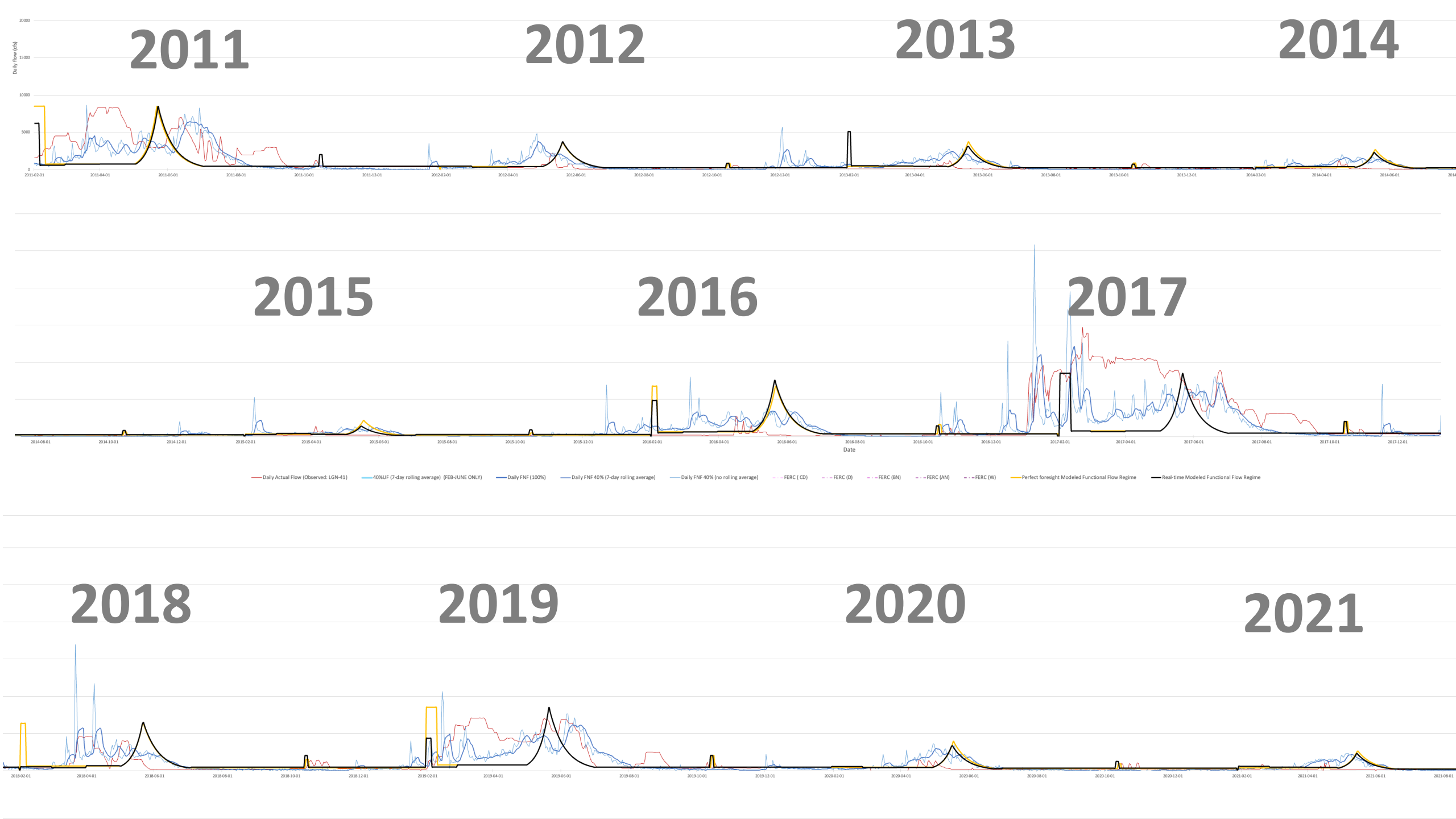


Cumulative Decisions





With perfect foresight: 32


2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Daily flow (cfs)
Date
Daily Actual Flow (Observed: LGN-41)
40%UF (7-day rolling average) (FEB-JUNE ONLY)
Daily FNF (100%)
Daily FNF 40% (7-day rolling average)
Daily FNF 40% (no rolling average)
FERC (CD)
FERC (D)
FERC (BN)
FERC (AN)
FERC (W)
Perfect foresight Modeled Functional Flow Regime
Real-time Modeled Functional Flow Regime

A Question and An Answer

Can an environmental flow budget (40% of February-June unimpaired flows) be allocated throughout the year, while adaptively managing for changing hydrologic conditions as the operating year develops?

- Use Functional Flows as a basis for shaping and shifting flows
- Apply Functional Flows approach using a variable flow-budget
- Use FFAIM for forecast-informed operations in real-time

Yarnell, S., Murdoch, L., Bellido-Leiva, F., Peek, R., Lund, J., 2024.
Flow management through a resilience lens: Allocation of an environmental water budget using the Functional Flows Adaptive Implementation Model.
In: Thoms, M., Fuller, I. (Eds.), Resilience and Riverine Landscapes. Elsevier, pp. 469–490.