Hydrologic Changes Over Time at the Baker Project

PUGET SOUND ENERGY

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Today's Talk

- Introduction
  - Context on region/Baker Project
  - Water management objectives
- Identifying hydrologic changes over time
  - Methodology
  - Results
- Conclusions
  - Water management adaptation
  - Considerations/implications

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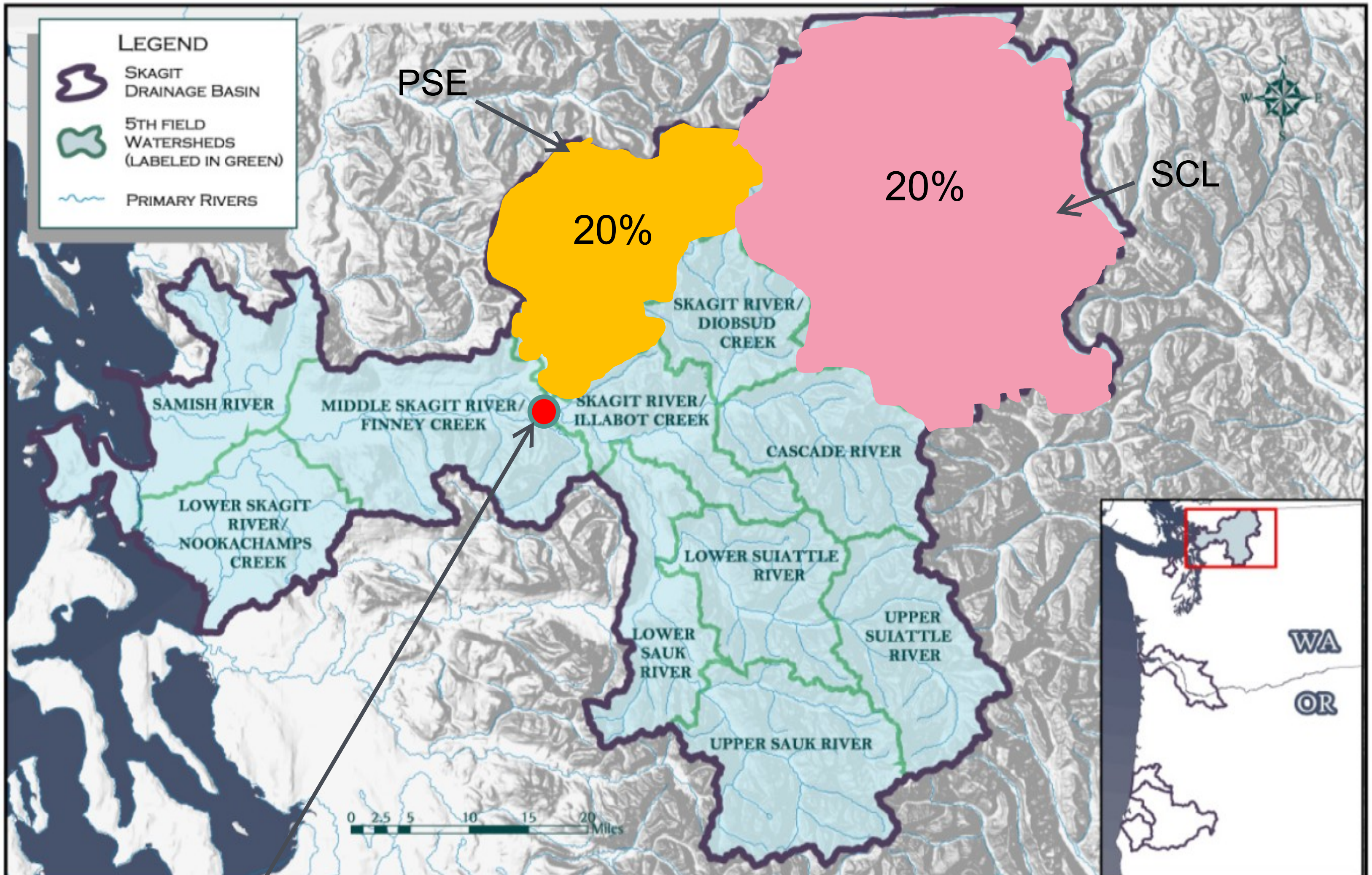
Skagit Valley



Overall goal is to minimize peak at Skagit near Concrete gage during flood events

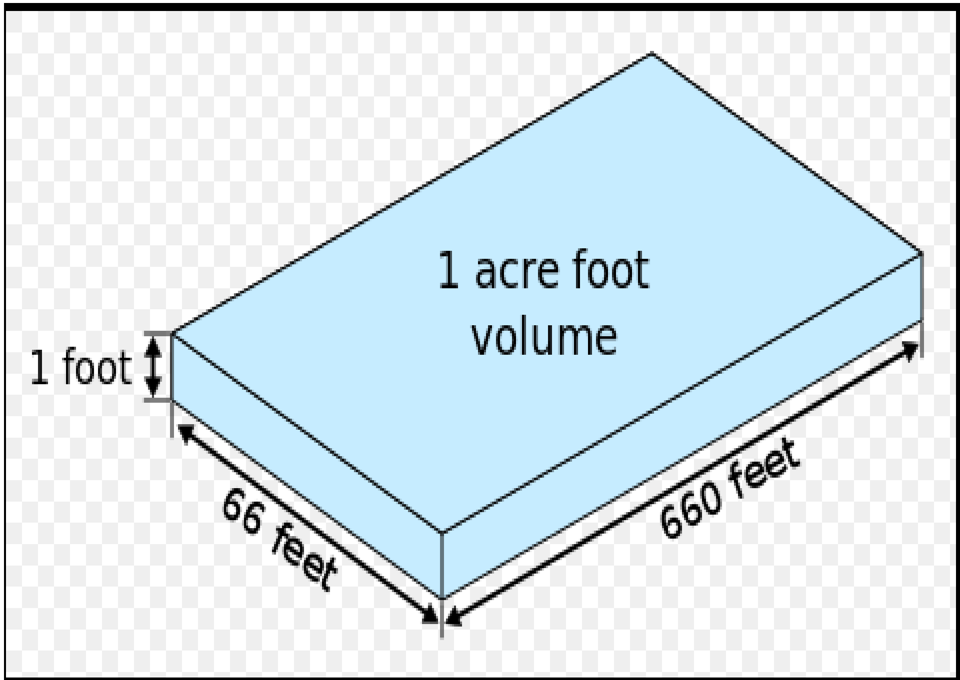
Only ~40% of the Skagit basin is regulated

Water Management Units of Measurement

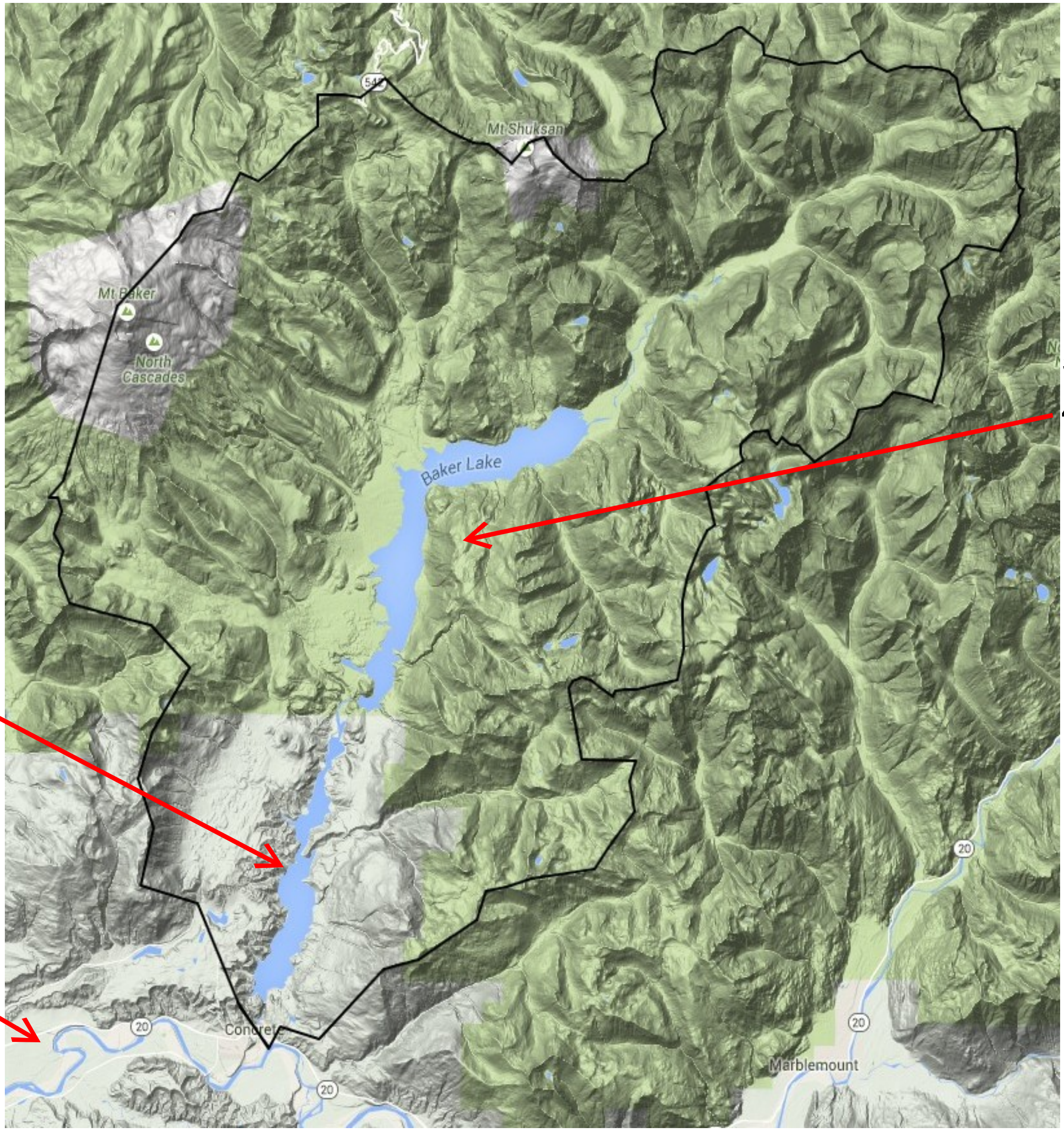
- Cubic feet per second (cfs) = ~450 gallons per minute
- Acre-foot = Volume of water covering an area of one acre a depth of one foot
  - ~326,000 gallons

Average annual inflow volume to Baker Project:

~1.9 million acre-feet
(620 billion gallons)



Baker River Basin



Upper Baker
5100 cfs max gen
46,000 cfs max spill

Lower Baker
6000 cfs max gen
40,000 cfs max spill

Skagit River

Important context:
Baker Basin only ~8 points in forecasting models

Upper Baker – Built 1959

- ~162,000 acre-feet of usable storage within FERC license constraints
- 100 MW capacity

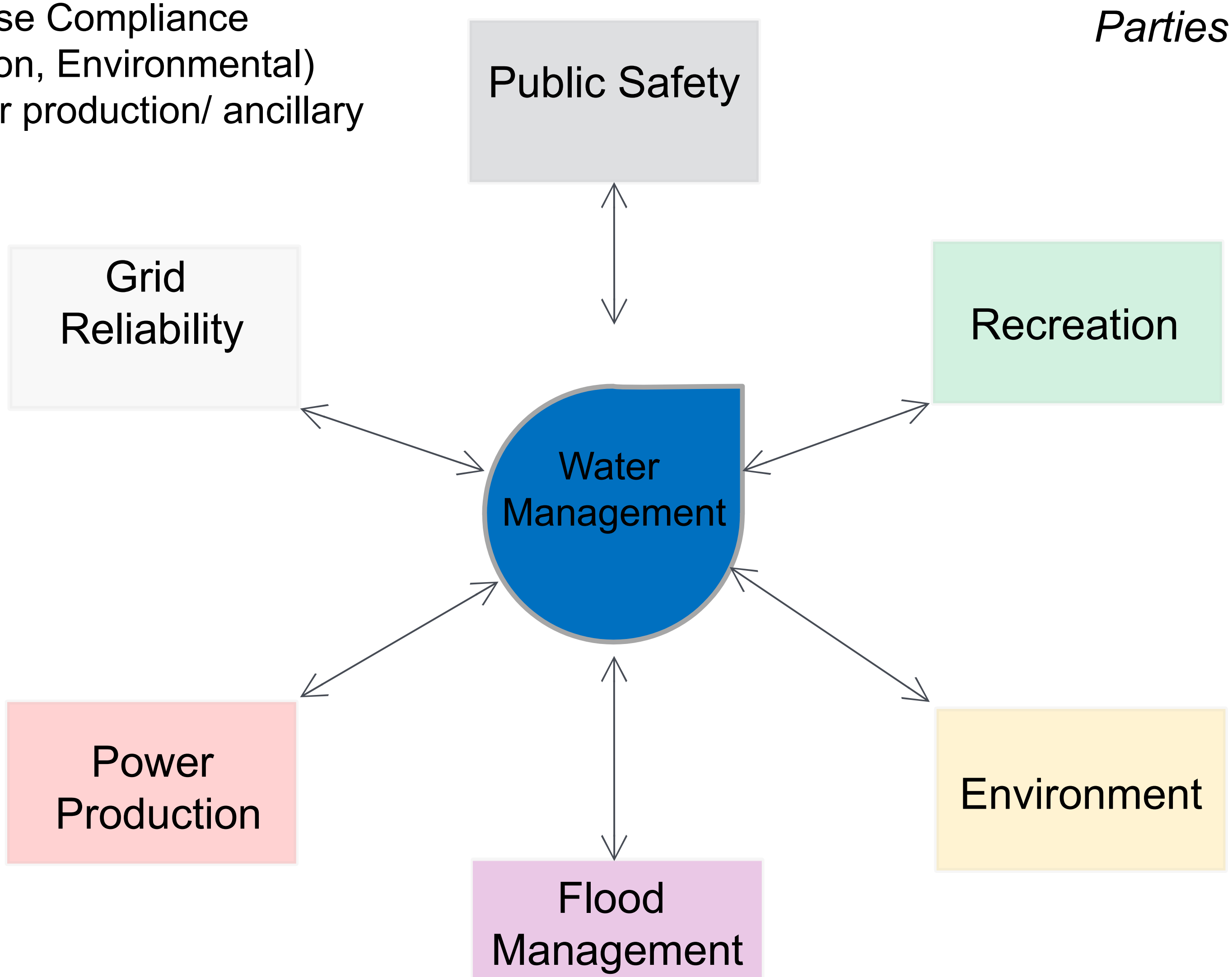
Lower Baker – Built 1925

- 97,000 acre-feet of usable storage under FERC license constraints
- 115 MW capacity

Water Management Objectives for Baker Project

#1- Public safety
#2- License Compliance (Recreation, Environmental)
#3- Power production/ ancillary benefits

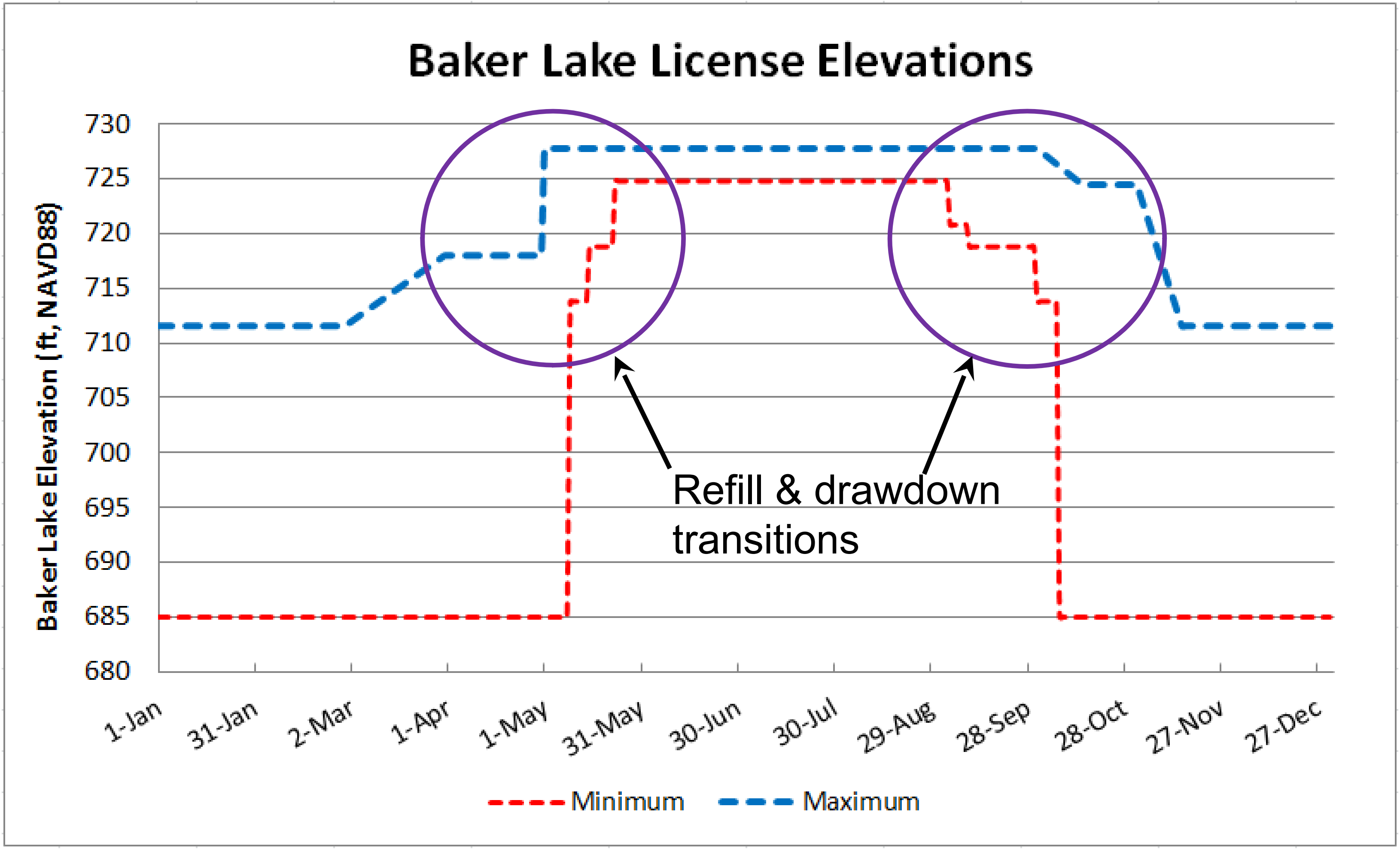
24 Settlement Parties in License



What Is Nonstationarity & Why Should I Care?

- Nonstationarity Time Series: when a dataset's mean and/ or variance isn't constant over time
- Is the data identically and independently distributed (iid)?
  - Example: Are floods more likely in recent years vs decades ago?
- Nonstationarity, if present, ruins a lot of statistical analyses (100 year flood, etc.)
  - Our risks may be very different than we thought

Biggest Water Management Risks from Climate Change



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Nonstationarity in the Baker Basin

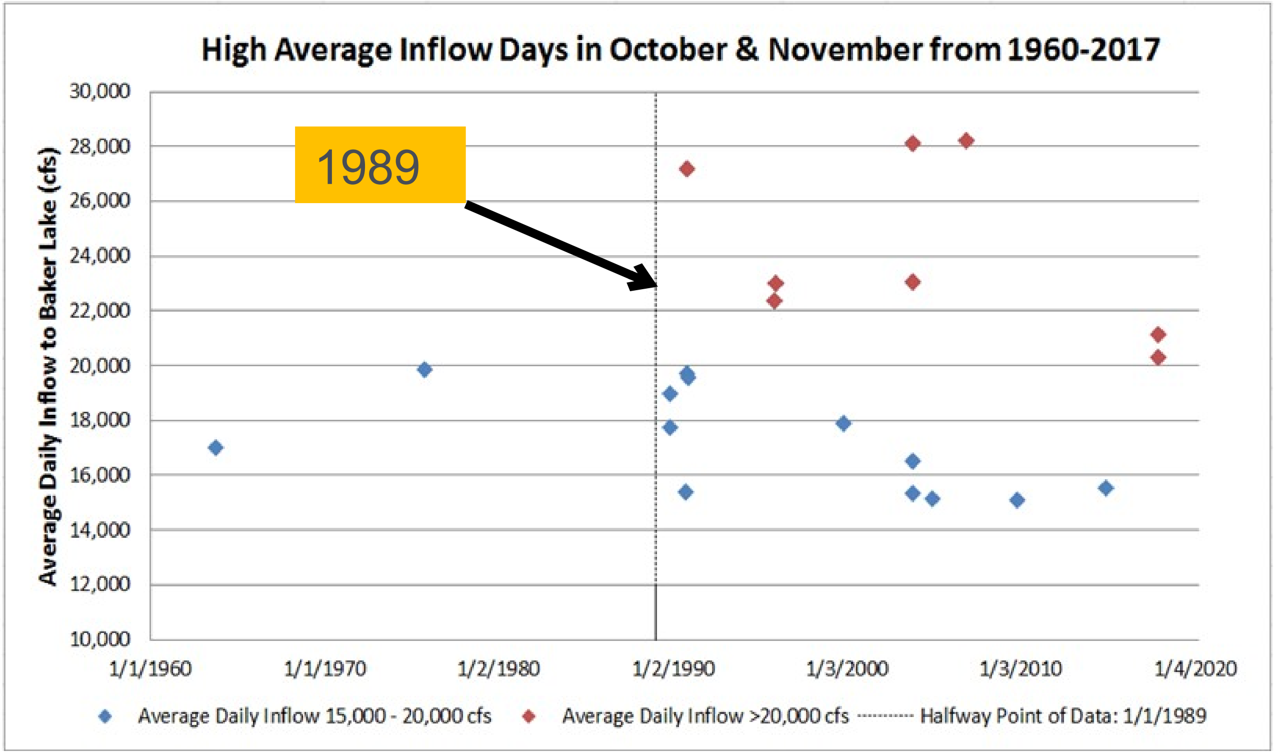
- Split hydrologic record in half: 1960-1988 vs 1989-2017
- Does this distribution look identical and independent over its range?
- Should we manage the reservoirs differently based on changes over time?

<u># of Days >15,000 cfs:</u>

1960 – 1988: 2
1989 – 2017: **19**

<u># of Days >20,000 cfs:</u>

1960 – 1988: 0
1989 – 2017: **8**



More Frequent High Inflow Days October & November

- Of top 10 daily average inflows since 1960, 9 have occurred since 1990
- Early flood season storms are high risk if aggressive drawdown hasn't produced significant storage
  - Two major storm events in top 10 happened on Oct 17th!

Rank	Date	Average Daily Inflow (cfs)
1	11/6/2006	28,224
2	10/17/2003	28,124
3	11/10/1990	27,185
4	10/20/2003	23,026
5	11/29/1995	23,022
6	11/8/1995	22,385
7	11/23/2017	21,140
8	11/22/2017	20,292
9	10/17/1975*	19,858
10	11/24/1990	19,851

*Only one in top 10 highest inflows since 1960 that occurred before 1989

Modeling Philosophy

"Everything should be made as simple as possible, but not simpler" - Einstein

Method of Analyzing Changes: Kernel Density Estimation

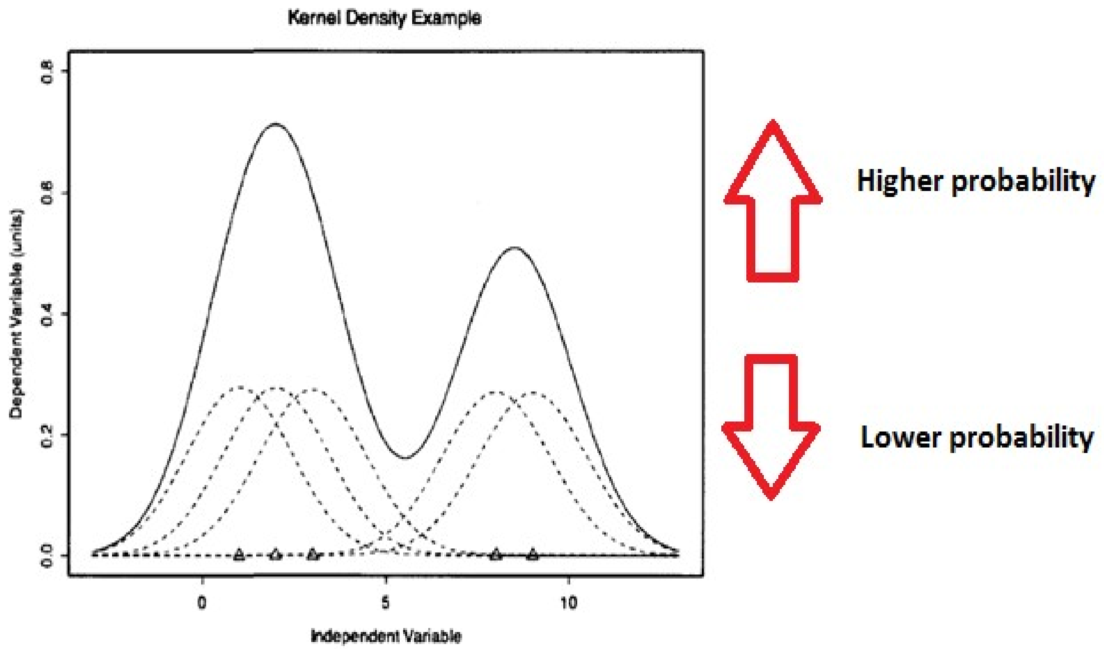
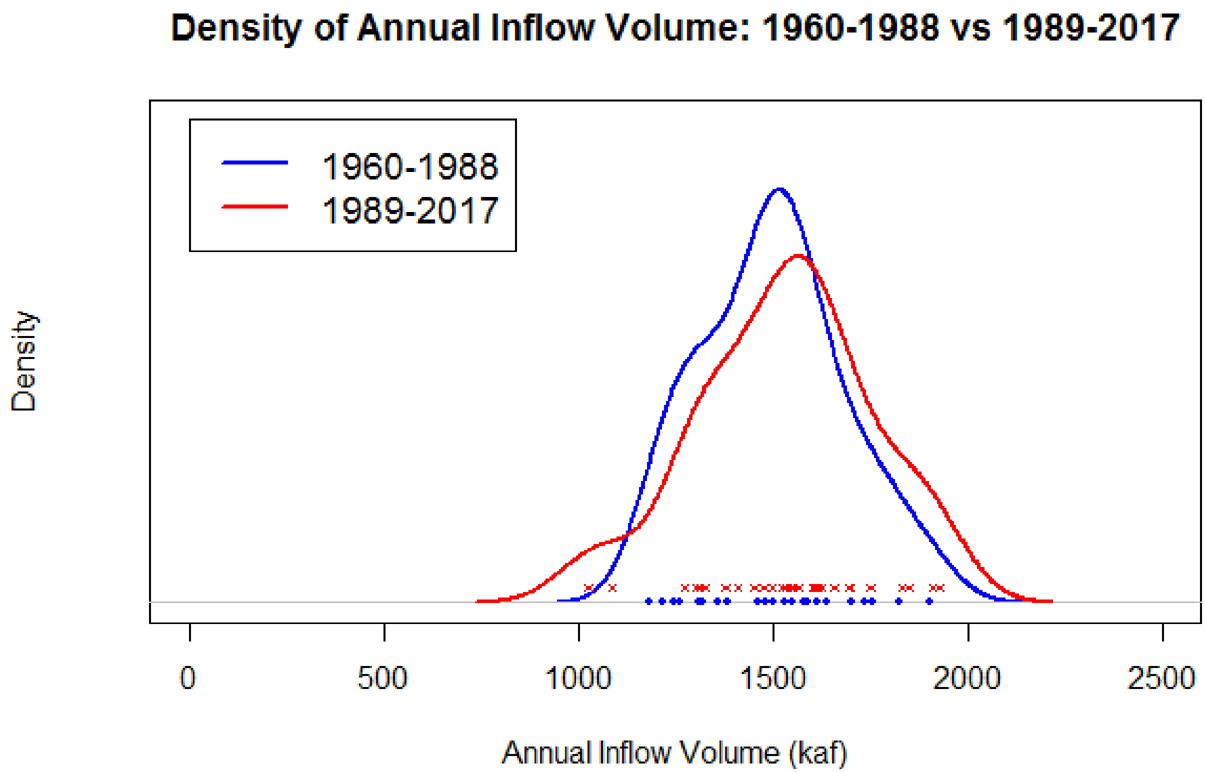


Figure A.1 Kernel Density Example. An example of how kernel density estimation works. The blue triangles are five data points. The dotted lines show the kernel function centered on each data point. The solid line is the sum of all five kernel function estimate at each value of x.

Nonparametric method that avoids issues of linearity and normality

Creates probability density function- with total area equal to one

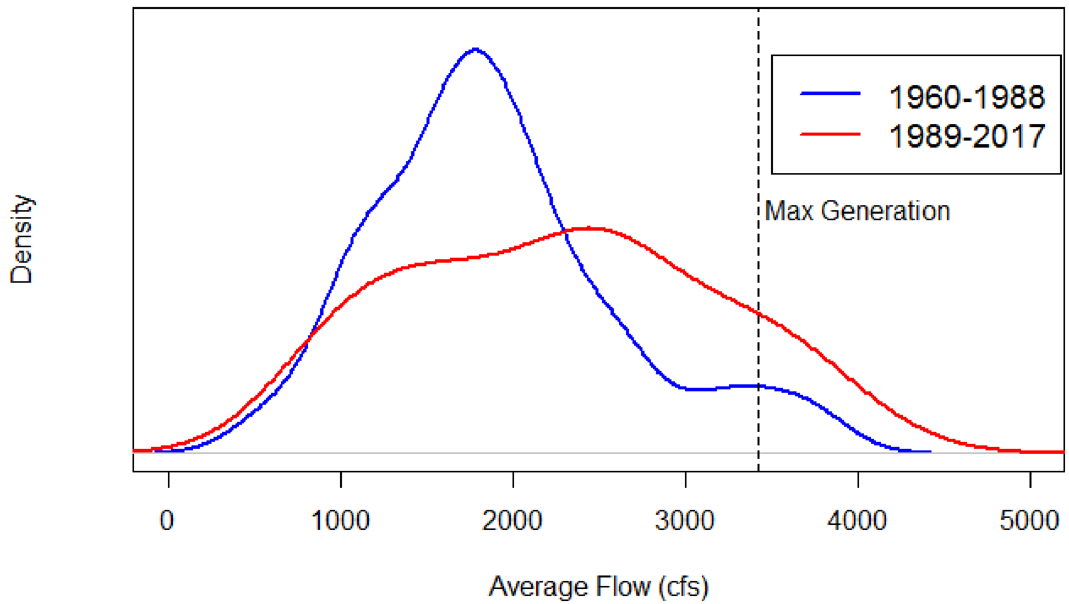


	1960-1988	1989-2017
Mean	1500	1530
Standard Deviation	183	223
Interquartile Range	230	280
Coefficient of Variation	12.2	14.6

Similar mean

Much more variability in recent period

Average Inflow October 1 - November 15: 1960-1988 vs 1989-2017



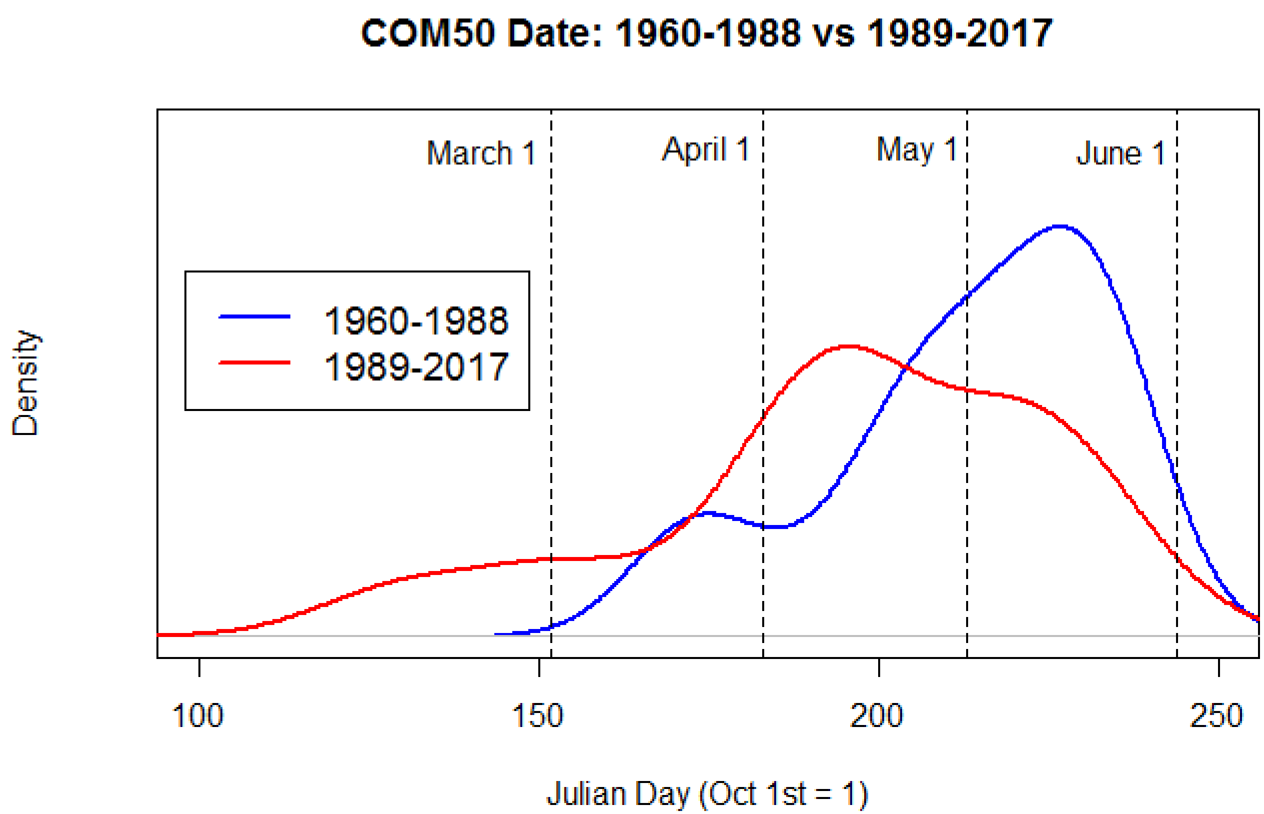
	1960-1988	1989-2017
Mean	1899	2272
Standard Deviation	726	901
Interquartile Range	664	1248
Coefficient of Variation	38.2	36.7

19.6% higher mean

Higher variability in recent period

Center of Mass Date

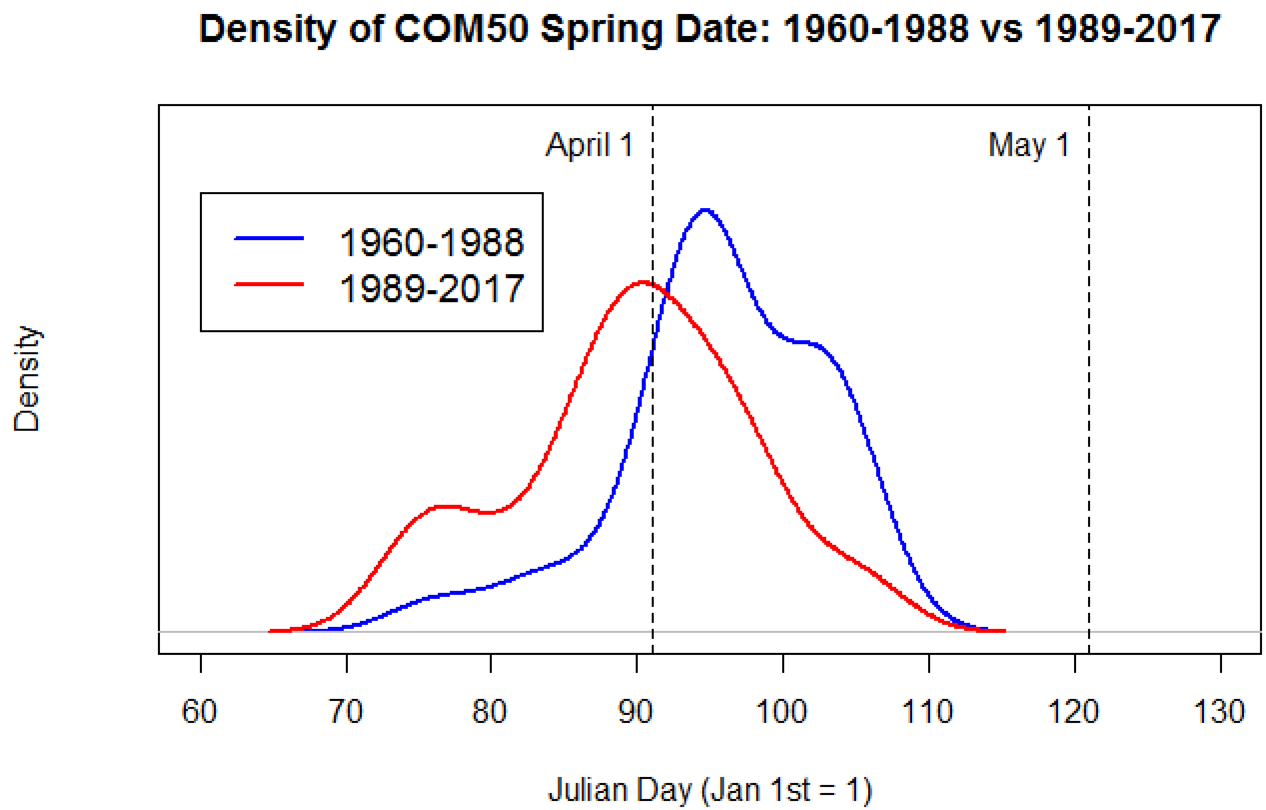
(Day that half of that water year's total volume has passed)



Center of Mass Date shifted about a full month earlier from:

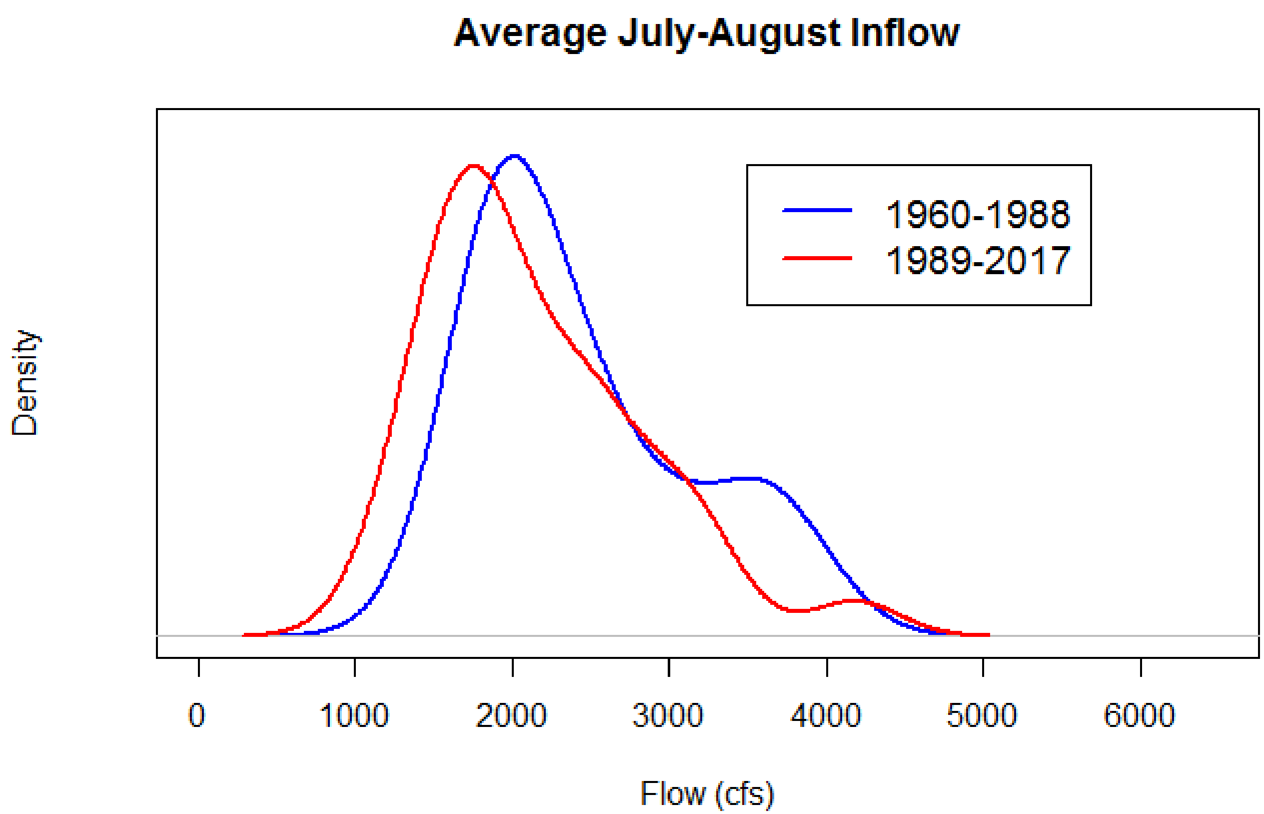
- More intense storms in the fall
- Earlier runoff

Center of Mass Date - Spring



Peak density of spring runoff about a week sooner

No concerns about refilling yet



	1960-1988	1989-2017
Mean	2440	2155
Standard Deviation	695	690
Interquartile Range	1053	835
Coefficient of Variation	28.5	32

Lower mean

Less variability

Summary of Changes & Implications

- Drawdown period (October 1 – November 15) is wetter & more variable
  - *More flood risk than previously known*
- Springtime runoff is coming slightly sooner, but still have sufficient water to refill
  - *More generation late winter/early spring to avoid spilling more in May/June*
- Summertime flows are lower and less variable
  - *Harder to provide minimum instream flows at Lower Baker for environmental purposes while keeping Baker Lake full for recreation*

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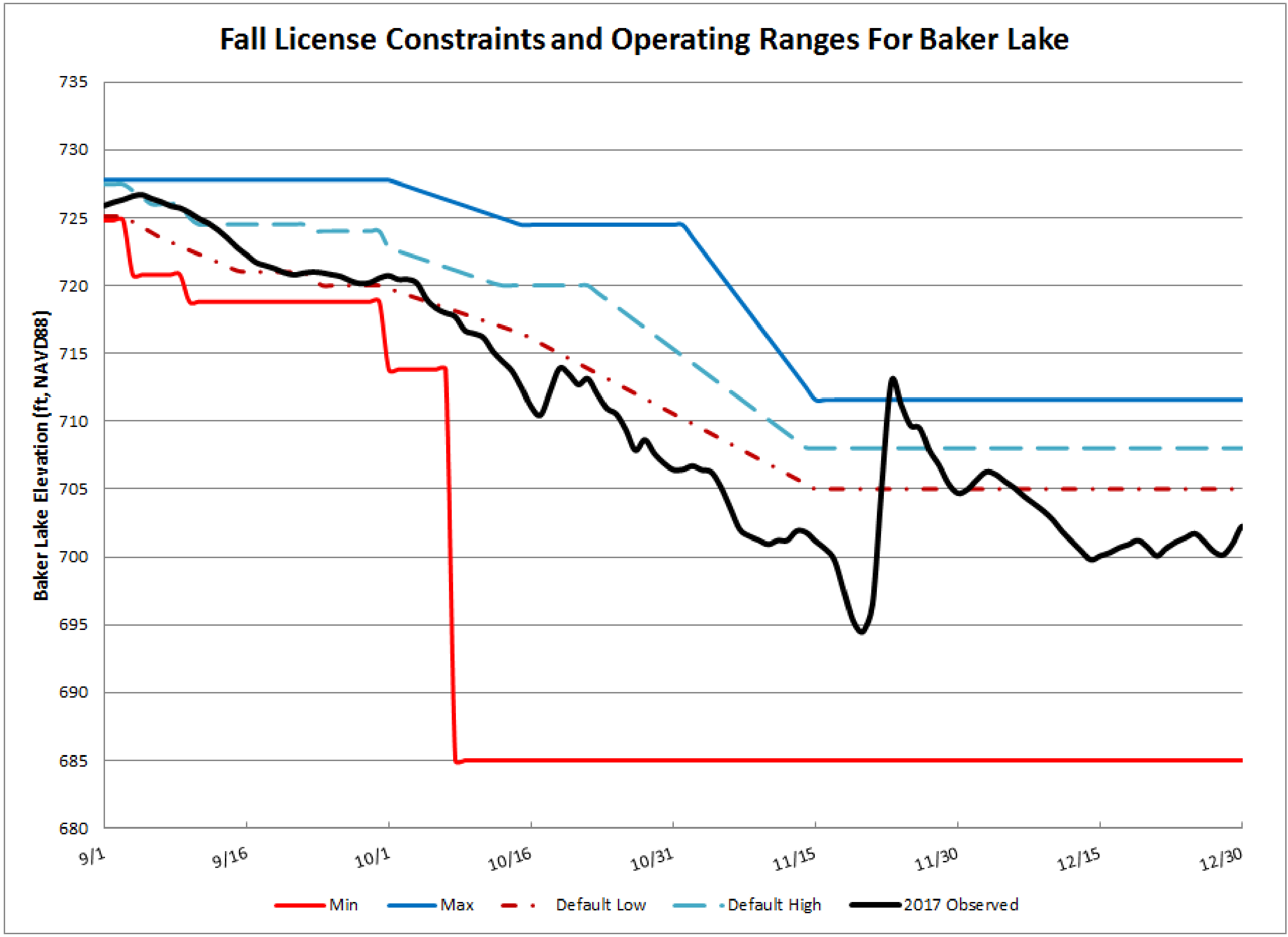
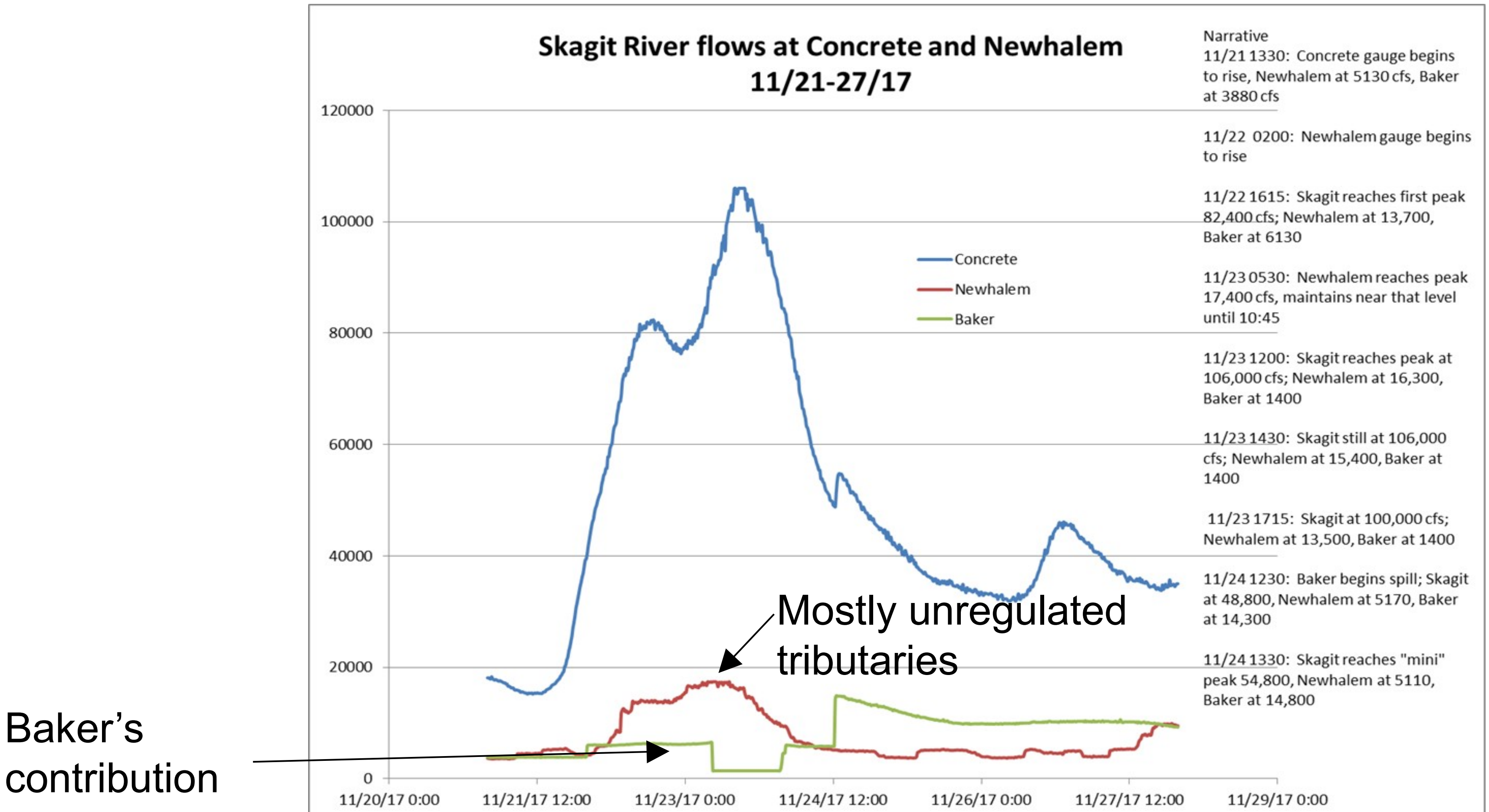
Water Management Adaptation Example

- Challenging drawdown period
- Limited maximum discharge due to license constraints
- Drafted lakes earlier and further in 2017 to offset newly discovered risks

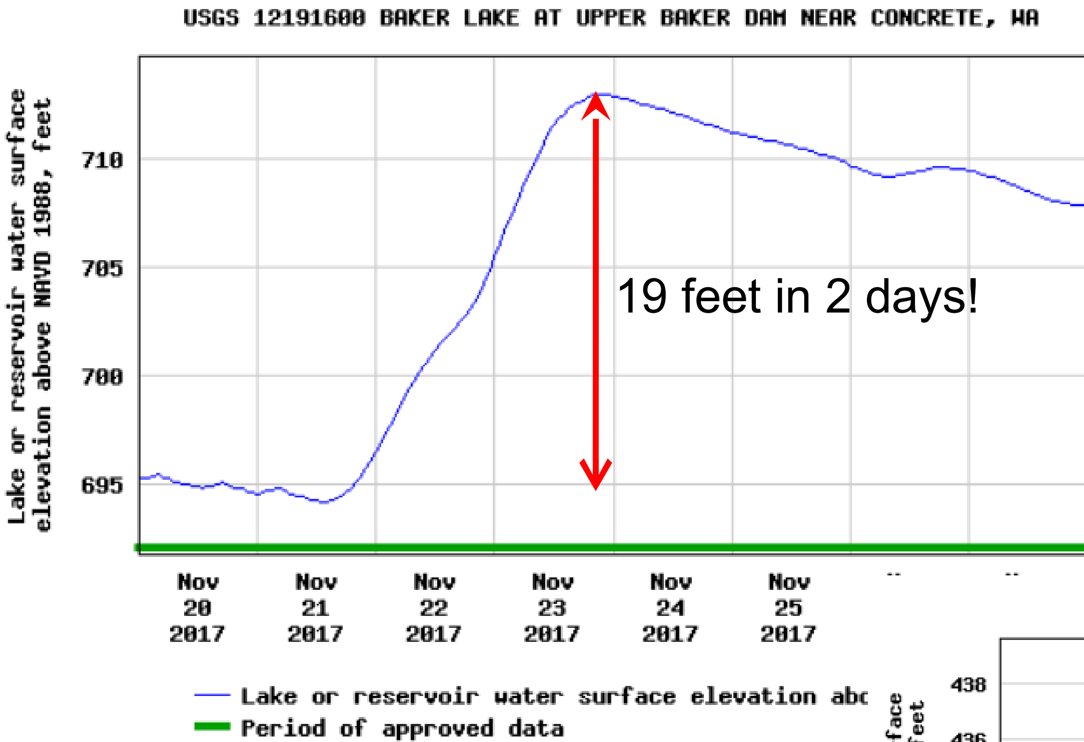


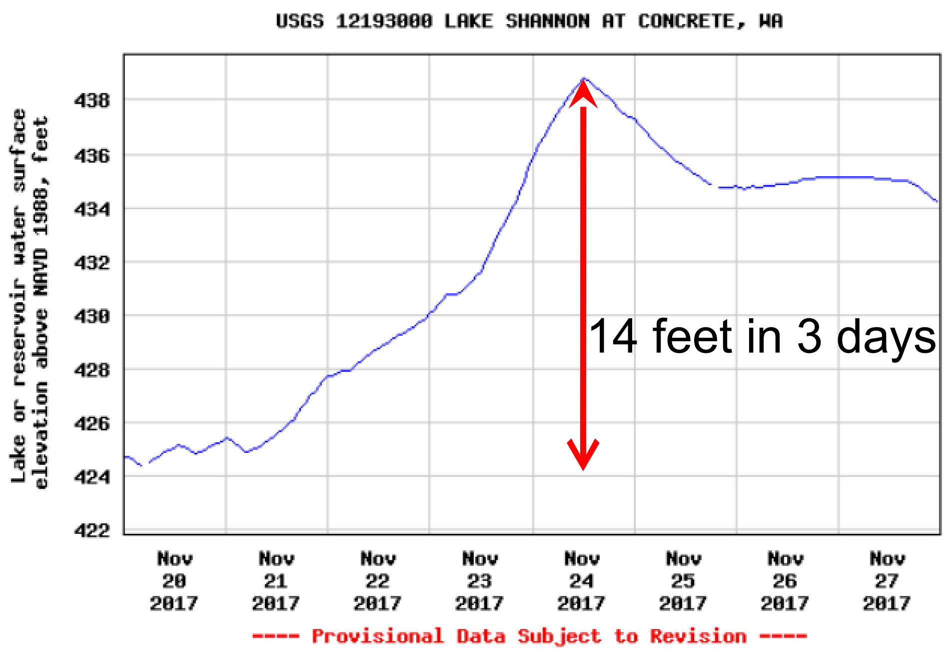
Extra Storage Helped with Major Flood on Thanksgiving 2017

- Figure below from the County (shared with permission)
- More aggressive drawdown allowed PSE to drop discharge to minimum instream flow during the peak of the flood on the Skagit



Good Thing The Lakes Were Drawn Down…





Largest flood in 11 years

Post Assessment Report

- According to Corps, the Baker & Skagit Projects collectively reduced the peak on the Skagit by 8 feet- likely preventing widespread catastrophic damage
- There were still major impacts in areas not protected by levee system

Lyman – 80 Feet of Bank Erosion

[From King5 News]

Hamilton – Evacuated

[From Q13 Fox News]

Summary

- Hydrologic changes are already occurring in the Baker basin (and likely elsewhere)
  - Wet period getting wetter, more variable
  - Dry period getting drier, less variable
- These changes make water management more challenging
  - More water comes when you don’t want it, less water comes when you do want it
  - Higher variability makes planning difficult
  - Some water management adaptation methods being used
- Using old hydrologic records for design and management periods may misrepresent the actual risk
  - Need to balance sample size vs relevance of older data points

What’s Next?

- Further analyze seasonal changes
- What about the role of ENSO?
- Bivariate density analysis (like temperature and spring runoff timing)
- Publish methodology herein- hopefully 2019

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Questions?