Hydrologic Changes Over Time at the Baker Project

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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
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

- Public Safety
- Grid Reliability
- Power Production
- Environment
- Flood Management
- Recreation

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

Baker Lake License Elevations

Refill & drawdown transitions
Nonstationarity in the Baker Basin

- Does this distribution look identical and independent over its range?
- Should we manage the reservoirs differently based on changes over time?

### # of Days >15,000 cfs:
- 1960 – 1988: 2
- 1989 – 2017: 19

### # of Days >20,000 cfs:
- 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!

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

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

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<tr>
<td>Mean</td>
<td>1500</td>
<td>1530</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>183</td>
<td>223</td>
</tr>
<tr>
<td>Interquartile Range</td>
<td>230</td>
<td>280</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>12.2</td>
<td>14.6</td>
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Similar mean

Much more variability in recent period

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<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>1899</td>
<td>2272</td>
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<tr>
<td><strong>Standard Deviation</strong></td>
<td>726</td>
<td>901</td>
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<tr>
<td><strong>Interquartile Range</strong></td>
<td>664</td>
<td>1248</td>
</tr>
<tr>
<td><strong>Coefficient of Variation</strong></td>
<td>38.2</td>
<td>36.7</td>
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- **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

Density of COM50 Spring Date: 1960-1988 vs 1989-2017

Peak density of spring runoff about a week sooner

No concerns about refilling yet
### Average July-August Inflow


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<tbody>
<tr>
<td>Mean</td>
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<td>2155</td>
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<tr>
<td>Standard Deviation</td>
<td>695</td>
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<tr>
<td>Interquartile Range</td>
<td>1053</td>
<td>835</td>
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<tr>
<td>Coefficient of Variation</td>
<td>28.5</td>
<td>32</td>
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- **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*
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

![Skagit River flows at Concrete and Newhalem](image)

- **Narrative**
  - 11/21 1330: Concrete gauge begins to rise, Newhalem at 5130 cfs, Baker at 3880 cfs
  - 11/22 0200: Newhalem gauge begins to rise
  - 11/22 1615: Skagit reaches first peak 82,400 cfs; Newhalem at 13,700, Baker at 6130
  - 11/23 0530: Newhalem reaches peak 17,400 cfs, maintains near that level until 10:45
  - 11/23 1200: Skagit reaches peak at 106,000 cfs; Newhalem at 16,300, Baker at 1400
  - 11/23 1430: Skagit still at 106,000 cfs; Newhalem at 15,400, Baker at 1400
  - 11/23 1715: Skagit at 100,000 cfs; Newhalem at 13,500, Baker at 1400
  - 11/24 1230: Baker begins spill; Skagit at 48,800, Newhalem at 5170, Baker at 14,300
  - 11/24 1330: Skagit reaches "mini" peak 54,800, Newhalem at 5110, Baker at 14,800

Baker’s contribution

Mostly unregulated tributaries
Good Thing The Lakes Were Drawn Down…

19 feet in 2 days!

Largest flood in 11 years

14 feet in 3 days
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

Hamilton – Evacuated

[From King5 News] [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
Questions?