Estimating Monthly Delta Outflow During the First Six Decades Following the Gold Rush

WYs 1851 – 1911 Reconstruction Based on Legacy Hydrologic Data

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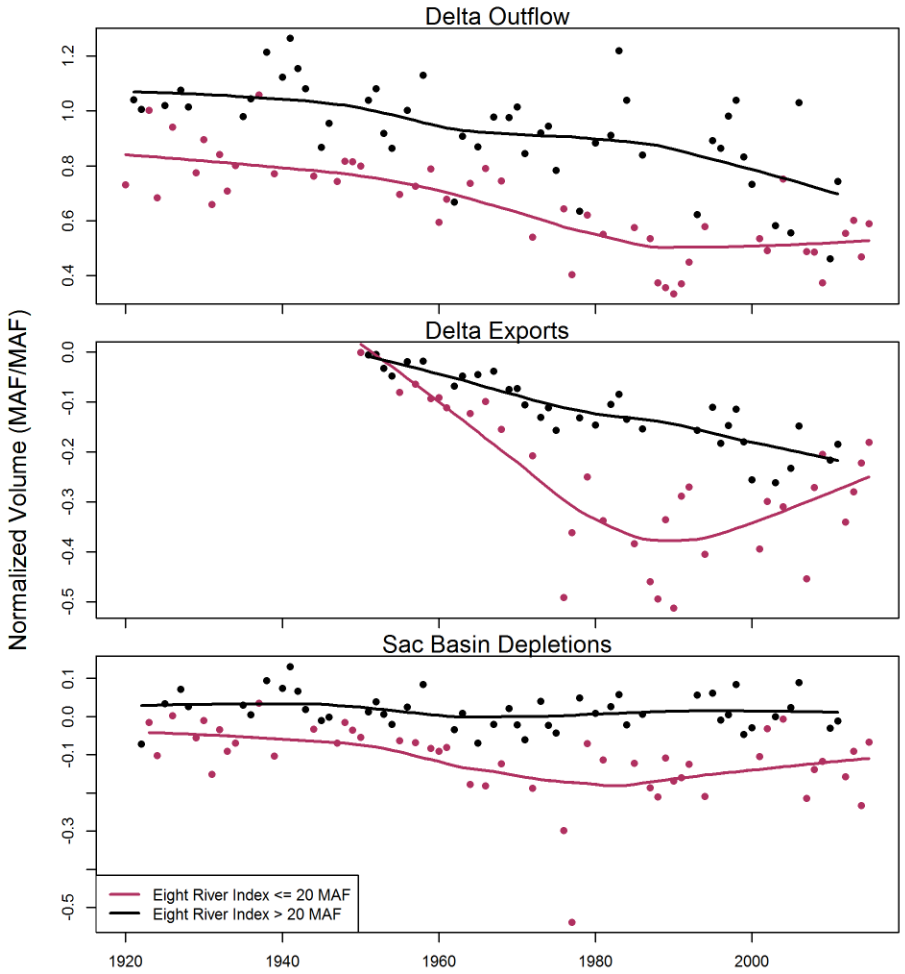
Study Objectives

- Extend available Delta outflow time series back to California Gold Rush era (circa 1850)
- Evaluate trends associated with “normalized” Delta outflow – normalized to unimpaired runoff
- Evaluate validity of hypothesis that a systemwide decrease in evapotranspiration occurred in the latter half of the 19th century, a trend that was driven by:
  - the removal of high water using natural vegetation and
  - reduction in overbank flows due to levee construction

From Hutton et al. (2017)

Freshwater Flow to the San Francisco Bay-Delta Estuary over Nine Decades (Part 1) : Trend Evaluation Hydrological Processes



Systemwide Decrease in ET During Latter Half of 19th Century Suggested by Gross et al. (2018)

OCTOBER 2018

SAN FRANCISCO ESTUARY & WATERSHED SCIENCE

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RESEARCH

A Comparison of Outflow and Salt Intrusion in the Pre-Development and Contemporary San Francisco Estuary

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ABSTRACT

The San Francisco Estuary and its upstream watershed have been highly altered by human development following the California Gold Rush in the mid-19th century. In this paper, we explore the inter- and intra-annual variability of freshwater flow to this estuary and the resulting salt intrusion under scenarios that represent pre-development and contemporary conditions. To place this comparison in context with the advent of systematic and accurate flow and salinity measurements in the estuary, we consider an additional "pre-project" scenario that represents early 20th-century water management (circa 1920), after major flood control and reclamation but before the introduction of large water storage, diversion, and export operations. We use an observed climate record that spans 82 years to compare freshwater flow associated with the scenarios' landscape and water use characteristics.

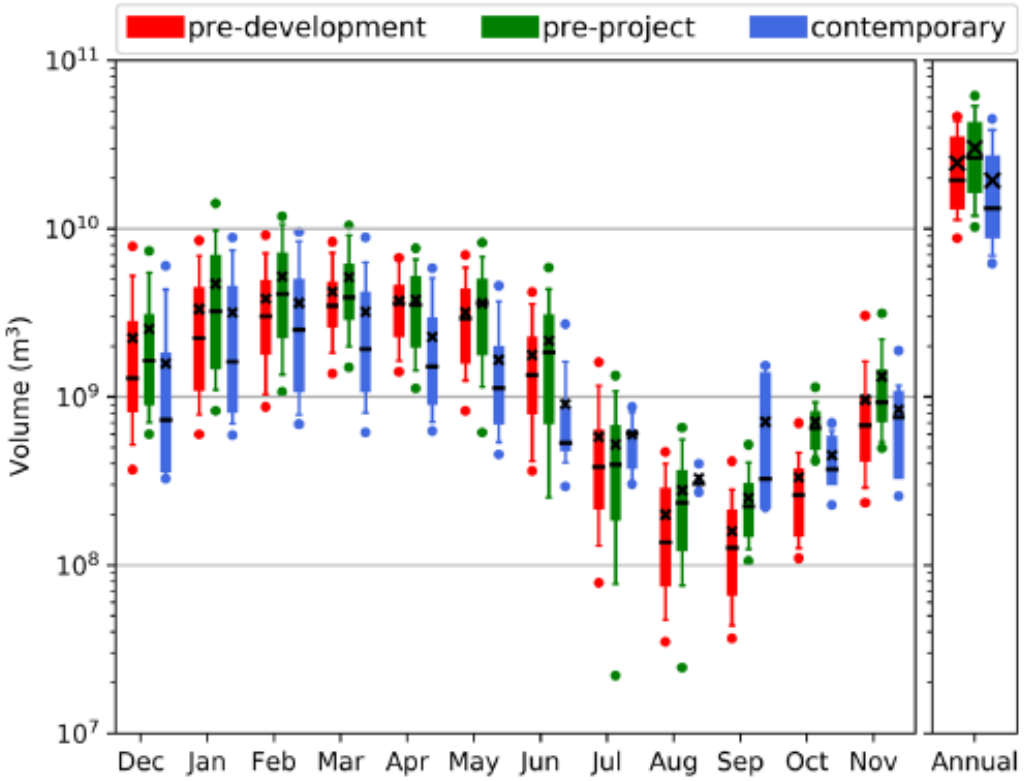
Using published relationships between flow and salt intrusion length developed from three-dimensional hydrodynamic modeling, we evaluate the effect of these flow alterations as well as estuarine geometry modifications and historically observed sea level rise on salt intrusion. We conclude that the pre-development estuary exhibited a more seasonally variable salinity regime, resulting from a more variable inflow regime from the upstream watershed.

KEY WORDS

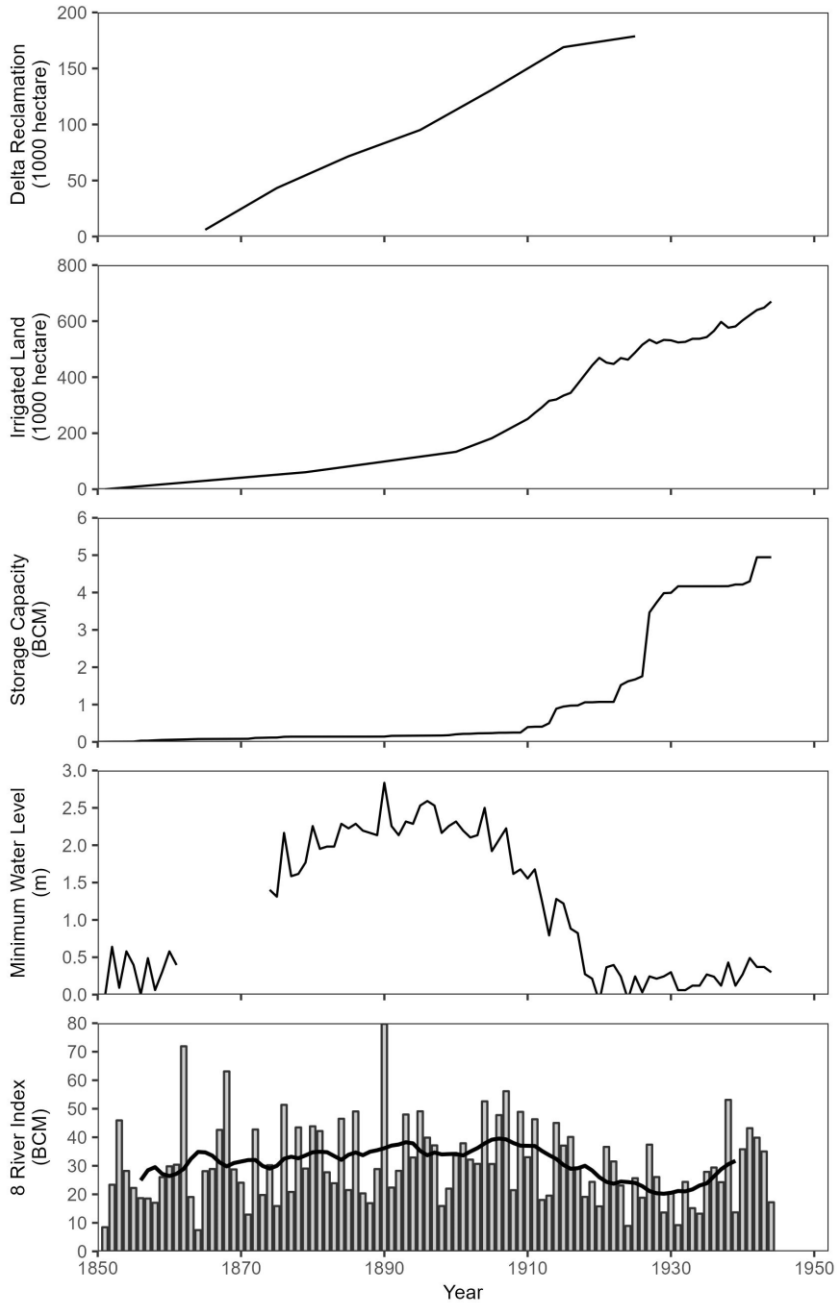
Sacramento–San Joaquin Delta, hydrology, natural flow, hydrodynamic modeling, salt intrusion, X2, pre-development Delta, ecology

INTRODUCTION

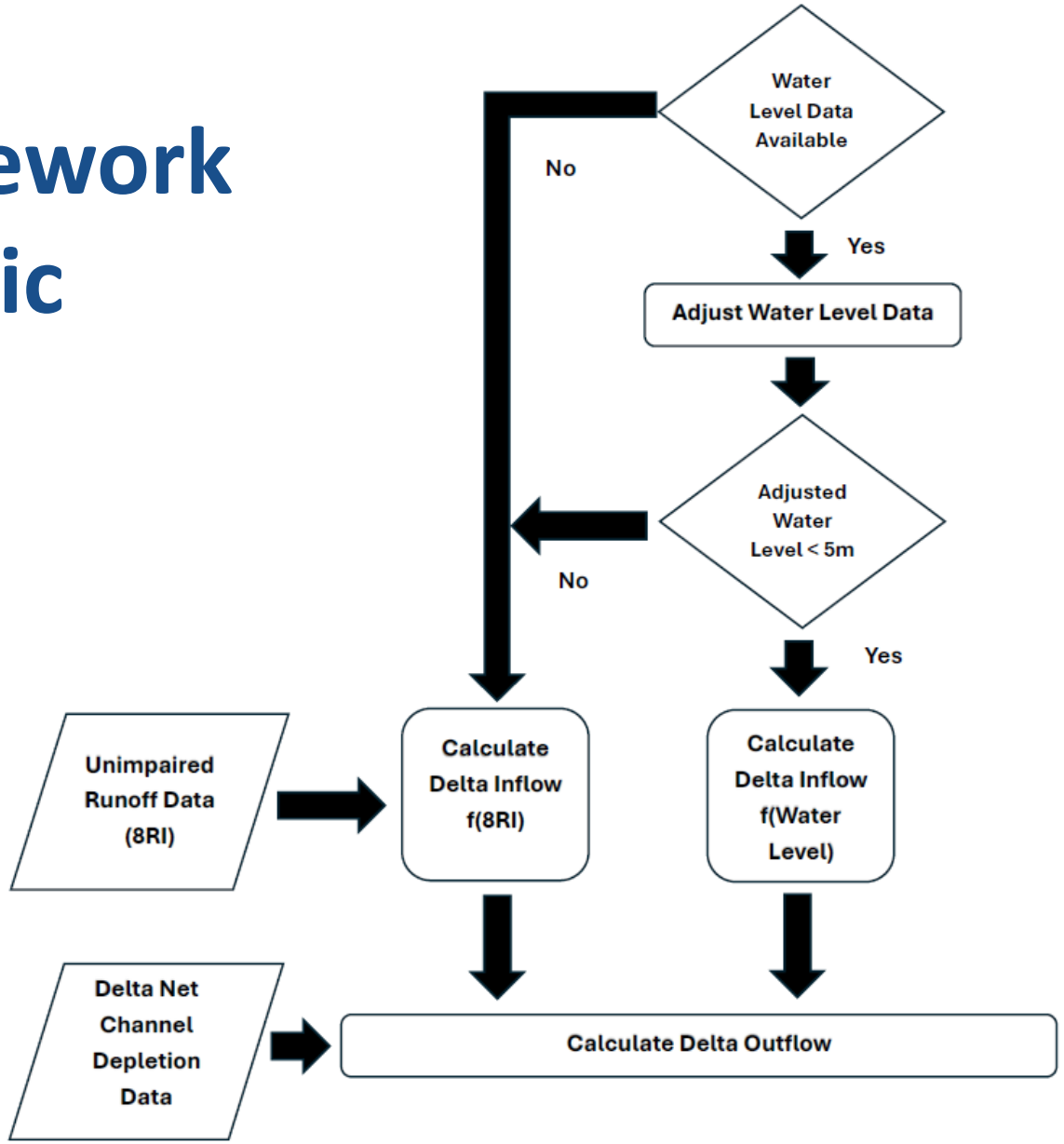
Estuaries throughout the world are exposed to a variety of stressors, including hydrologic alteration, invasive species, pollutants, eutrophication, and habitat loss (Kennish 2002). International restoration efforts are responding to these stressors, with the recognition that ecosystem effects are a consequence of multiple interacting factors that are often poorly understood (Kennish 1999; Williams and Orr 2002; Thom et al. 2005; Elliott et al. 2007). Defining a restoration target or baseline is implicit in identifying ecosystem effects, and is important in structuring flow regulations and other restoration actions.



Timeline of Alterations WYs 1851 - 1944



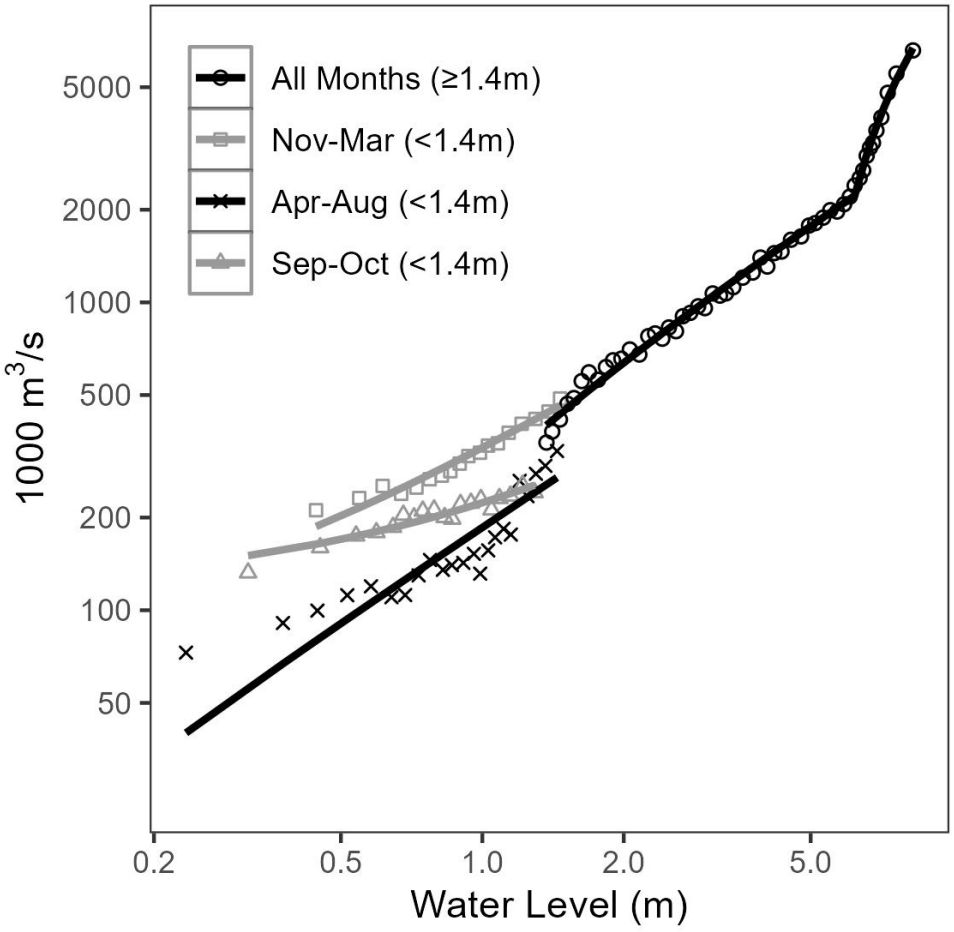
Model Framework Schematic

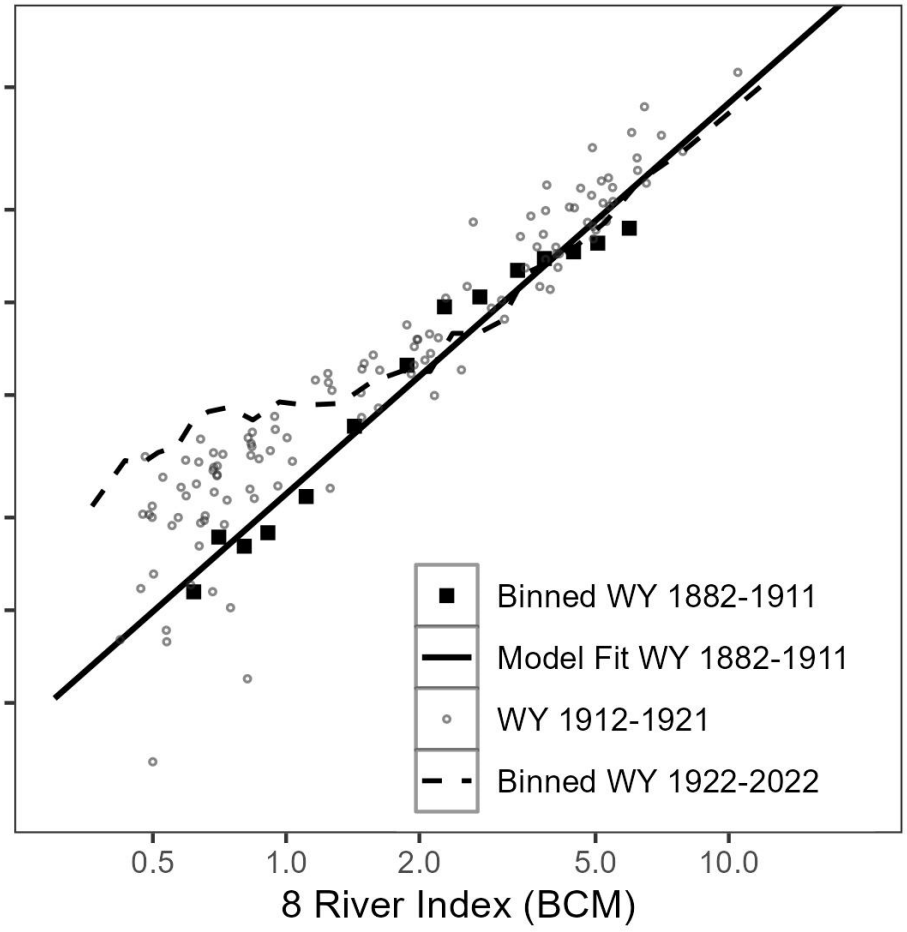


Motivation for Not Adopting Moftakhari et al. (2013, 2015) Outflow Estimates

- Implicitly assumes stationary in-Delta water use over study period
- Stage discharge estimates are insensitive under low flow conditions
- Tidal discharge estimates were deemed unreliable
  - do not show credible seasonal variability over key periods when Sacramento water level data are unavailable
  - Poor predictive ability under low flow conditions

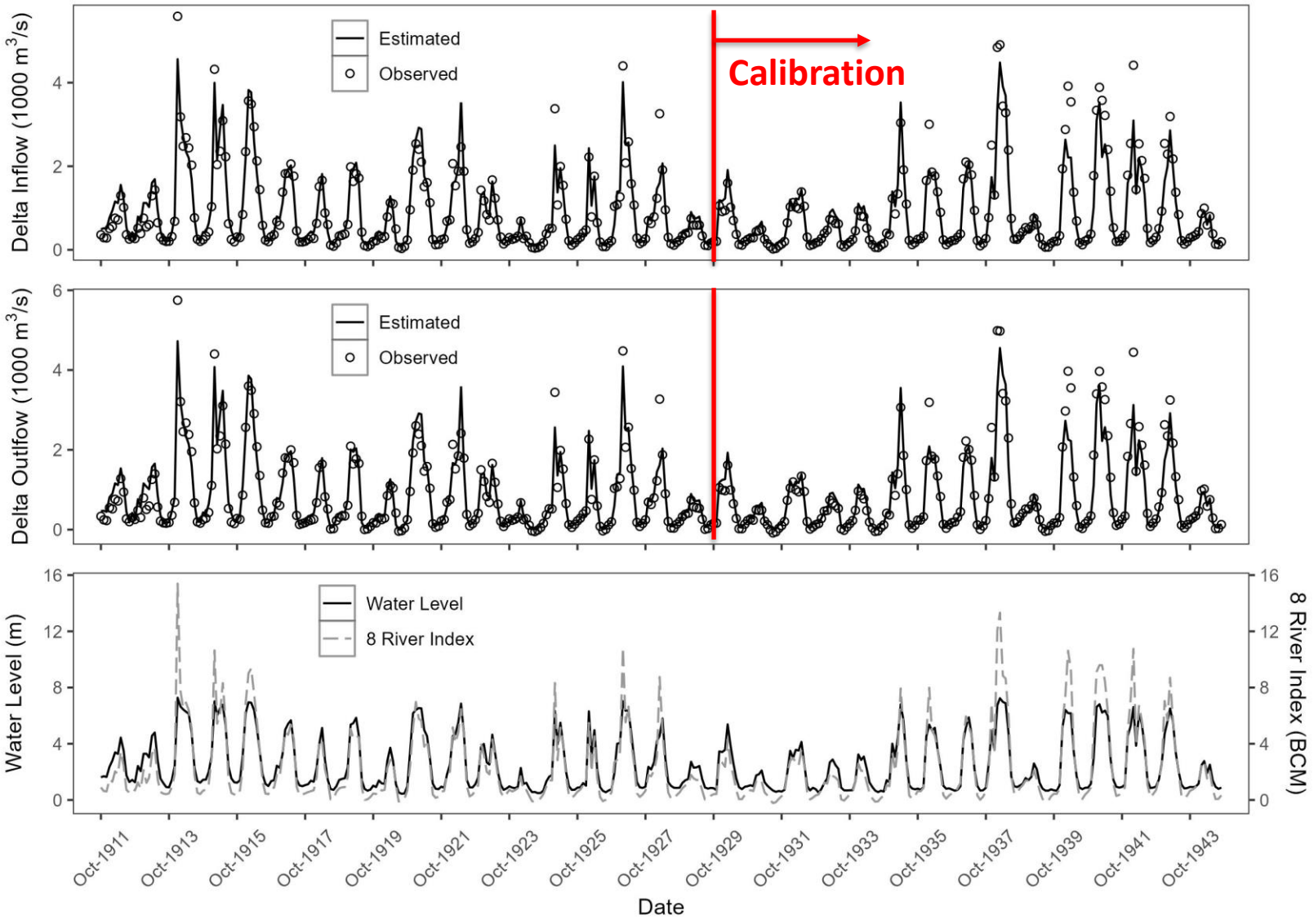
Delta Inflow Models



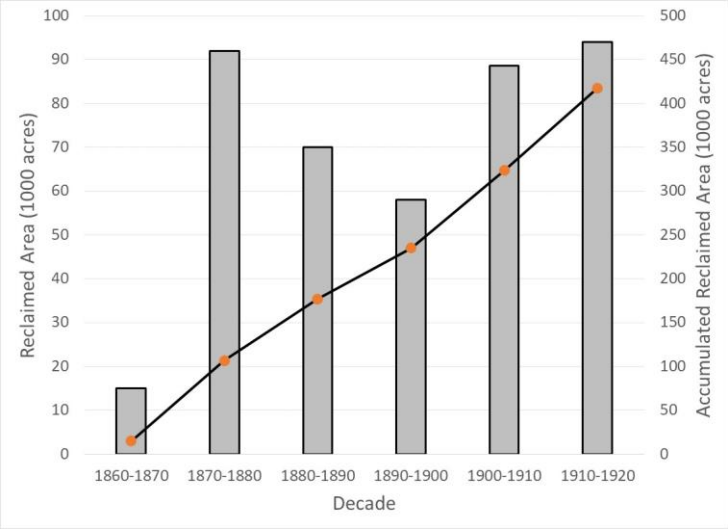


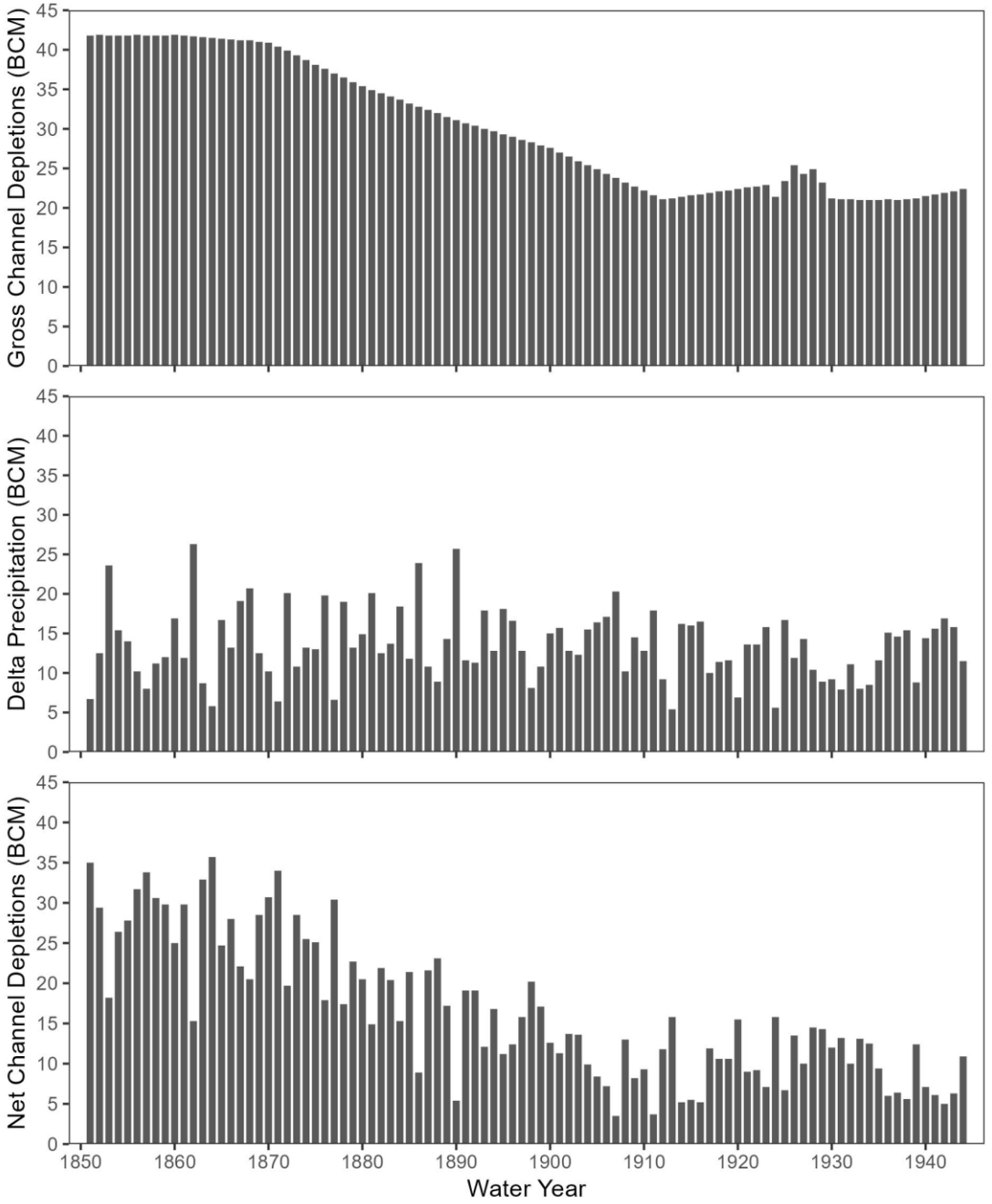
Calibration – Validation – Input Time Series

WYs 1912 - 1944



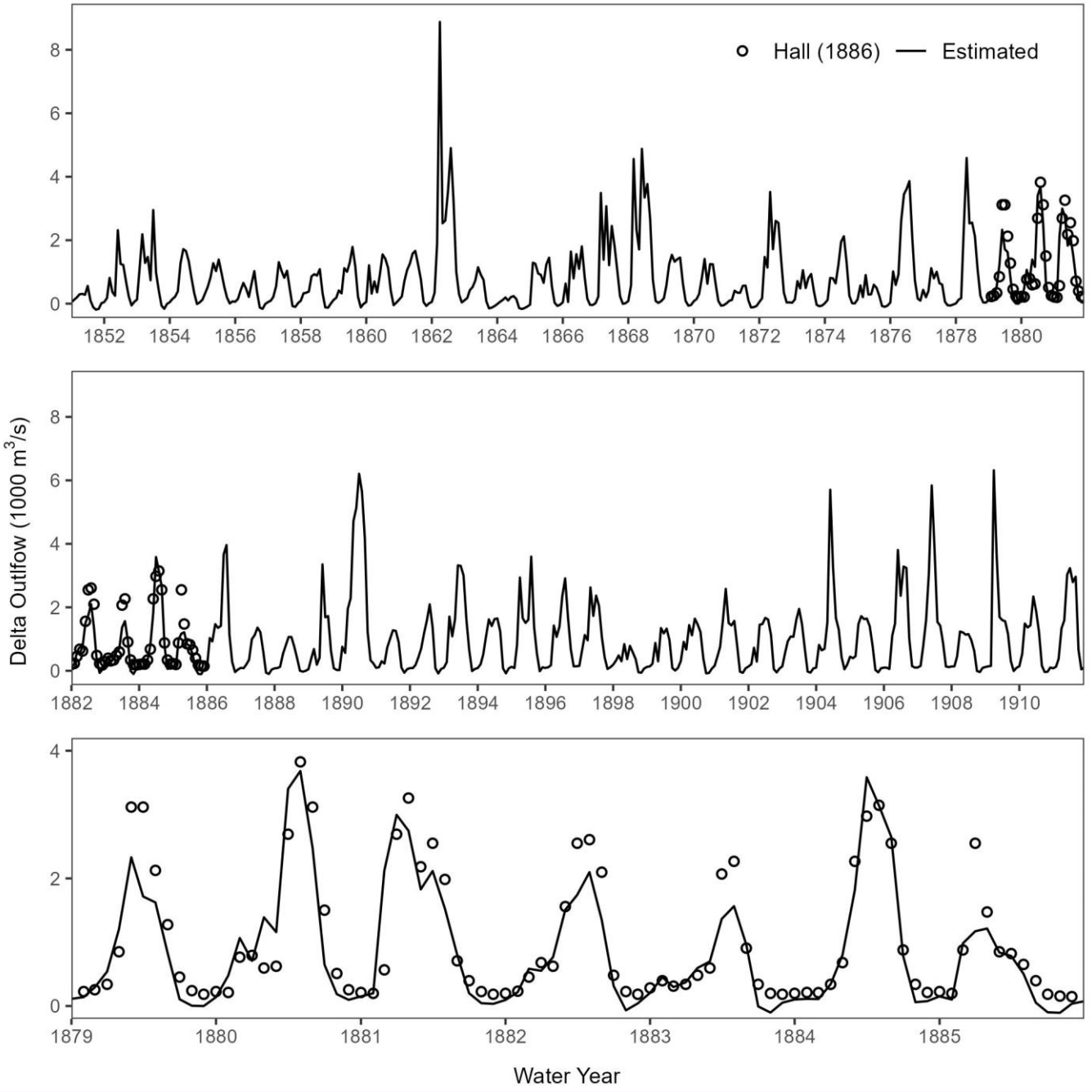
Delta Water Use Time Series WYs 1851 - 1944





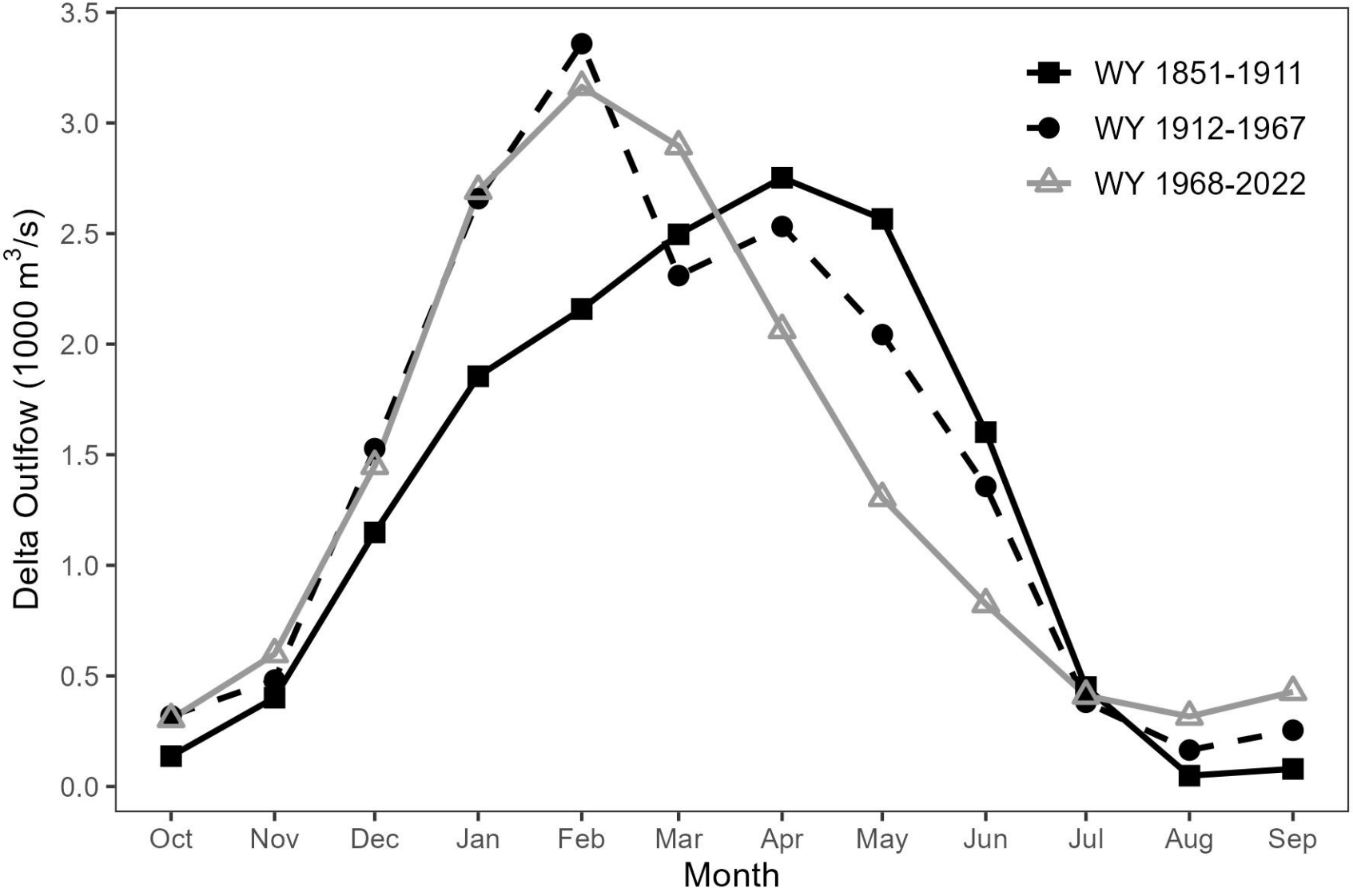
Delta Outflow Reconstruction

WYs 1851 - 1911

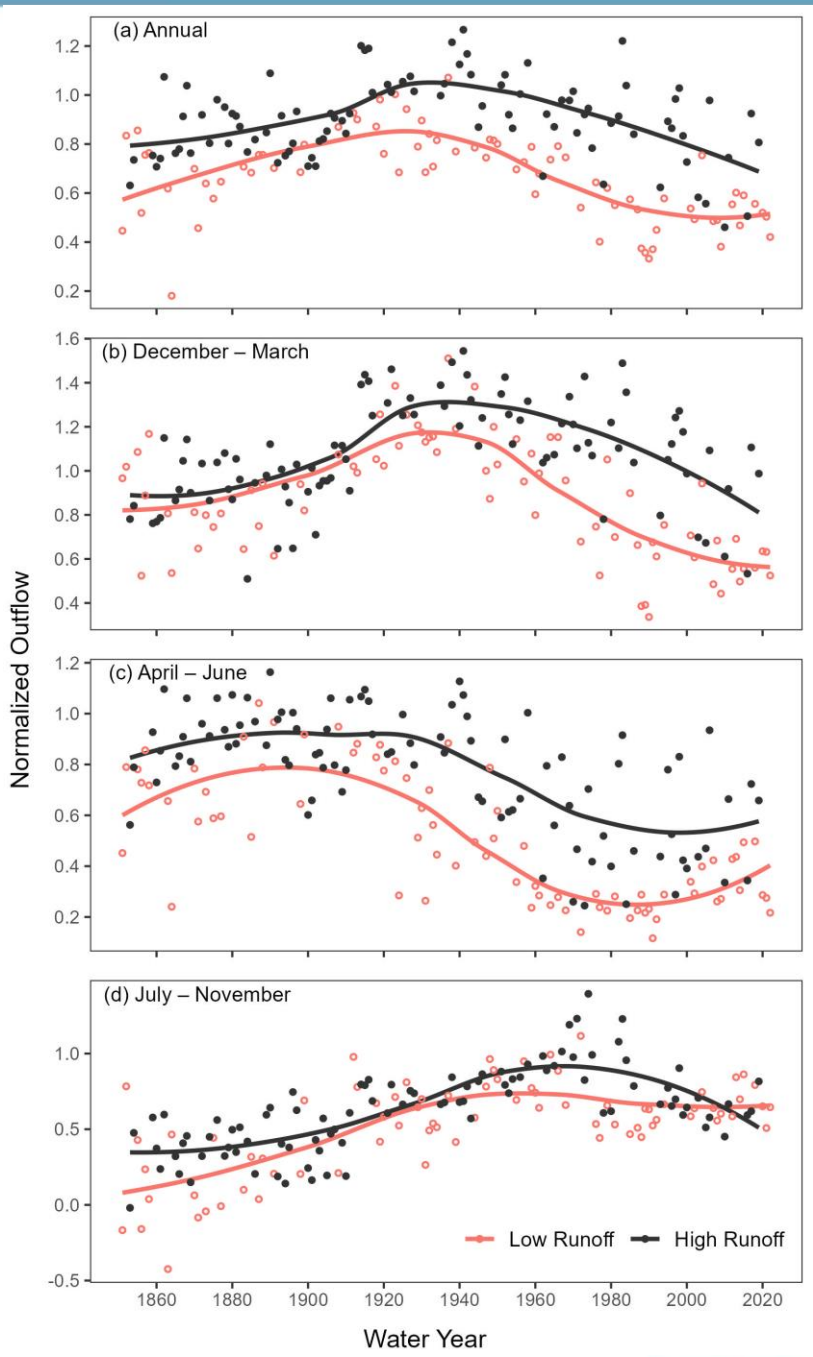


Change in Outflow Distribution

Wet Years



Normalized Outflow Trends WYs 1851 - 2022



Summary & Conclusions

- Extended available Delta outflow time series back to California Gold Rush era (circa 1850)
- Evaluated trends associated with “normalized” Delta outflow – normalized to unimpaired runoff
- A systemwide decrease in evapotranspiration likely occurred in the latter half of the 19th century, a trend that was driven by:
  - the removal of high water using natural vegetation and
  - reduction in overbank flows due to levee construction
- Contemporary annual water use similar to pre-development conditions; shift in seasonal timing

EXTRA SLIDES

Sacramento Water Level Data

Period	# Months	Comments
Oct 1850 – Dec 1850	3	Data not used - Data appear to be duplicates of Oct-Dec 1849
Jan 1851 – Aug 1862	140	Several missing values were filled through linear interpolation; data prior to 1857 appear to be smoothed;
Sep 1862 – Aug 1881	228	No data
Sep 1881 – Apr 1888	80	Complete data set
May 1888 – Nov 1890	31	No data
Dec 1890 – Sep 1944	646	Complete data set

Other Data

Inflow	Period	# Months	Source
Delta Inflow	Oct 1911 – Sep 1944	396	Hutton & Roy (2019) Hutton et al. (2015) DAYFLOW (1986)
Delta Outflow	Oct 1911 – Sep 2022	396	Hutton & Roy (2019) Hutton et al. (2015) DAYFLOW (1986)
Gross Delta Channel Depletions	Oct 1911 – Sep 1944	96	Hutton & Roy (2019) Hutton et al. (2015) DAYFLOW (1986)
Precipitation at Stockton, CA	Jan 1853 – Jan 1857 Sep 1867 – Aug 1884 Dec 1904 – Sep 1944	719	Hall (1886) CDEC
Precipitation at Sacramento, CA	Oct 1850 – Sep 1944	1128	Masters – Bevan (2000)
Net Delta Channel Depletions	Oct 1911 – Sep 1944	96	Hutton & Roy (2019) Hutton et al. (2015) DAYFLOW (1986)
Sacramento River at Collinsville, CA	Nov 1878 – Sep 1885	83	Hall (1886) McGlashan & Henshaw (1912)
SDE Reconstruction (Water Level Based Outflow Estimate)	Oct 1850 – Aug 1862 Sep 1881 – Apr 1888 Dec 1890 – Sep 1944	864	Moftakhari et al. (2015)
TDE Reconstruction (Tide Based Outflow Estimate)	Jan 1859 – Sep 1944	1029	Moftakhari et al. (2013)
Central Valley Unimpaired Runoff (8 River Index)	Oct 1850 – Sep 2022	2064	Lai et al. (in review) CDEC

Moftakhari et al (2015)
Model Framework Schematic

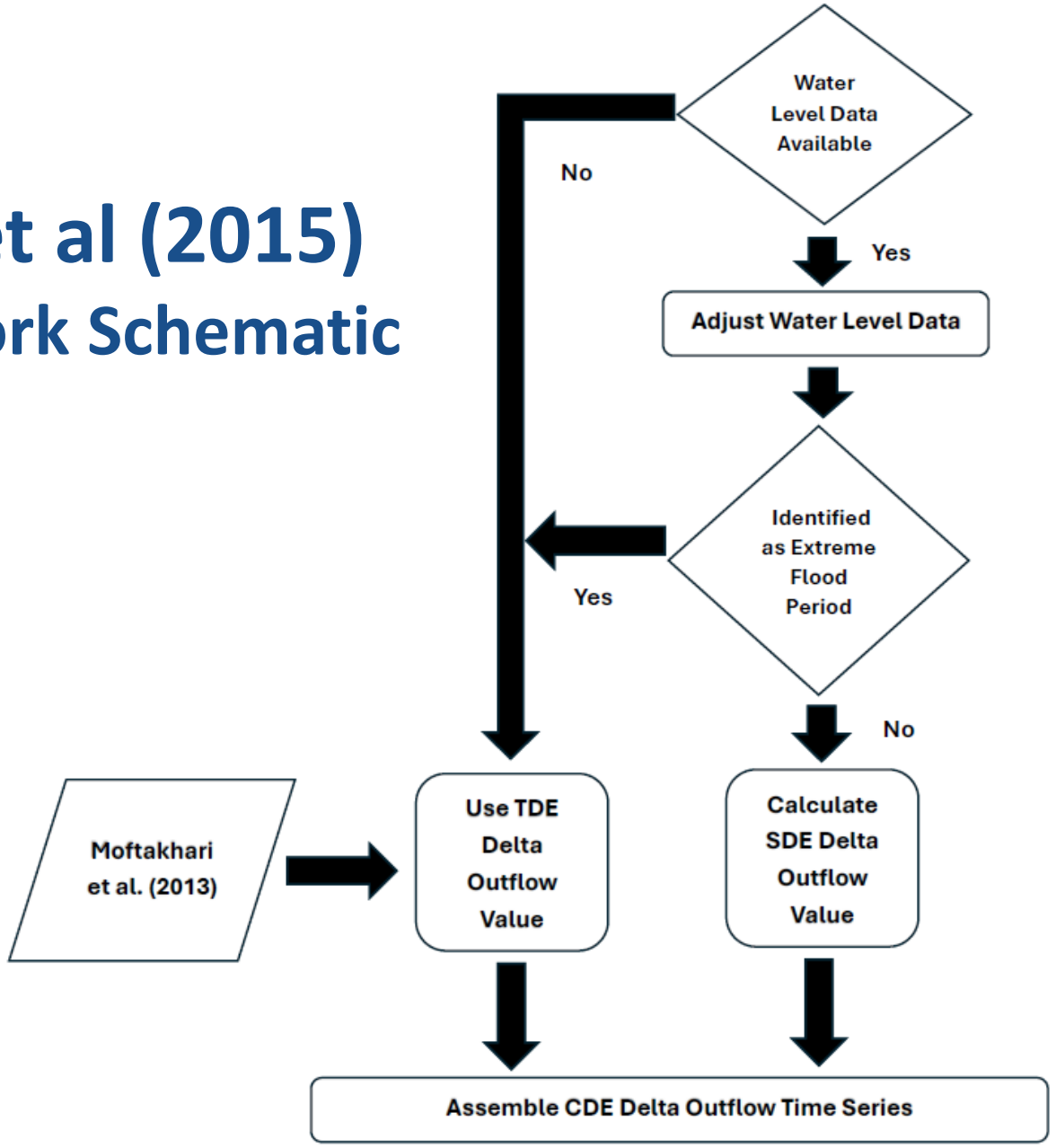
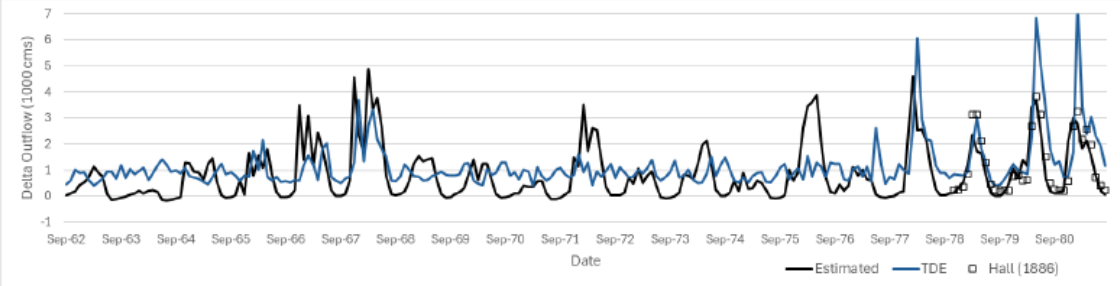
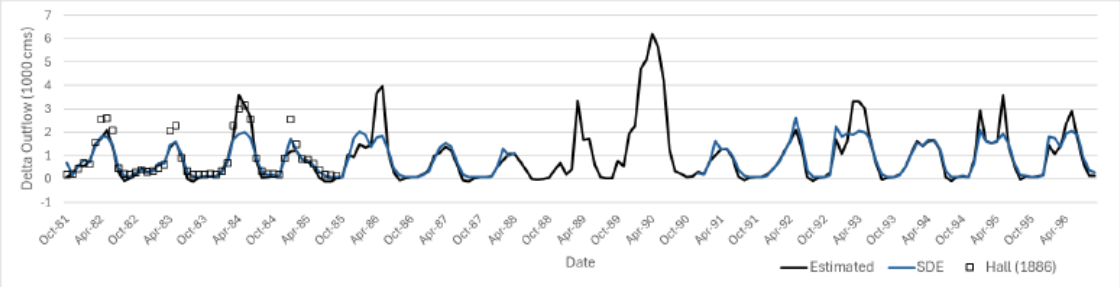


Figure S-2. Time Series Comparison of Estimated Outflow Reconstruction with Moftakhari et al. (2015) – indicated by "TDE" and "SDE". Panel (a) shows comparison for September 1862 – August 1881 when outflow estimates are not based on Sacramento water level data. Panels (b and (c) show comparisons for WYs 1882 – 1911 when outflow estimates are generally based on water level data. Flow measurements at Collinsville (Hall, 1886) overlay outflow estimates for comparison.

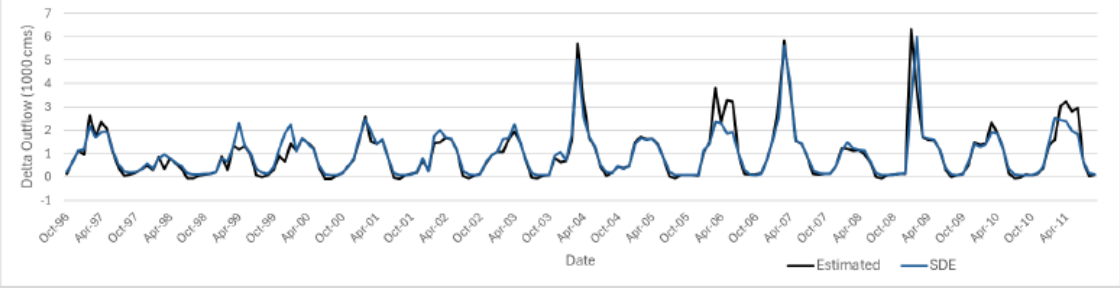
(a)



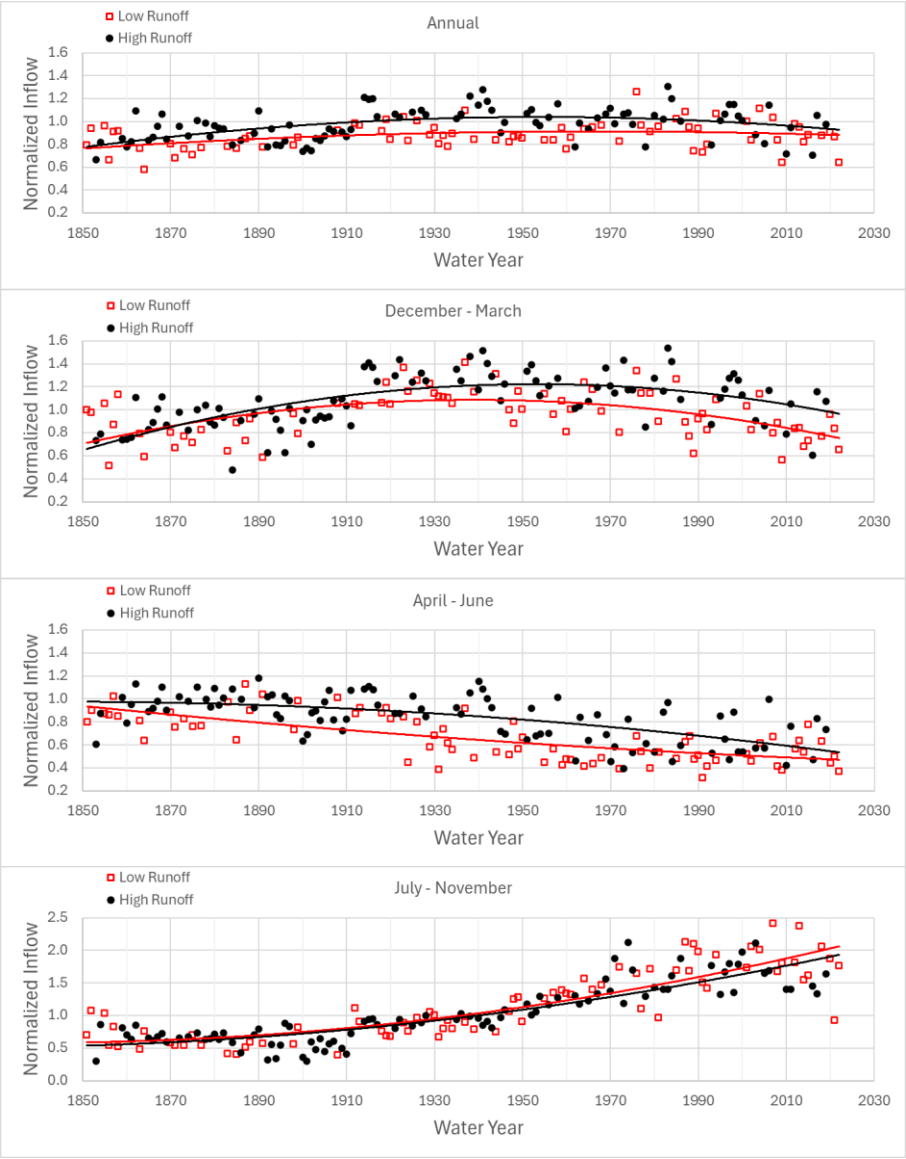
(b)



(c)



Normalized Inflow Trends WYs 1851 - 2022



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