# Trends in Hydrology and Salinity in Suisun Bay and the Western Delta

Variable Delta Workshop

June 11, 2007

Dr. Greg Gartrell

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# Questions addressed
## and not addressed

- Questions – addressed
  - How does the salinity regime today compare to historical levels?
  - How are current operations altering the salinity regime?
- Questions – <u>not addressed</u>
  - What salinity regime should be imposed on the Suisun Bay and Delta?
  - Is salinity the best metric to evaluate ecosystem dynamics? What other metrics should be considered?

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# Key Findings

- Is the Delta fresher than it was historically?
  - **NO**
  - Currently as salty as or saltier than conditions through 2,500 years ago
  - Last fresh period was 1200 – 1860
  - Salinity has been increasing since 1860's even as runoff has been increasing, with rapid increase in summer in the 1920-30's due to upstream water use, with freshening in fall during major dam construction period (1945-1975)
  - Salinity has been increasing (year-round) since 1980's

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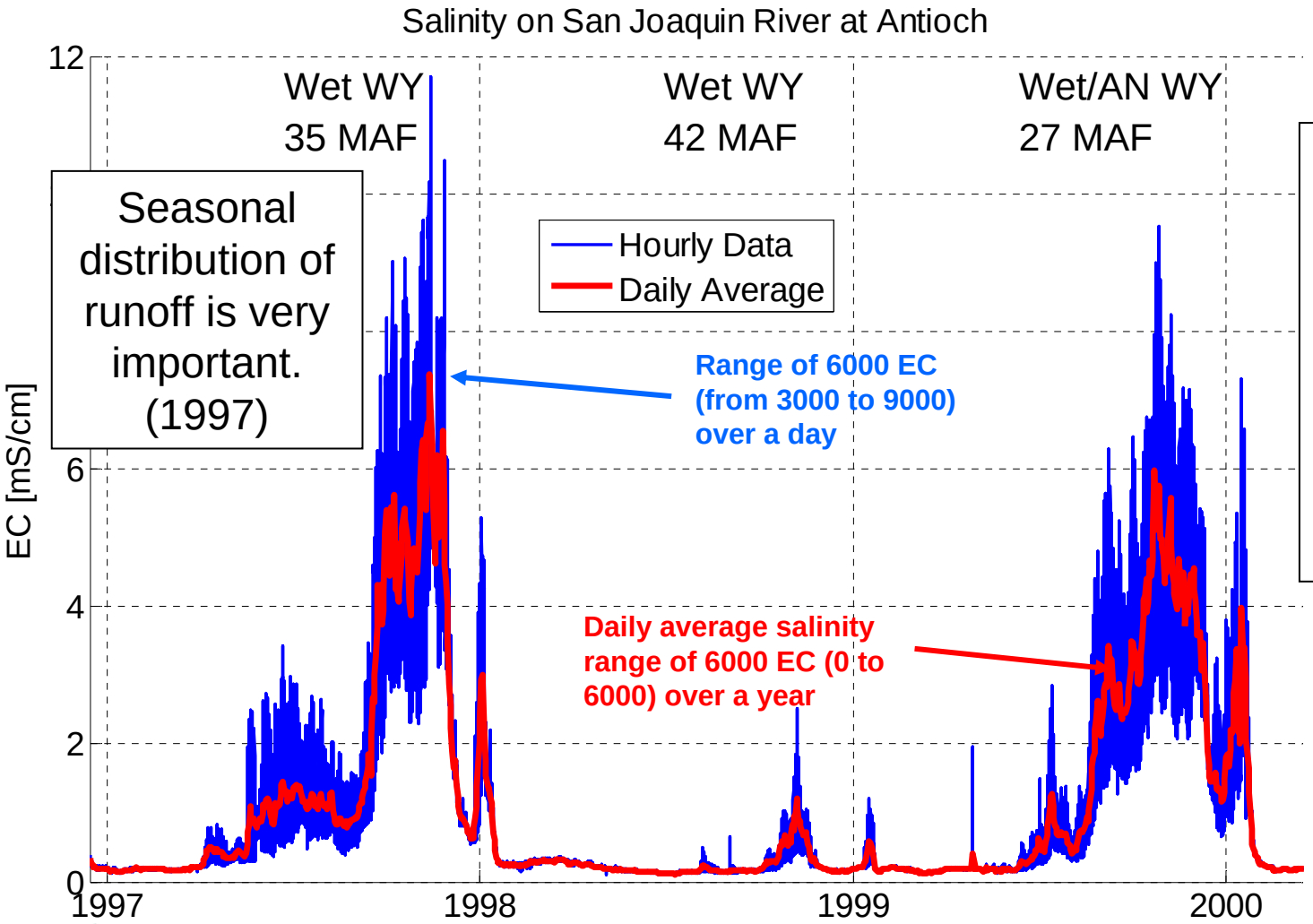
# Salinity Variability

## Tidal variability ~ Seasonal variability ~ Inter-annual variability




Seasonal distribution of runoff is very important. (1997)

Variability depends on salinity level:

Daily fluctuations (blue) can exceed daily average variability over years!

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# Factors that Impact Salinity

| Category | Factors (increase salinity) |
|---|---|
| **Regional Climate Change** | • Sea level rise<br>• Ocean conditions (POD, ENSO)<br>• Shift in precipitation patterns |
| **Physical Changes to the Central Valley and Delta Landscape** | • Deepening, widening, and straightening of Delta channels<br>• Separation of natural floodplains from valley rivers<br>• Reclamation of Delta islands<br>• Creation of canals and channel "cuts"<br>• Deepening (erosion) of Suisun Bay (since 1887) |
| **Flow Management** | • Decreasing net Delta outflow (NDO)<br>o Increasing upstream diversions<br>o Increasing in-Delta diversions<br>o Increasing south of Delta exports<br>• Increasing upstream storage capacity |

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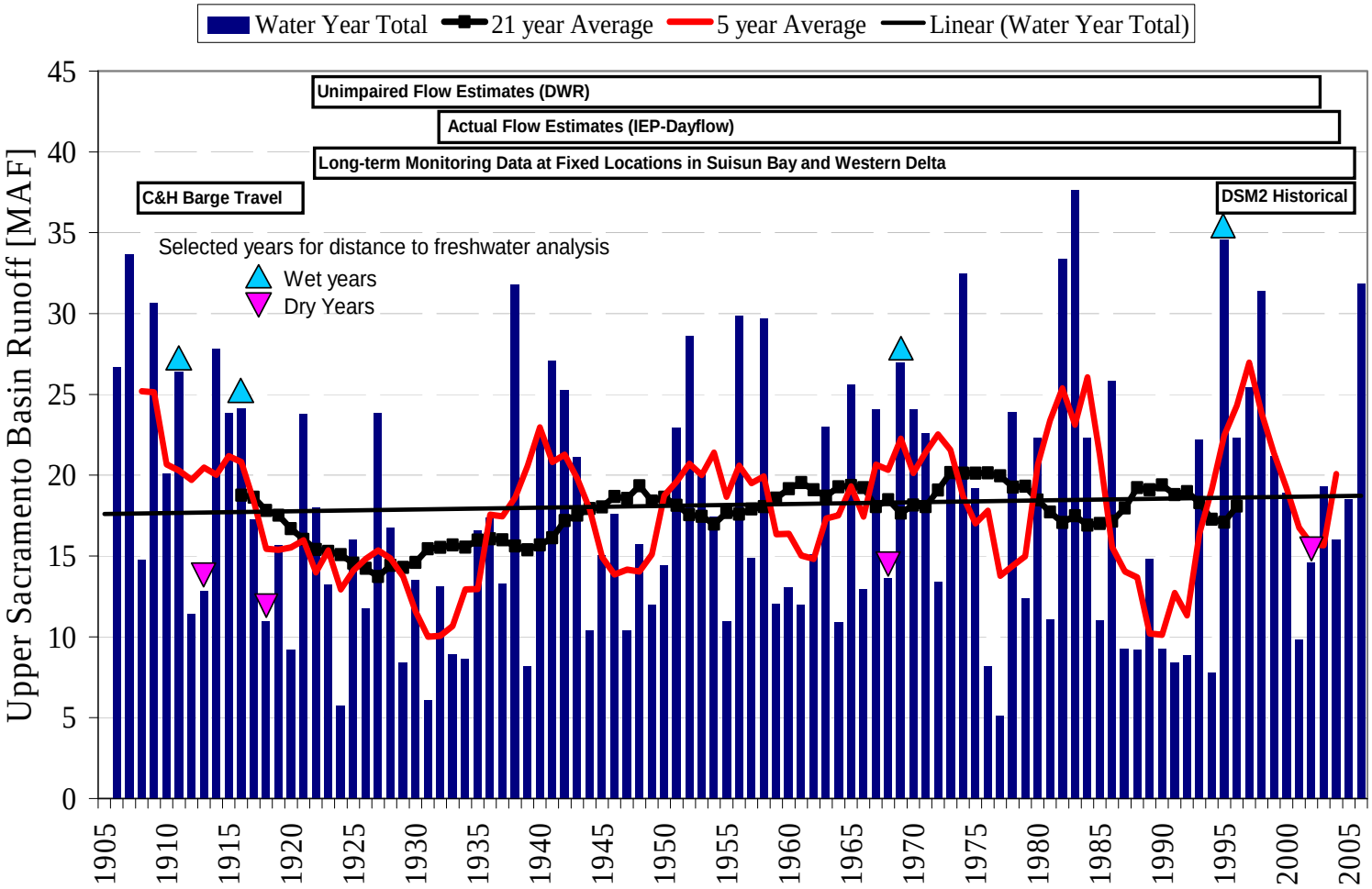
# Annual Hydrology

## Long term trend is wetter with less April-July snowmelt

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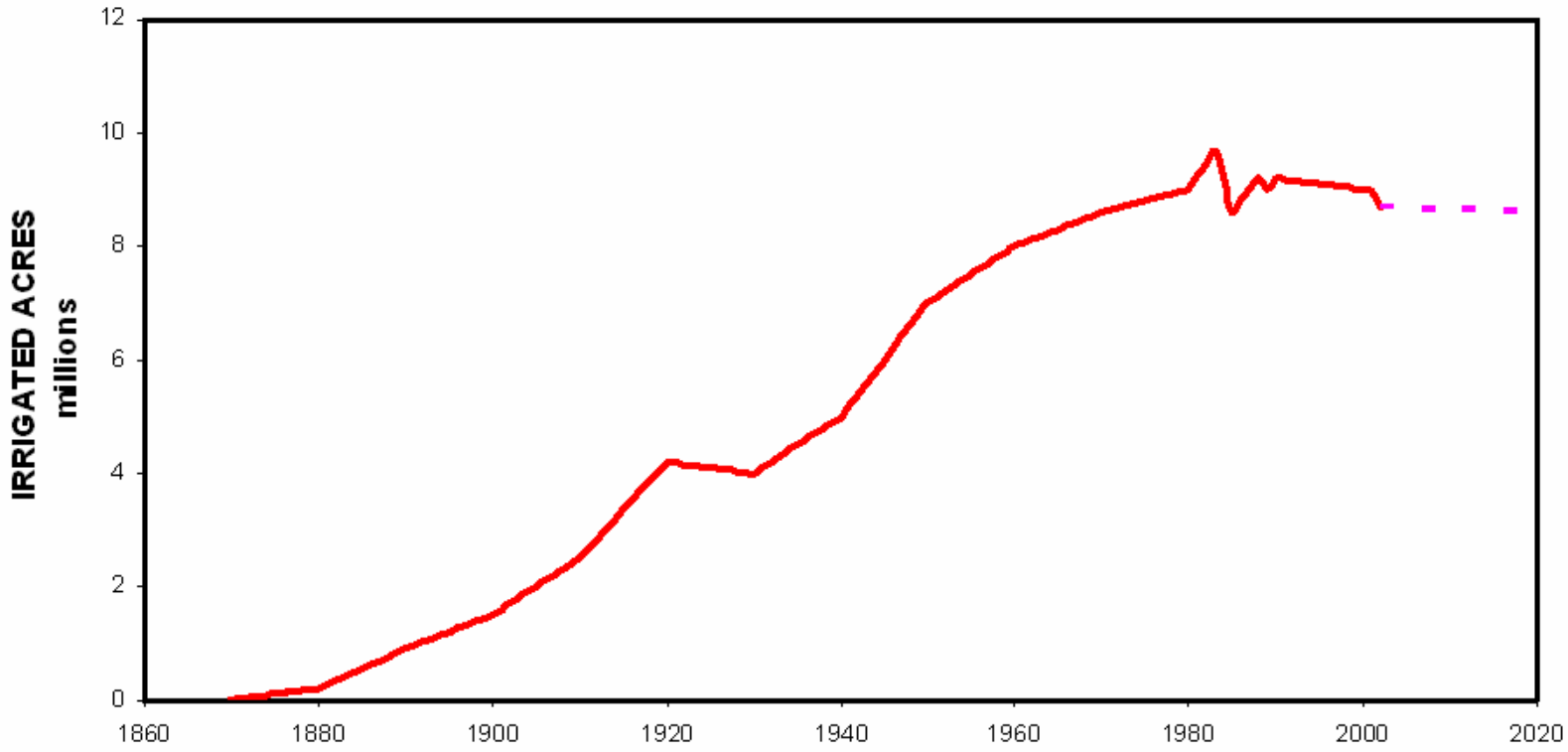
# Central Valley Irrigated Acres over time




Adapted from California Water Plan Updates, Bulletins 160-93 and 160-98, Dept. of Water Resources

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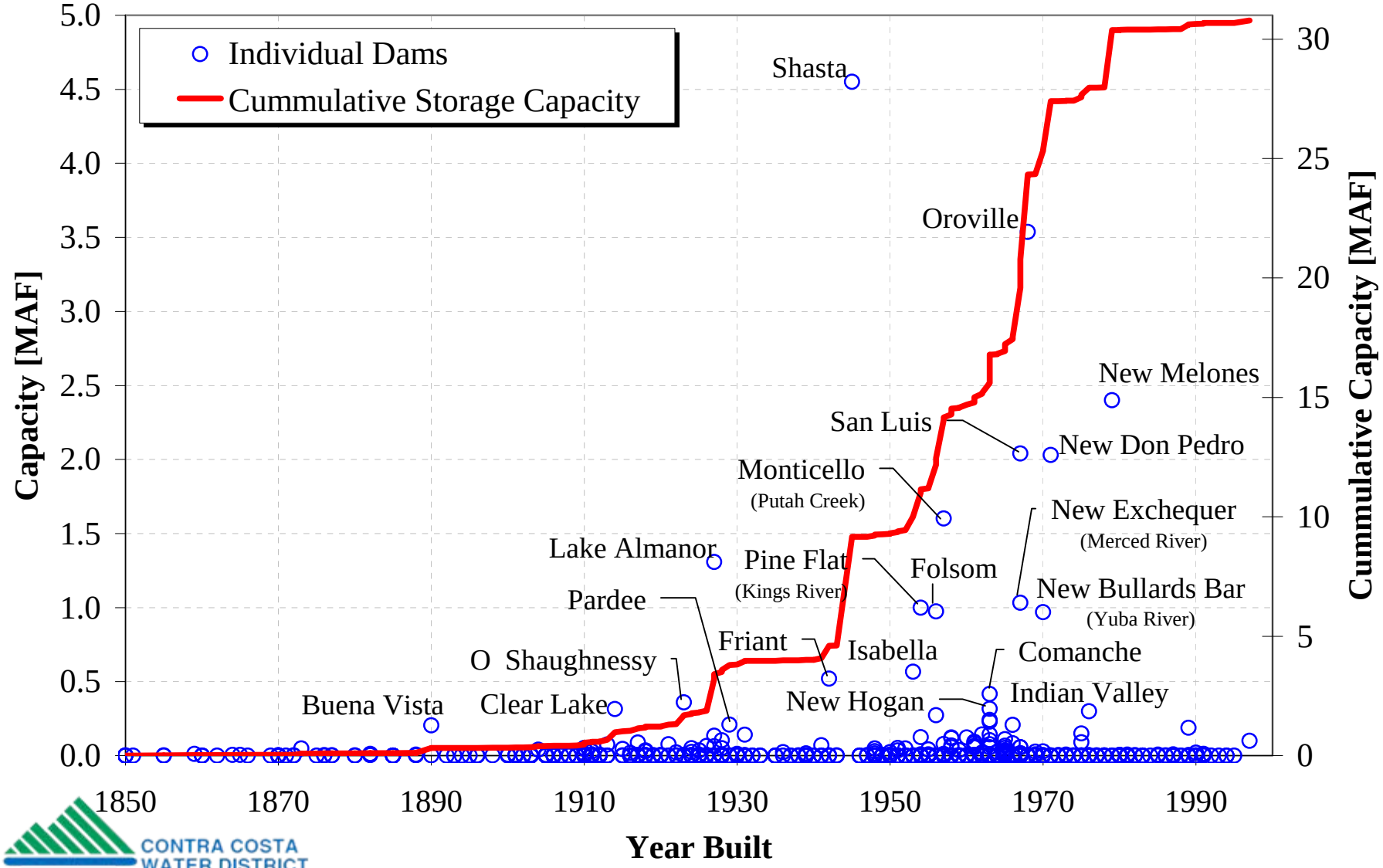
# Central Valley Reservoirs

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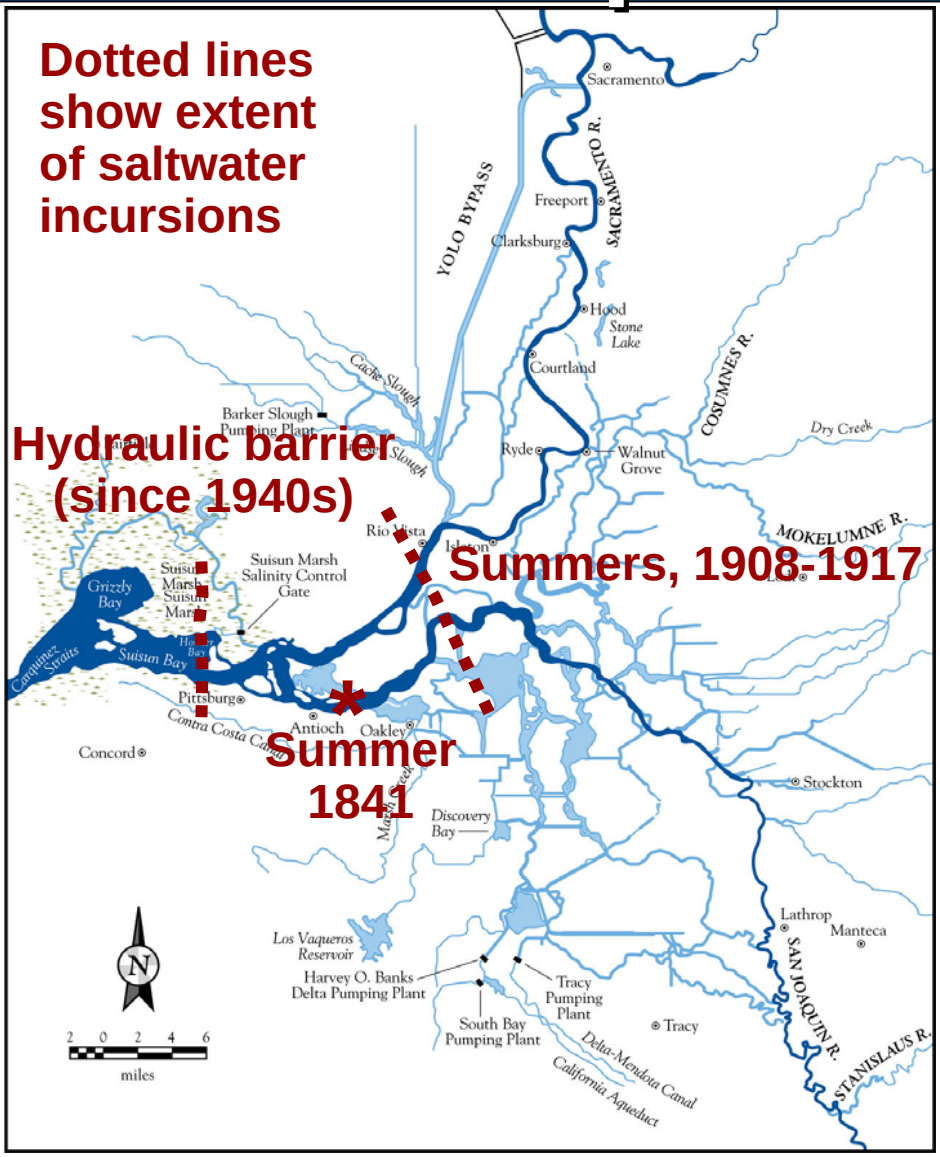
# Caution Required on Data from Multiple Sources

**"Brackish" and "fresh" are qualitative terms.**

**Must use comparable variables or quantitative values.**




Source of Graphic:

University of California
California Colloquium on Water

April 10, 2007
Ellen Hanak
Public Policy Institute of California

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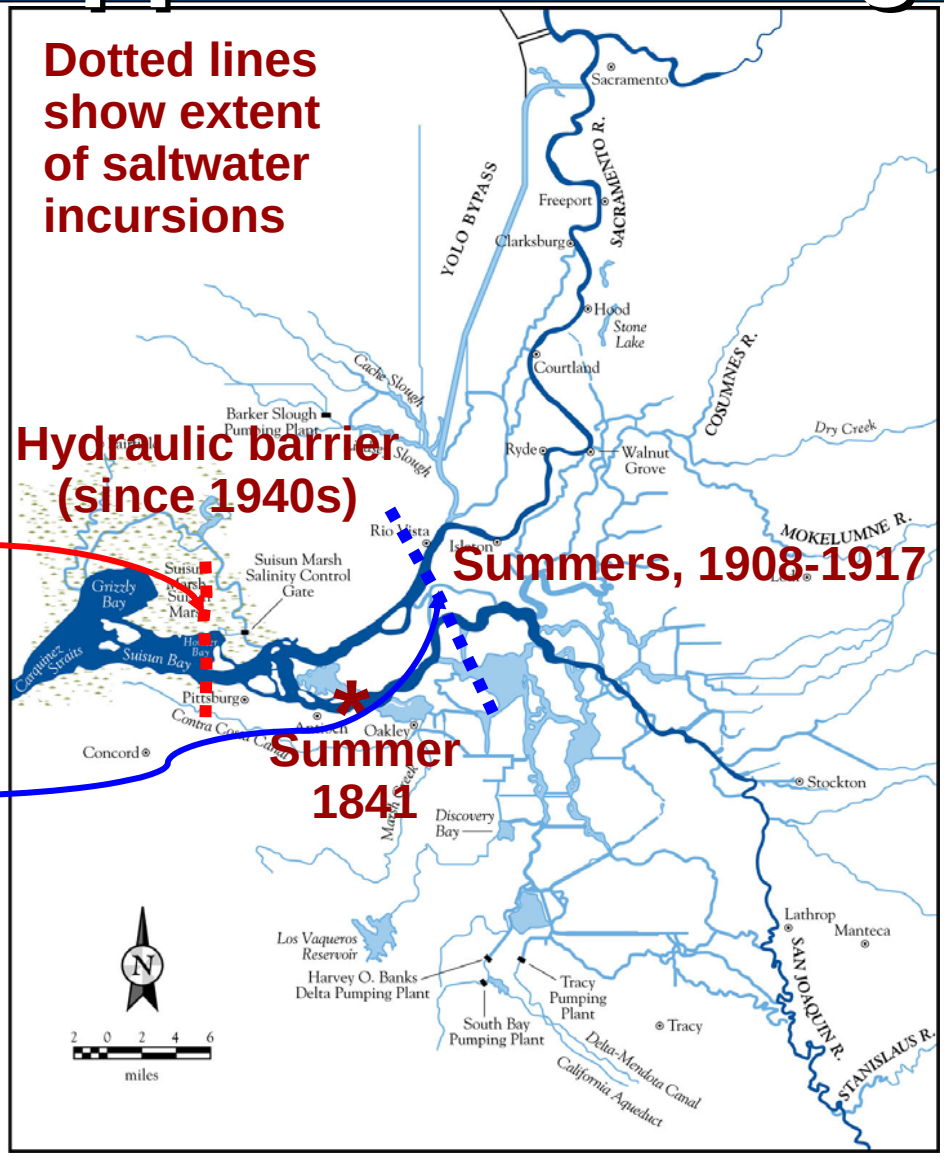
# Comparison of Apples and Oranges

Salinity expressed as concentration of chlorides

**1,000 mg/L**
(DWR Delta Atlas)

**50 mg/L**
(C&H Observations)




Source of Graphic:

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# Salinity Incursion October 2000

Salinity Incursion October 2000

**50 mg/L** chlorides

**1,000 mg/L** chlorides

Water year 2000 was an Above Normal water year on both the Sacramento and San Joaquin Rivers

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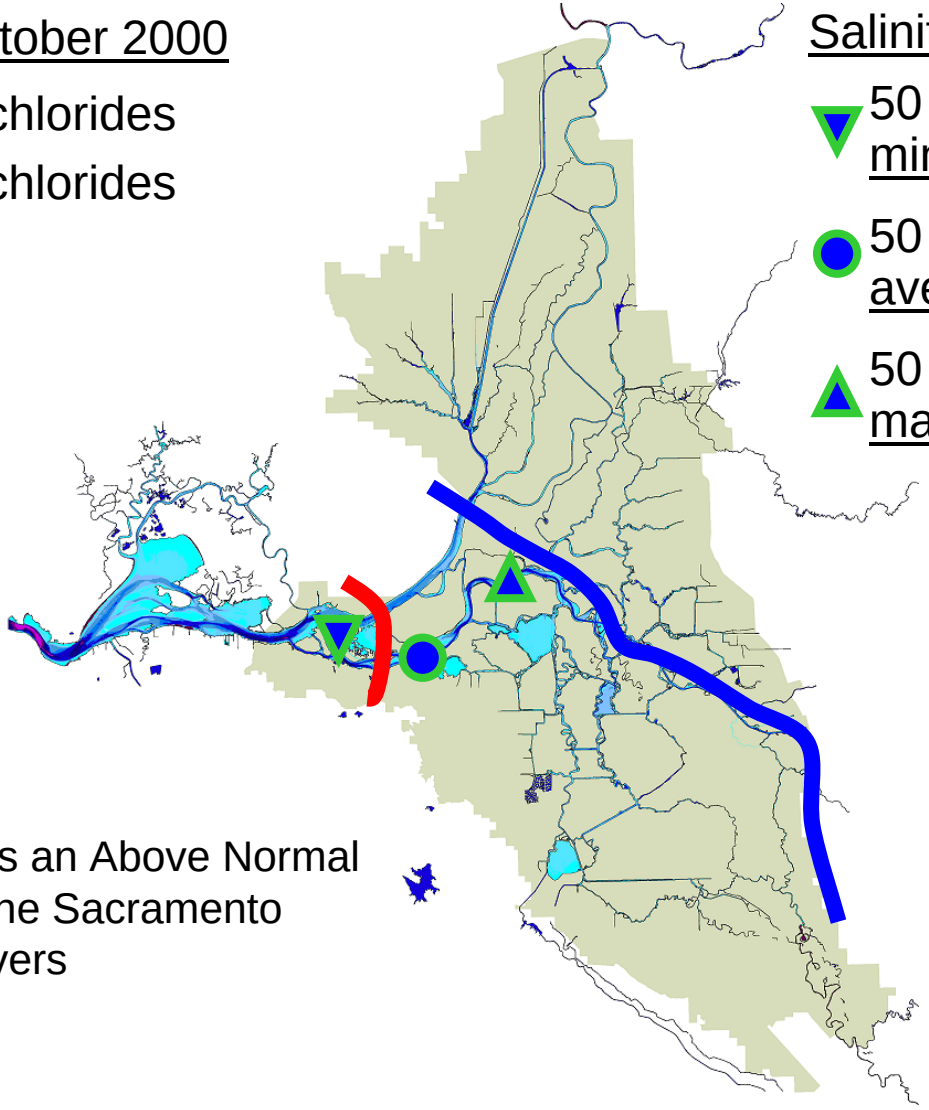
# Salinity Incursion Then and Now

Salinity Incursion October 2000

- **50 mg/L** chlorides
- **1,000 mg/L** chlorides

Salinity Incursion 1908-1917

- 50 mg/L chlorides minimum annual incursion
- 50 mg/L chlorides average annual incursion
- 50 mg/L chlorides maximum annual incursion



Water year 2000 was an Above Normal water year on both the Sacramento and San Joaquin Rivers

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# Paleosalinity Analysis

## Reveals significant long-term changes in salinity over 3,000 years

- Rush Ranch (study site), northwest portion of the historical Suisun Marsh has remained un-reclaimed
- Sediment core analyzed for diatoms, pollen, and carbon isotopes as salinity surrogates
- Illustrates that most recent time period is comparable to the saltiest periods since the marsh was formed

References:

Starratt, S.W. 2001. "Diatoms as Indicators of Freshwater Flow Variation in Central California." PACLIM Conference Proceedings, pp. 129-144.

Byrne, Roger, B. Lynn Ingram, Scott Starratt, Frances Malamud-Roam, Joshua N. Collins, Mark E. Conrad. 2001. "Carbon-Isotope, Diatom, and Pollen Evidence for Late Holocene Salinity Change in a Brackish March in the San Francisco Estuary". Quaternary Research.


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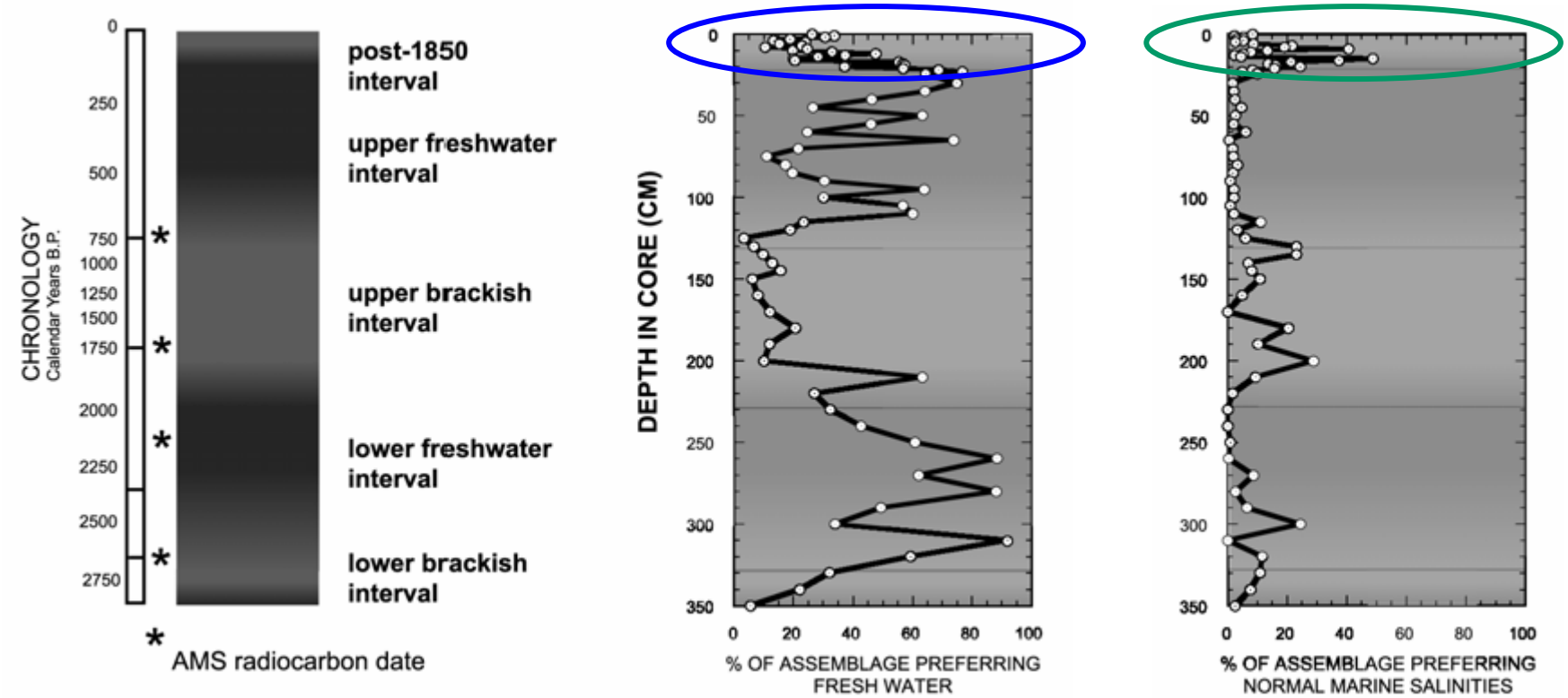
# Paleosalinity Analysis

## shows Suisun Marsh was generally fresher prior to 1850

Post-1850 **decrease** in fraction of assemblage preferring **fresh water**

Post-1850 **increase** in fraction of assemblage preferring **marine salinity**




From: Starratt, S.W. 2001. "Diatoms as Indicators of Freshwater Flow Variation in Central California." PACLIM Conference Proceedings, pp. 129-144.

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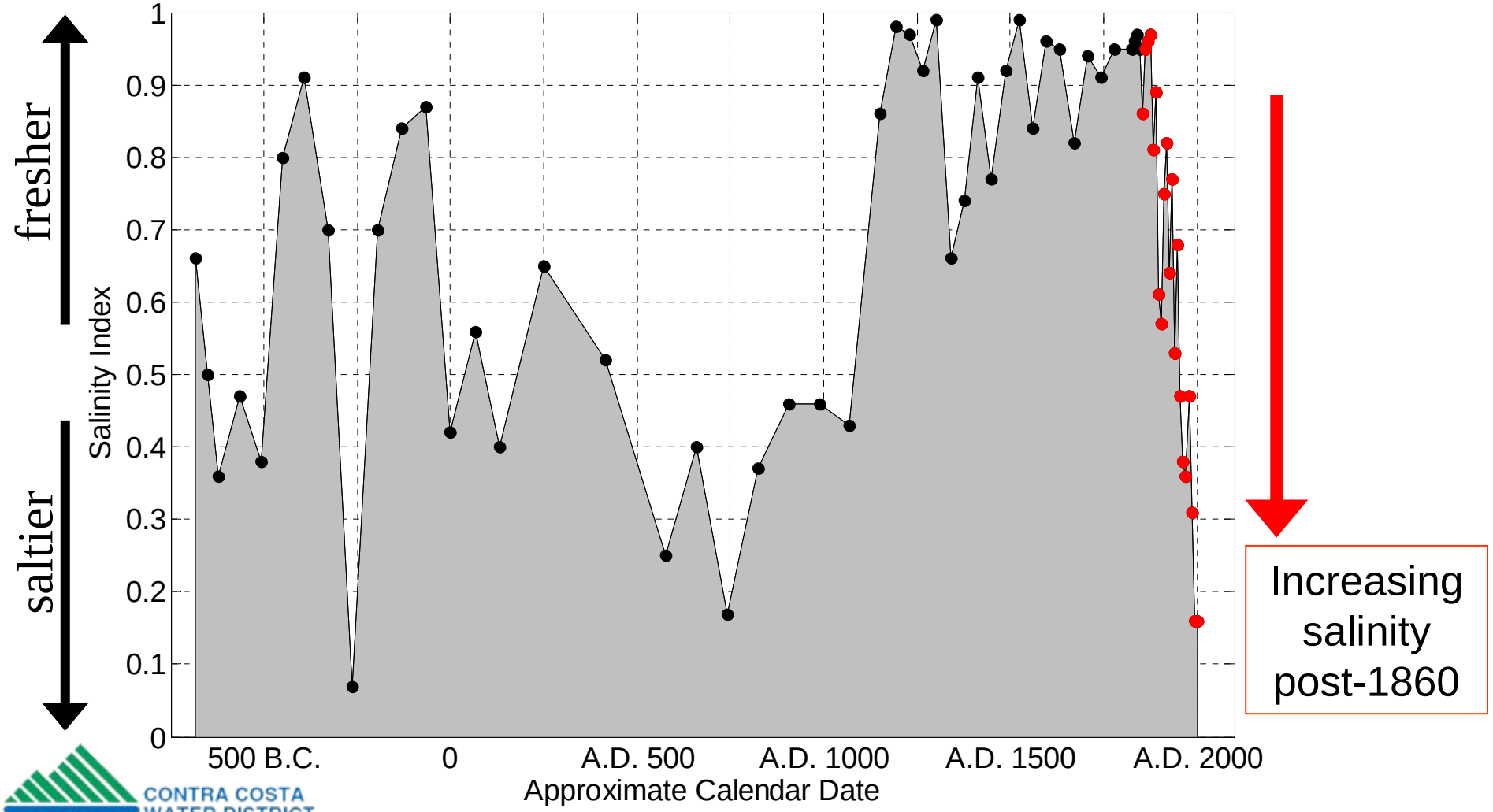
# Paleosalinity Analysis

## shows Suisun Marsh has become saltier in the past century

Composite Salinity Index based on Diatom Assemblages (courtesy Dr. Scott W. Starratt, USGS)

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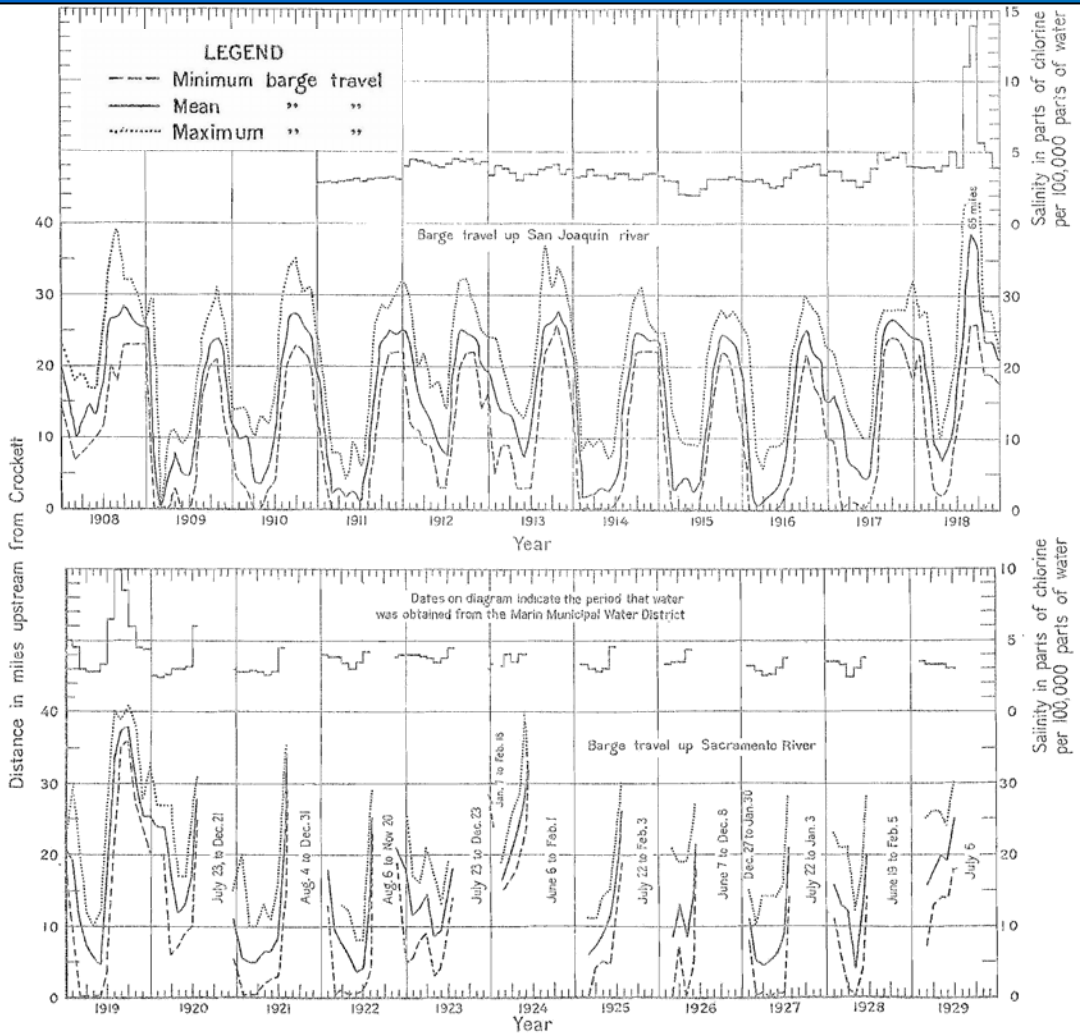
# C&H Barge Travel
# Distance to Fresh Water (50 mg/l Cl)




**California & Hawaiian Sugar Refining Corporation (1908-1929)**

C&H required "very pure" water, not to exceed 50 mg/L chloride. C&H obtained their water year-round from San Joaquin and Sacramento Rivers from 1905 to 1920.

<u>What happened?</u>

Upstream diversions

- rice cultivations (started ~1916)
- diversions during dry years removed the majority of flow from the rivers.

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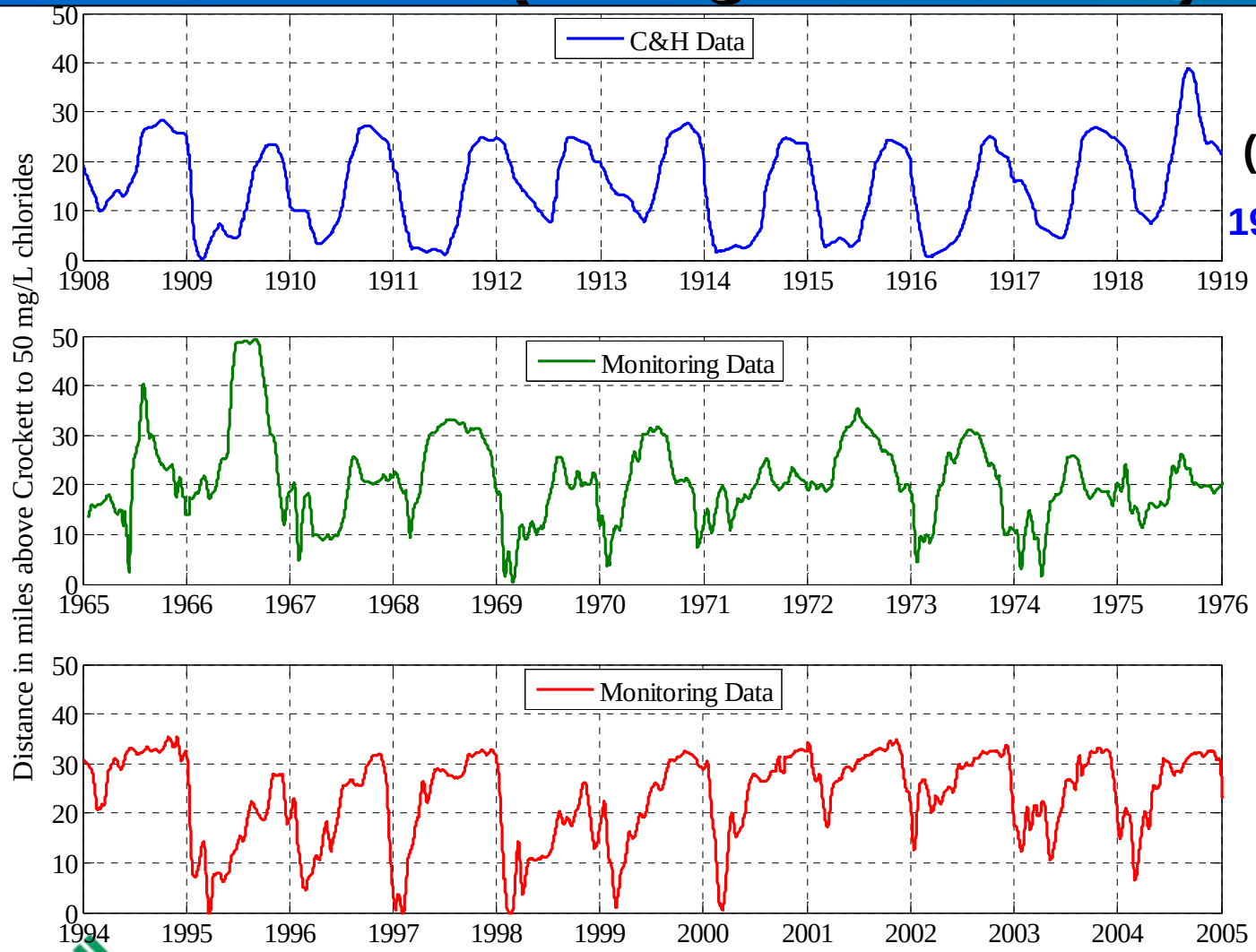
# Distance to Fresh Water
## (50 mg/L chlorides)




**Three decades with similar hydrology (wetter than average)**

**1908-1917: pre-reservoirs**

**1965-1976: early-SWP**

**1994-2005: post-ESA**

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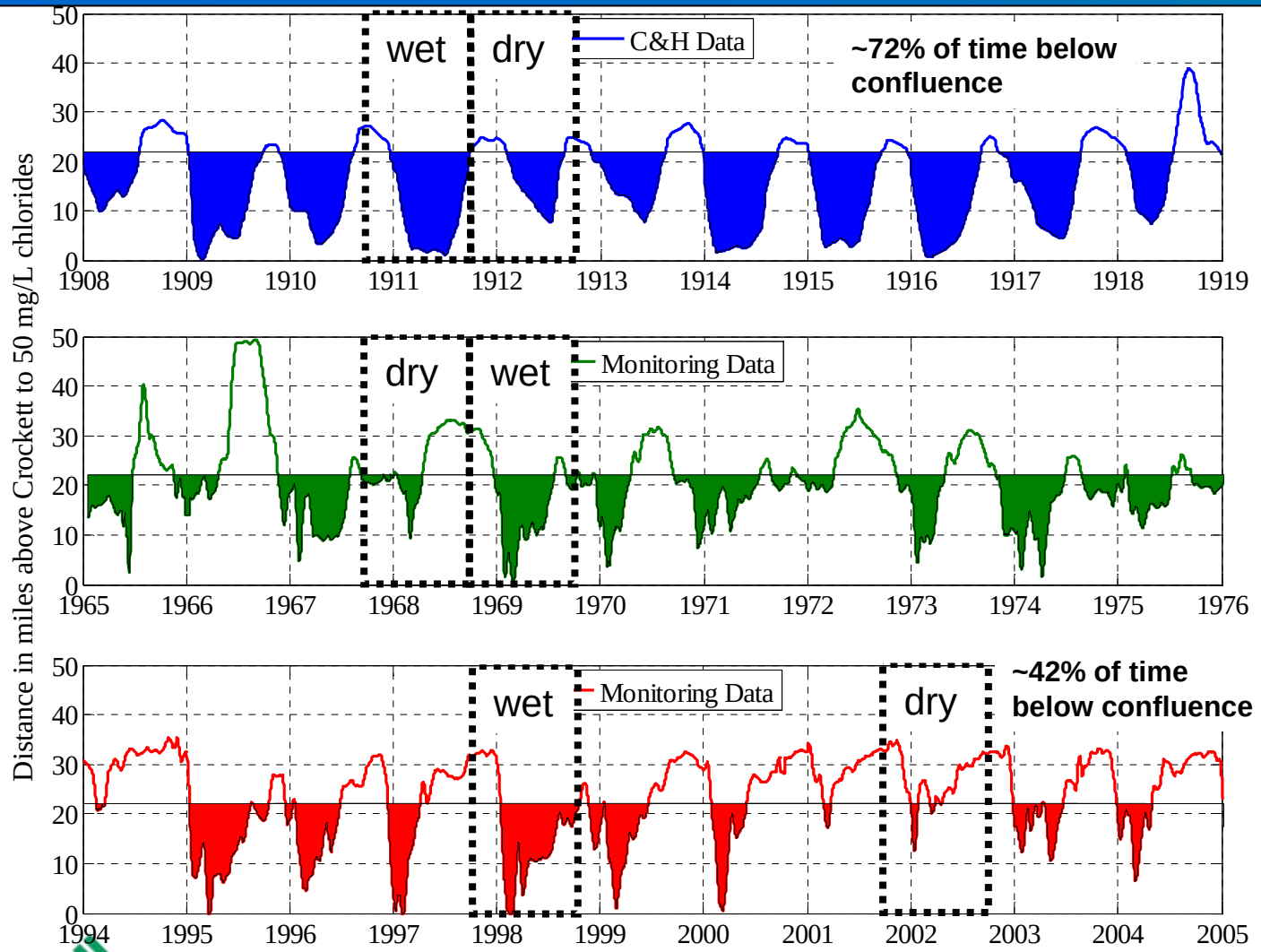
# Distance to 50 mg/l Water

## amount of fresh water below confluence has decreased




Shading represents amount of fresh water (50 mg/L chlorides) below the confluence.

Similar wet and dry water years highlight the reduction in fresh water below the confluence during **1965-1976** and **1994-2005** compared to **1908-1917**

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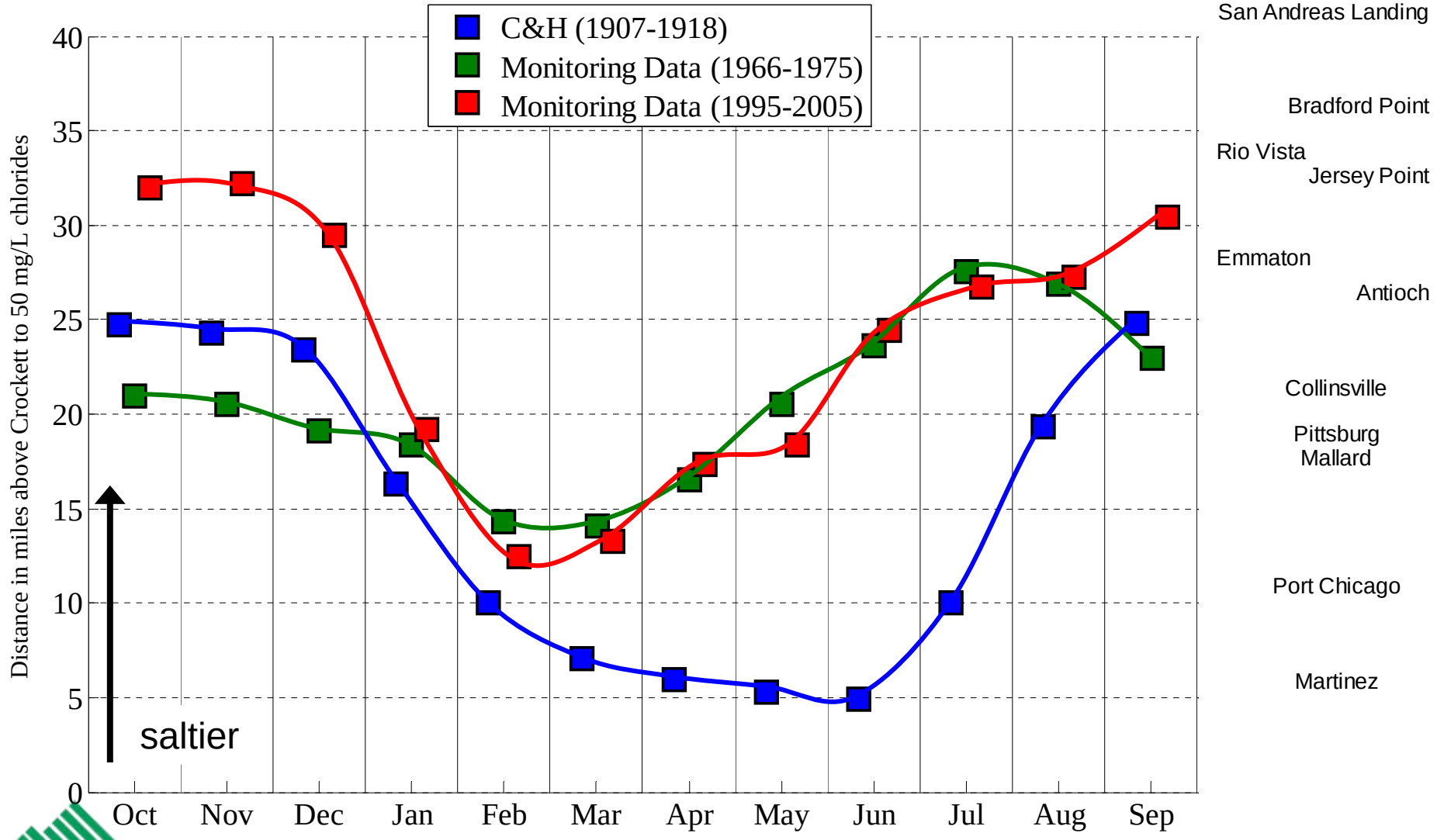
# Seasonal Distance to Fresh Water

## (50 mg/l Cl)

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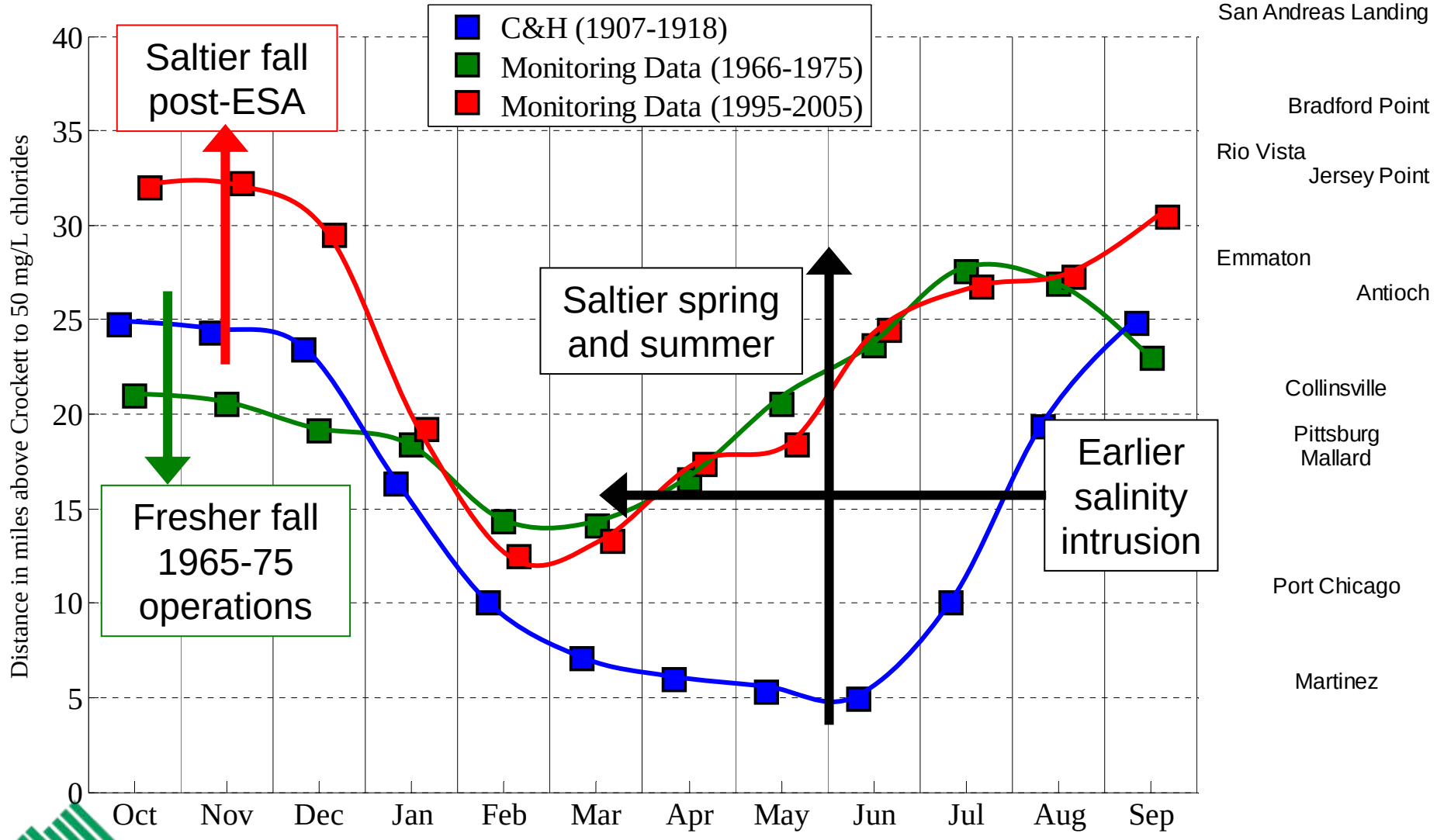
# Distance to Fresh Water (50 mg/l)

## has increased dramatically in spring, early summer and fall

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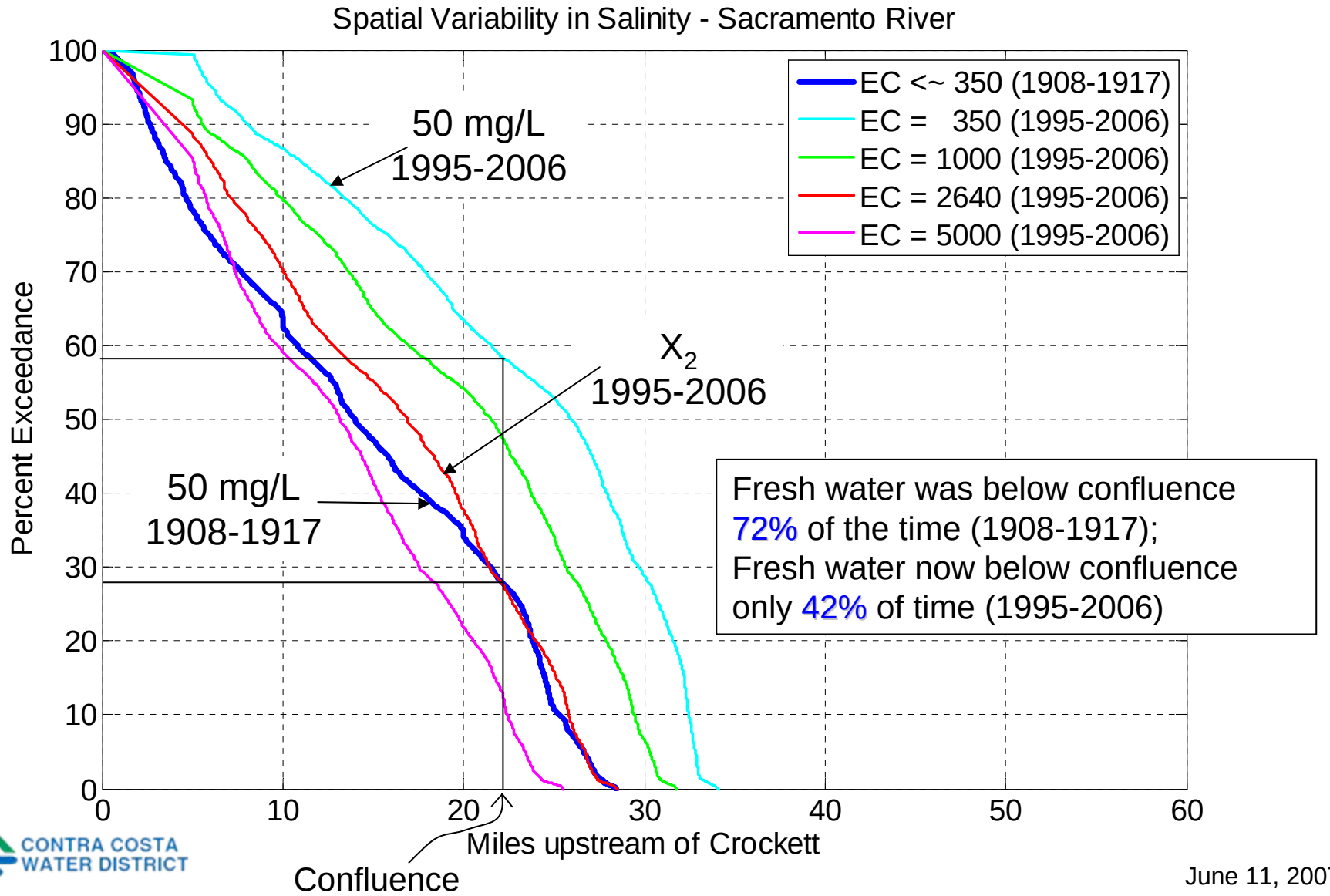
# Current spatial location of $X_2$ (brackish, 1000 mg/l Cl) was fresh (50 mg/l) during the early 1900s

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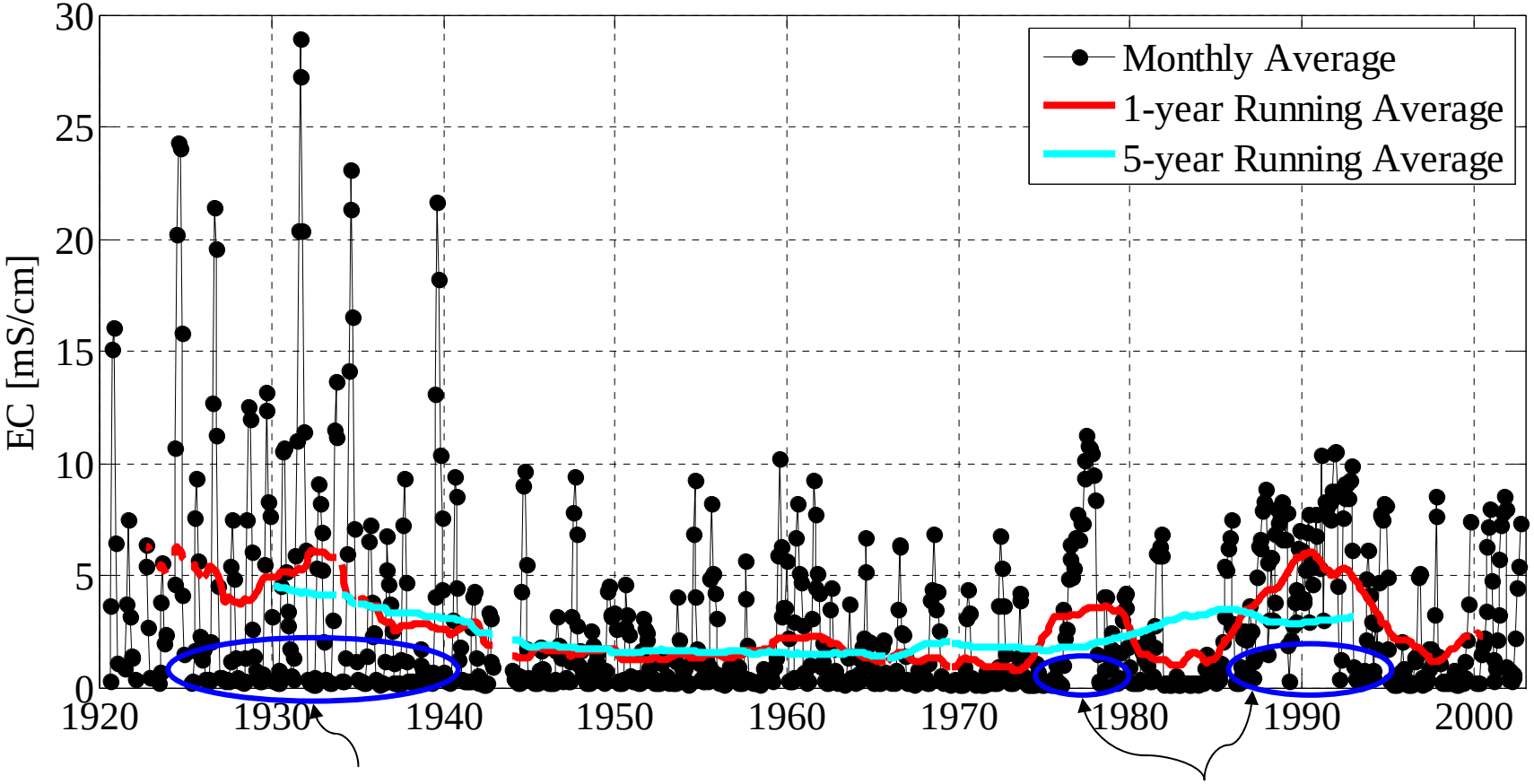
# Monthly Salinity at Collinsville

## No longer fresh in winter and spring of dry years

Monthly Salinity at Collinsville (courtesy Chris Enright, DWR)




Delta was seasonally fresh; even during dry years

Delta is no longer seasonally fresh during dry years

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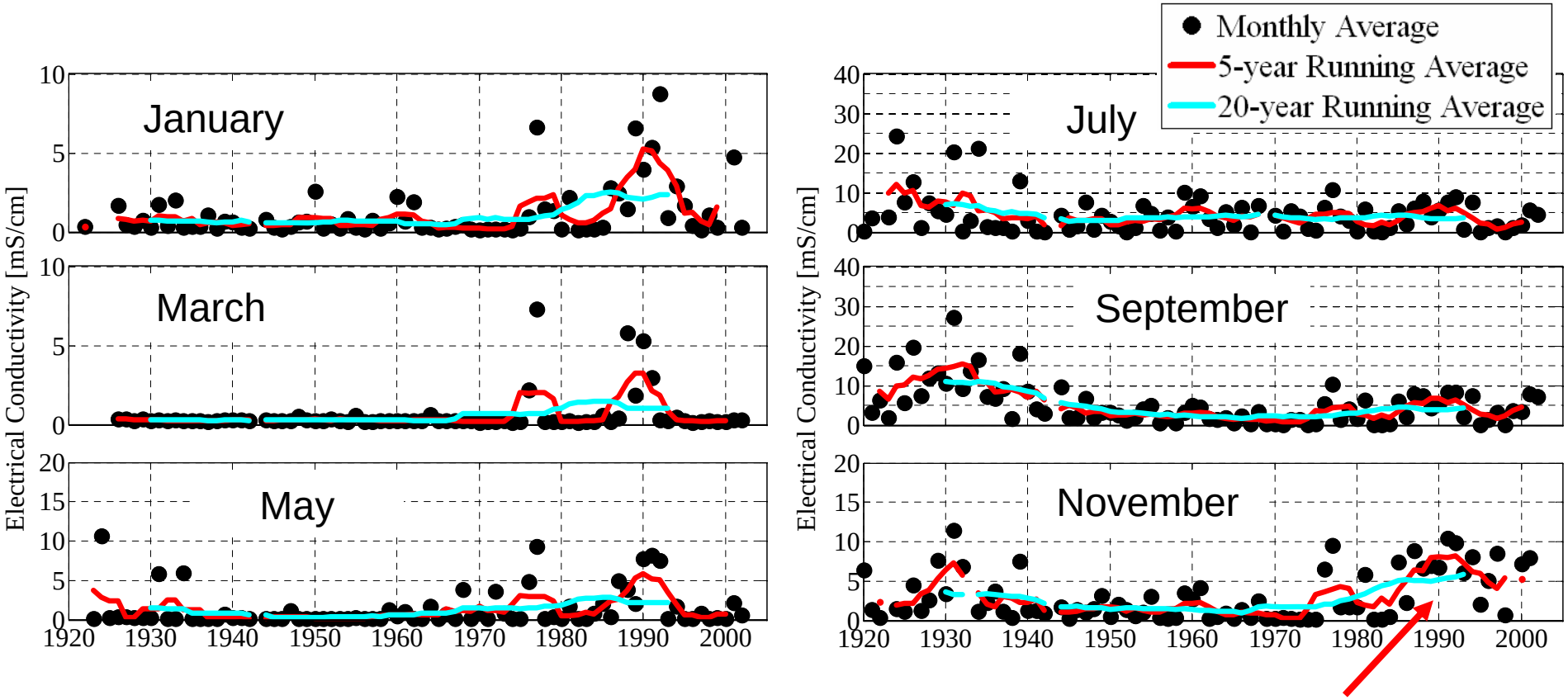
# Year-to-Year Trends in Monthly Salinity at Collinsville




Fall salinity now as high as 1930's drought, even in wetter years!

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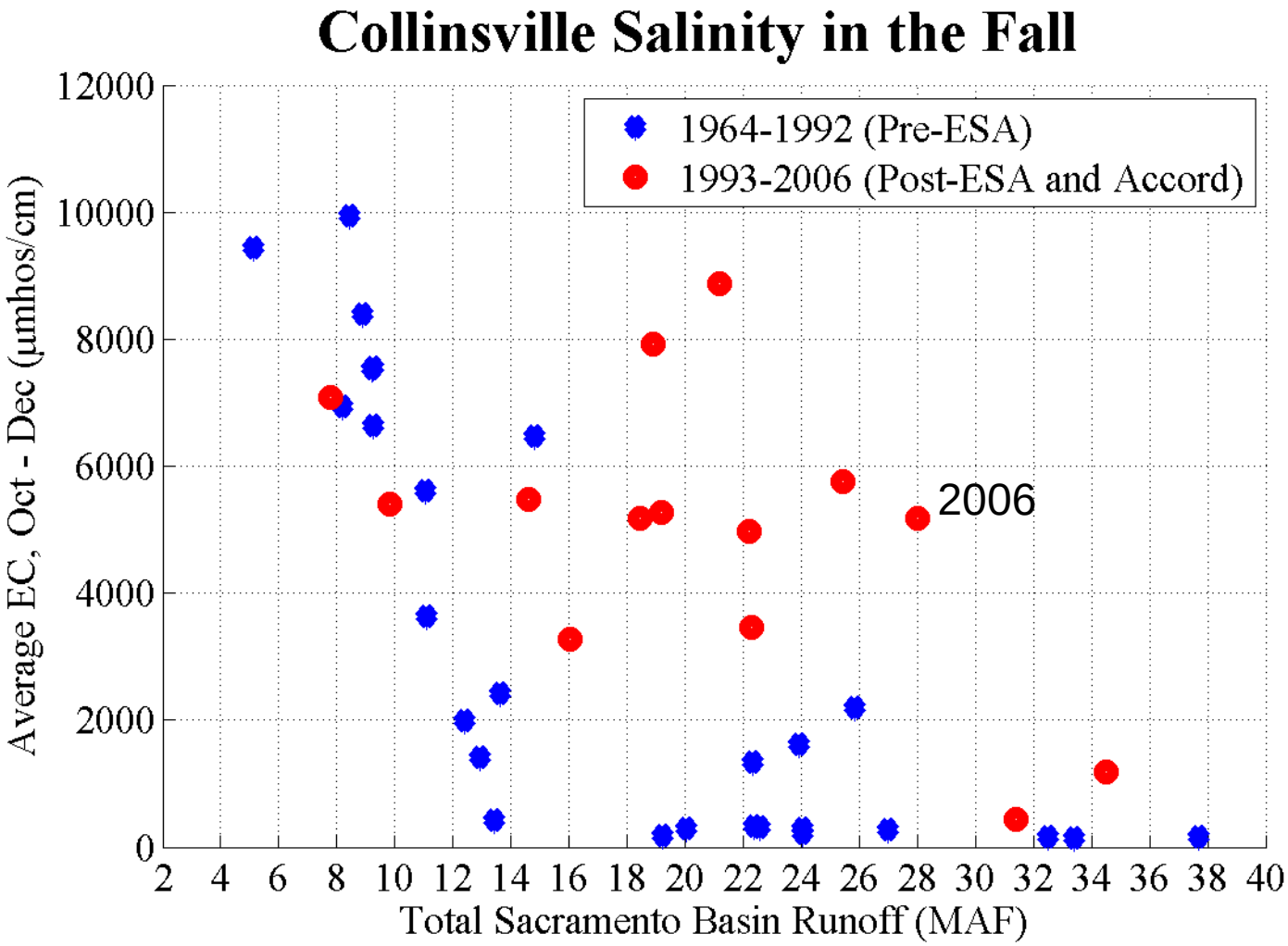
# Fall salinity at Collinsville has significantly increased since 1993

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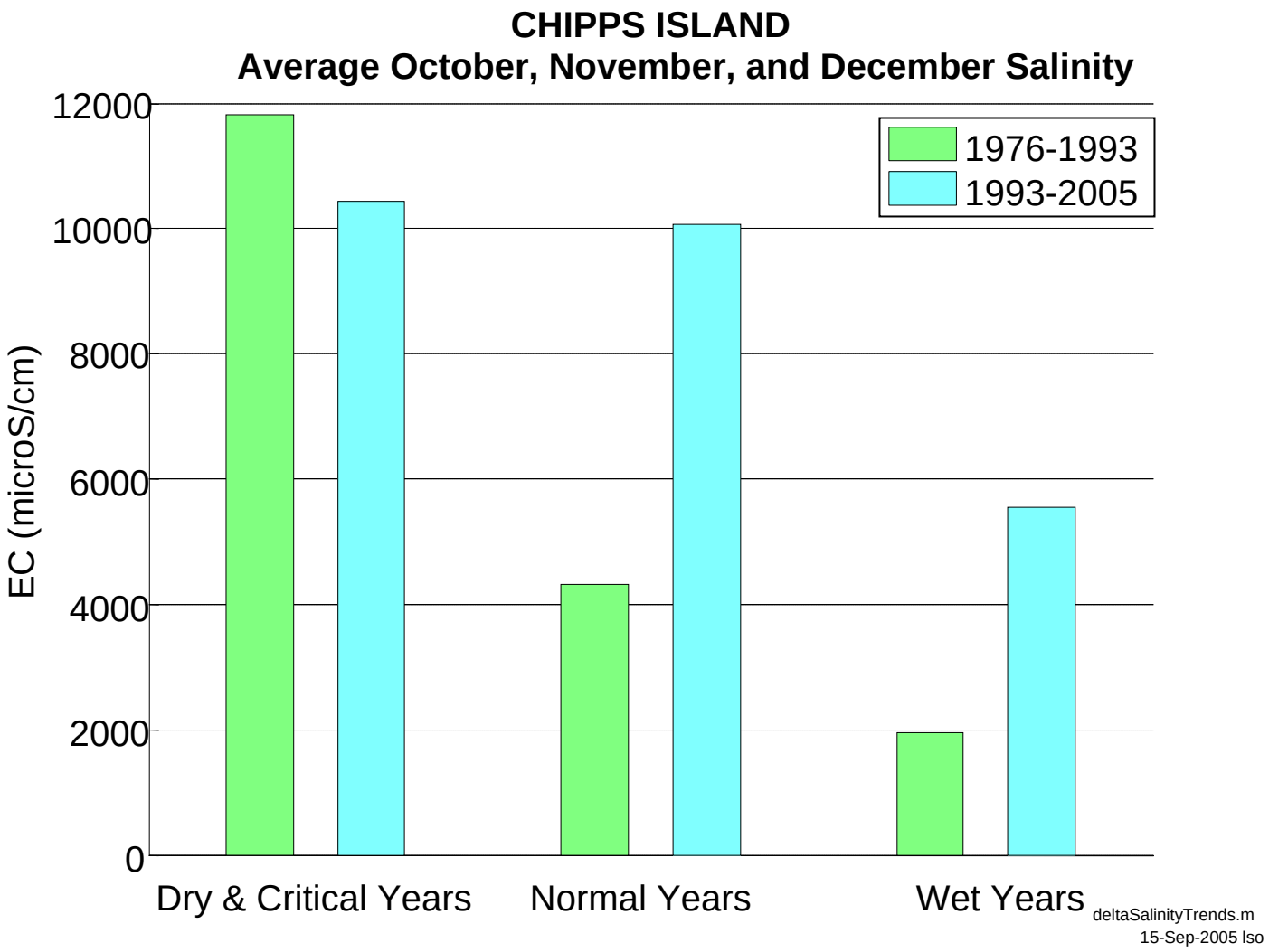
# Fall salinity at Chipps Island has significantly increased since 1993



# Impact of Operations

- Isolate effects of operations by comparing actual conditions to unimpaired conditions
  - UNIMPAIRED IS NOT NATURAL
  - Removes hydrologic variability to demonstrate effects of alterations
  - Assumes current Delta and tributary configuration
- Metrics
  - Net Delta Outflow (NDO)
  - Distance from the Golden Gate to 2 psu near-bottom salinity ($X_2$)

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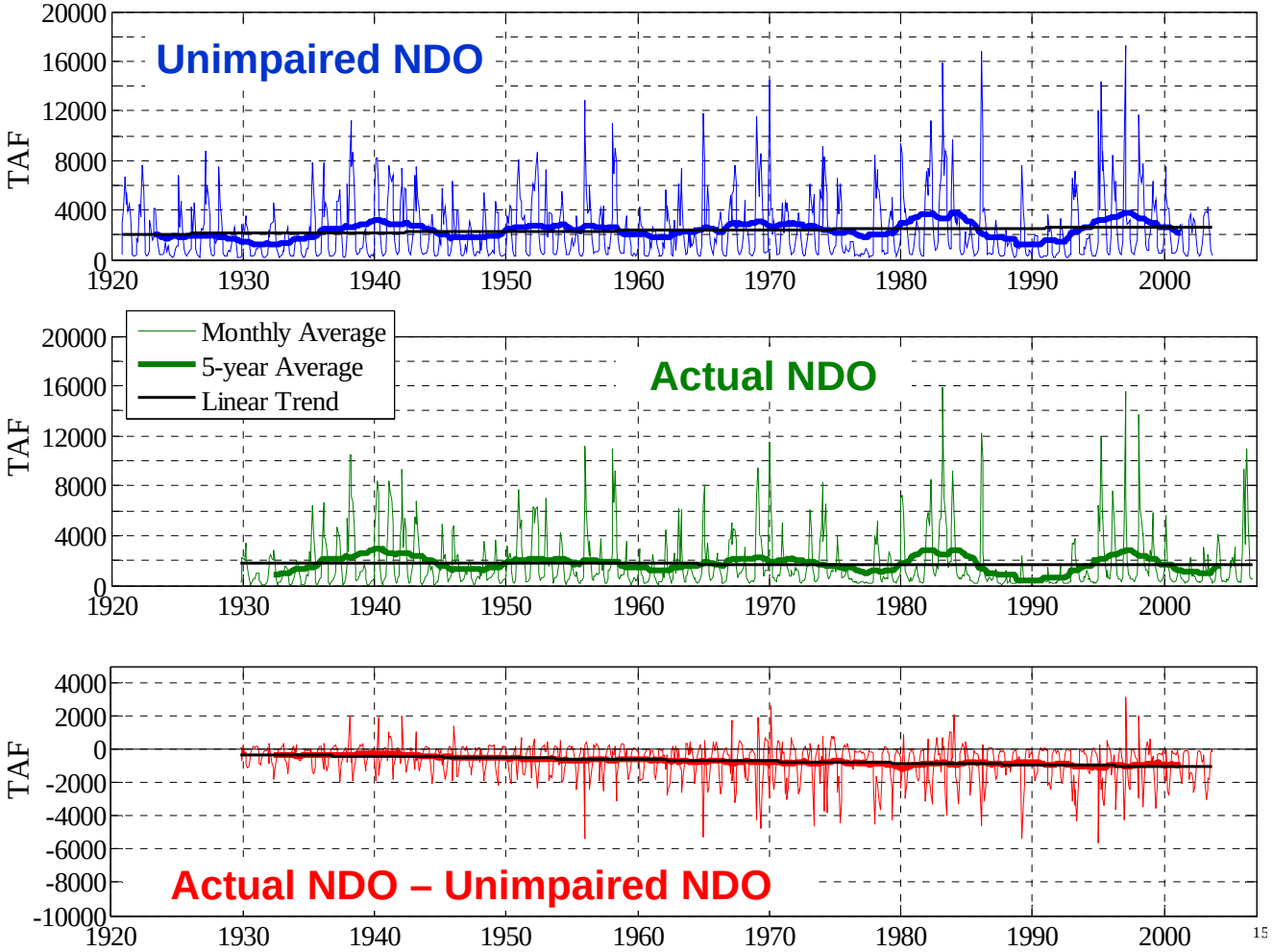
# Monthly Net Delta Outflow




Hydrology is getting wetter

Actual outflow is decreasing

Effect of operations is progressively more substantial

(increased water usage)

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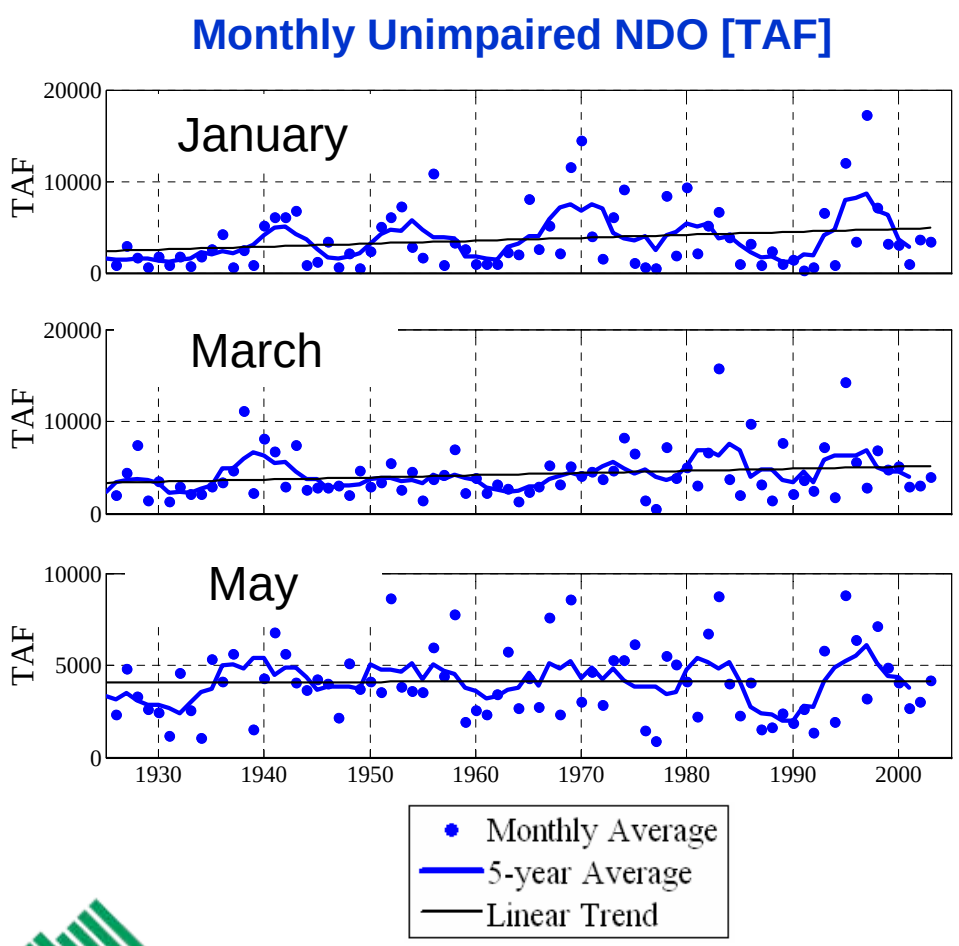
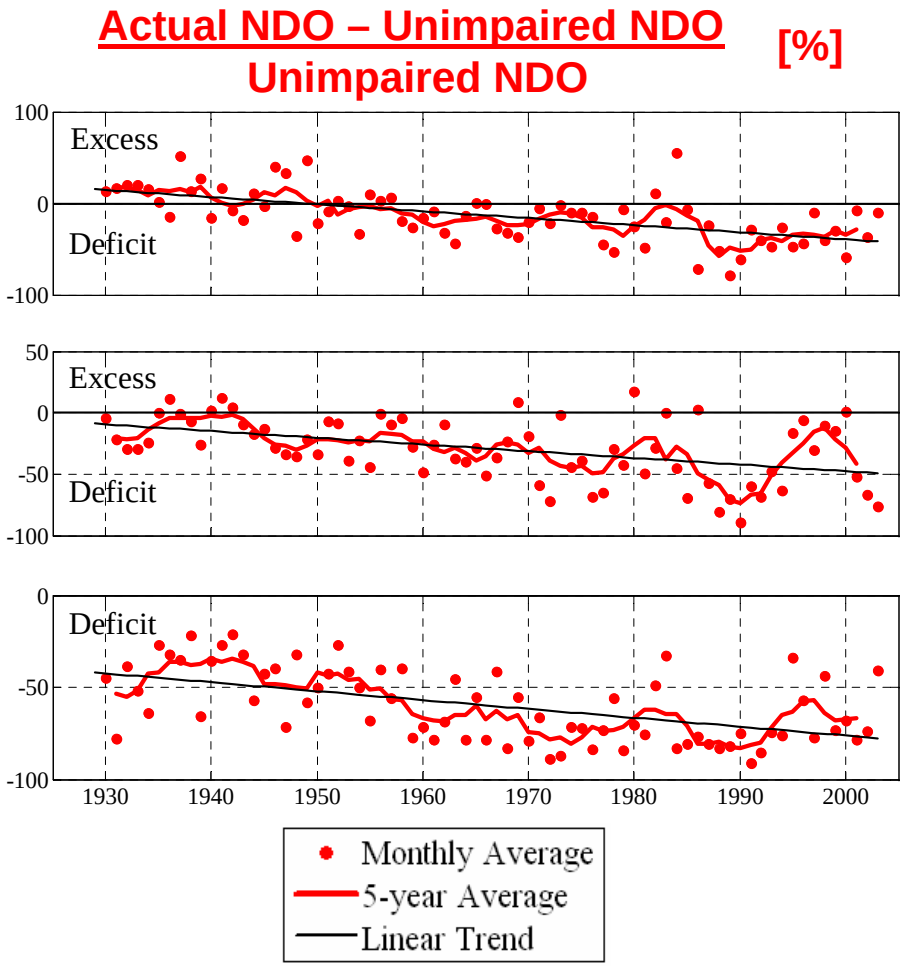
# Year-to-Year Trends in Monthly Net Delta Outflow

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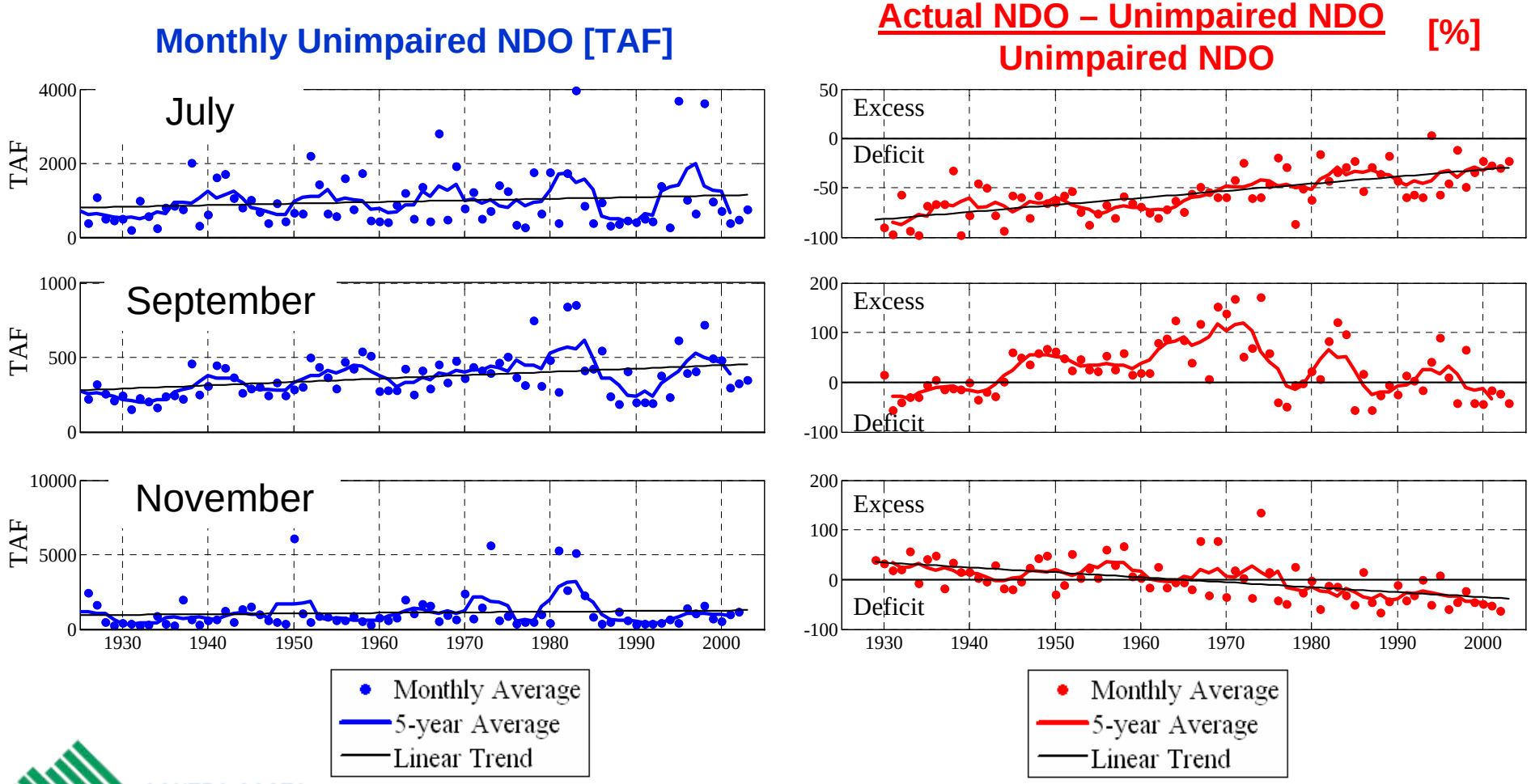
# Year-to-Year Trends in Monthly Net Delta Outflow

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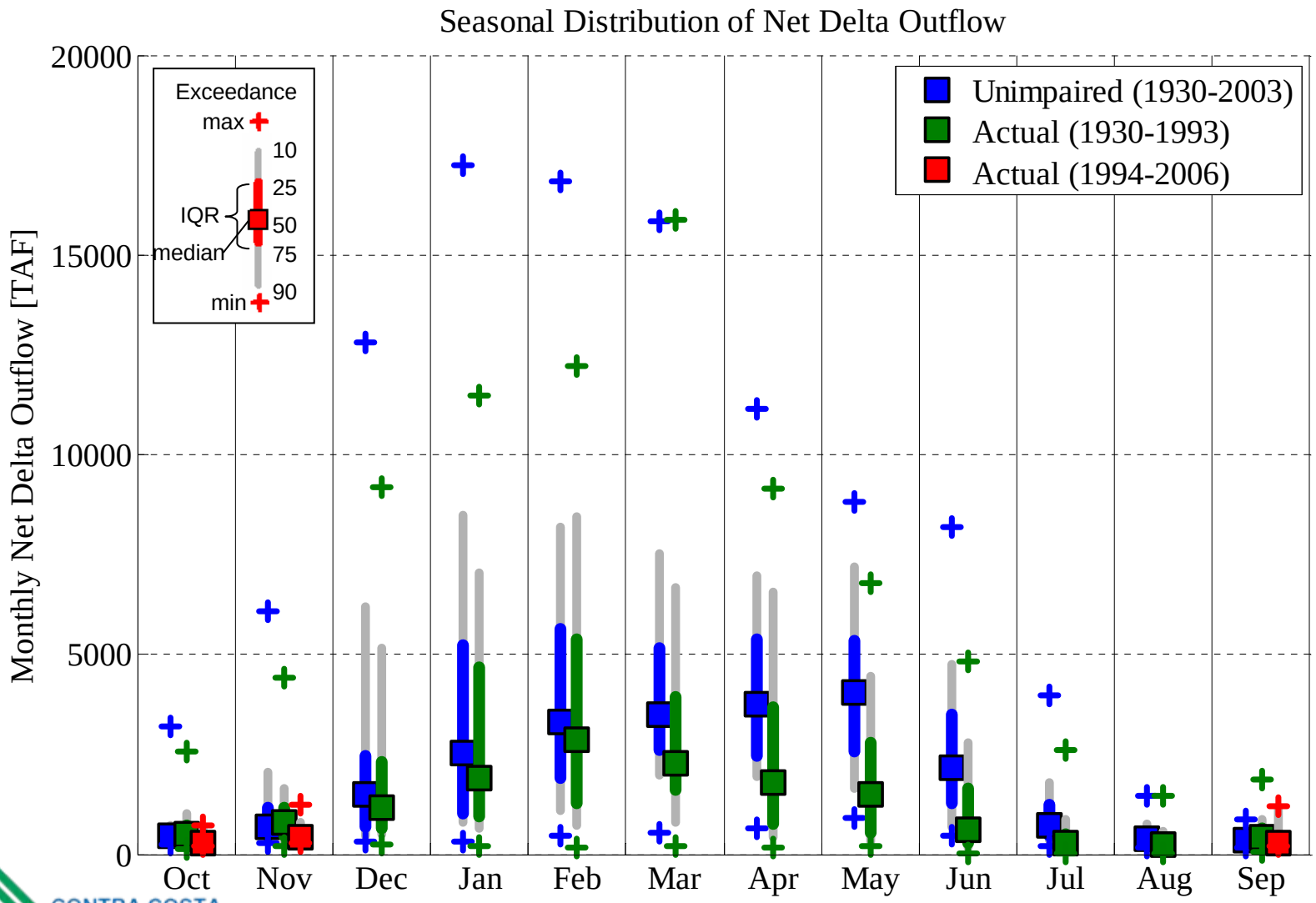
# Seasonal Distribution of Outflow (1930-2006)

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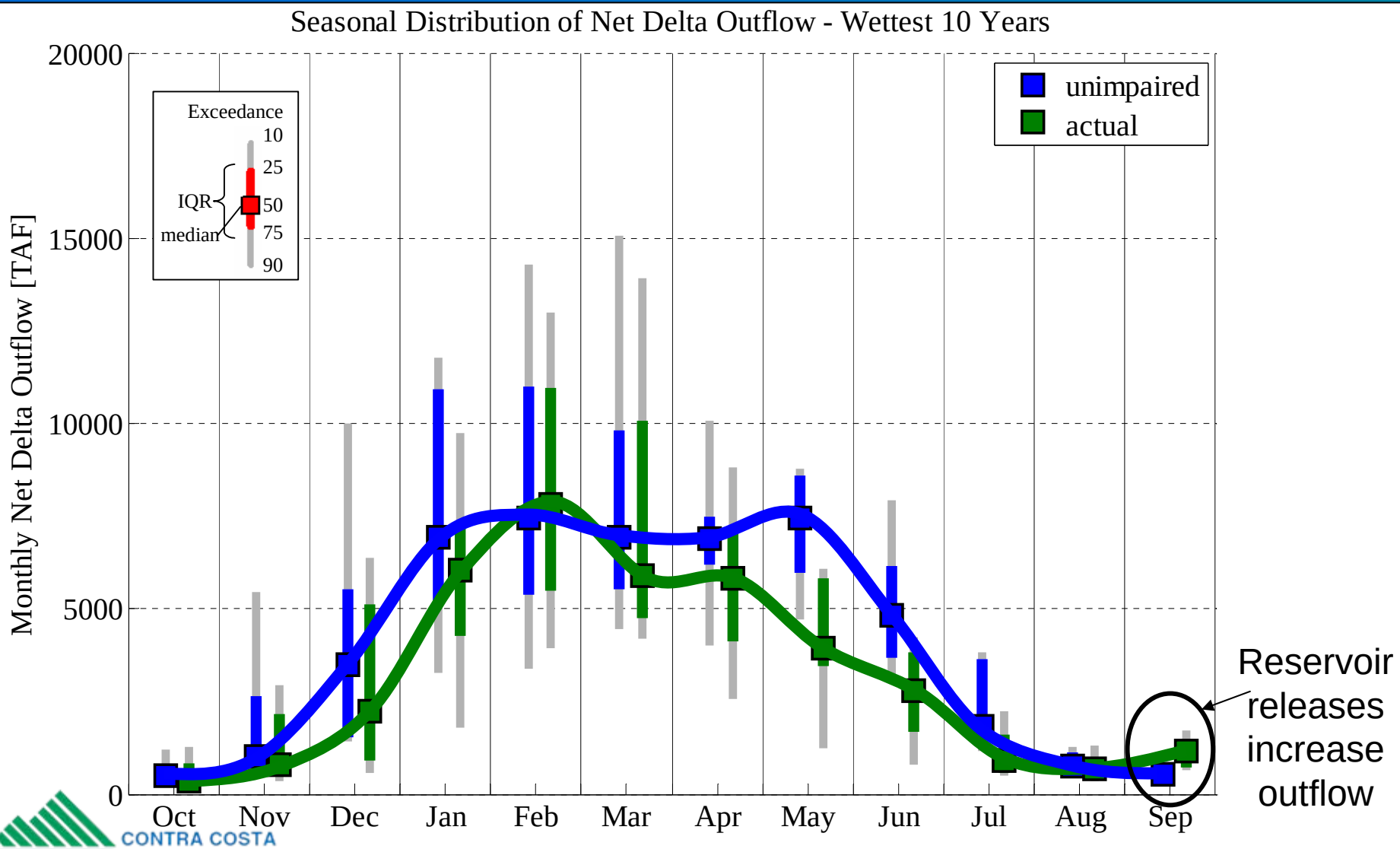
# Seasonal Distribution of Outflow
## WETTEST 10 Years from 1945-2003

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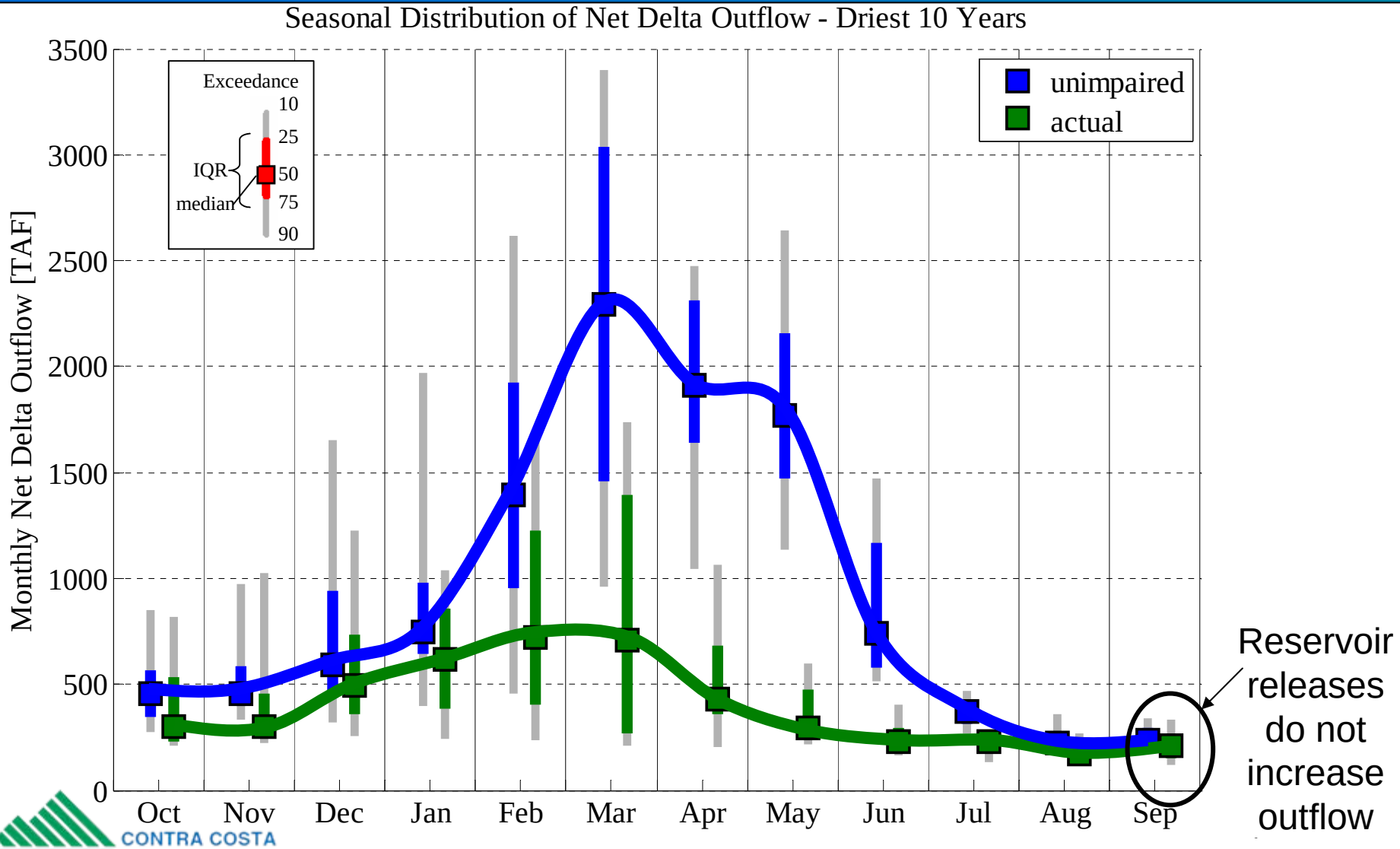
# Seasonal Distribution of Outflow

## DRIEST 10 Years from 1945-2003

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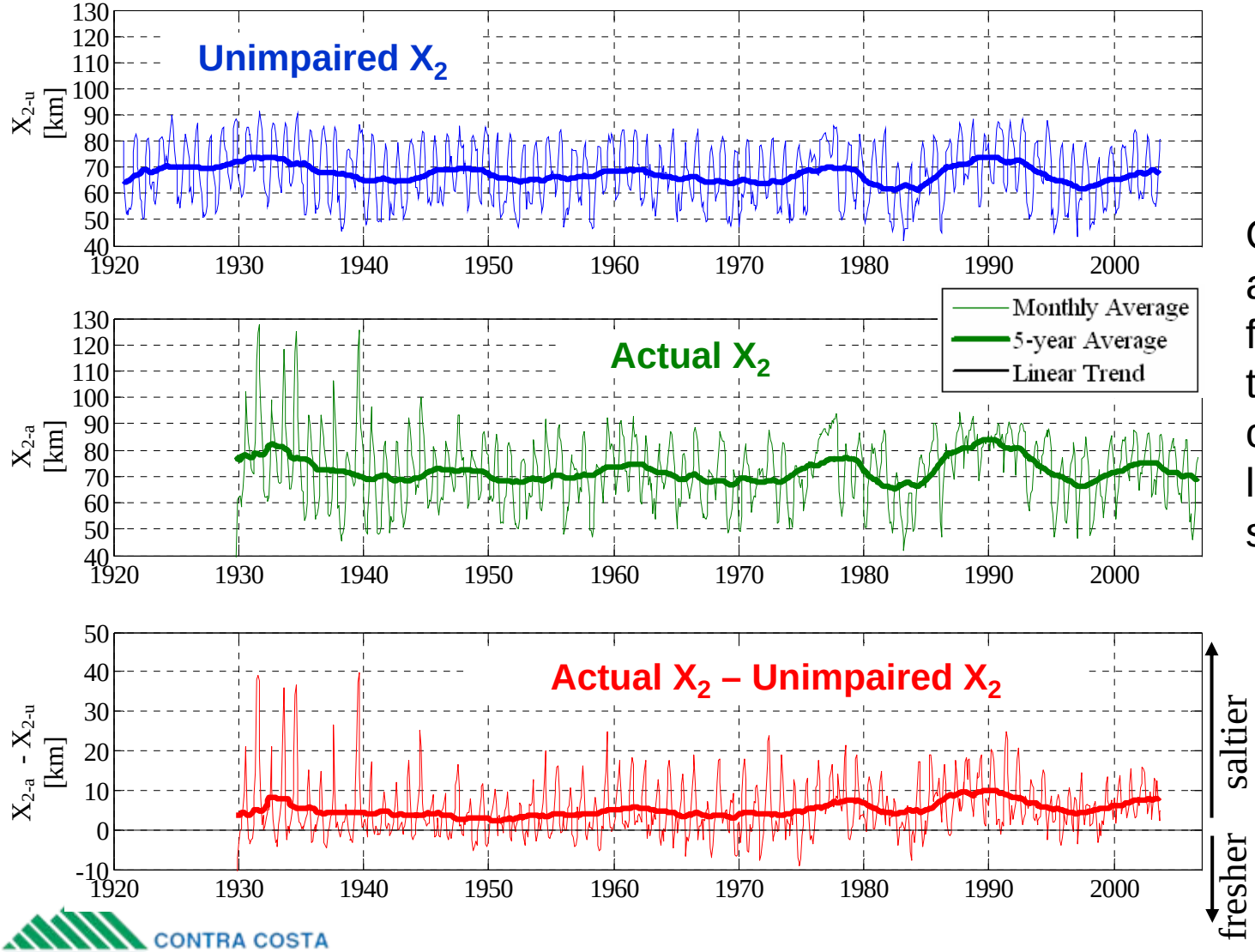
# Monthly $X_2$ location




On average, actual $X_2$ is 5-10 km farther upstream than unimpaired conditions, leading to a saltier Delta.

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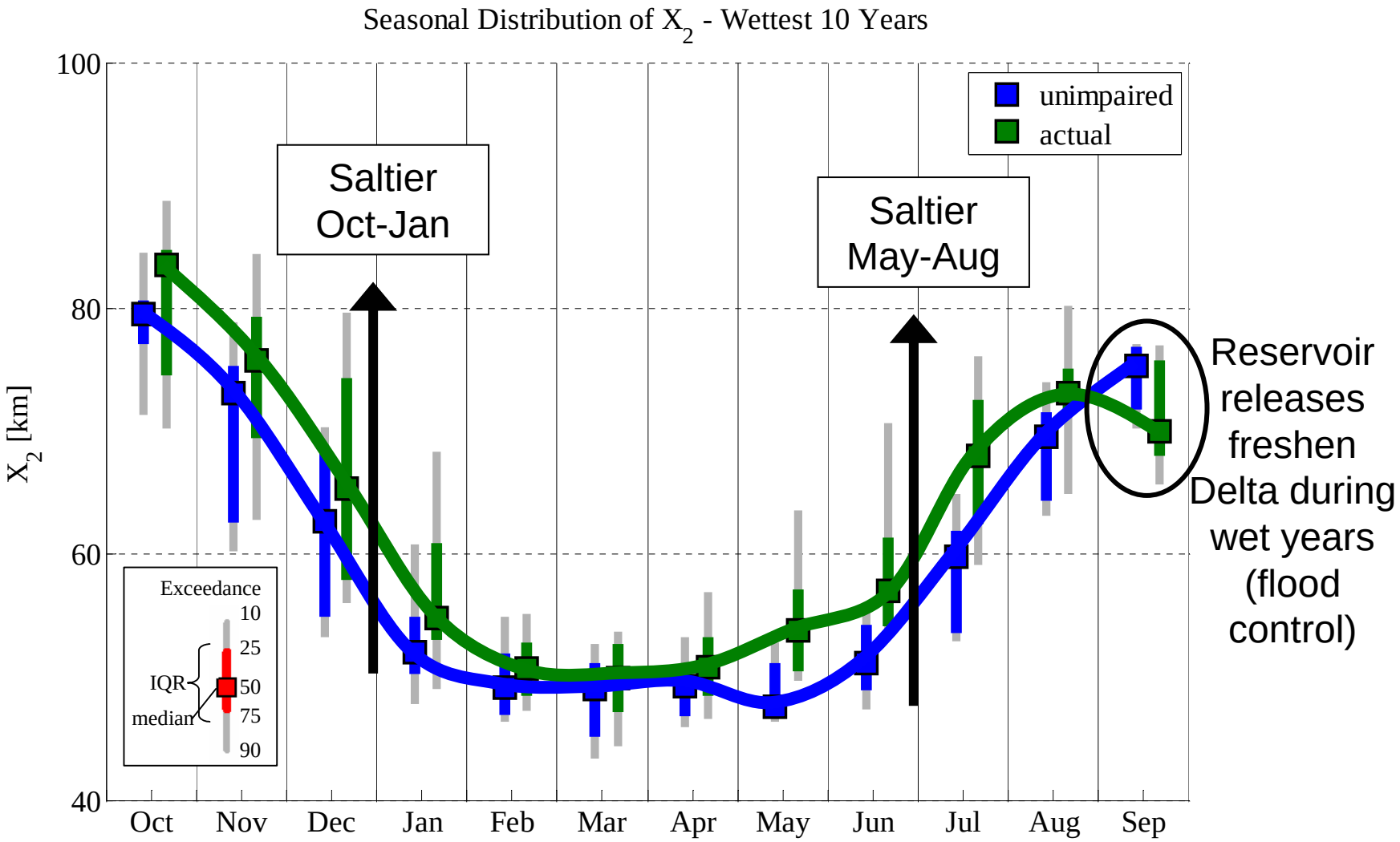
# Seasonal Distribution of $X_2$
## WETTEST 10 Years from 1945-2003

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21-May-2007

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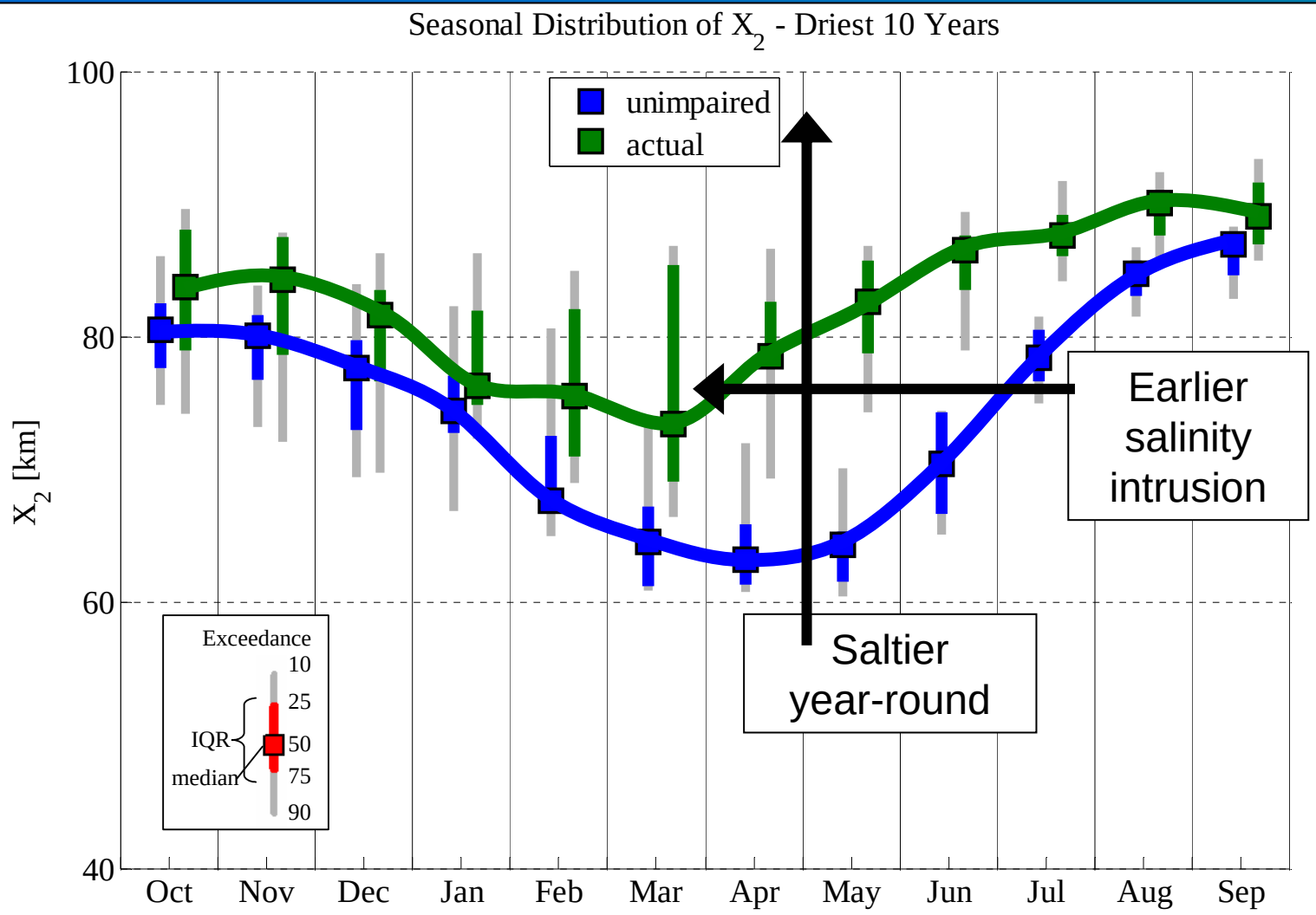
# Seasonal Distribution of $X_2$
## DRIEST 10 Years from 1945-2003

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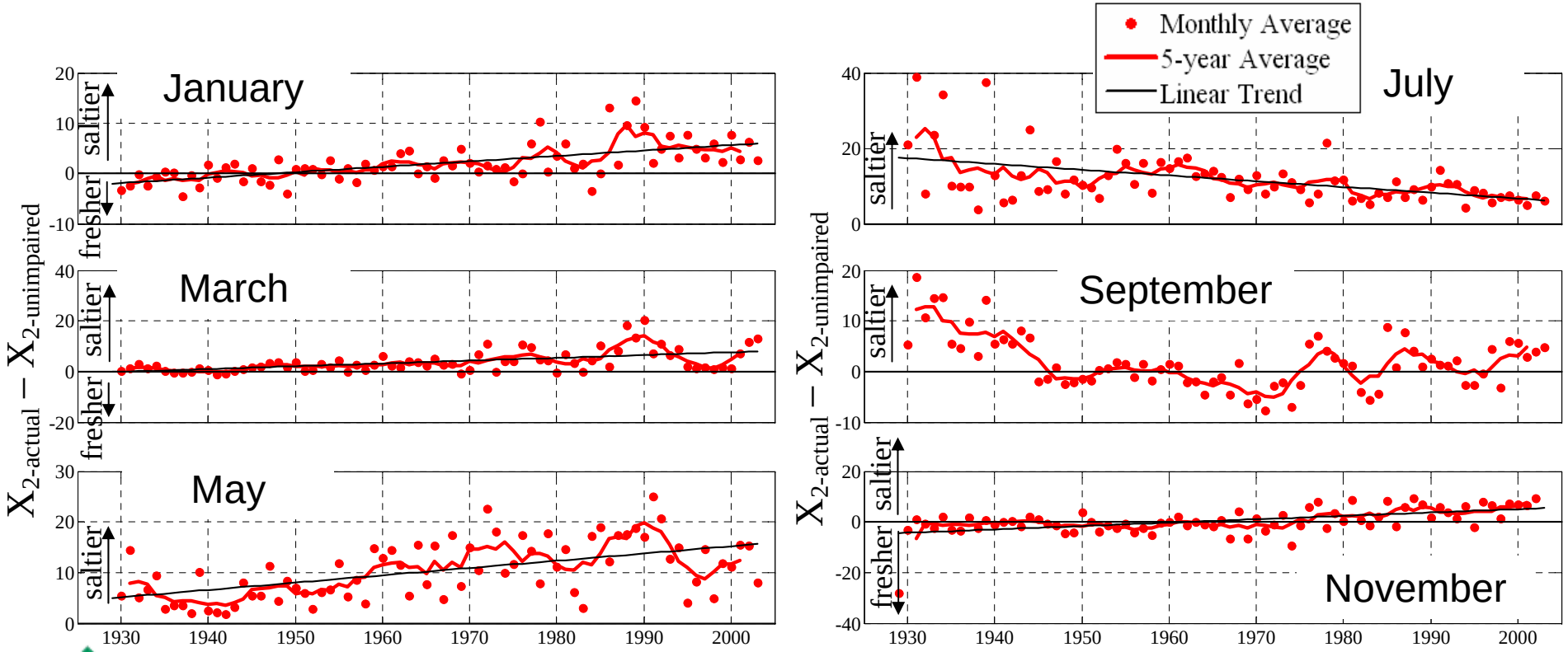
# Year-to-Year Trend in Actual Monthly $X_2$ relative to Unimpaired Conditions

Currently, $X_2$ is typically 5-15 km farther inland than it would be under unimpaired conditions.

$X_2$ is moving progressively farther inland in all months except July and August.

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# Key Trends

- How are current operations (1975-2007) altering the regime?
  - All years
    - Substantial increase in fall salinity intrusion in all but the very wettest years (previously just during droughts)
  - Dry years
    - Bay-Delta does not get as fresh, especially in spring
    - Seasonal fluctuation is limited;
      Unimpaired $X_2$ would be 10-20 km farther downstream
  - Wet years
    - Salinity intrudes 3-months earlier;
      rising salinity in early spring instead of summer

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# Conclusions

- Historical Context
  - Centennial-scale variability in salinity
    - Currently as salty as or saltier than conditions through 2,500 years ago
  - Last 100-150 years
    - Last fresh period ~1200-1860
    - ~1860 salinity began to increase
    - ~1930 rapid increase

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# Conclusions

- Pre – "salinity control" (1920s and 1930s)
  - Upstream diversions led to greater salinity intrusion than was ever known before (DWR, 1931)
  - Even during dry years, salinity retreated to below the confluence during winter months
- Early post-project conditions (1945-1975)
  - "salinity control" limited the impact of upstream diversions during the dry season
  - "salinity control" did not make the dry season fresh compared to unimpaired conditions
  - Reservoir releases for flood control did freshen February and September a small amount

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# Conclusions

- Recent Operations (1994-2006)
  - Substantial increase in fall salinity in the western Delta during all but the wettest years
  - During dry years, Suisun Bay and western Delta no longer freshen during the winter and spring
    - Dry years of 1920s and 1930s: fresh water (less than 50 mg/L chlorides) present below confluence
  - During wet years, flood control releases have less of an impact on reducing salinity than they did during 1945-1975

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# Questions?

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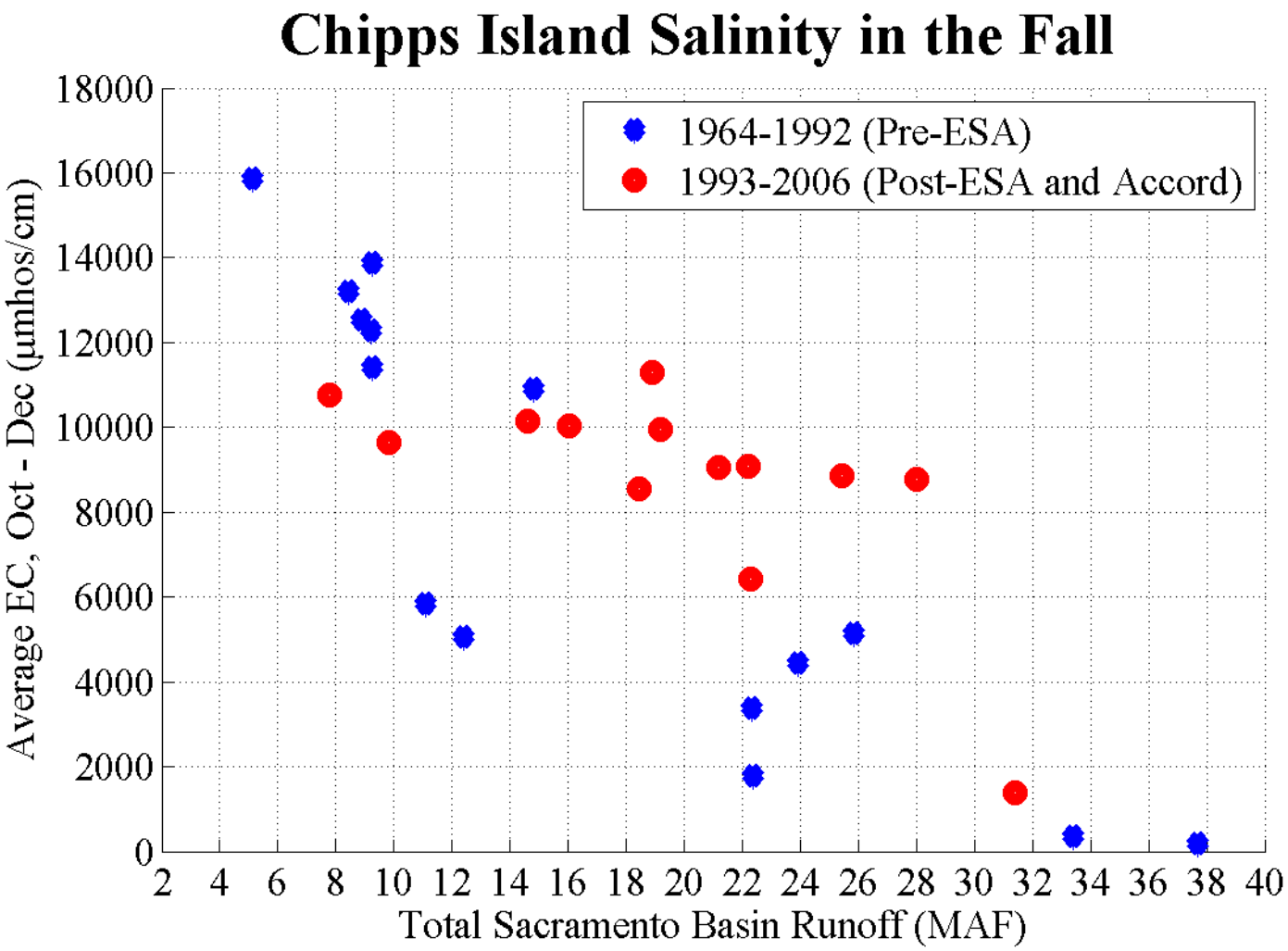
# Extra graphs

# Fall salinity at Chipps Island has significantly increased since 1993

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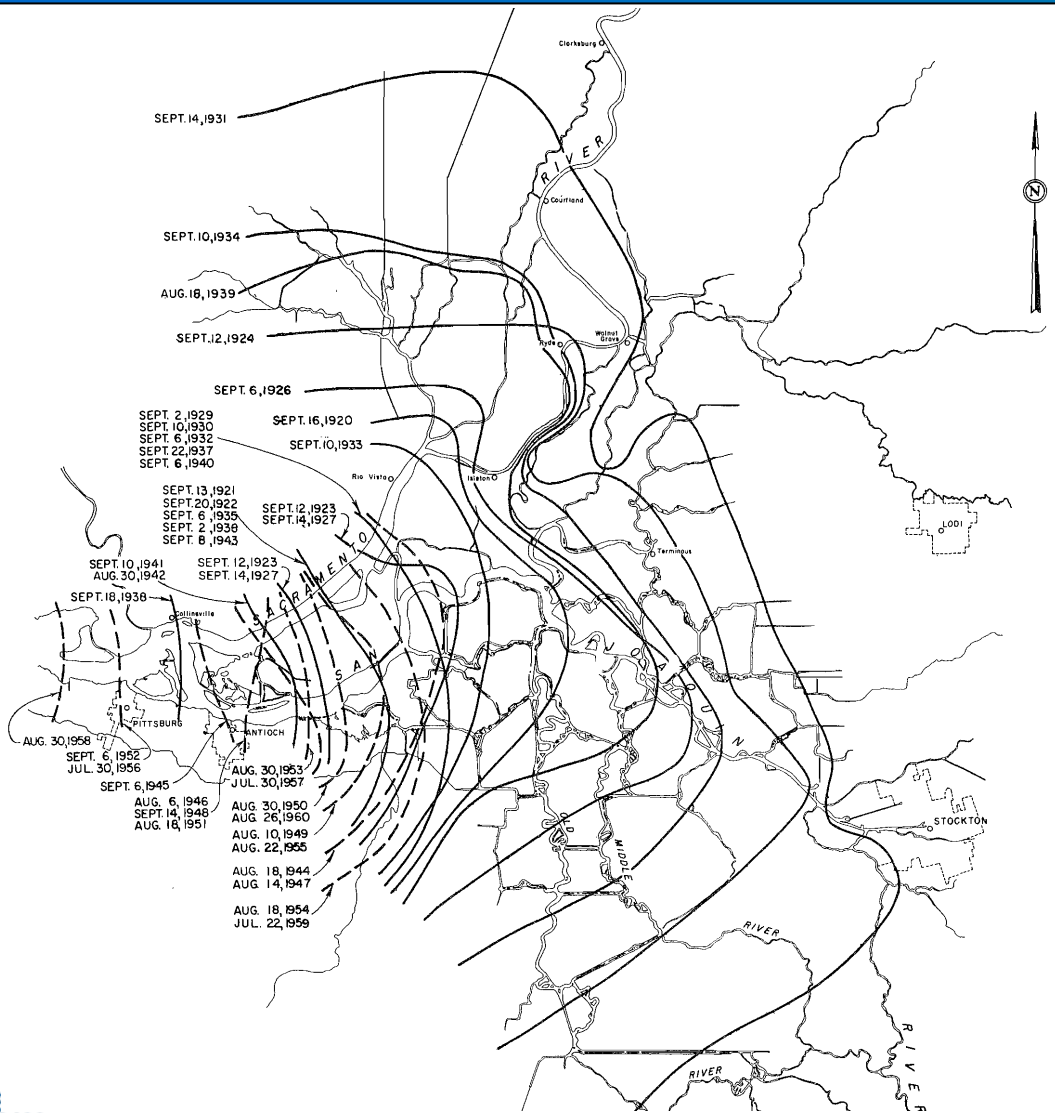
# Salinity Intrusion (pre-Shasta)




Iso-chlors determined from interpolation of data that represent the worst single day ***at high tide***.

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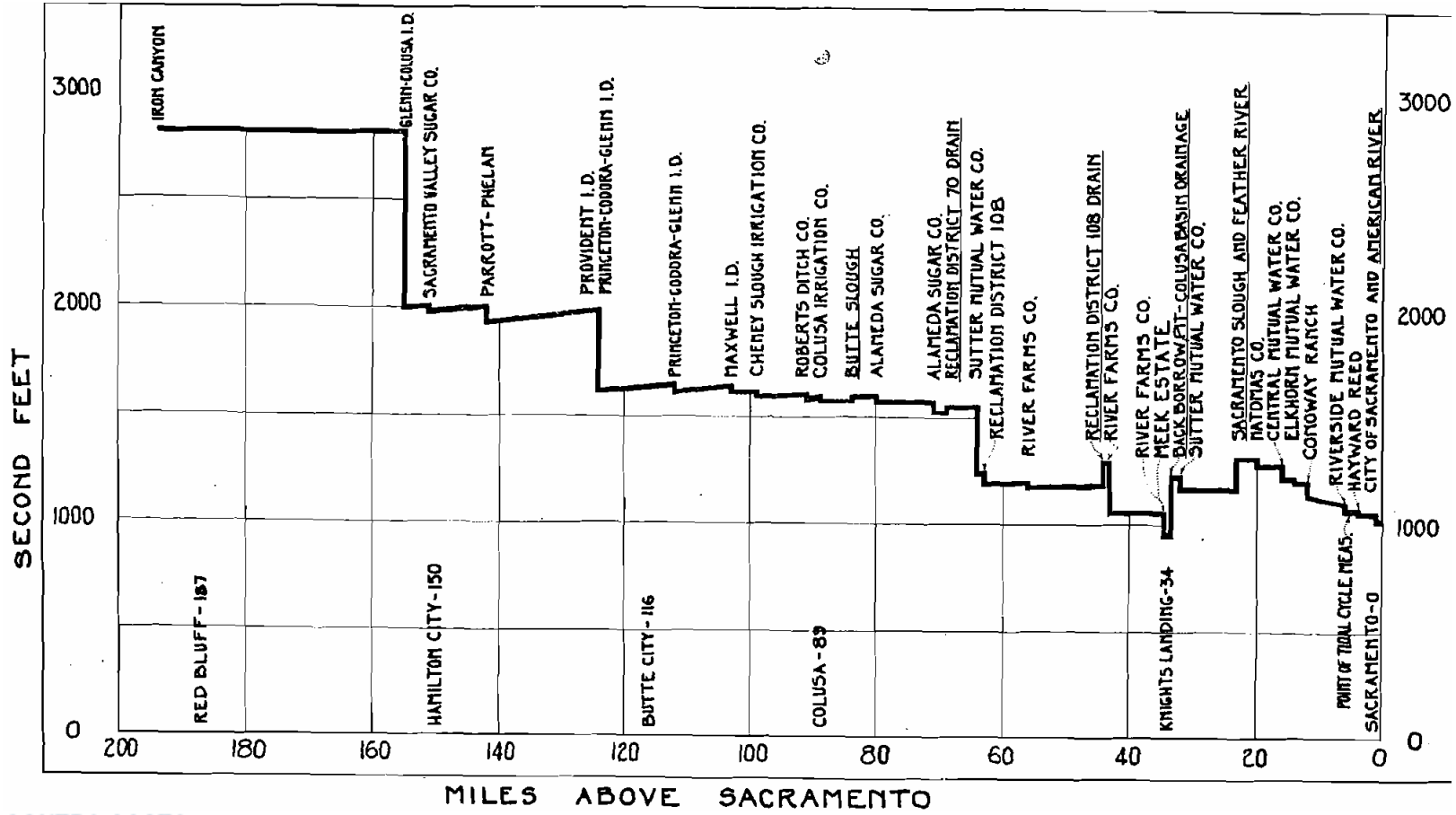
# Upstream Diversions 1924

## Removed Majority of Flow from Sacramento River above Sacramento

Sacramento River Discharge, Diversions, and Inflow - Red Bluff to Sacramento, California, causing on August 7 and 8, 1924, a Measured flow near Sacramento of 1070 cfs

From: Proceedings of the Second Sacramento-San Joaquin River Problems Conference (December 12, 1924)

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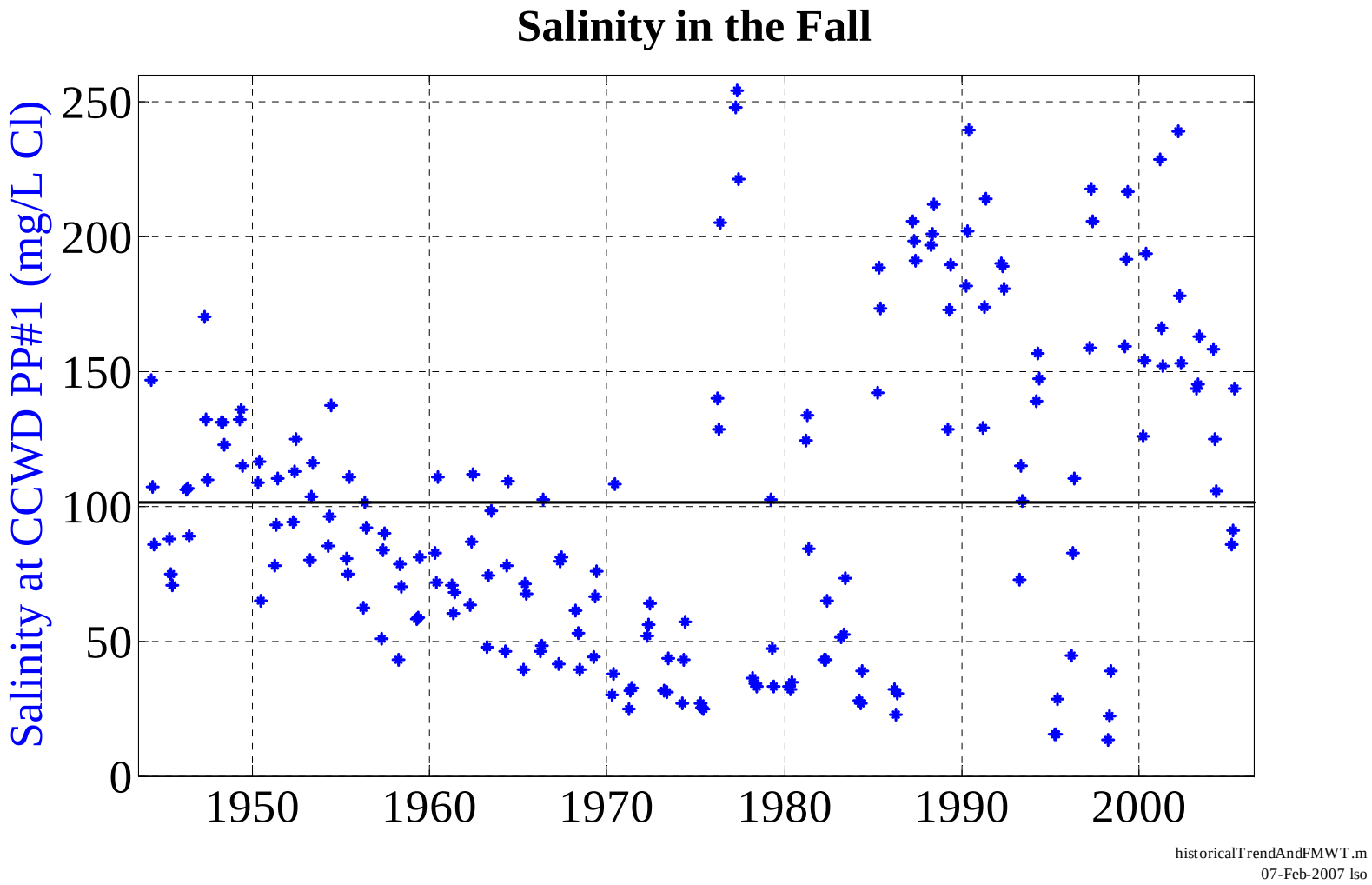
# Salinity in the Fall at Rock Slough, 1944 to Present

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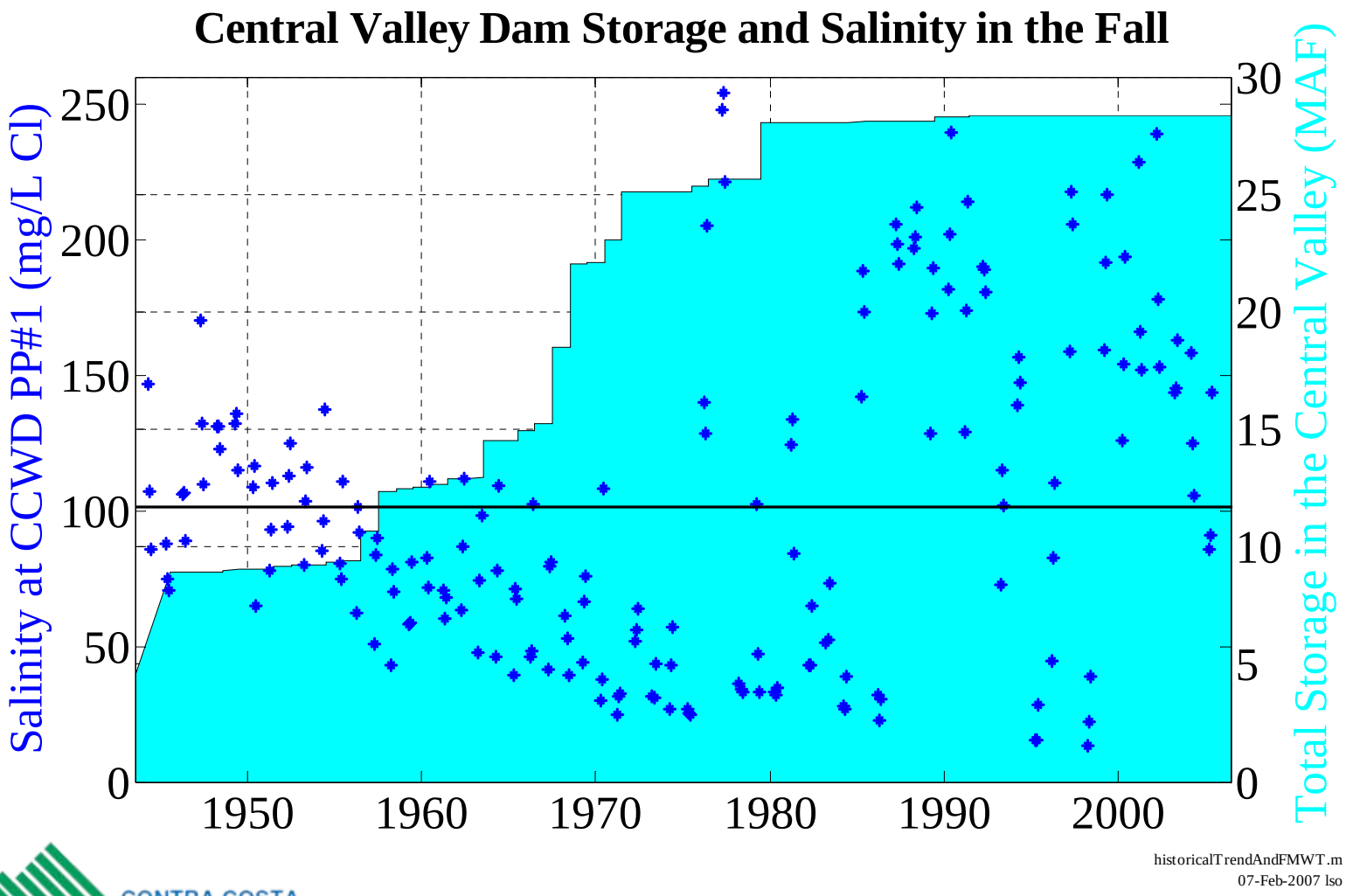
# Reservoir Construction and Delta Fall Salinity

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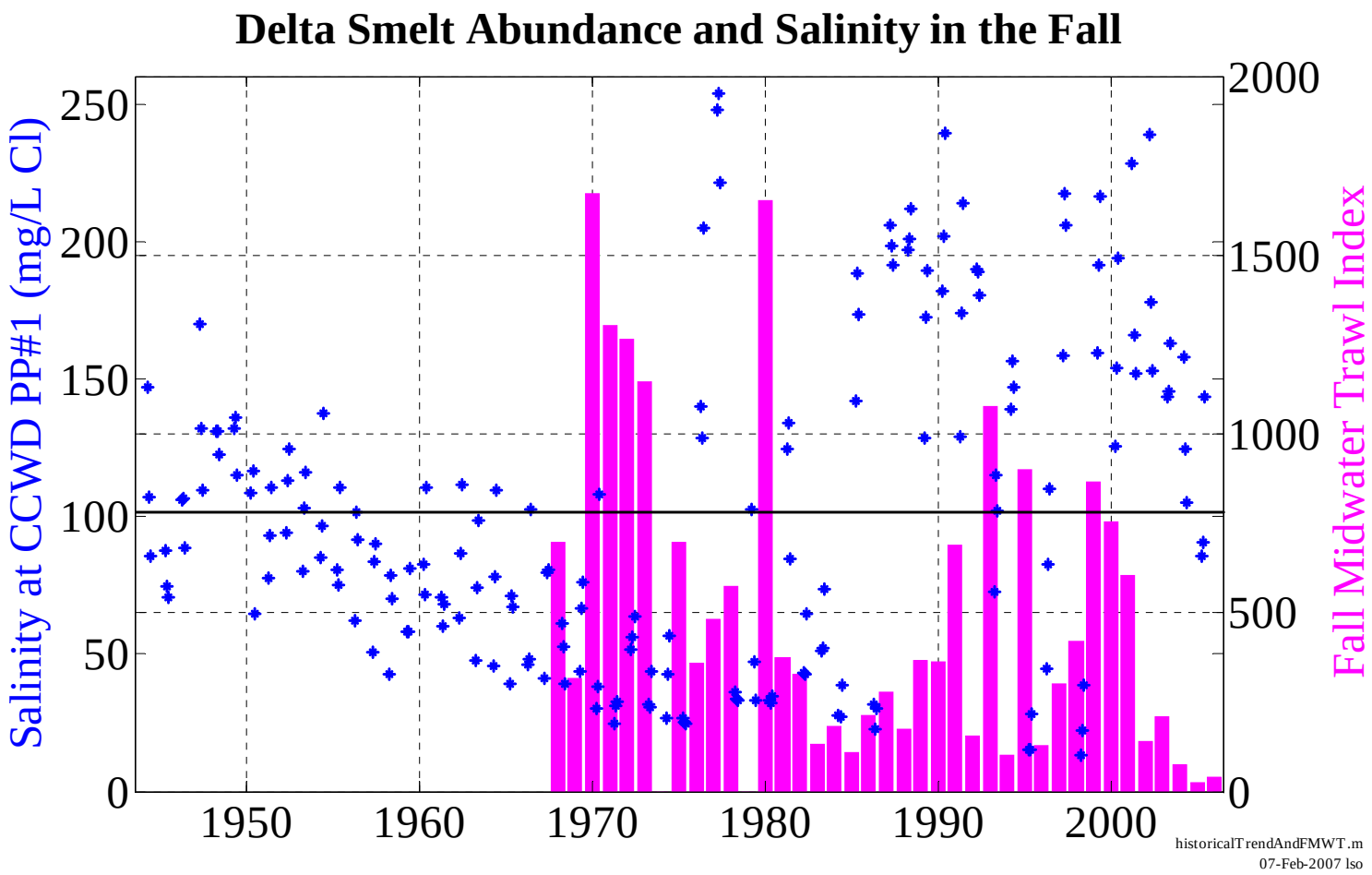
# Fall Salinity and Delta Smelt Abundance

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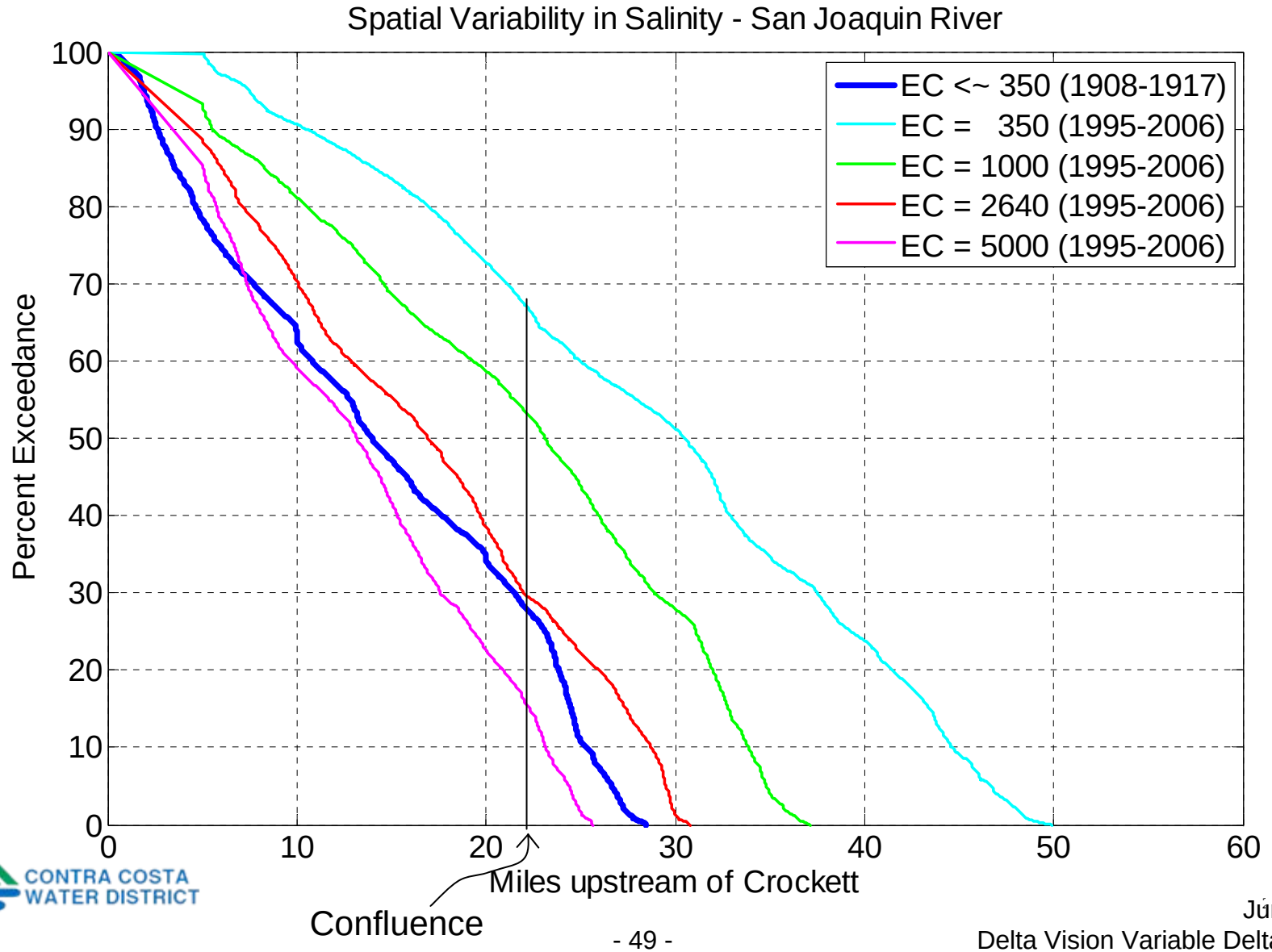
# Salinity intrudes even farther up the San Joaquin River

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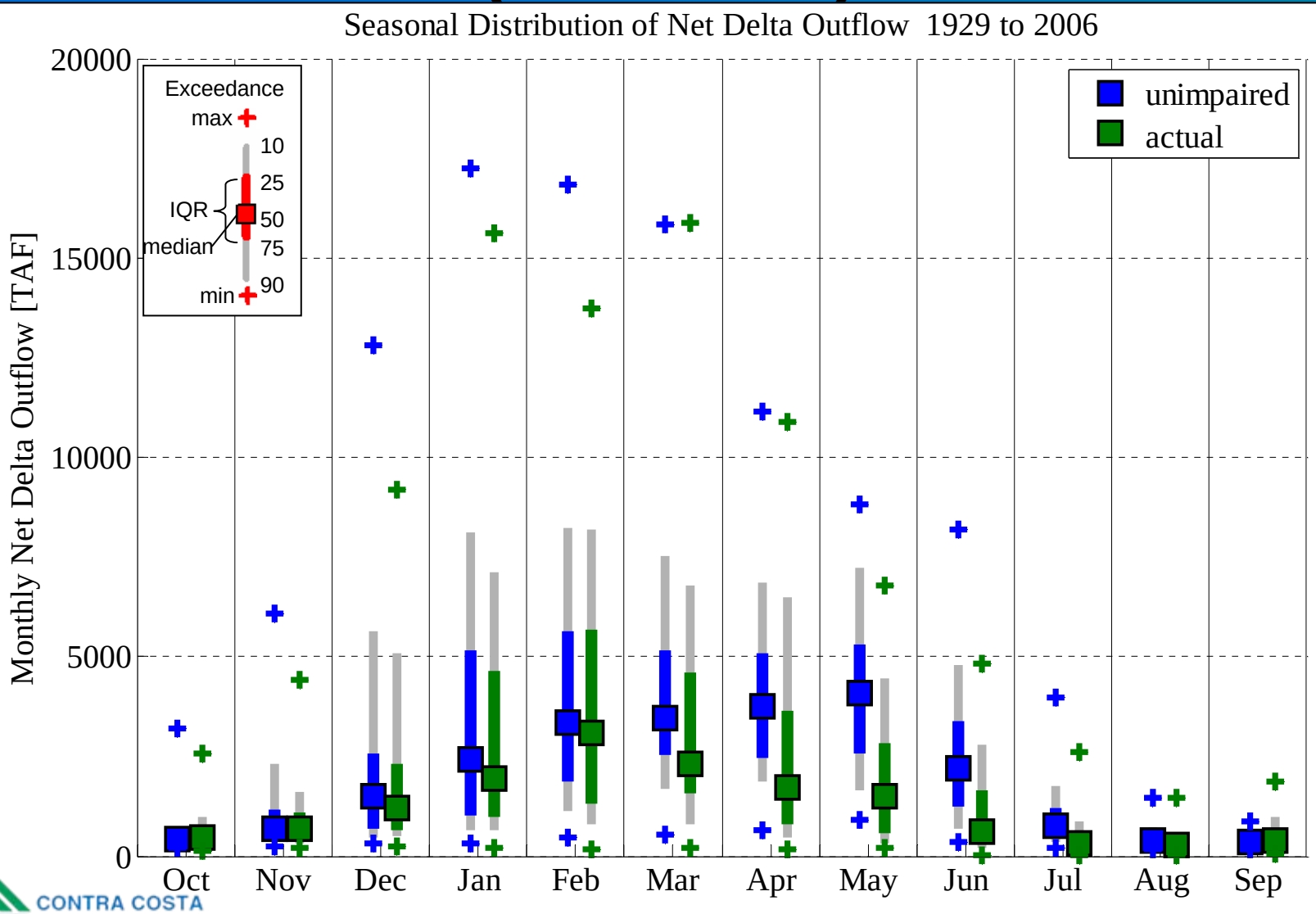
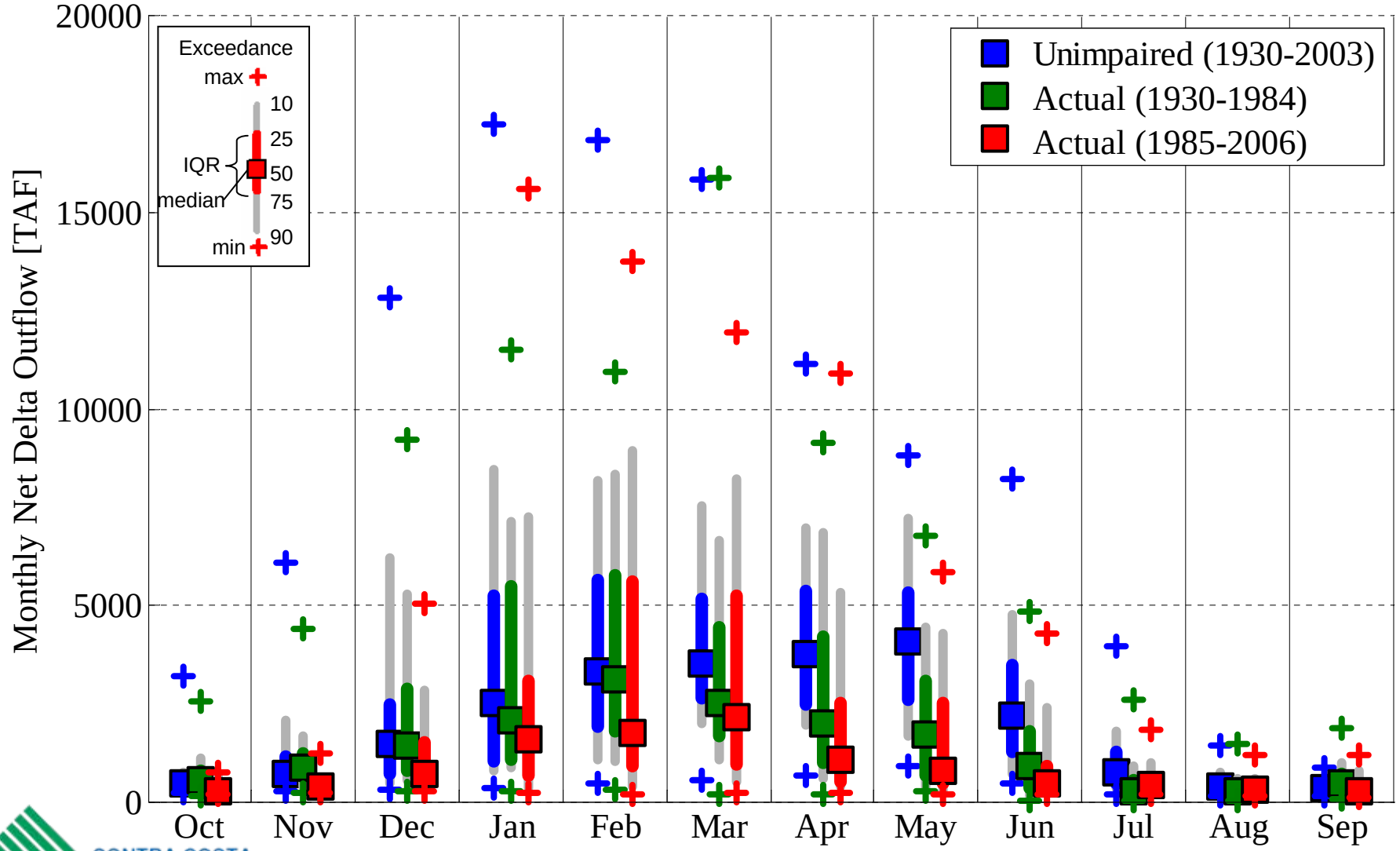
# Seasonal Distribution of Outflow (1929-2006)




CONTRA COSTA WATER DISTRICT

# Seasonal Distribution of Outflow (1930-2006)

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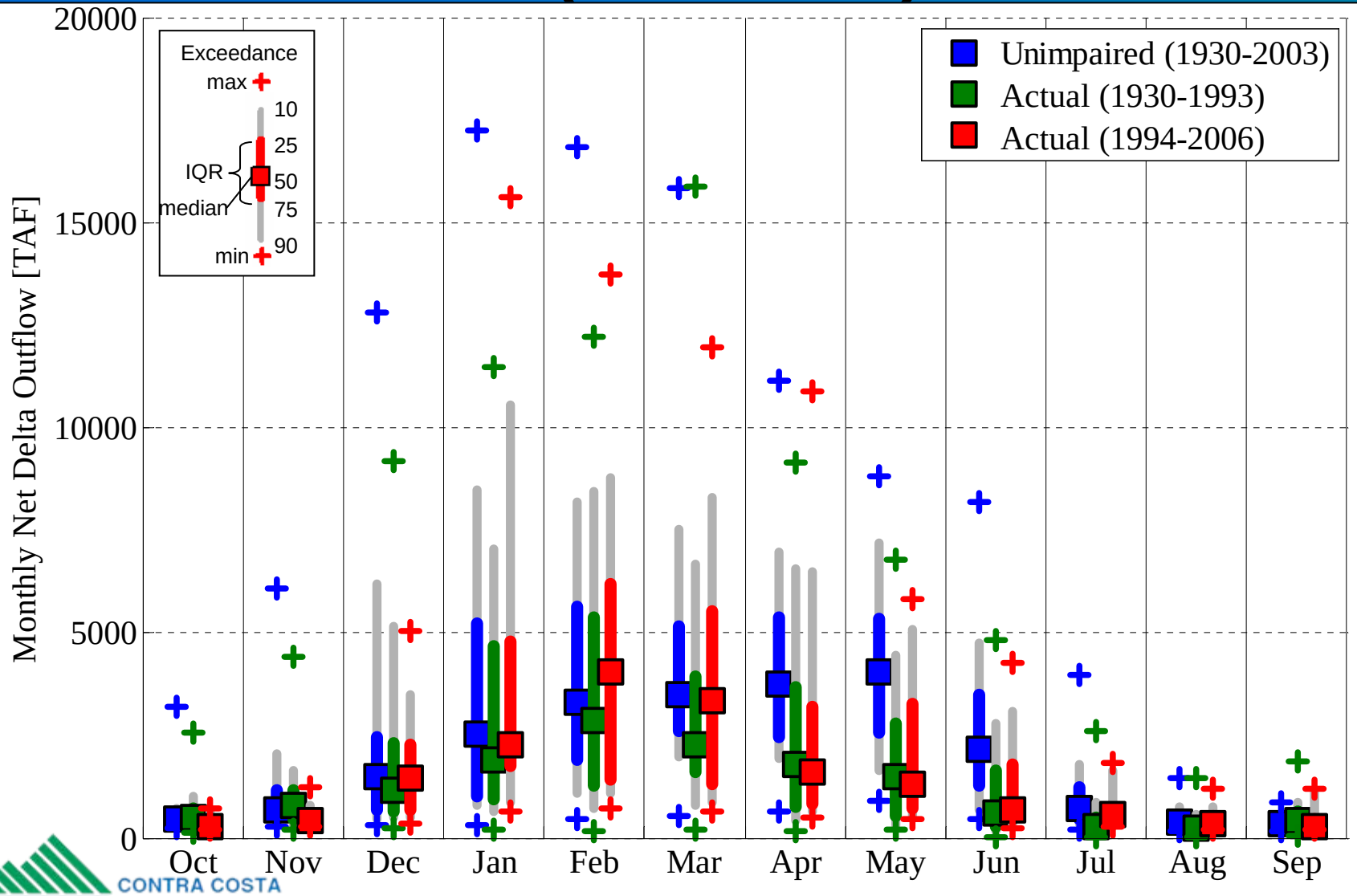
# Seasonal Distribution of Outflow (1930-2006)

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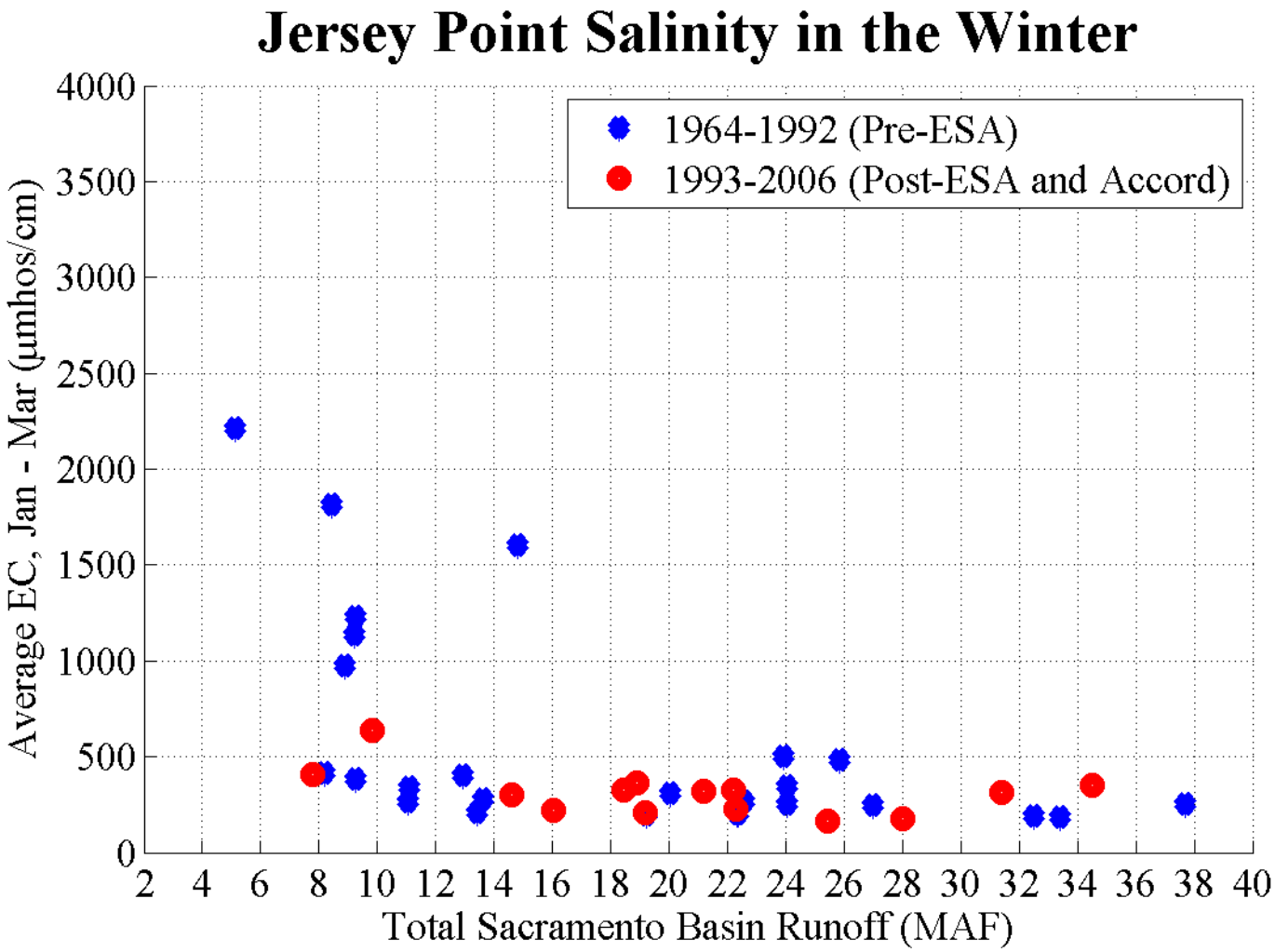
# Winter salinity at Jersey Point has not increased since 1993

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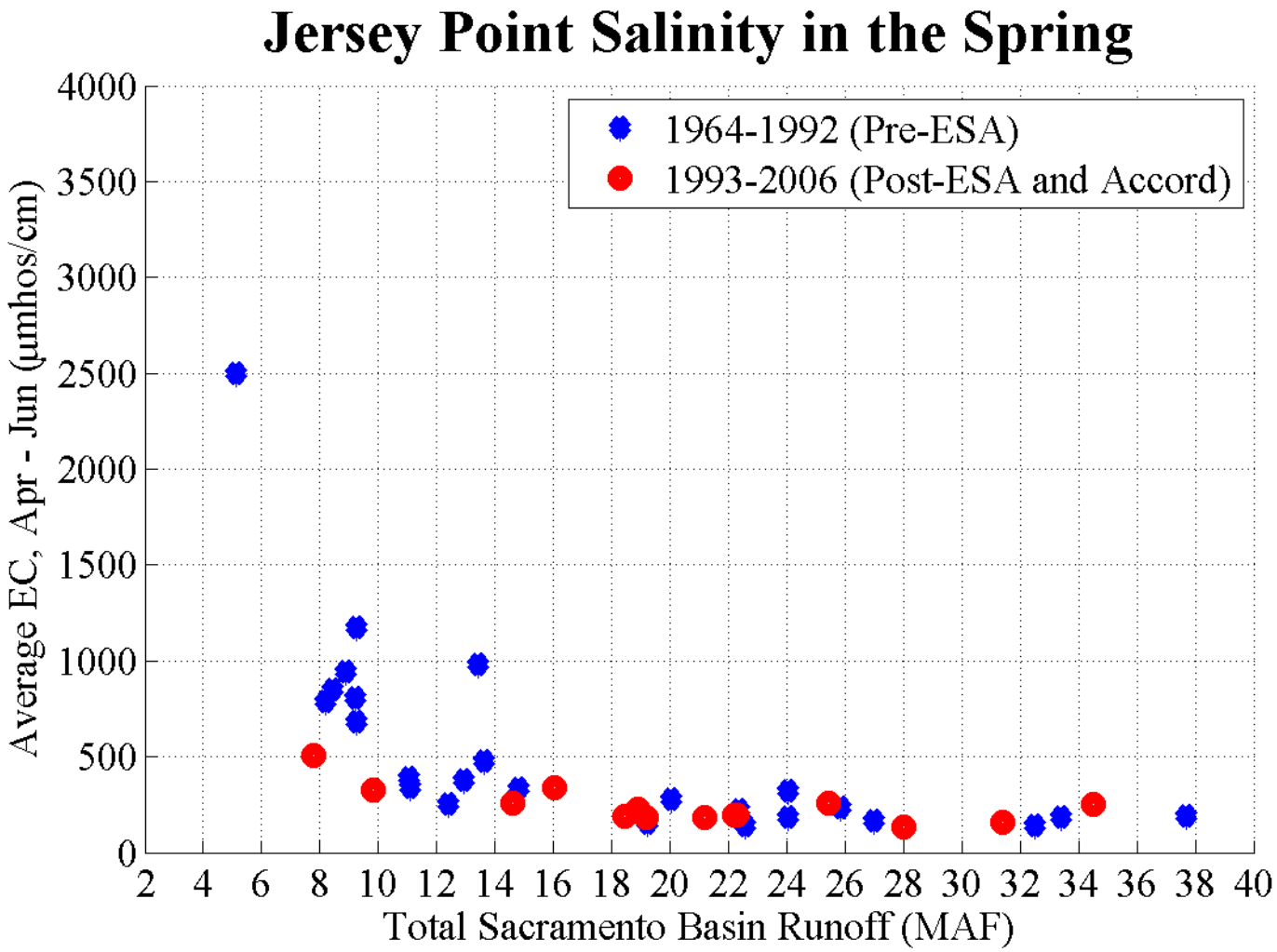
# Spring salinity at Jersey Point has not increased since 1993

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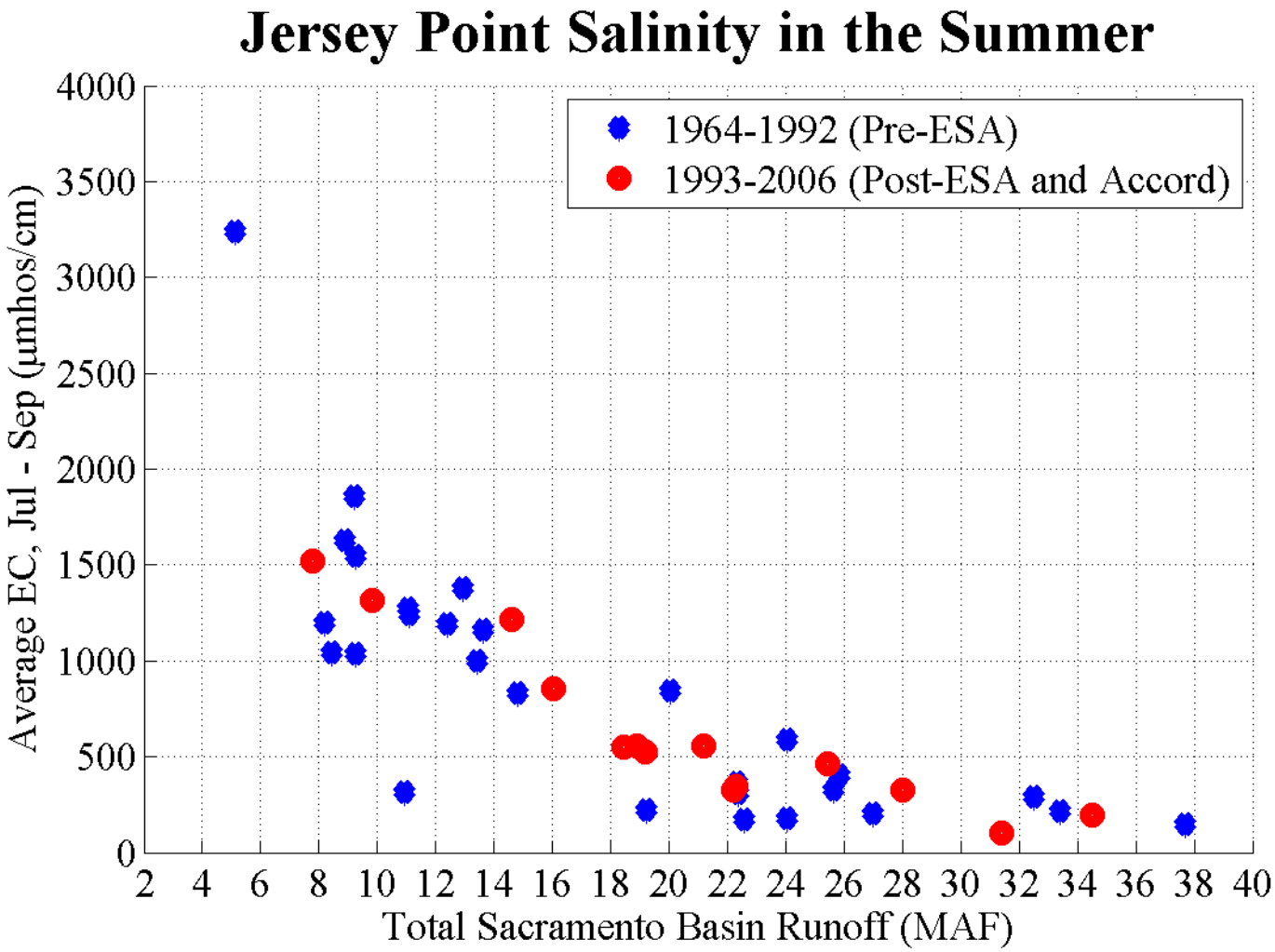
# Summer salinity at Jersey Point has not increased since 1993

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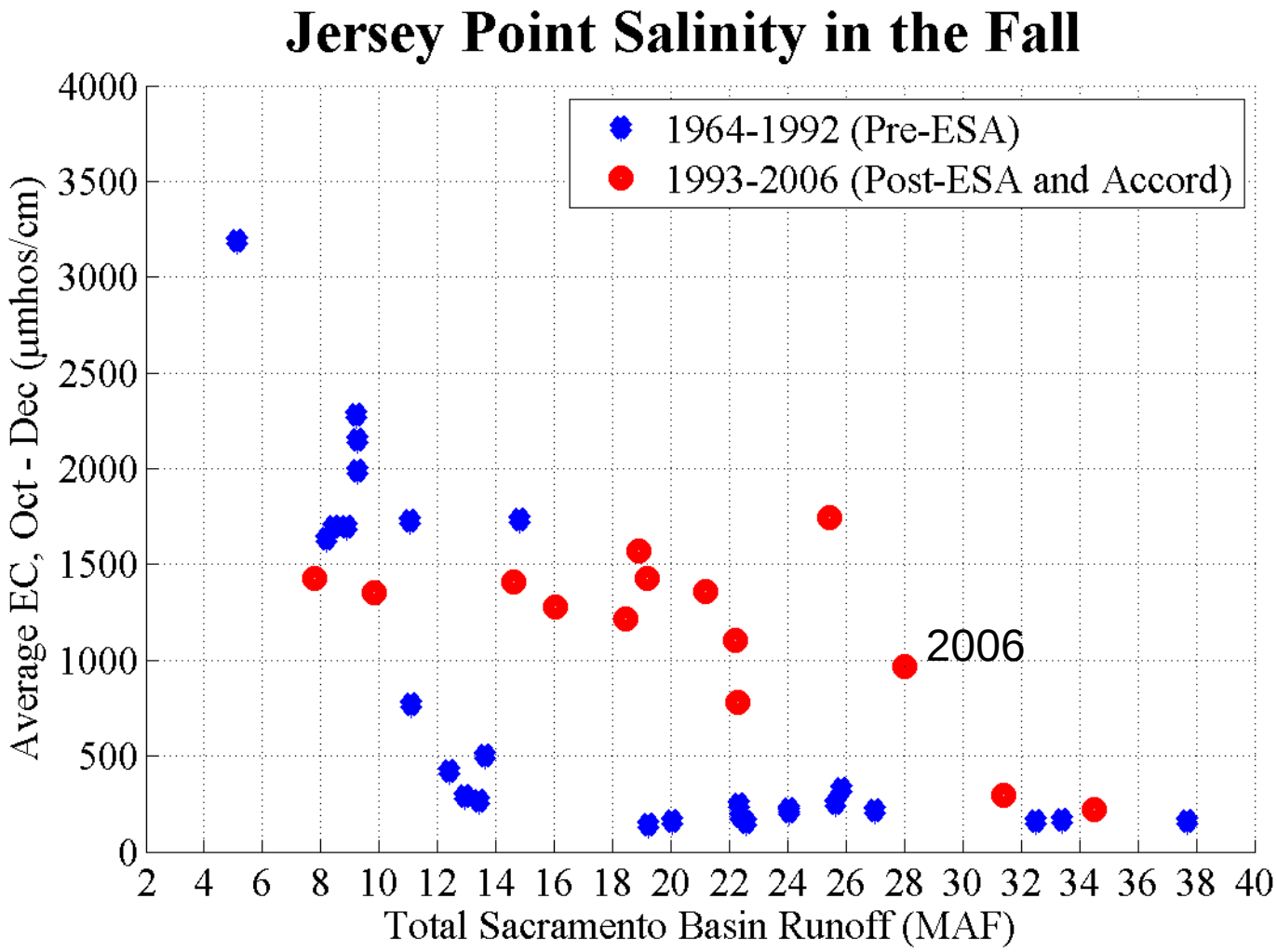
# Fall salinity at Jersey Point has significantly increased since 1993

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