Managing Drought-related Financial Risks for Agricultural Water Users

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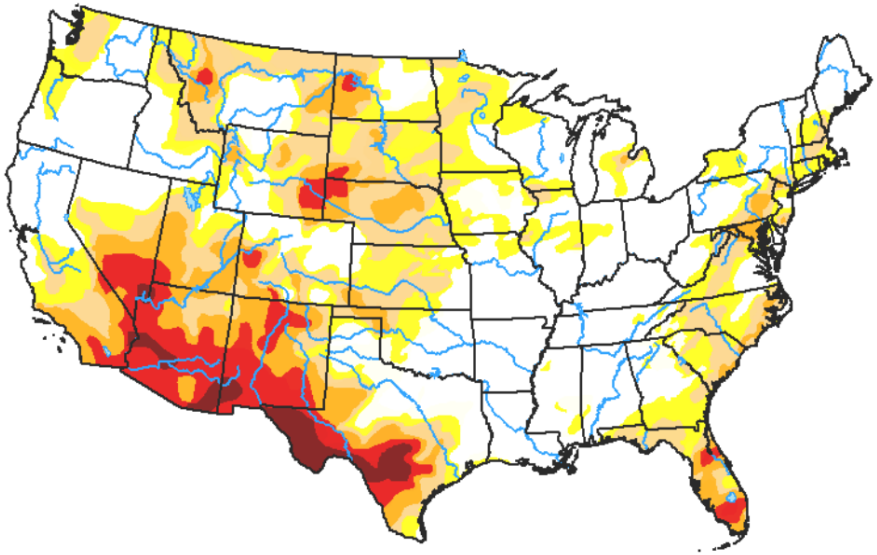
The Institute for Risk Management and Insurance Innovation (IRMII)

University of North Carolina

California Water and Environmental Modeling Forum
May 14th, 2025

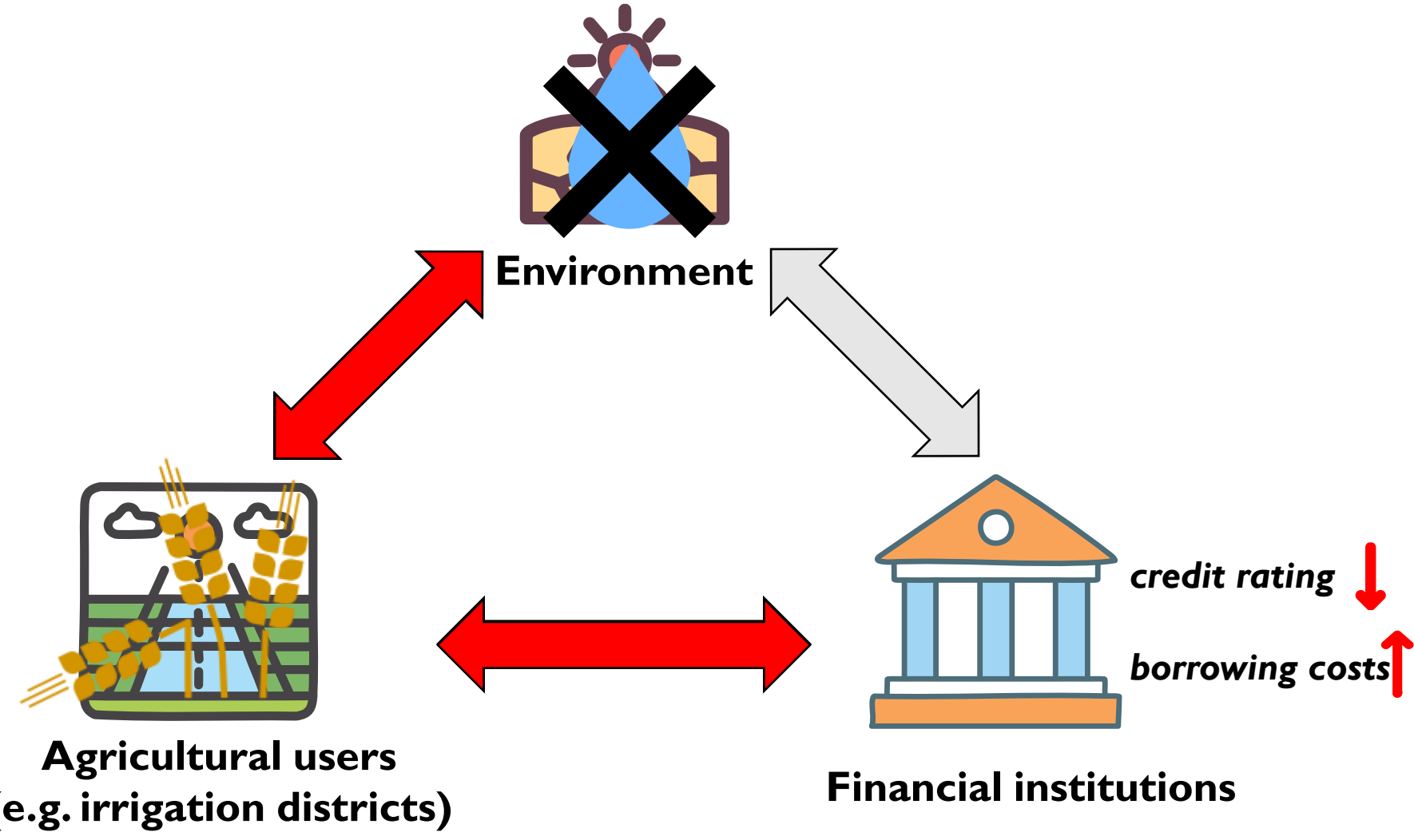


Source: National Drought Mitigation Center, May 6, 2025

Outline

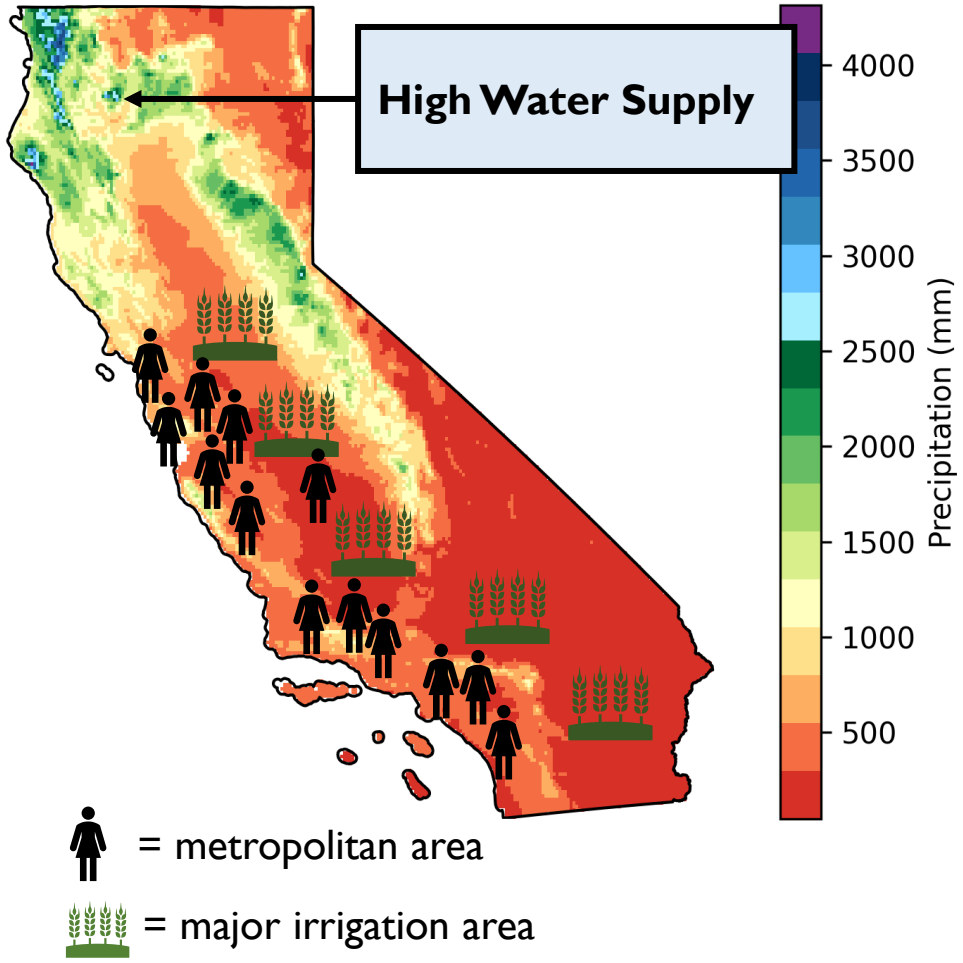
- Background
- Simulation model and research design
- Applications:
  - Index based insurance
  - Prediction of Nasdaq Veles California Water Index

Drought-related financial risks



Regional mismatch of water supply and demand

- Highest agricultural output in the U.S.
- Central Valley's Agricultural Hub
- California's precipitation primarily occurs in the northern regions, while the southern regions are much drier.



30-Year normal precipitation data (sourced from PRISM)

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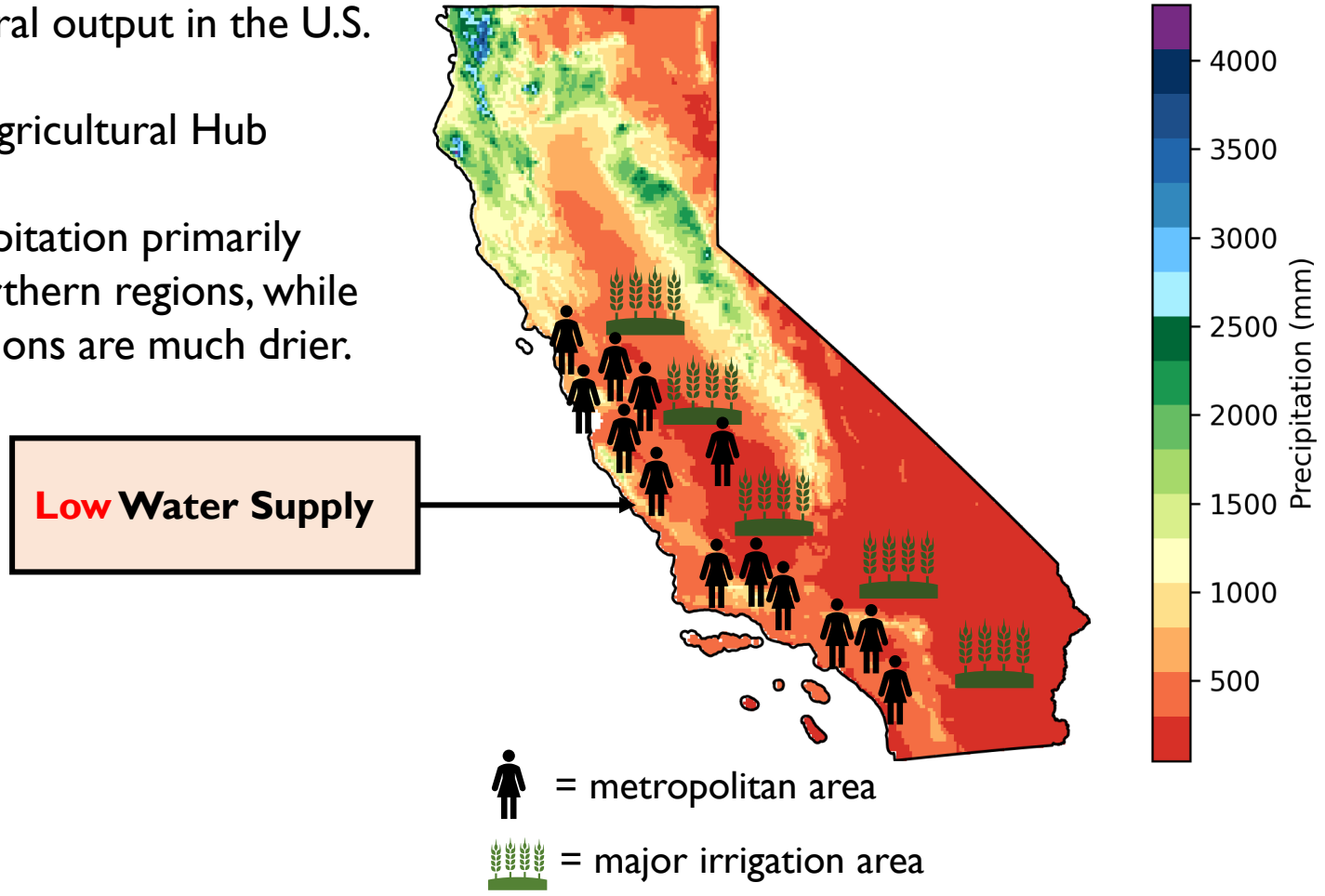

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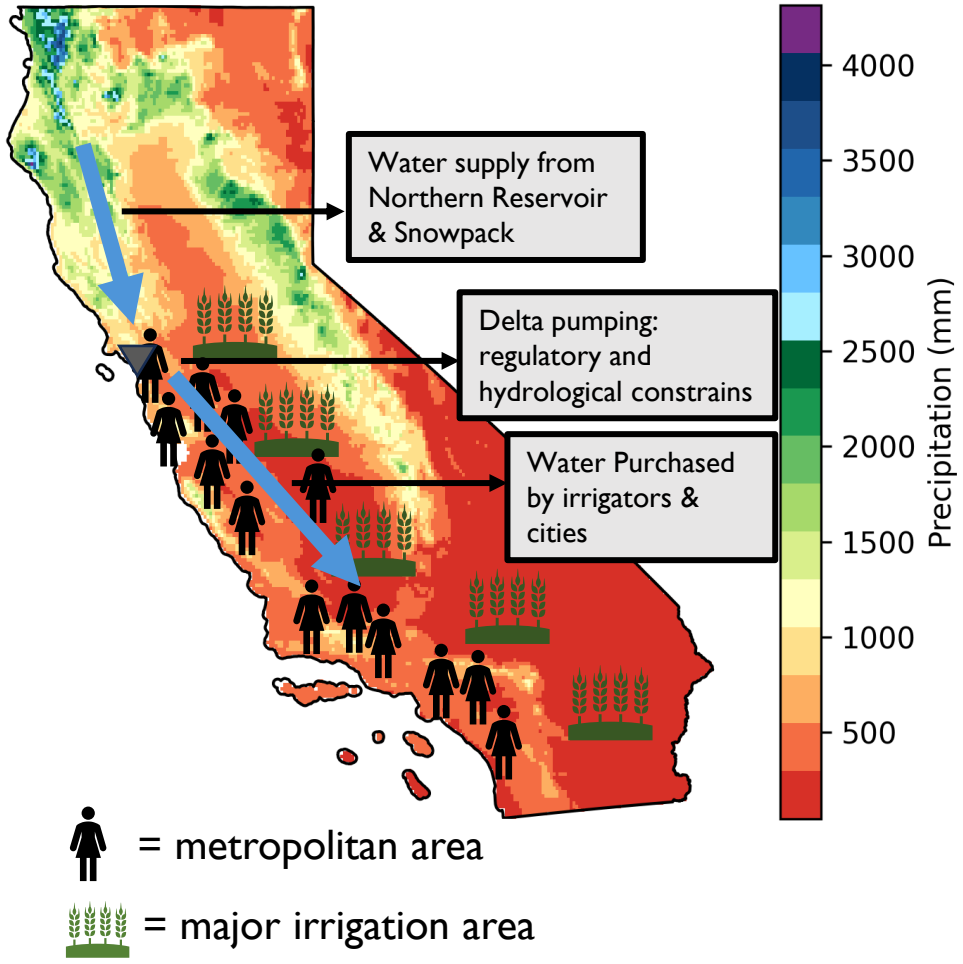

30-Year normal precipitation data (sourced from PRISM)

Structure of water allocation in California

Federal and state project
(**State Water Project, Central Valley Project**, etc.)

Nick Hagerty. "What Holds Back Water Markets? Transaction Costs and the Gains from Trade." *Review of Economics and Statistics*, under review.

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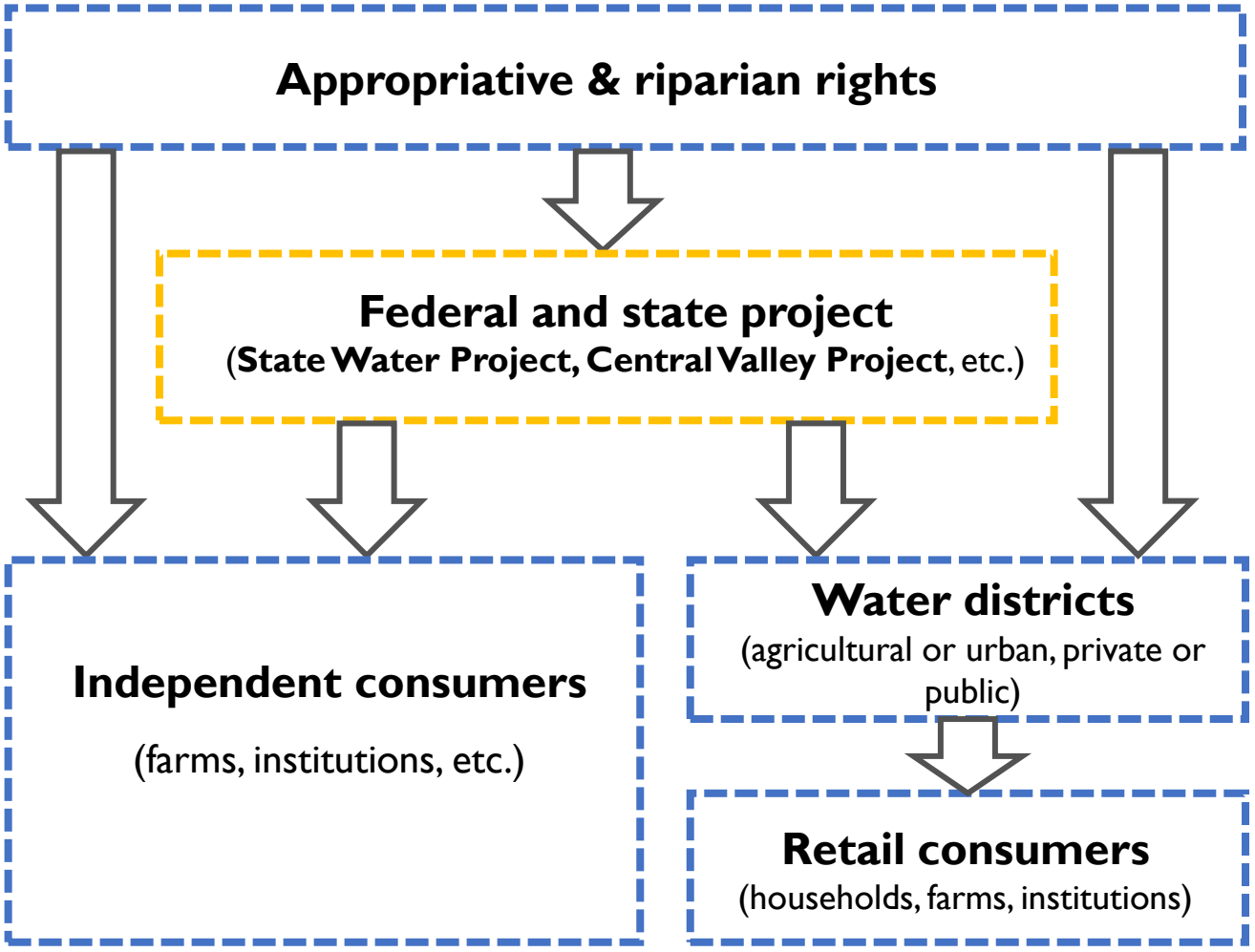


Nick Hagerty. "What Holds Back Water Markets? Transaction Costs and the Gains from Trade." *Review of Economics and Statistics*, under review.

Research questions

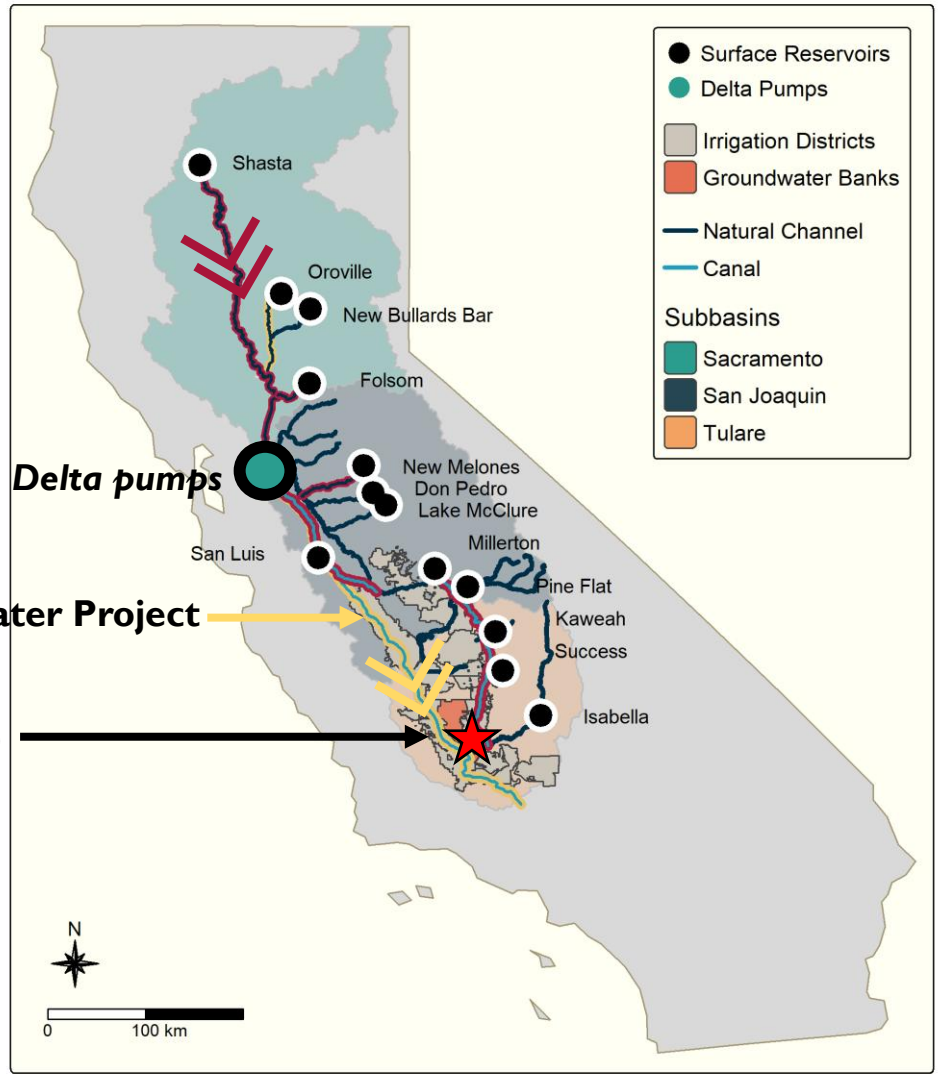
How can we better manage drought-related financial risks for irrigation districts through index-based insurance?

Study areas

An **irrigation district** in the U.S. is a special-purpose district established by statute to develop large irrigation projects. These districts have the authority to tax, borrow, and manage water distribution for irrigation within their geographic boundaries.

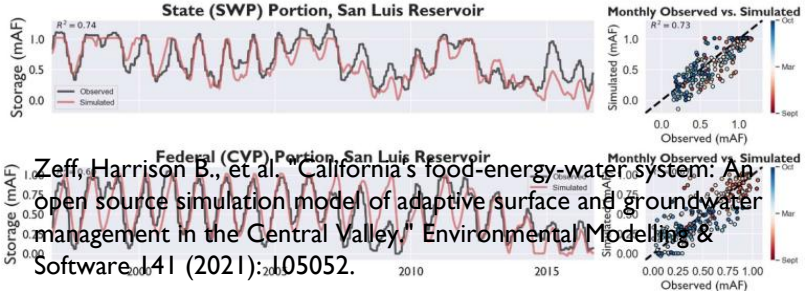
State Water Project

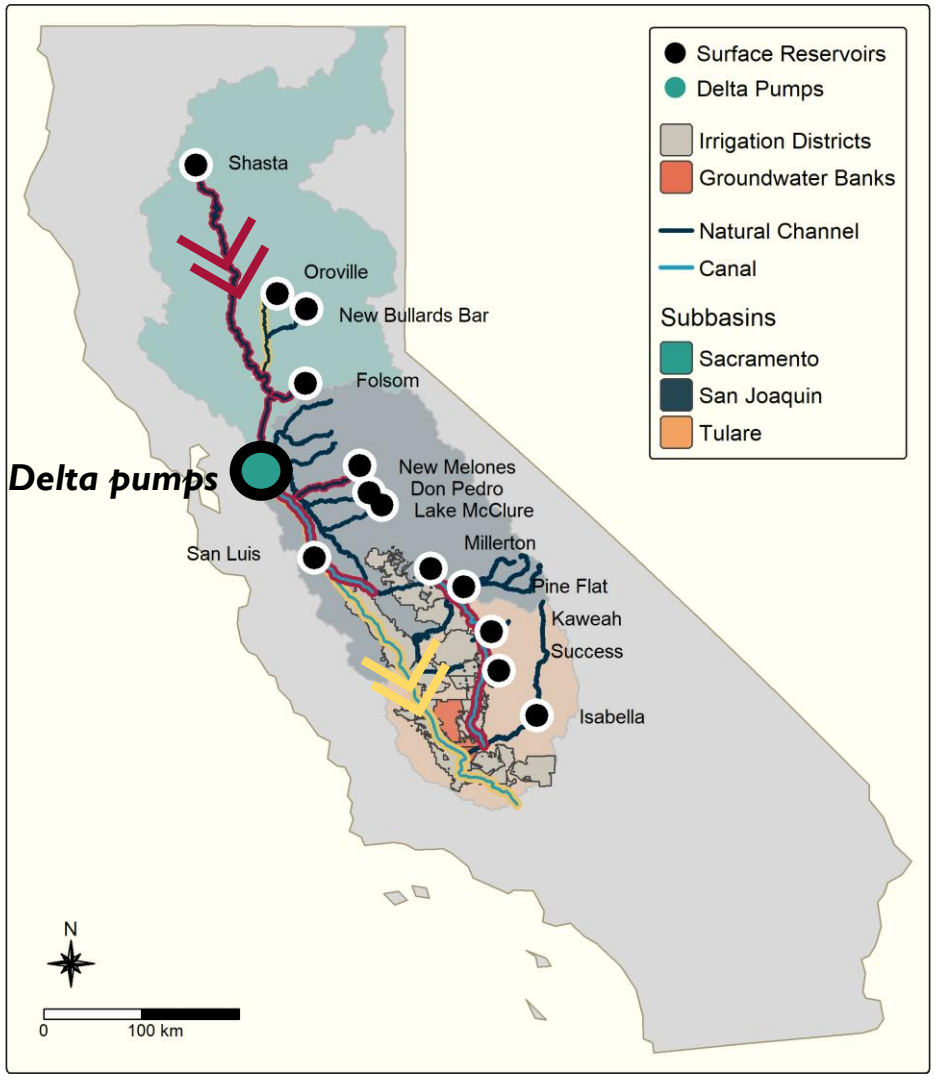
Kern County Water Agency (KCWA)



Simulation model - CALFEWS

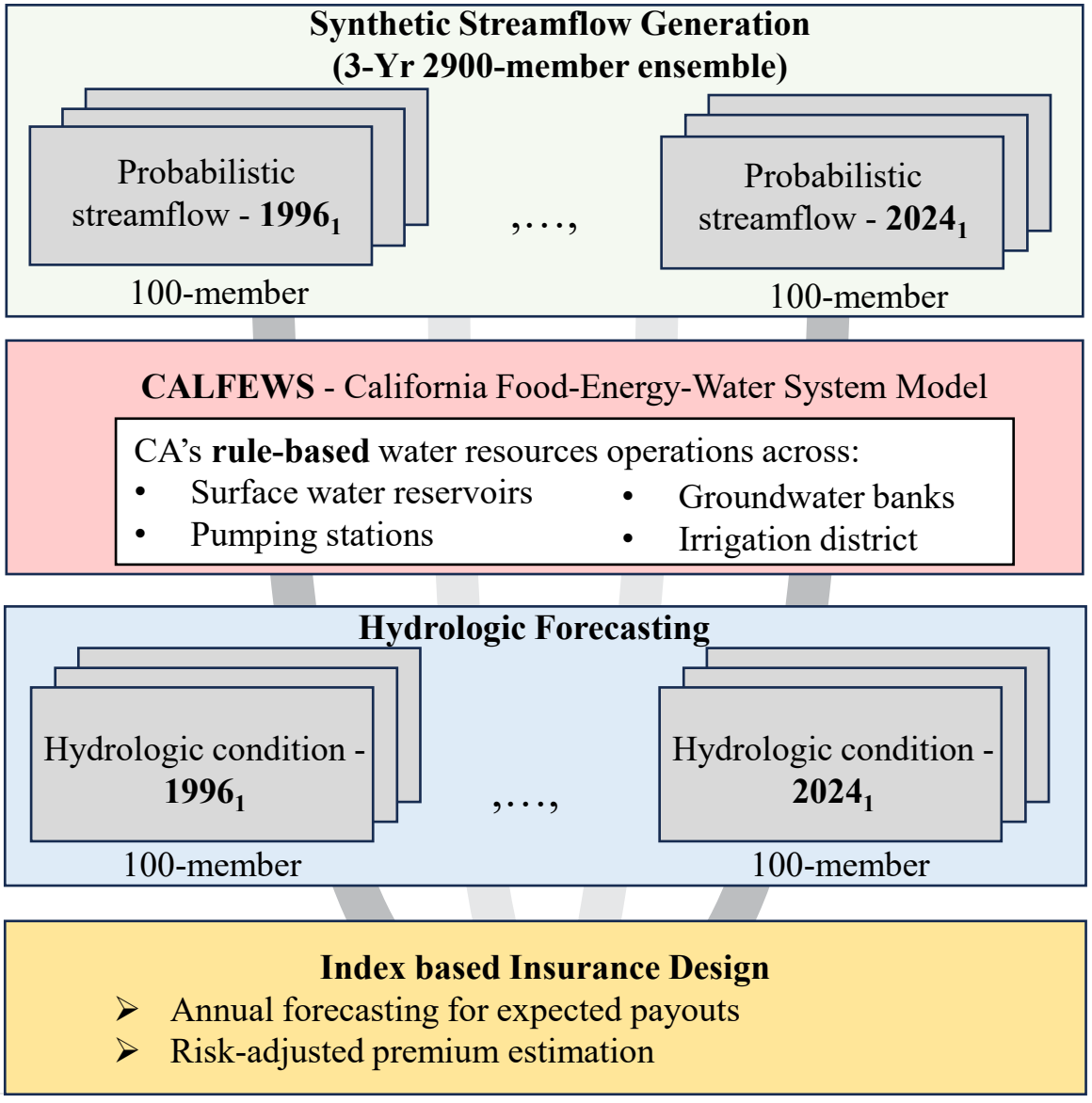
- Daily timestep
- The California Food-Energy-Water Syster (CALFEWS) is a rules-based simulation model.
- CALFEWS represents CA's coordinated water resources operations across institutionally complex system, including:
  - Surface water reservoirs
  - Delta pumping stations
  - Groundwater banks
  - Irrigation district



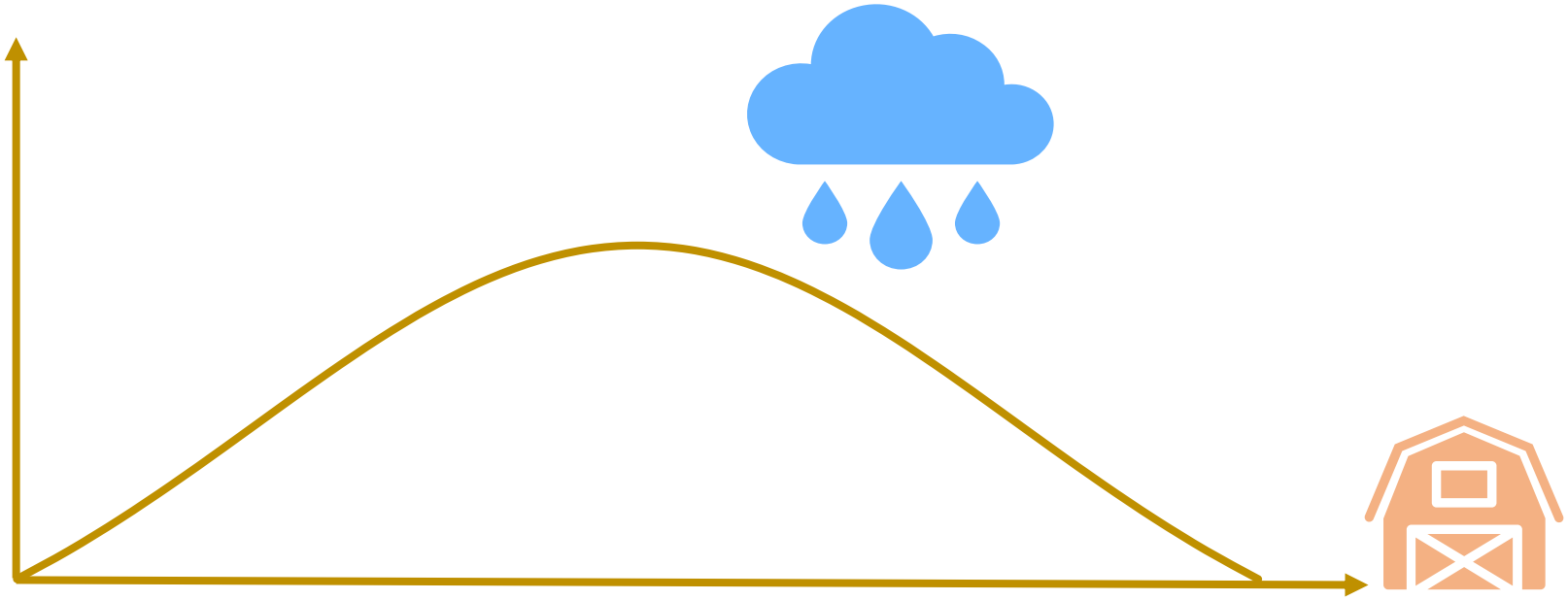


Zeff, Harrison B., et al. "California's food-energy-water system: An open source simulation model of adaptive surface and groundwater management in the Central Valley." Environmental Modelling & Software 141 (2021): 105052.

Research framework overview



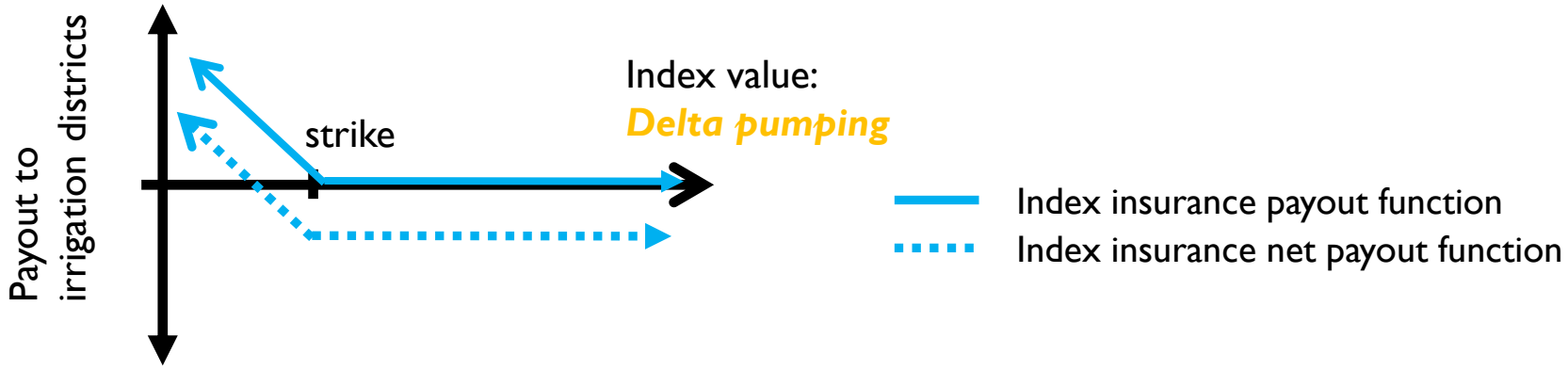
Index-based insurance



Linking payment to an index

$$Payout_{Index} = \begin{cases} A^{*} \times (strike - index\ value), & if\ index\ value < strike \\ 0, & otherwise \end{cases}$$

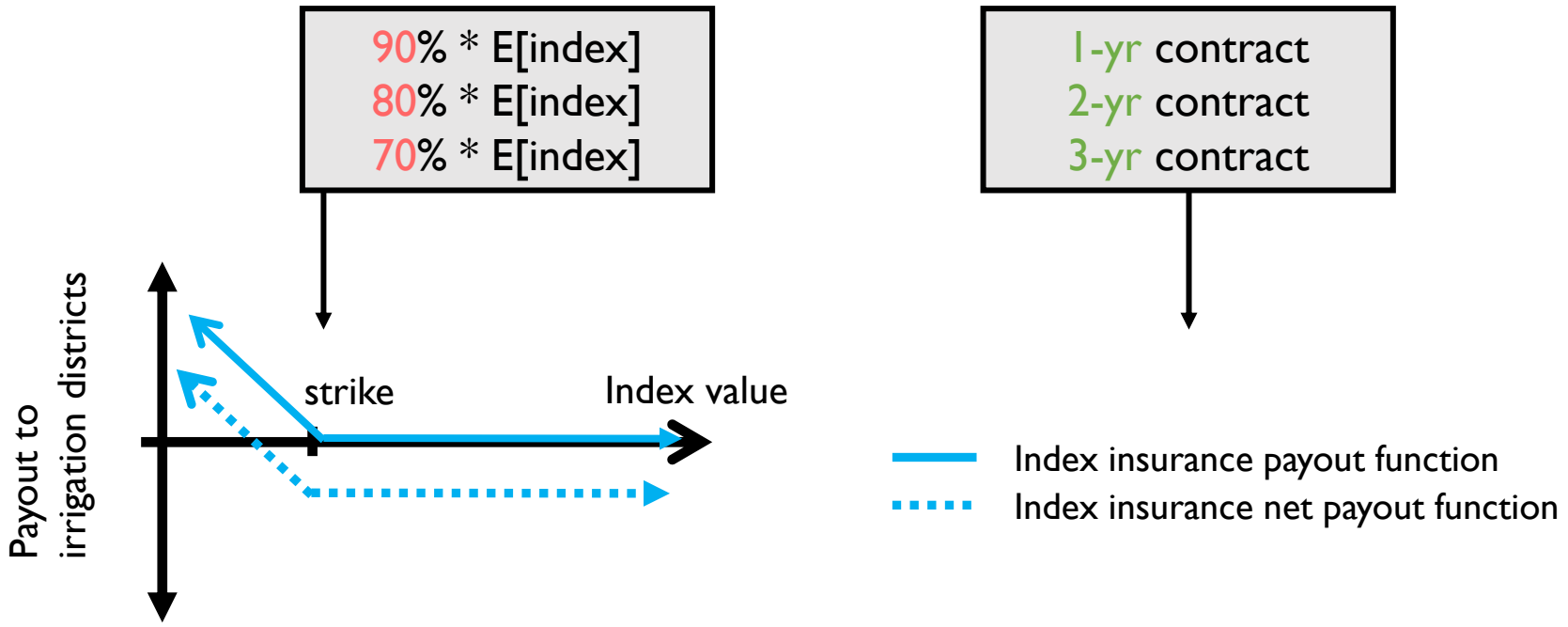
$$^{*}\ A\ (slope) = \frac{\sum_{i=1}^{365} Daily\ revenue(i)}{\sum_{i=1}^{365} Index\ value(i)}$$



Premium = E[payout] + loading

Loading: insurer's return, admin costs, development costs, etc.

Linking payment to an index



Premium = E[payout] + loading

Loading: insurer's return, admin costs, development costs, etc.

Identifying an index

Rainfall

> The role of weather derivatives and portfolio effects in agricultural water management
> M Buchholz, O Musshoff
> Agricultural Water Management, 2014 · Elsevier

Reservoir inflow

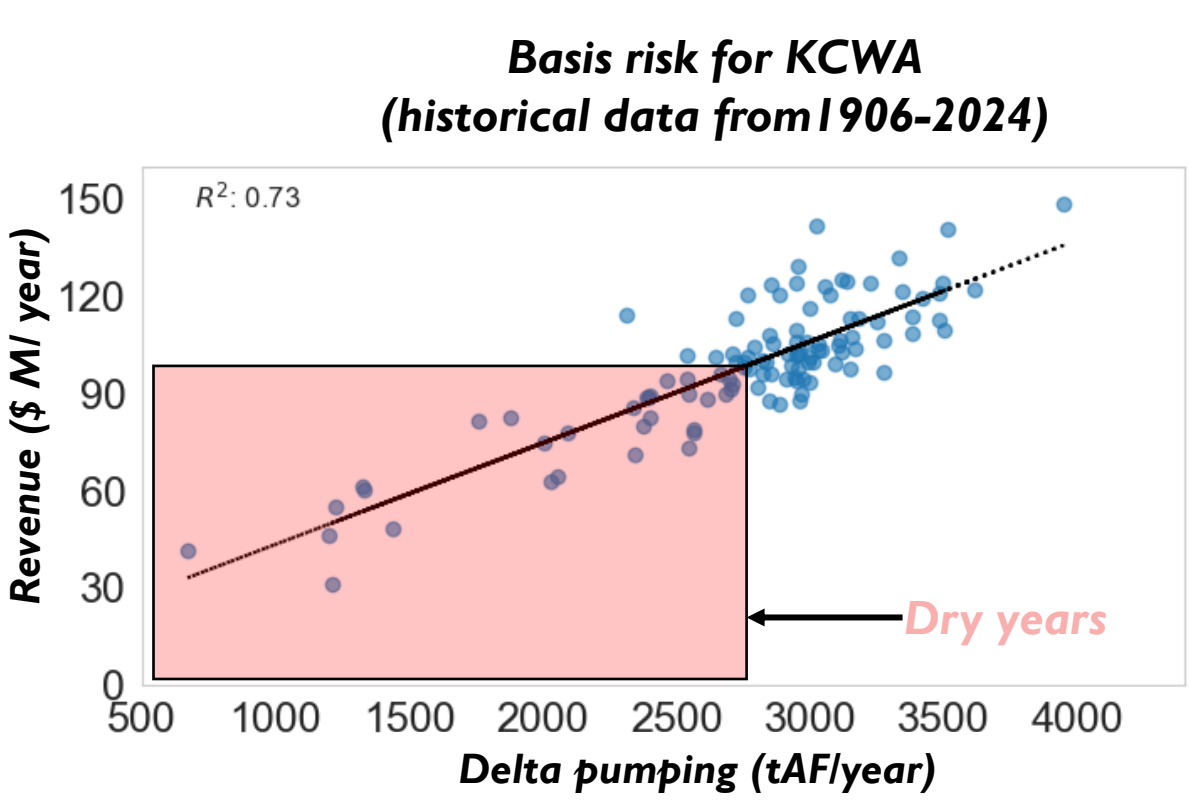
> **Managing hydroclimatological risk to water supply with option contracts and reservoir index insurance**
> Casey Brown, Miguel Carriquiry
> First published: 29 November 2007 | https://doi.org/10.1029/2007WR006093 | Citations: 45

Streamflow

> **Drought Index Insurance for the Central Valley Project in California**
> Teresa Maestro, Barry J. Barnett, Keith H. Coble, Alberto Garrido, María Bielza
> First published: 13 July 2016 | https://doi.org/10.1093/aepp/ppw013 |
> JEL classification: Q14, Q15, Q54 | Citations: 20

Prior studies use indirect indices → not correlate well with financial risk in irrigation districts

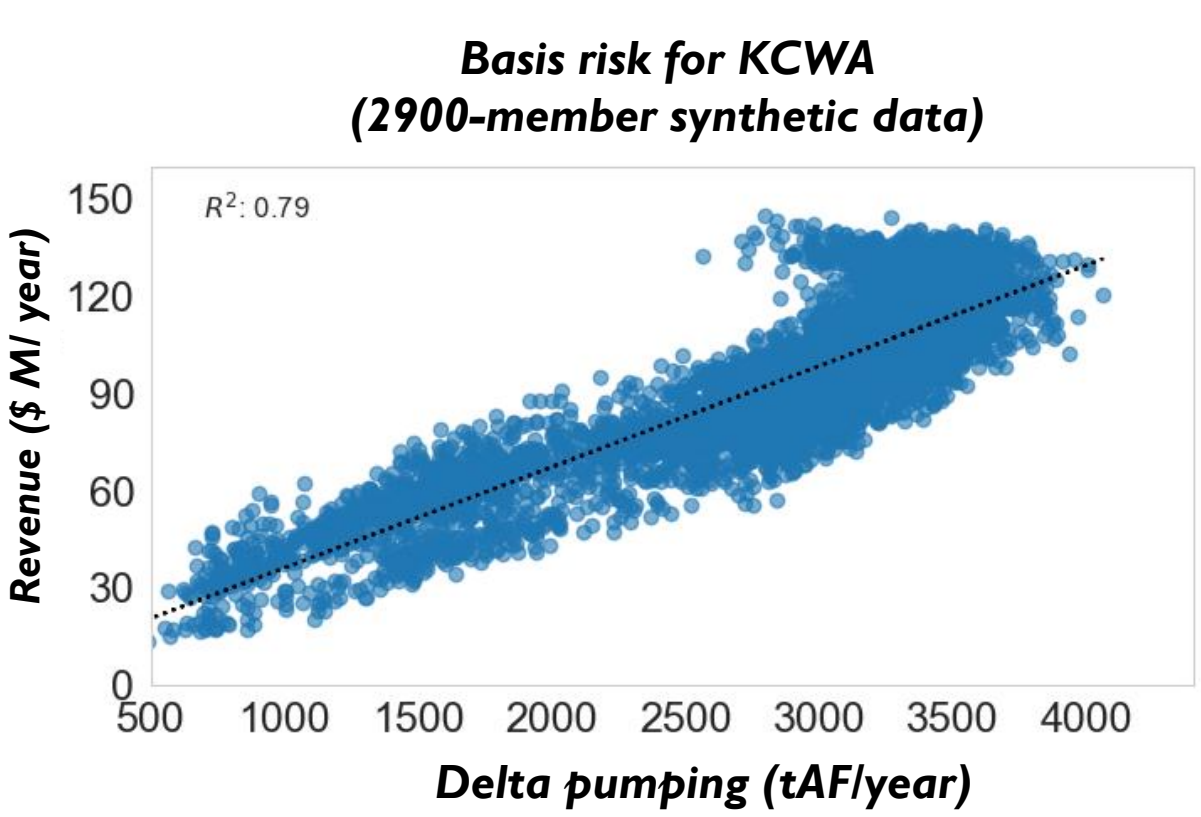
Designing an index



Delta pumping ~ water delivery ~ net revenues

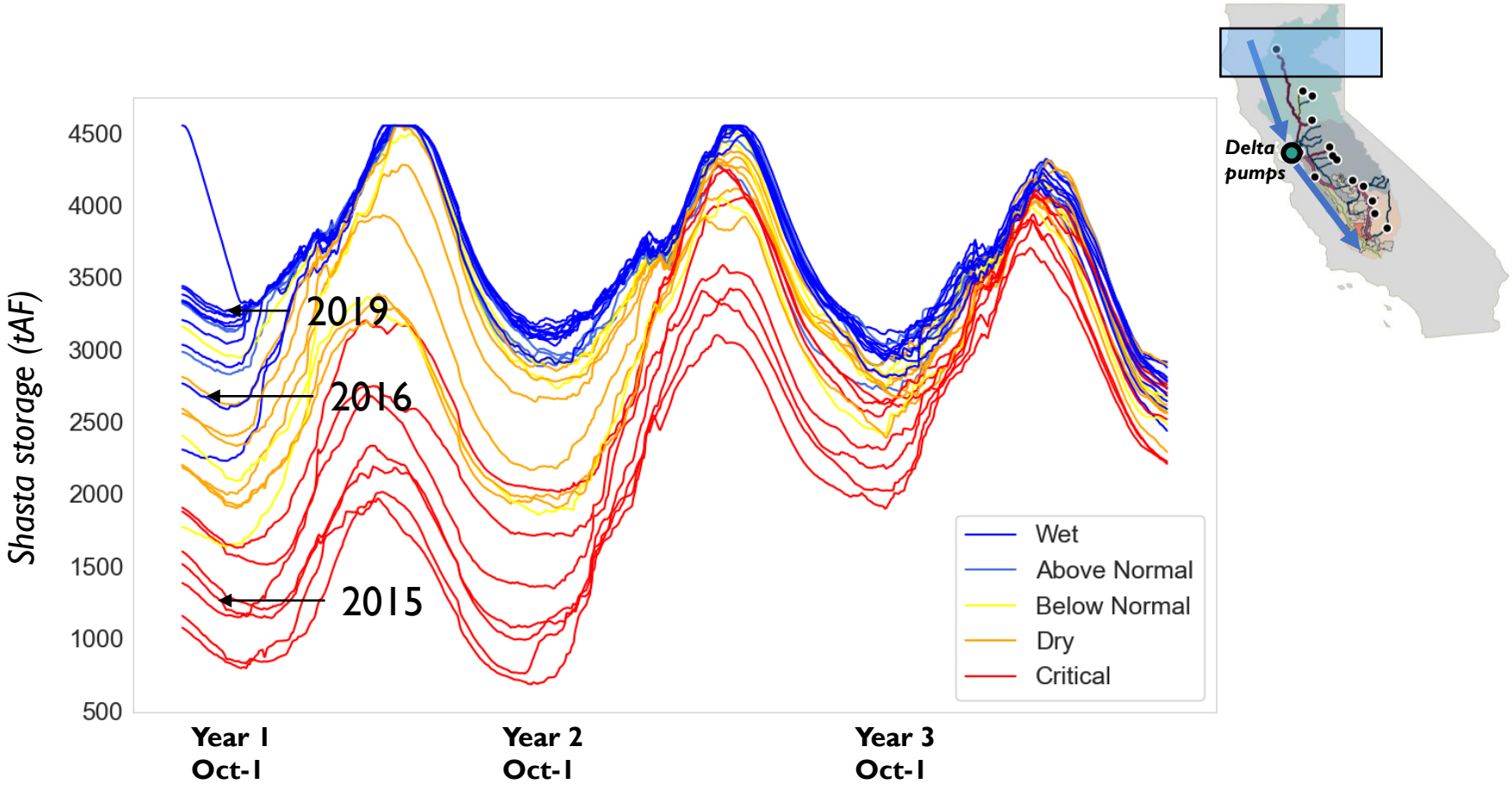
Insufficient sample size;
Limited hydrological scenarios!

Identifying an index: SWP exports



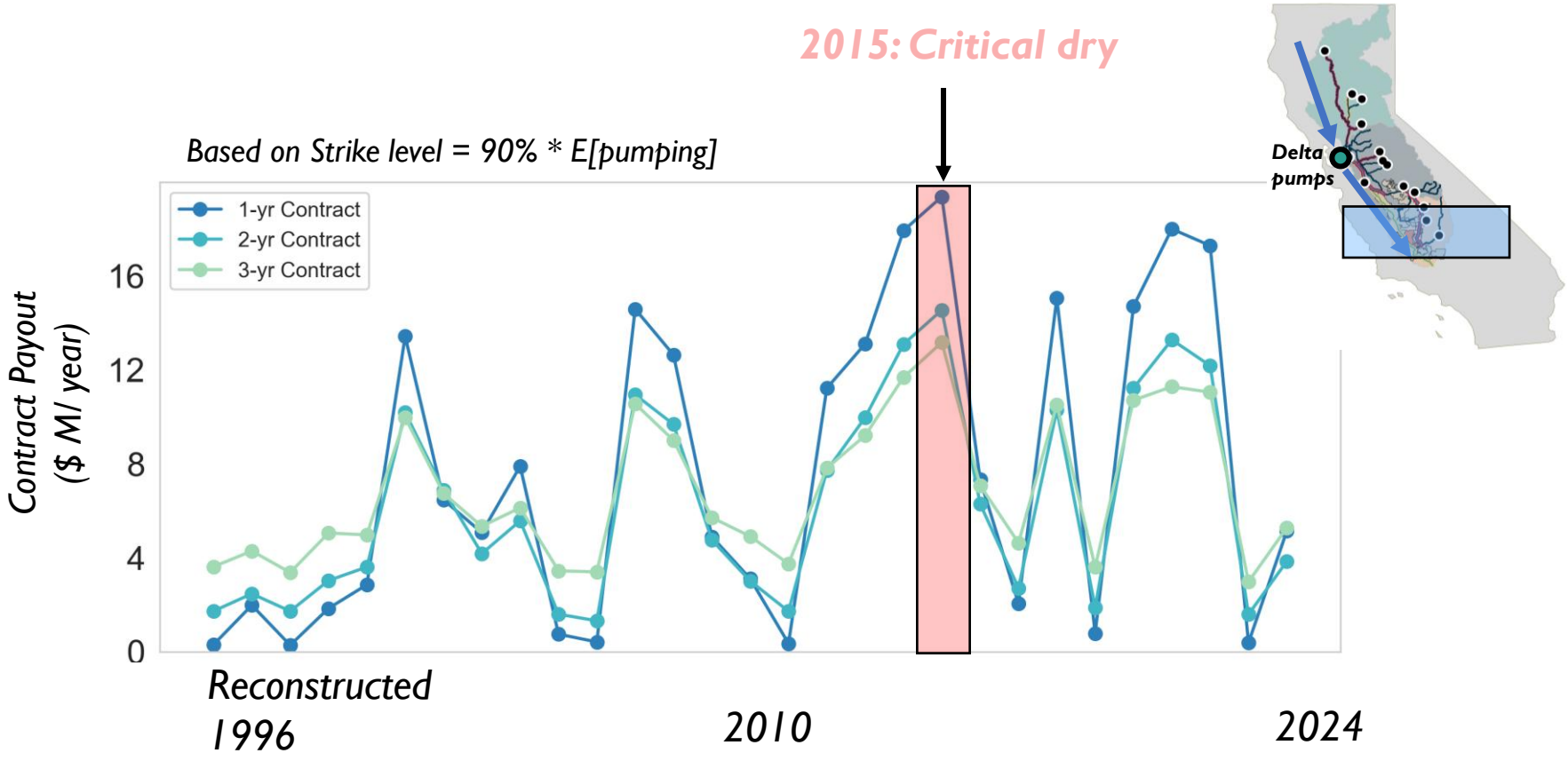
Delta pumping ~ water delivery ~ net revenues

Initial condition design



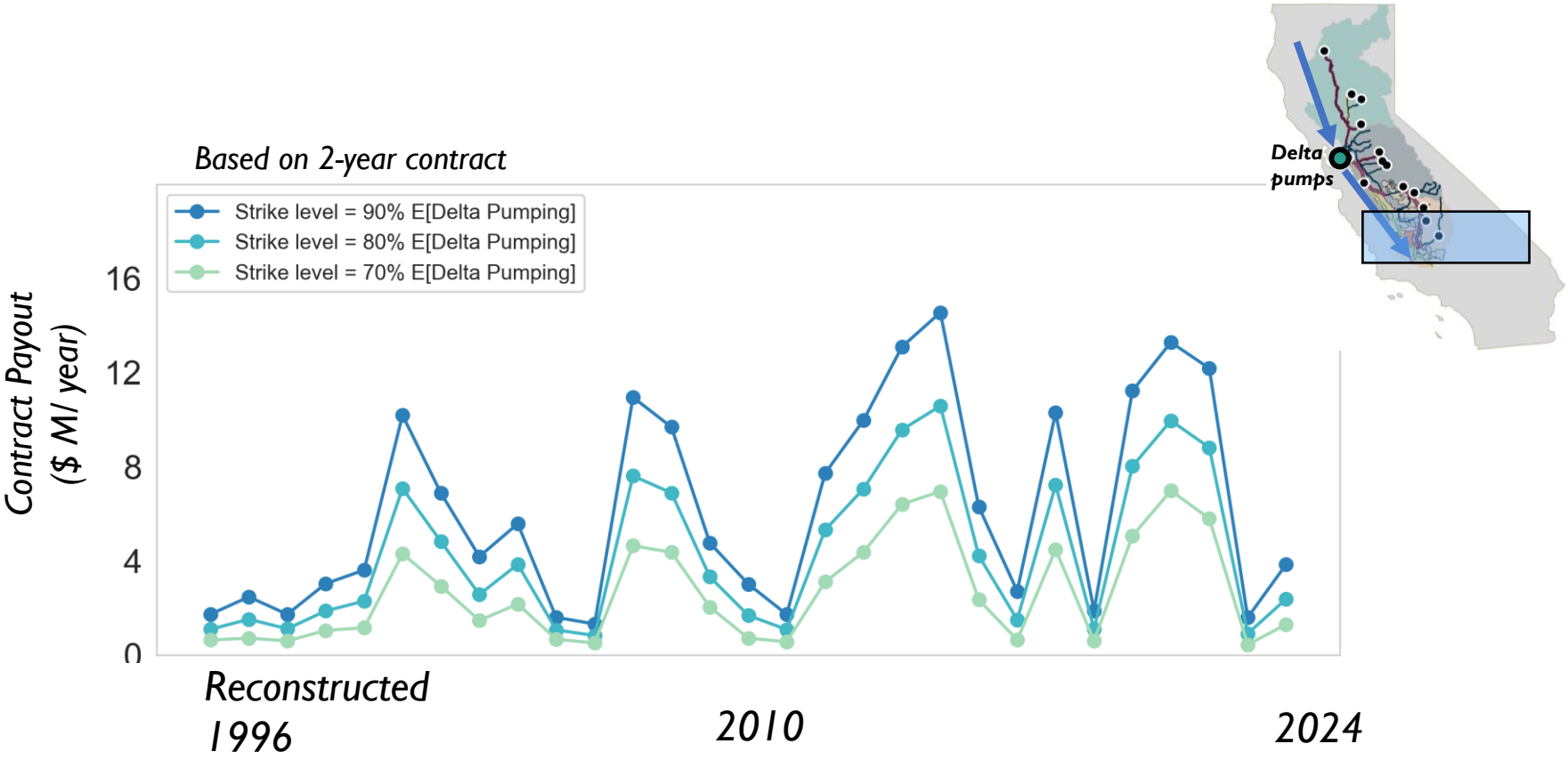
*Each trace shows the median Shasta Reservoir storage from a 100-member forecast based on initial flow levels from 1996 to 2024.

Designing an index: contract period



*Each data point represents the E[payout] from a reconstructed 100-member forecast, based on initial reservoir flow level from 1996 to 2024.

Designing an index: strike level

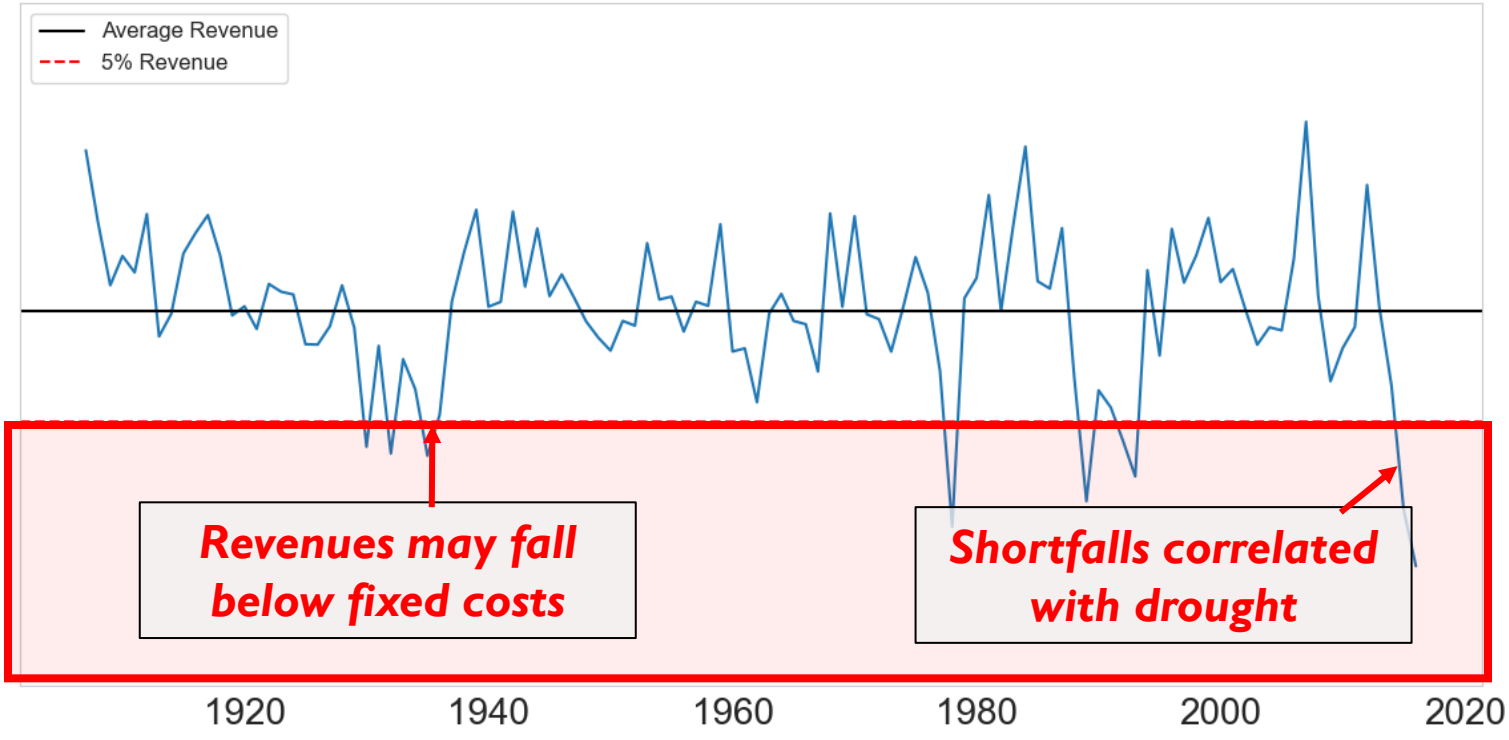


*Each data point represents the E[payout] from a reconstructed 100-member forecast, based on initial reservoir flow level from 1996 to 2024.

What is VaR?

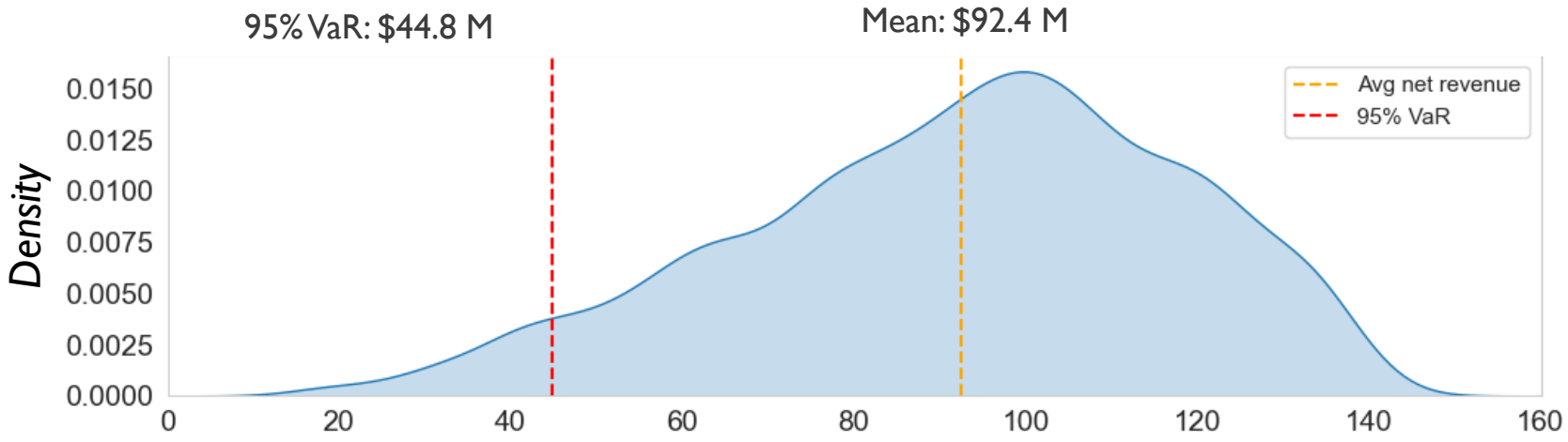
Value at Risk (VaR) is financial metric used to quantify the potential downside risk or extreme loss events.

1. Delay infrastructure maintenance
2. Staff layoffs
3. Missed debt payments

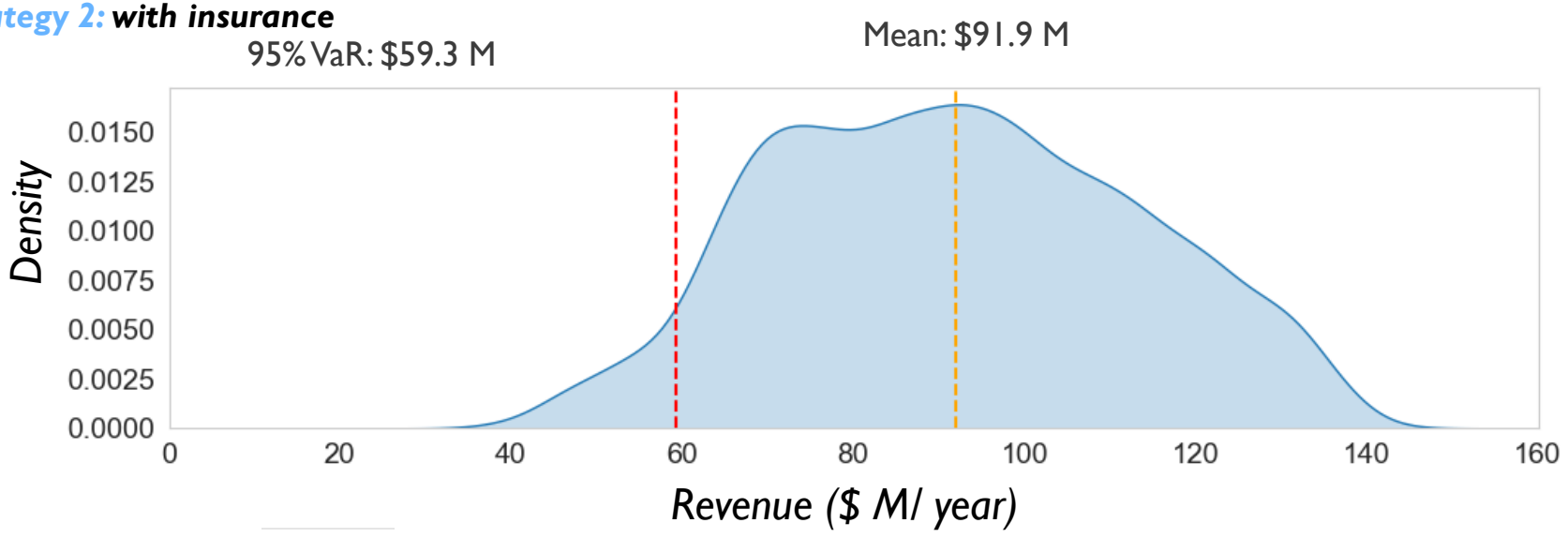


How does index insurance perform?

Strategy 1: ***no protection***



Strategy 2: ***with insurance***



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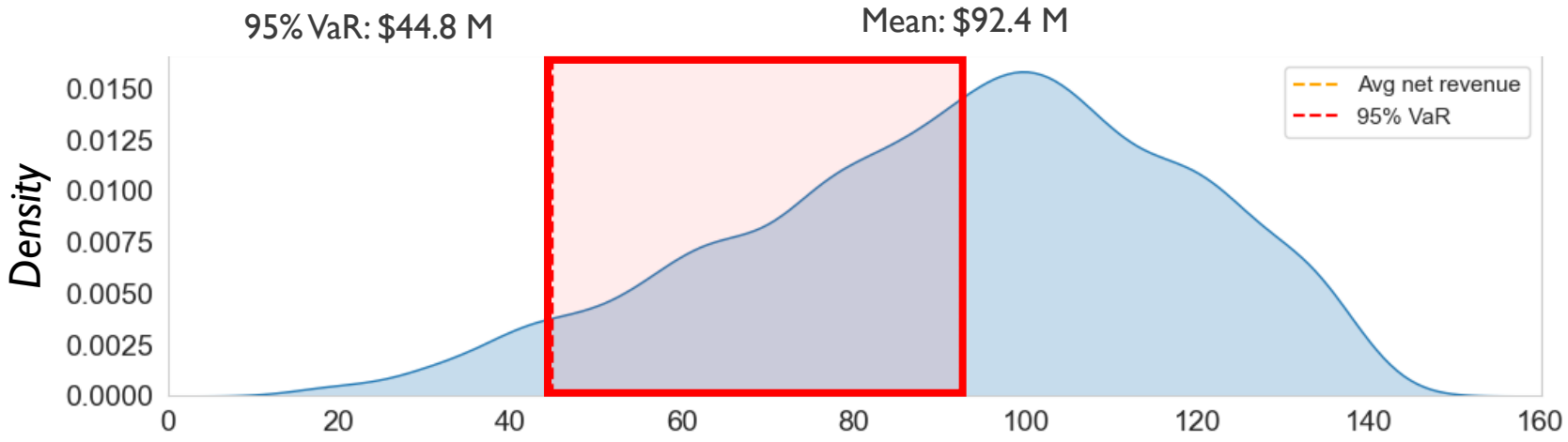

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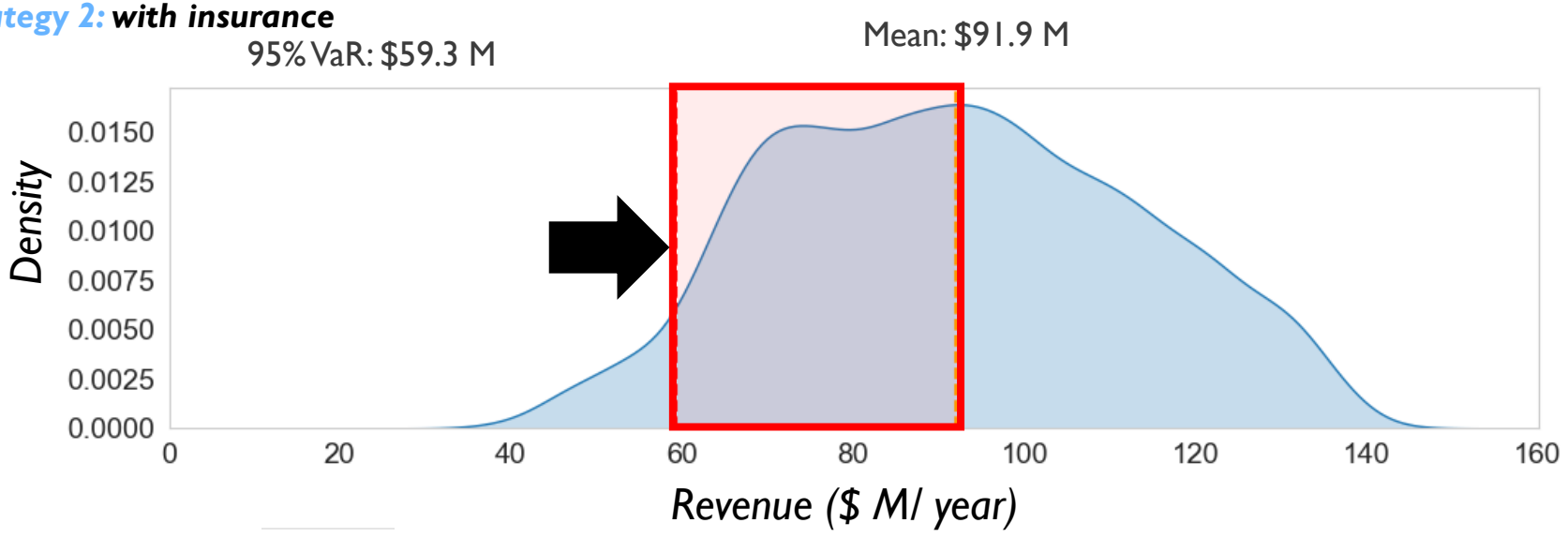

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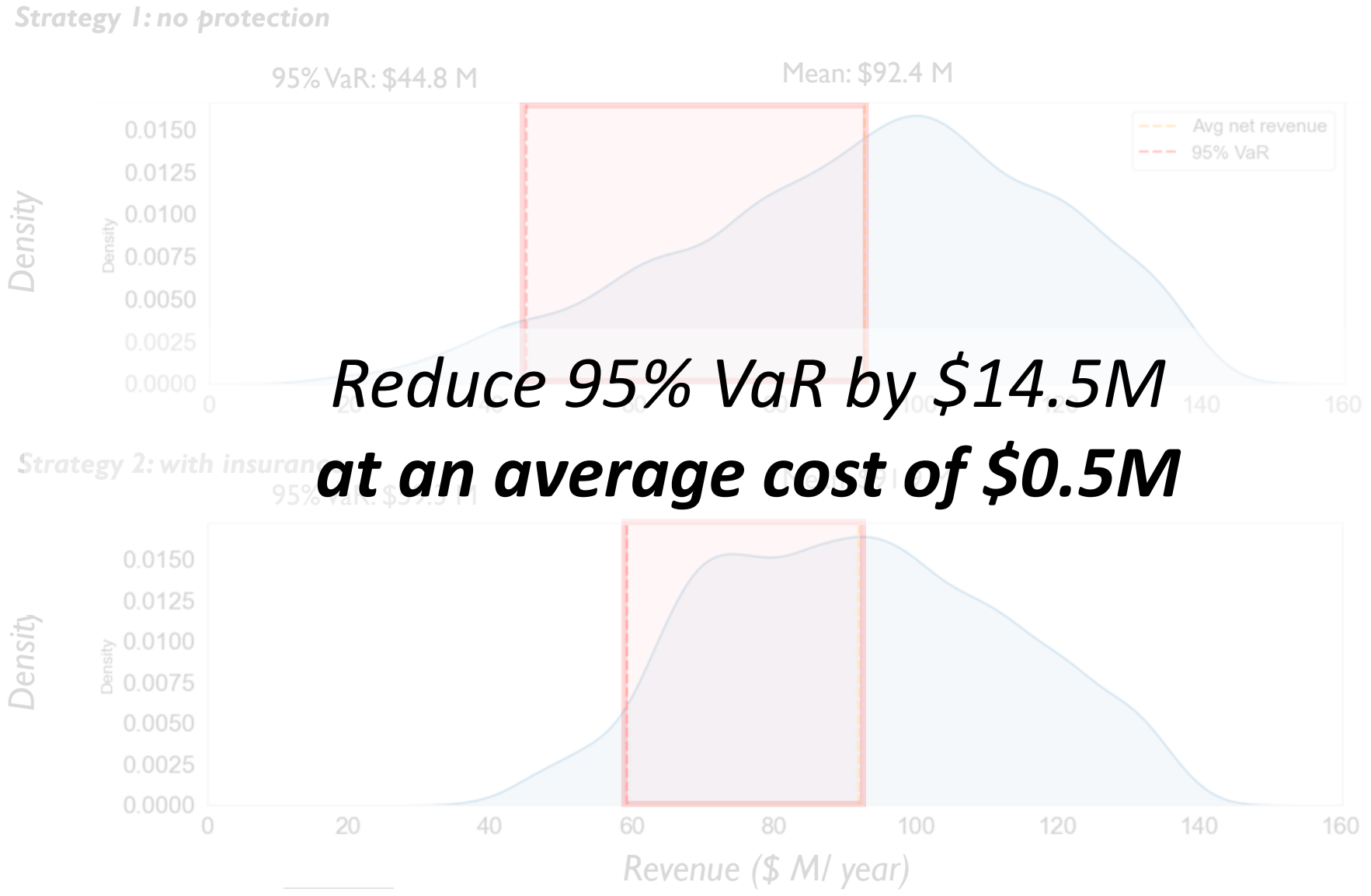

Reduce 95% VaR by $14.5M

at an average cost of $0.5M

How to predict water price (e.g. Nasdaq Veles California Water Index (NQH2O)?

Research questions

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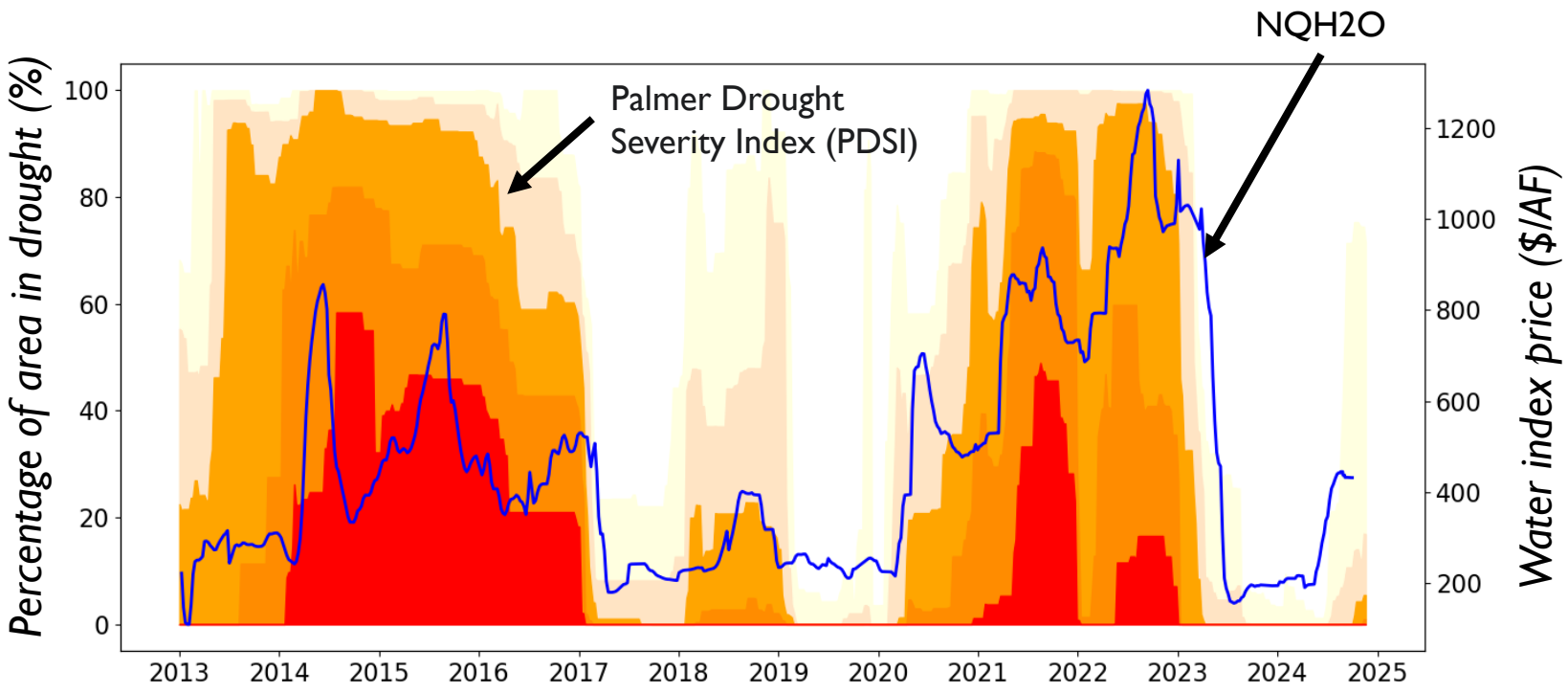
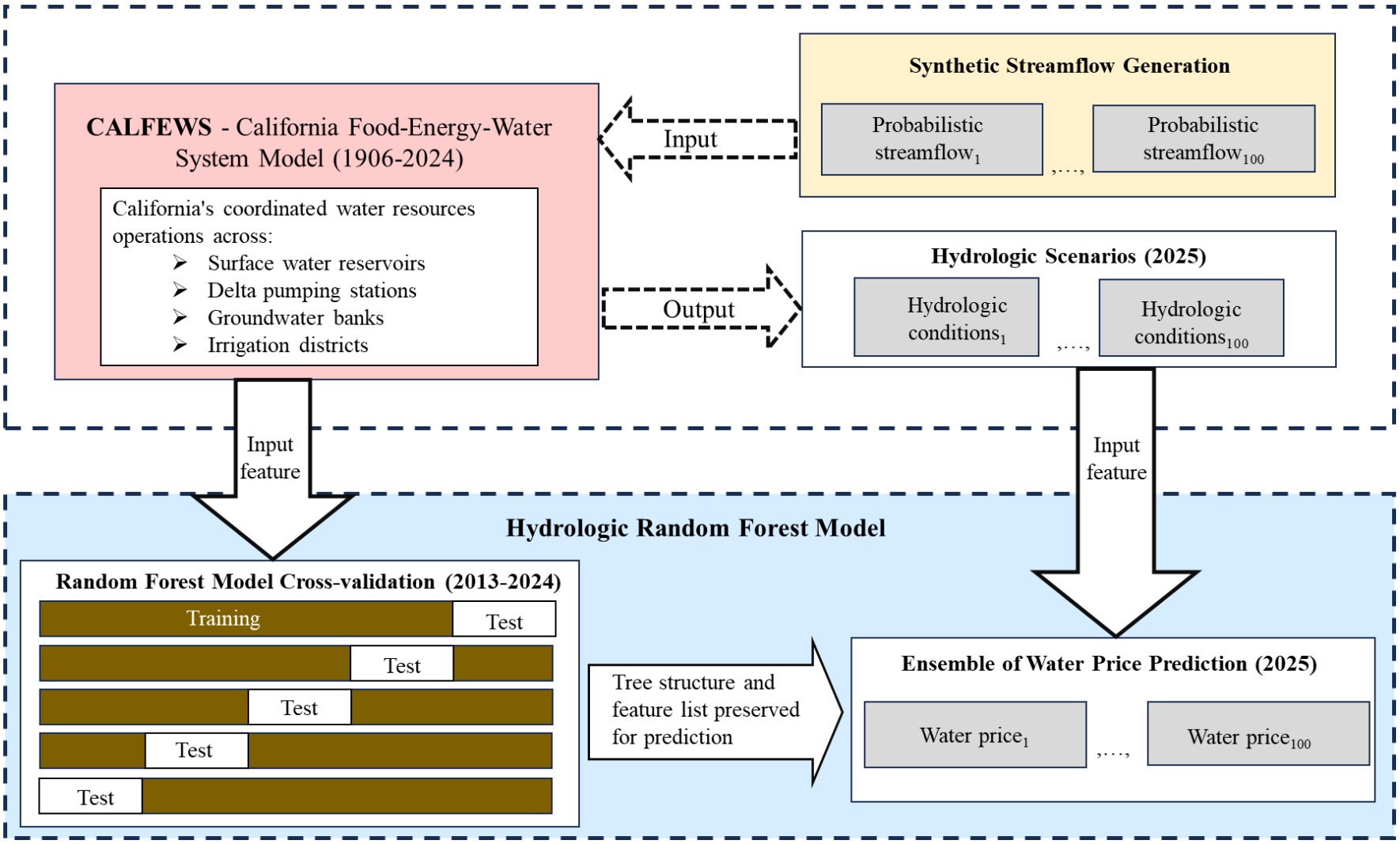
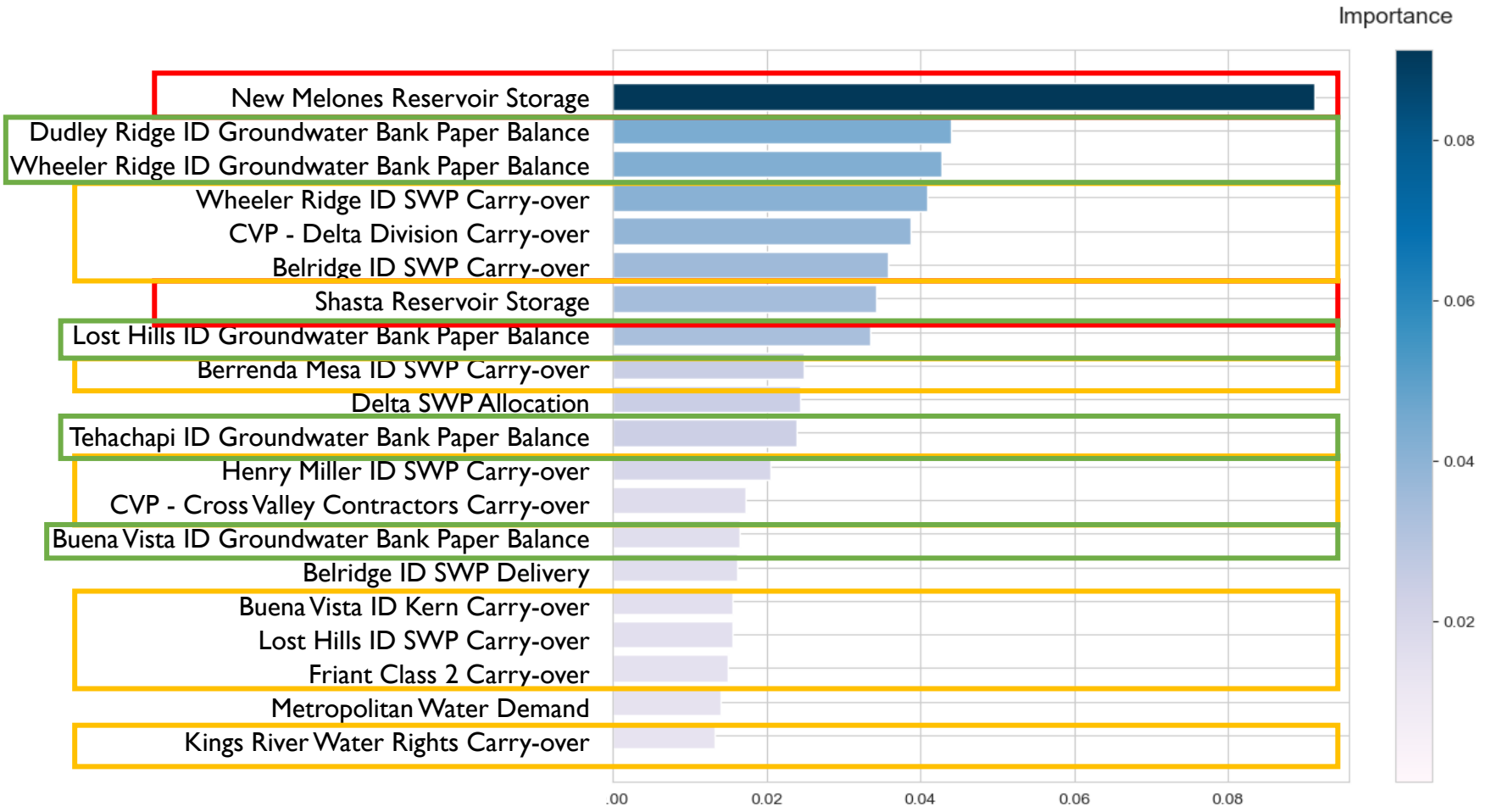


Research framework

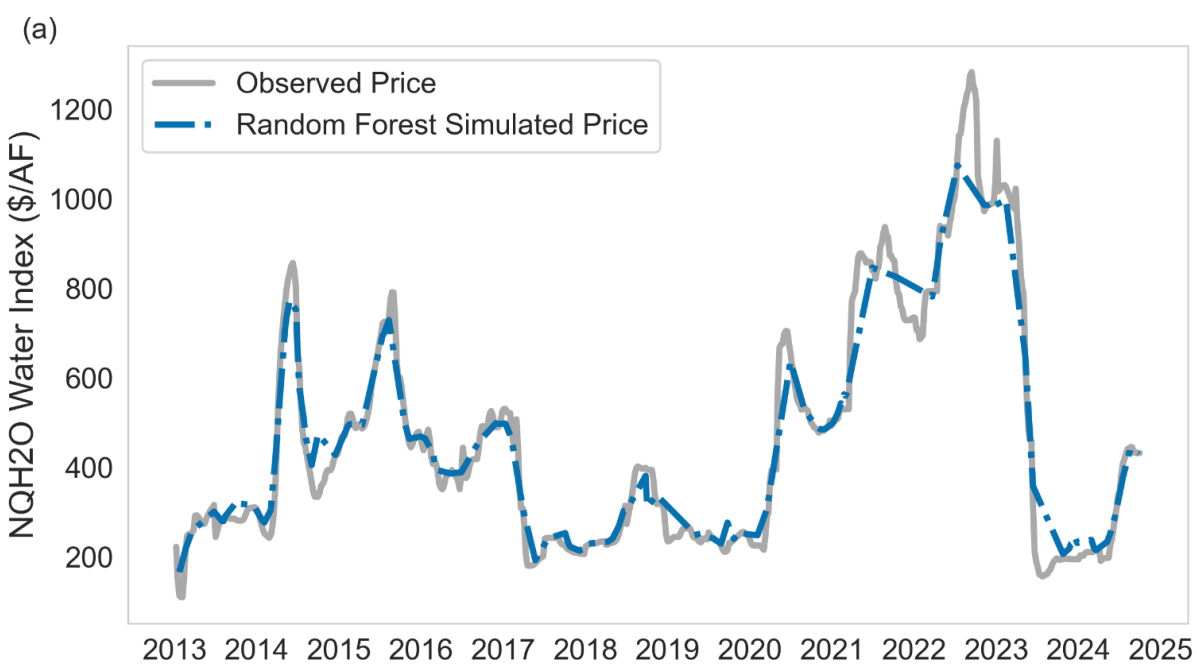


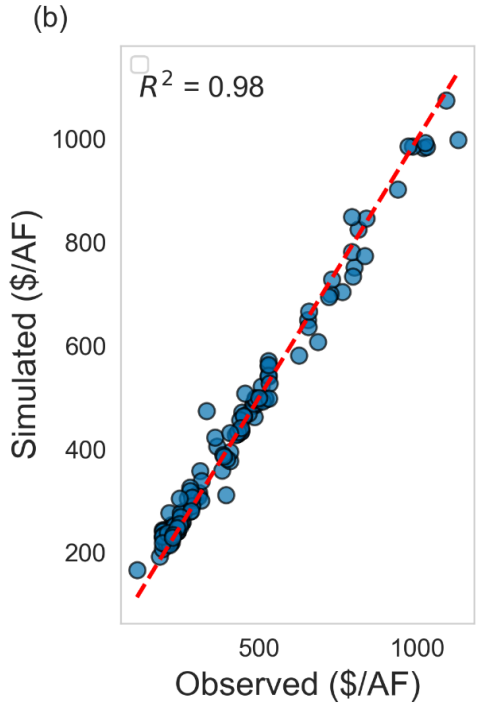
Feature importance



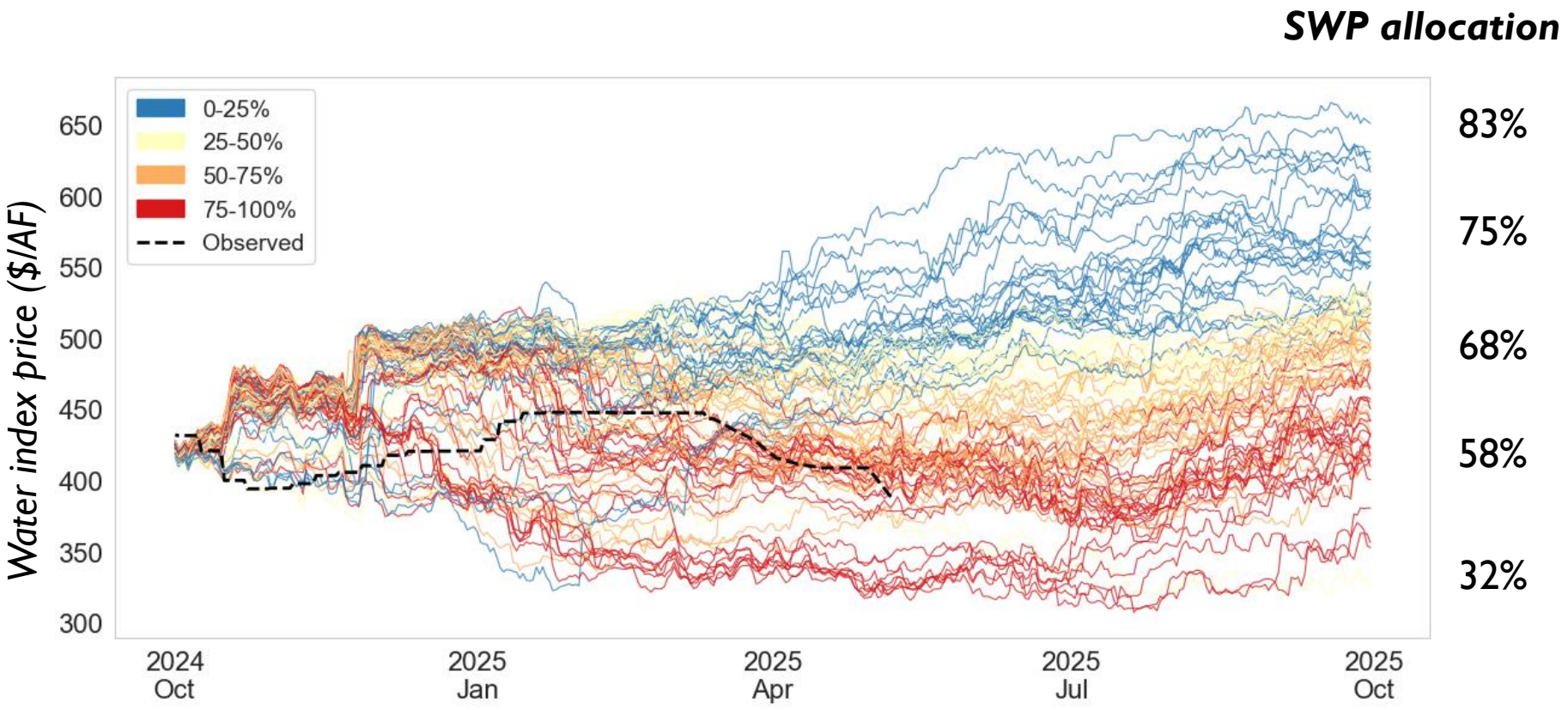
*ID: irrigation district; SWP: State Water Project

Model prediction of the water price index





Projected price movement



Key takeaways

- Developed **hydrologic** based forecasting of index-based insurance.
- Model can be utilized to **predict water price** movements.
- Provides an **affordable** financial tool for water users to mitigate revenue volatility.

Source: Los Angeles Times, 2021.

Thank you!

Funding support provided by:

UNC Institute for Risk Management and Insurance Innovation

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Contact Info:

Email: danli@unc.edu

LinkedIn:

How does index insurance perform?

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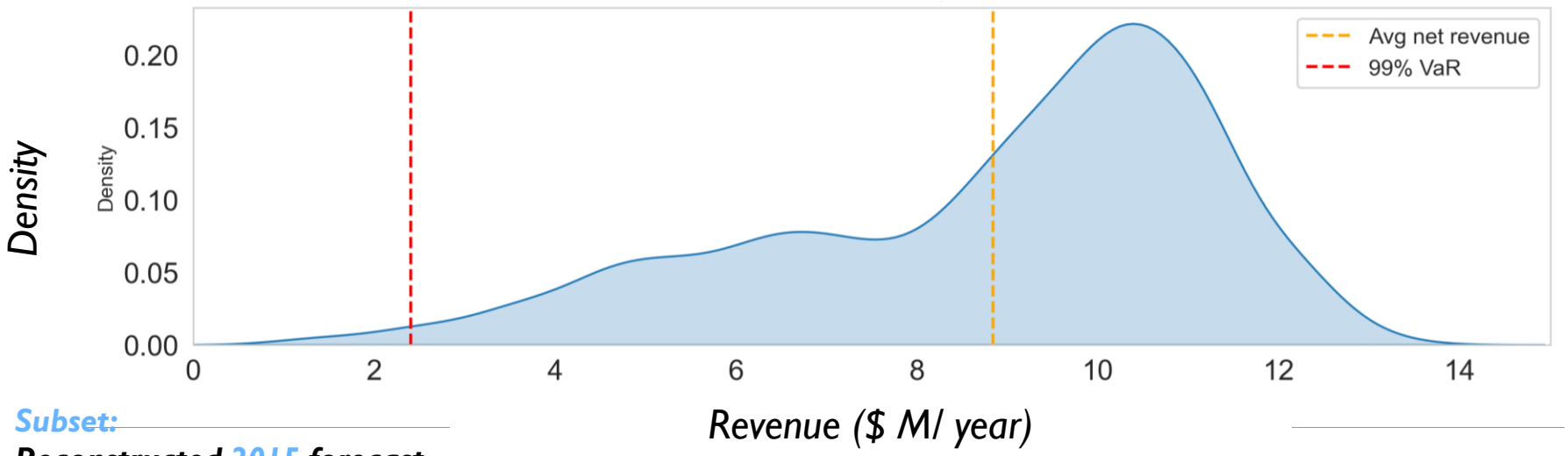
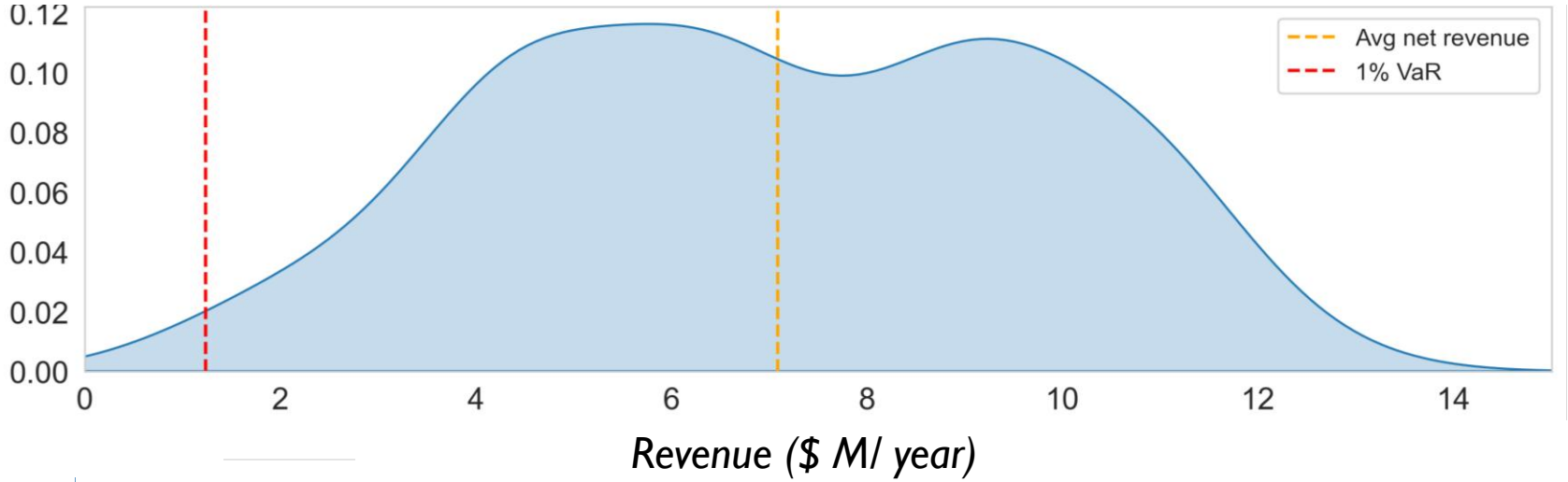
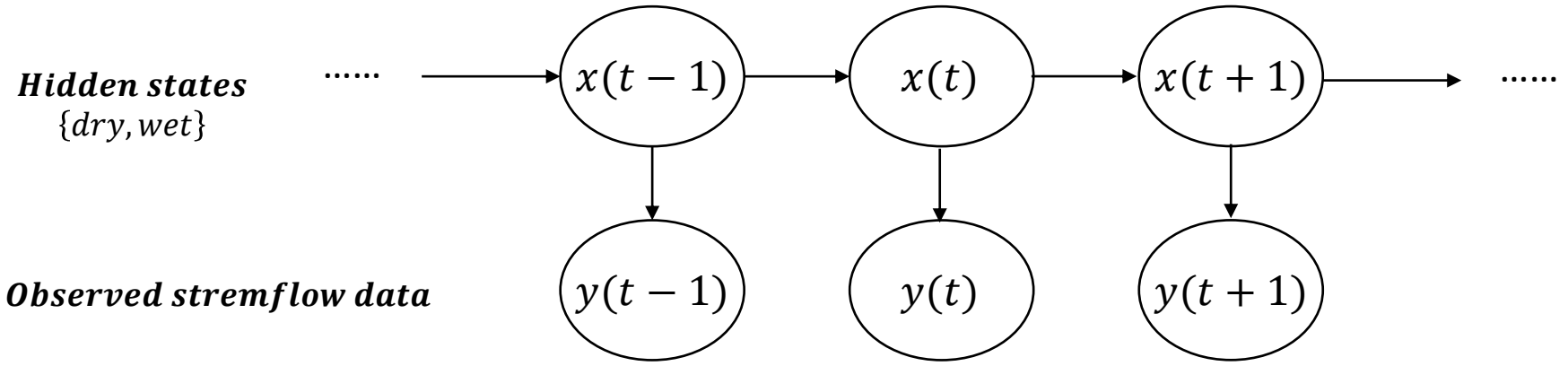


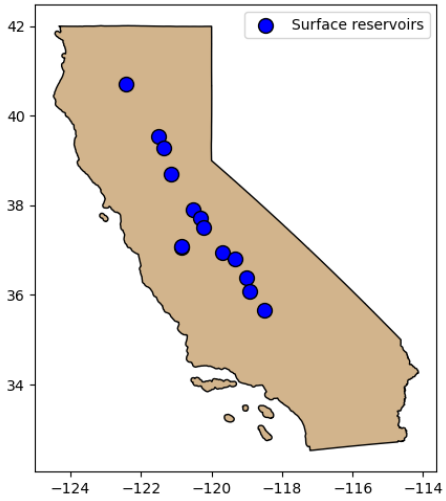
Subset:

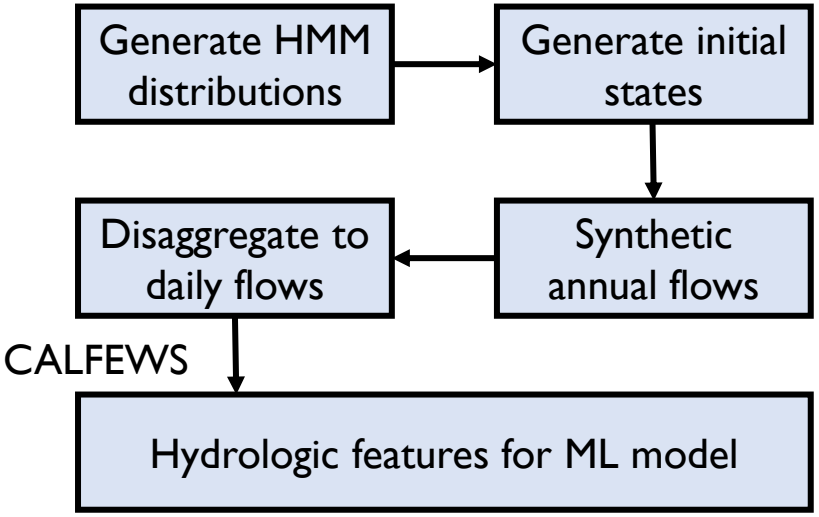
Reconstructed 2015 forecast



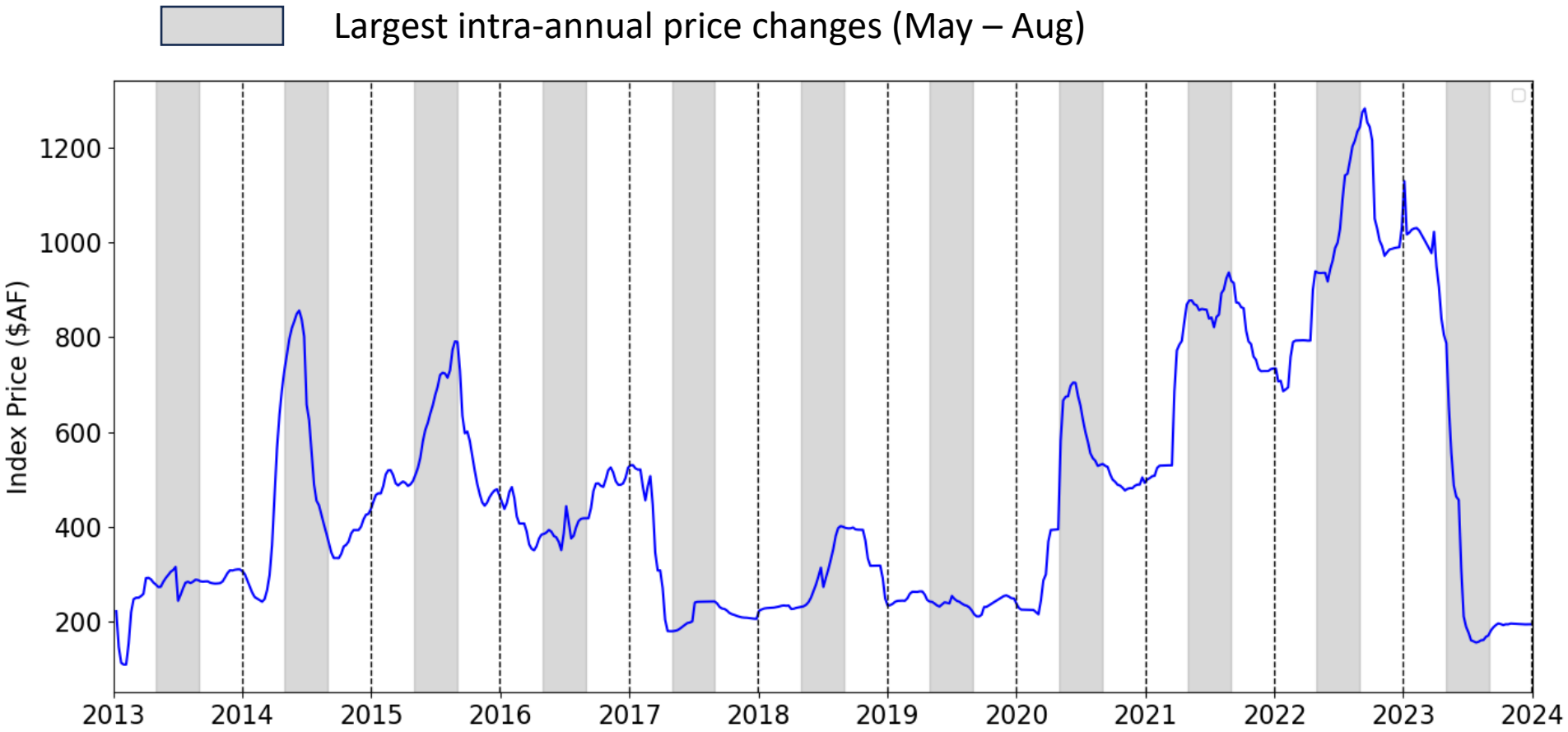
Multi-site HMM to generate synthetic streamflow







Water index price spike between May to Aug



- SWP/CWP allocation announcements typically occur from Jan to April
- Environmental regulation and groundwater regulations

Does ML model make physical sense?