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Use Probabilistic Forecasts in Reliable and Economic Electricity Market Scheduling and Operations

October 2022

Changing the World's Energy Future

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Idaho National Laboratory

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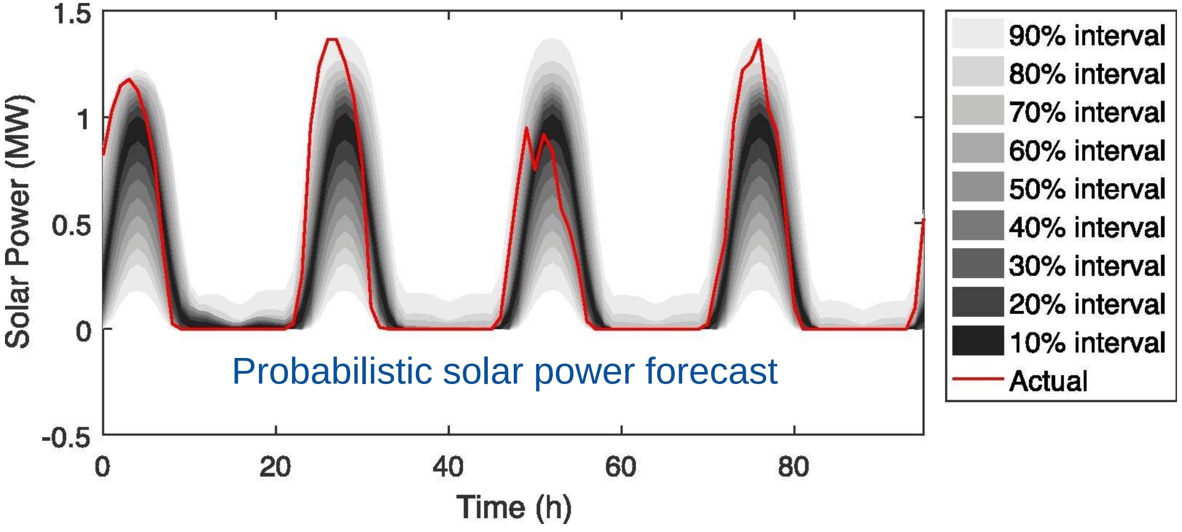
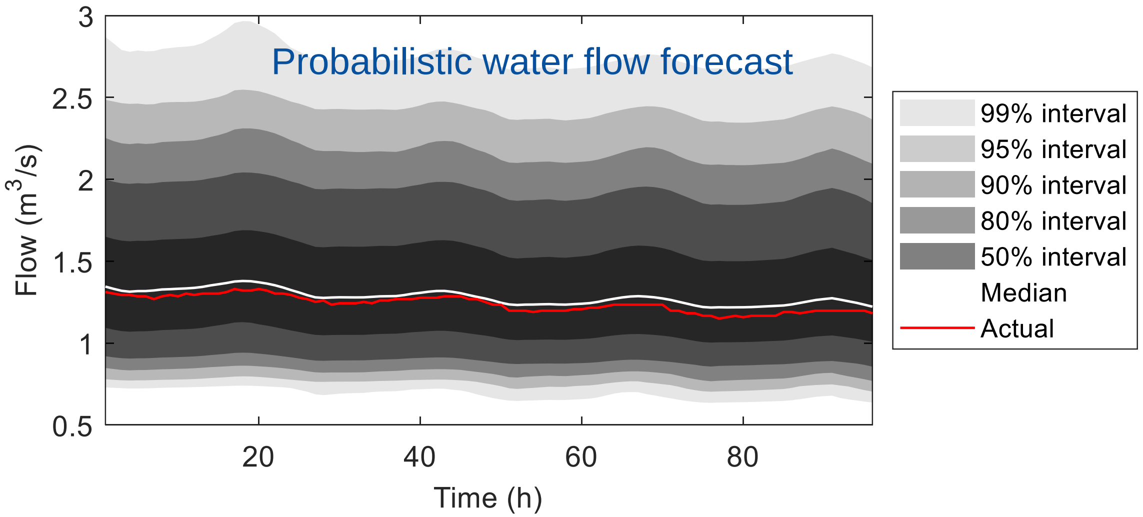
What is probabilistic forecasts?

- Conventional forecasts are deterministic, or point forecasts
- Forms of probabilistic forecasts
  - Parametric: distribution functions
  - Non-parametric: Intervals, percentiles
- To date, point forecasts are used in power systems predominantly
- Probabilistic forecasts are gaining tractions in power systems
  - Situational awareness
  - Scheduling and operations
  - Reserve determination





Two studies

I. Determine reserve requirements in electricity market
II. Determine operating schedules of hydroelectricity

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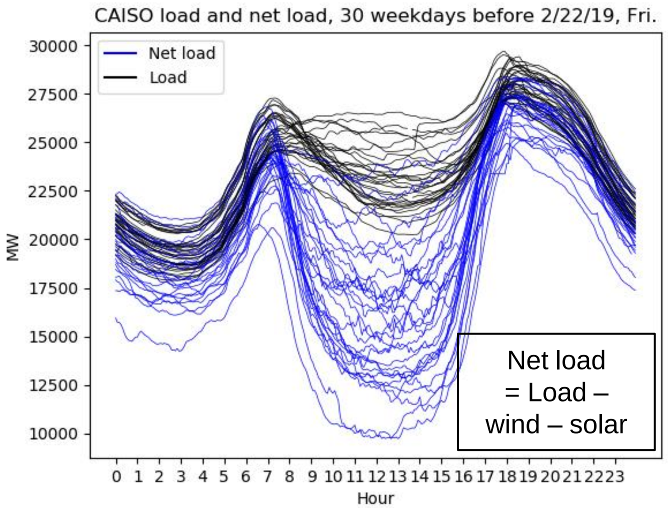
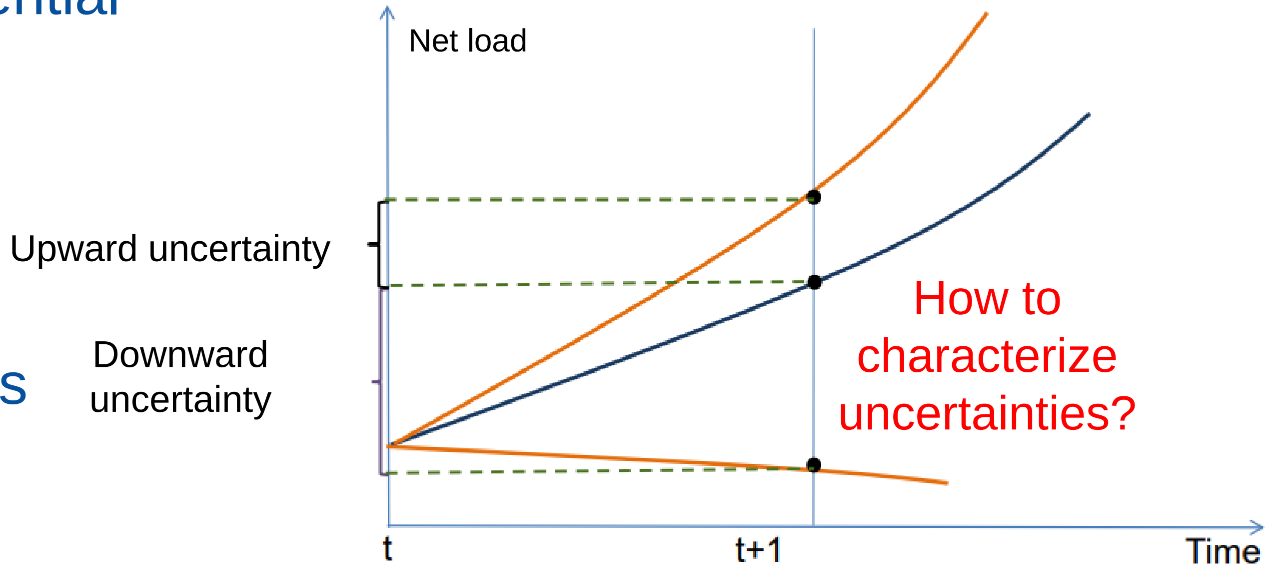
Impact of uncertainties on ramping requirements

- California has a **large share of solar** capacity, **32% in 2020** (EIA, 2020)
  - Huge net load (NL) ramps
  - Net load uncertainty mainly due to solar (>50%)
- **Flexible ramp products** (FRP) are introduced
  - To mitigate the impact due to net load uncertainties
  - Currently in real-time market only, potential extension to day-ahead market
- FRP Components
  - Net load movements
  - **Net load uncertainties**: up and down
- California Determine ramping requirements (CAISO)
  - 40 prior days if weekdays
  - 20 prior days if weekends

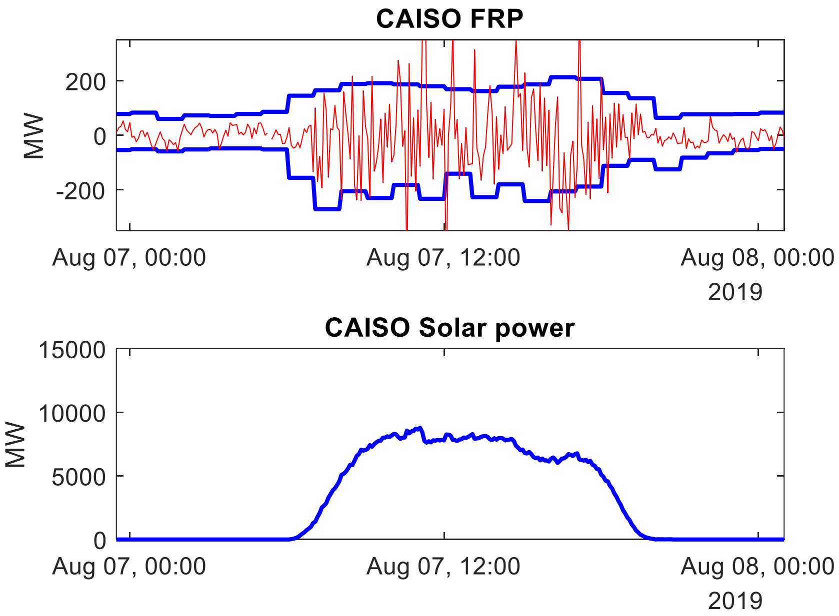


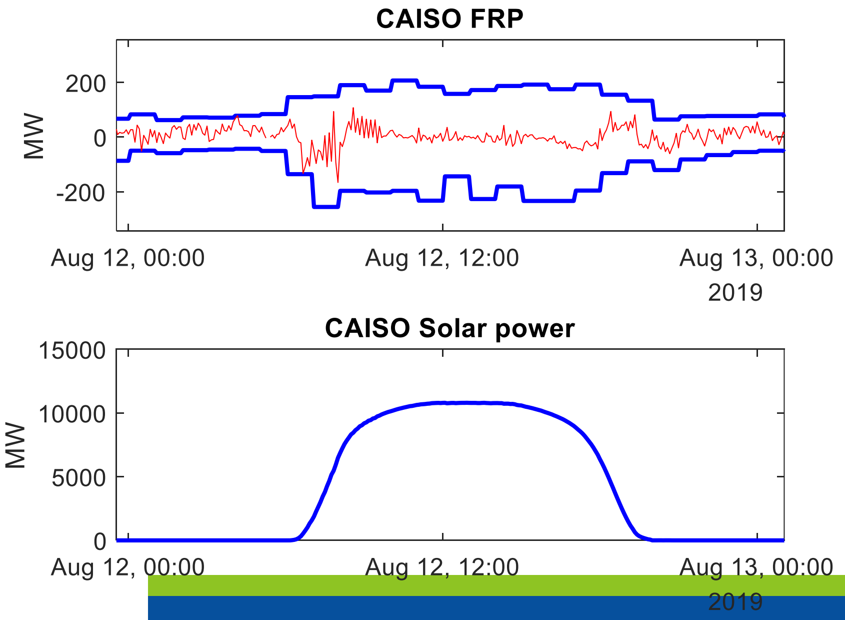


Day type categorization

- Type of days *vs.* uncertainties

	Cloudy day	Sunny day
NL forecasting uncertainties	**Greater** ($\epsilon_t^{NL}\uparrow$)	**Smaller** ($\epsilon_t^{NL}\downarrow$)
Solar power profile	**Jagged**	**Smooth**
Problems with CAISO's baseline	**Under** procurement, risk of reserve shortage	**Over** procurement, reduced market efficiency





CAISO's baseline does not consider weather types, and sunny and cloudy days are all mixed up.

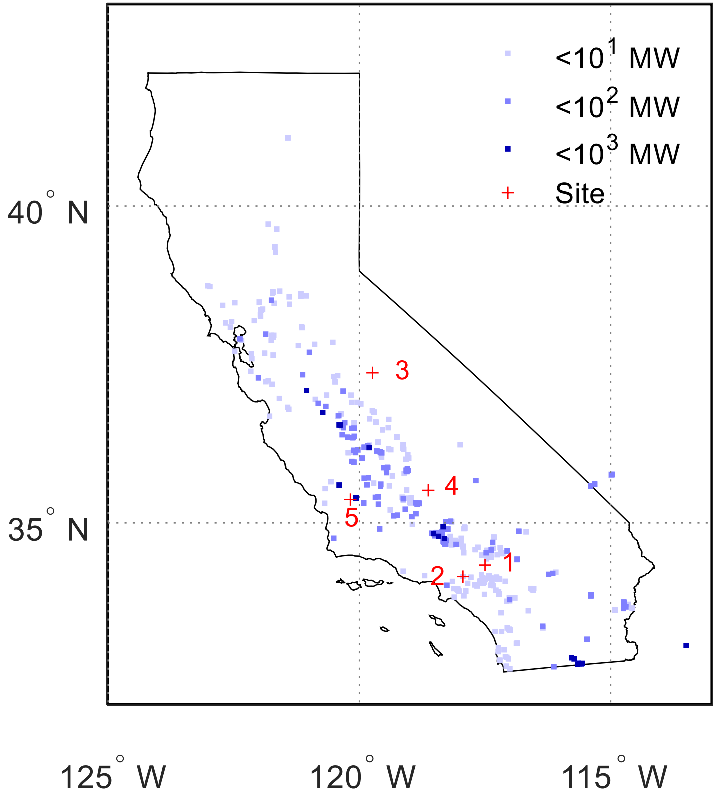
Weather-informed requirements: The kNN-based method

- IBM provides 5th, 25th, 50th, 75th, and 95th percentiles of GHI **every 15 min**
  - **Cloudiness conditions**: k -- Clear-sky index, k^{PV} -- clear-sky power index
  - **Uncertainty**: w -- Width of k, w^{PV} -- width of k^{PV}

Step 1: Weather characterization
- Define a set of hourly numerical classifiers: mean, std, variability

Step 2: Distance calculation
- Dimension reduction using PCA
- Find similar weather-day in history

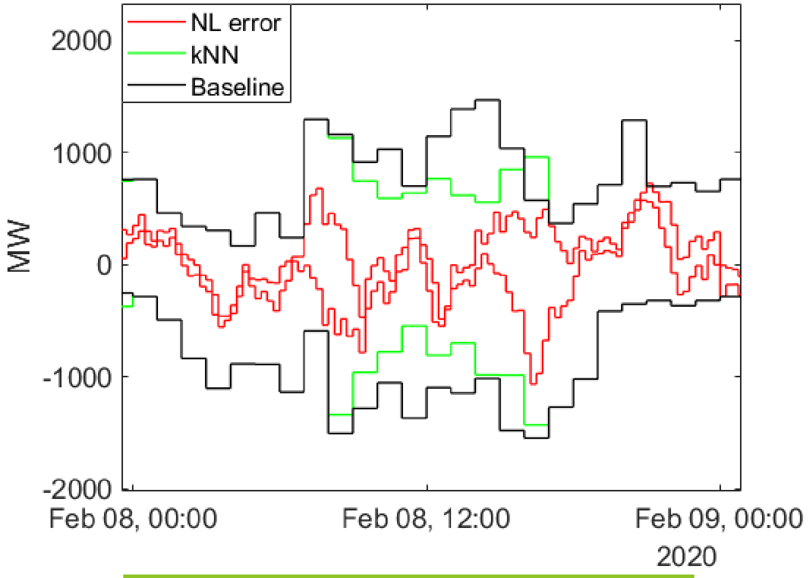
Step 3: FRP determination
- 95% confidence interval from weather-conditioned distributions of NL forecast errors



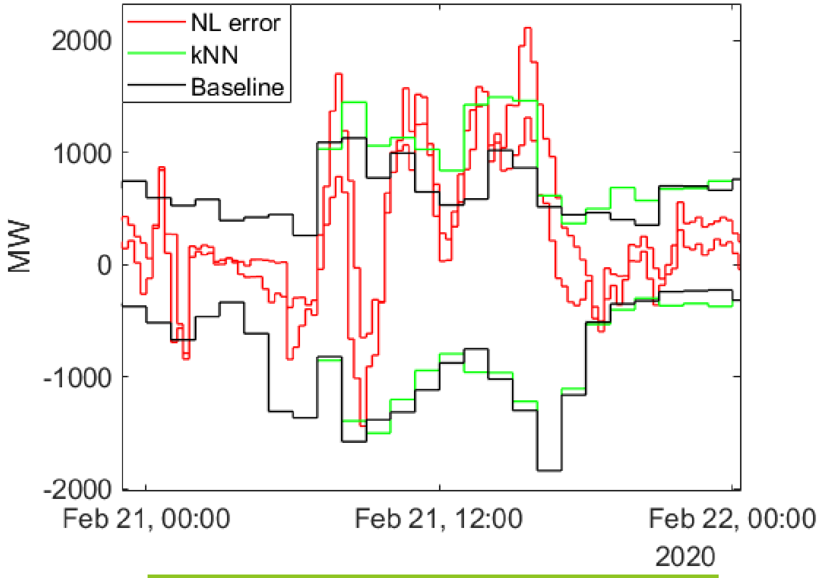
CAISO solar PV plants and IBM sites

Source: EIA Annual Energy Outlook 2019.

The kNN-based method: A snapshot



Less cloudy day
Smaller forecast error ($\epsilon_t^{NL}\downarrow$)
kNN < Baseline
Reduce reserve to **improve market efficiency**

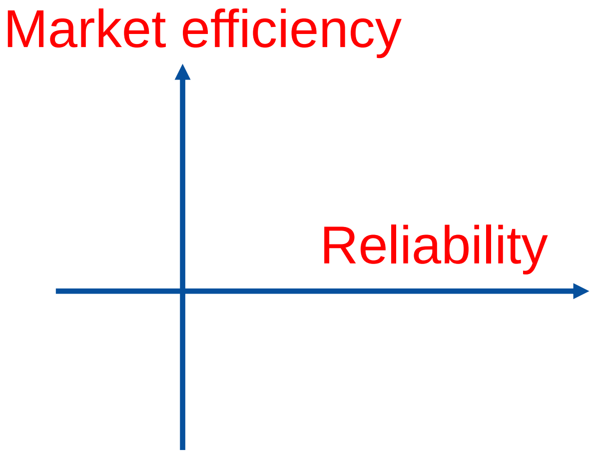


More cloudy day
Greater forecast error ($\epsilon_t^{NL}\uparrow$)
kNN > Baseline
Increase reserve to **improve reliability**

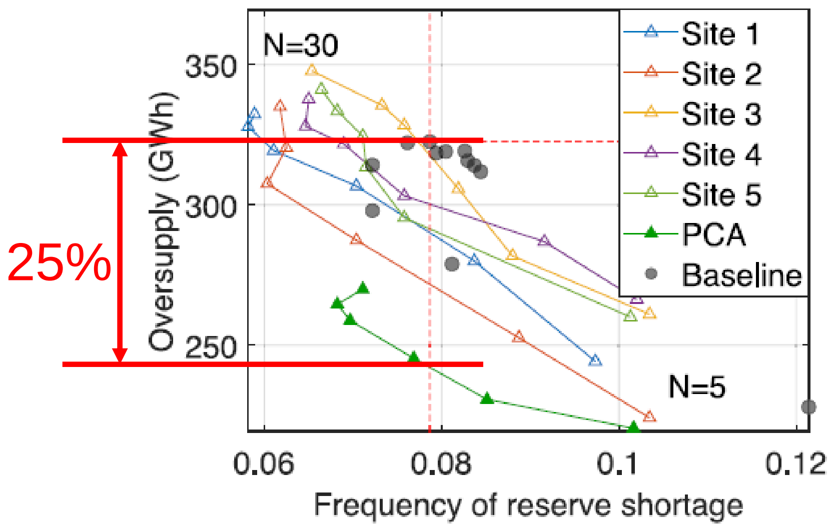
- RTPD market, use a 2-d classifier, number of days K = 20

The kNN-based method: Pareto frontiers

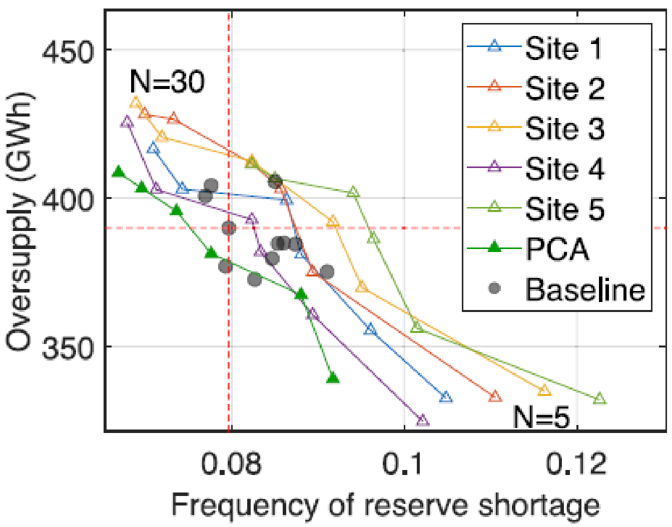
- We examine two metrics
  - Market efficiency: Oversupply (GWh)
  - System reliability: Frequency of reserve shortage



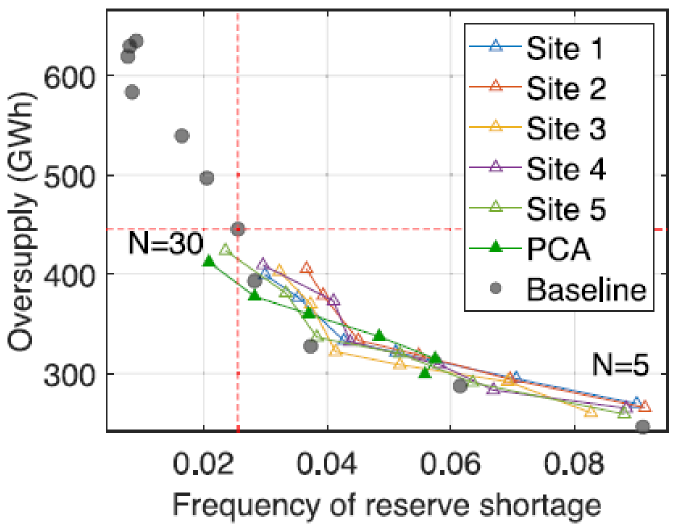
February 2020



August 2020



October 2020



Source: Li, Binghui, et al. "Sizing ramping reserve using probabilistic solar forecasts: A data-driven method." Applied Energy 313 (2022): 118812.

Two studies

I. Determine reserve requirements in electricity market
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Background

- FERC hydropower relicensing process considers values from multiple aspects
  - Provision of electricity
  - Environment
  - Recreation
- Flexibility of hydropower project needs to be maximized under the growing renewable penetration
- We develops a tool to maximizes the value of hydropower projects under environmental flow requirements

Model formulation

- The hydro power plant follows the CAISO timeline

Water flow

DA Market

Maximize DA market revenue
- DA revenue = DA LMP × DA schedule

Subject to:
- Water flow constraints (**DA forecast**)
- Physical limits (storage limits, ramp limits etc.)

DA forecast

DA schedules and revenues

RT Market

Maximize: RT market revenue
- DA revenue
- Imbalance cost: RT LMP × ||RT schedule – DA schedule||

Subject to:
- Water flow constraints (**Observation**)
- Physical limits (storage limits, ramp limits etc.)

Observations

RT schedules and revenues

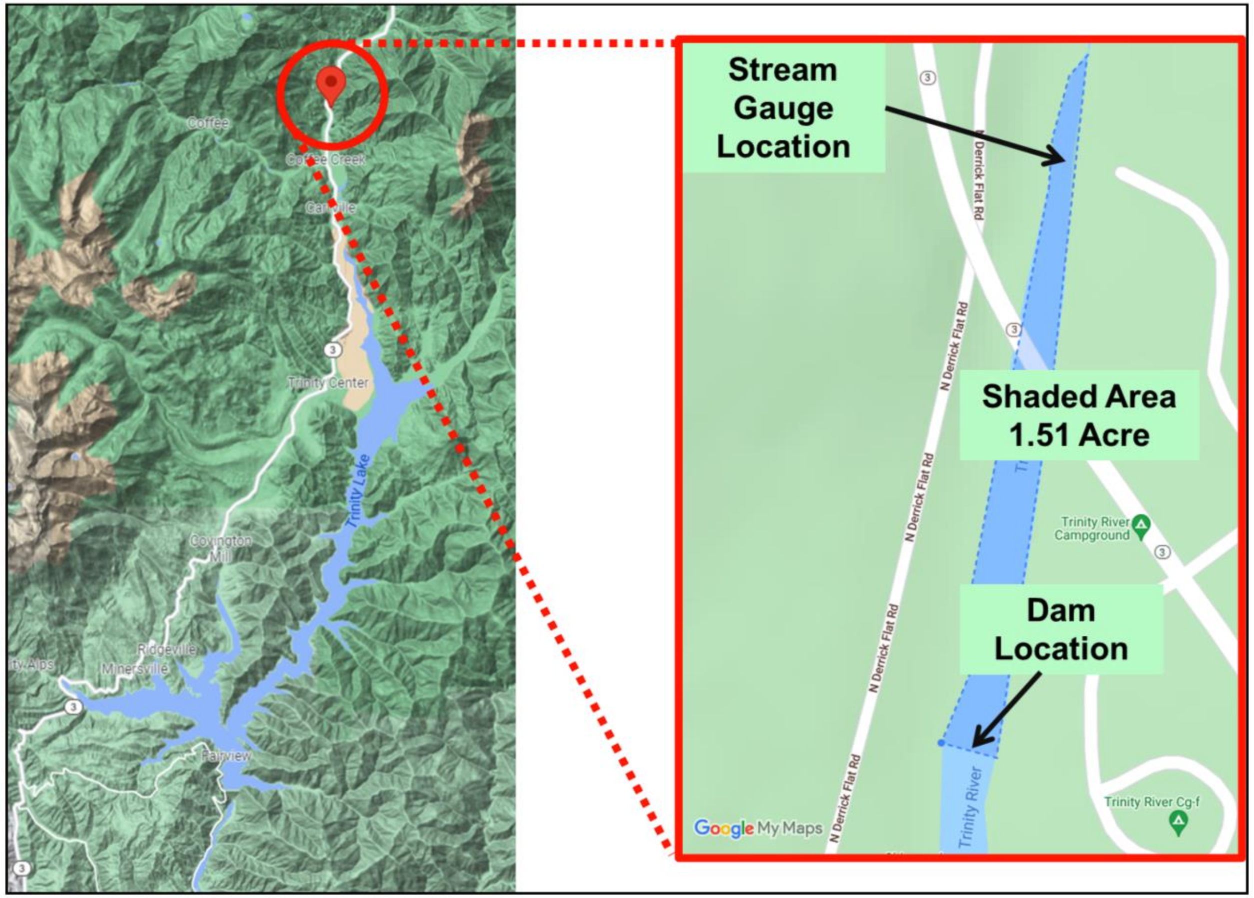
Final settlement

Market timeline

Decision variables
- Water flow to powerhouse
- Water flow to storage
- Water flow to bypass

Physical limits
- Storage limits
- Ramp limits
- Bypass flow limits
- *Can include other regulatory limits as needed*

Case study assumes a non powered dam on Trinity River retrofitted with generation



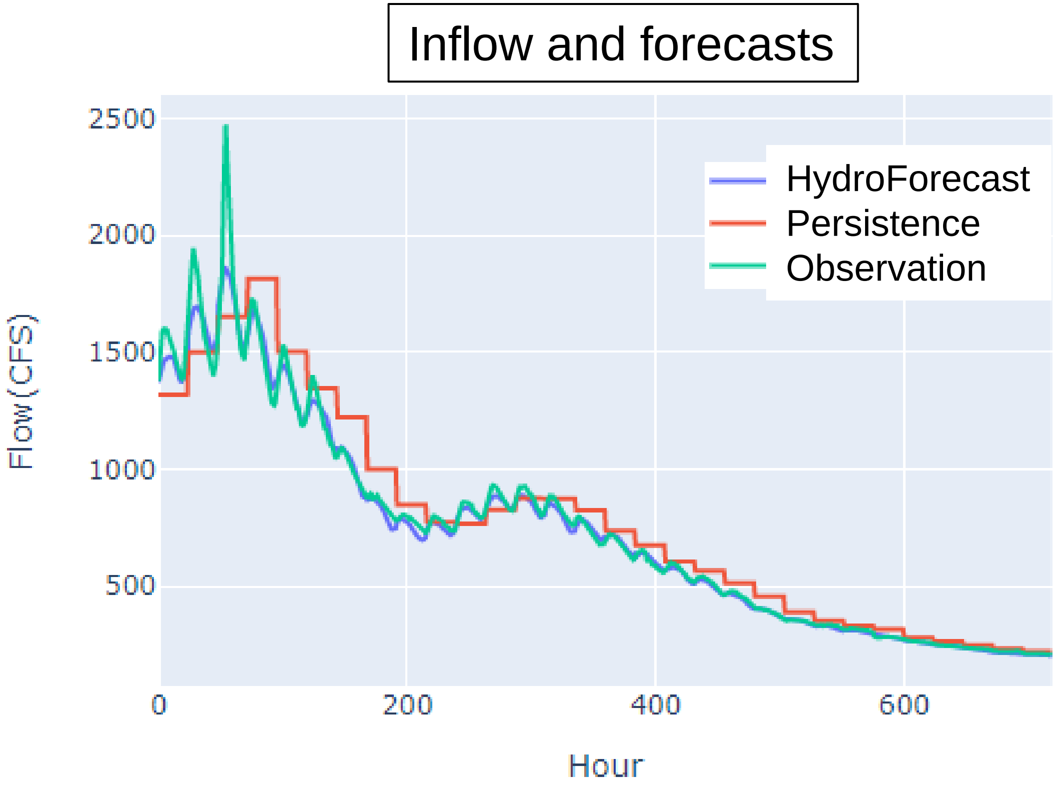
Plant Attributes	Values
Reservoir operating range (acre-ft)	336.5 to 570
Maximum water head (ft)	375
Flow (CFS)	20 to 1,500
Capacity (MW)	18.3

Types of scenarios tool can consider:

- Flow constraints
  - Minimum flows
  - Ramp rate limits
  - Storage limits
  - Design flows (e.g., recreation flows)
  - Spill limits
- **Forecasts**
- Market price scenarios

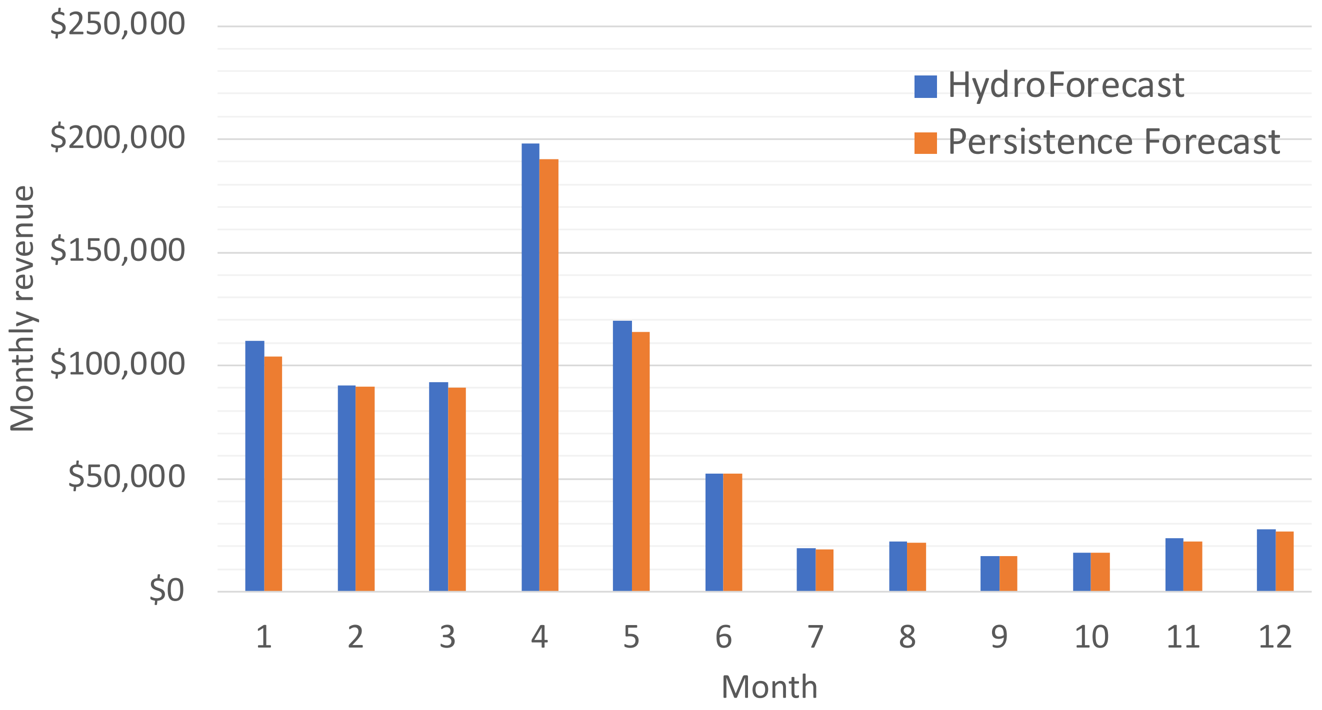
Data

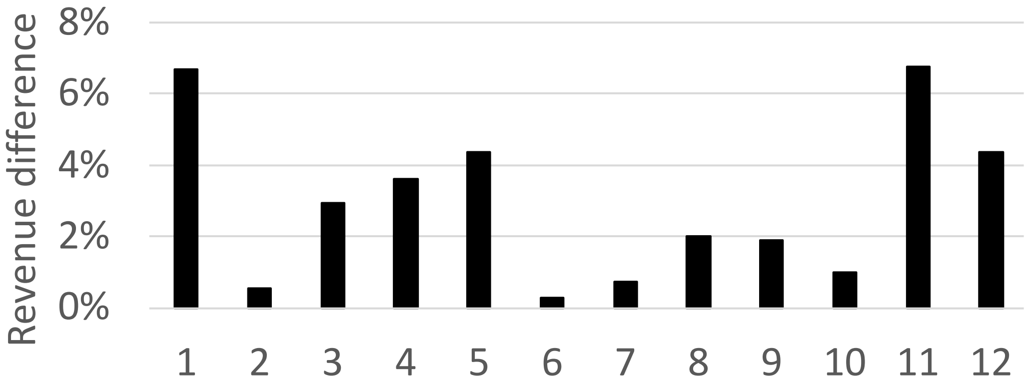
- Inflow forecasts
  - Persistence forecasts
  - Probabilistic forecasts (only median is used)
- Actual inflow
  - USGS website
- Electricity prices
  - Day-ahead and real-time LMP prices from CAISO



Scenario: 50 CFS, 10% ramping

More accurate forecast increases revenue





Preliminary results show 1% to 7% increase of monthly revenues.

Future work

- Account for predictive intervals by using robust optimization
- Comparison between using probabilistic forecasts and deterministic forecasts to show improvement

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