

A policy tree optimization approach to dynamic adaptation under climate uncertainty

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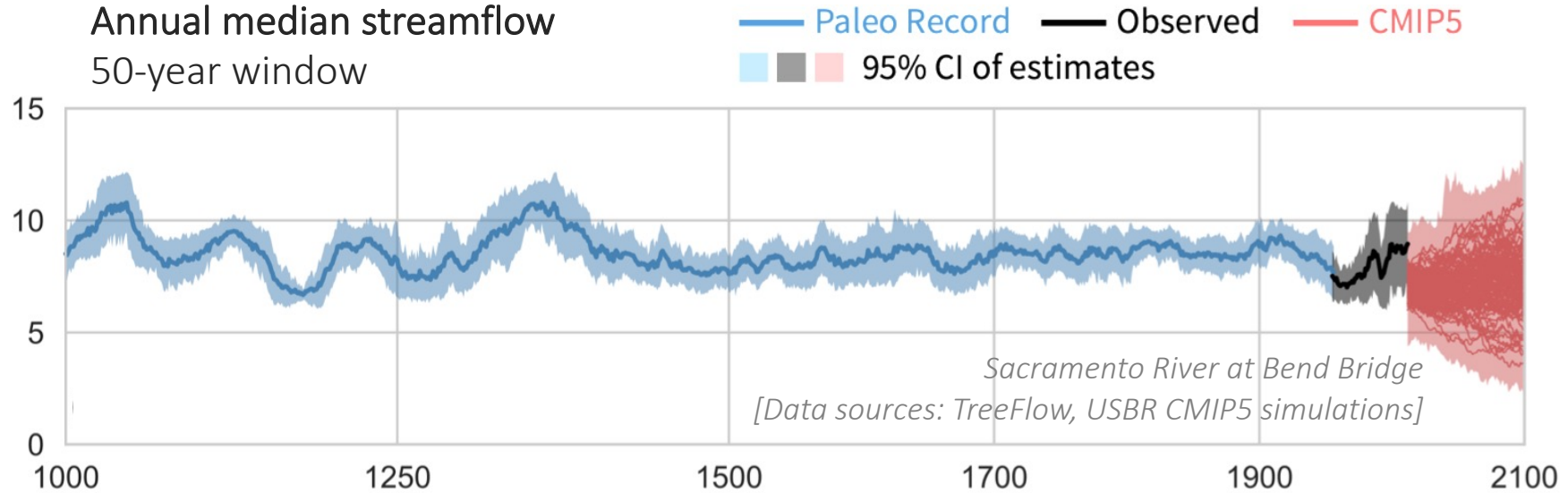
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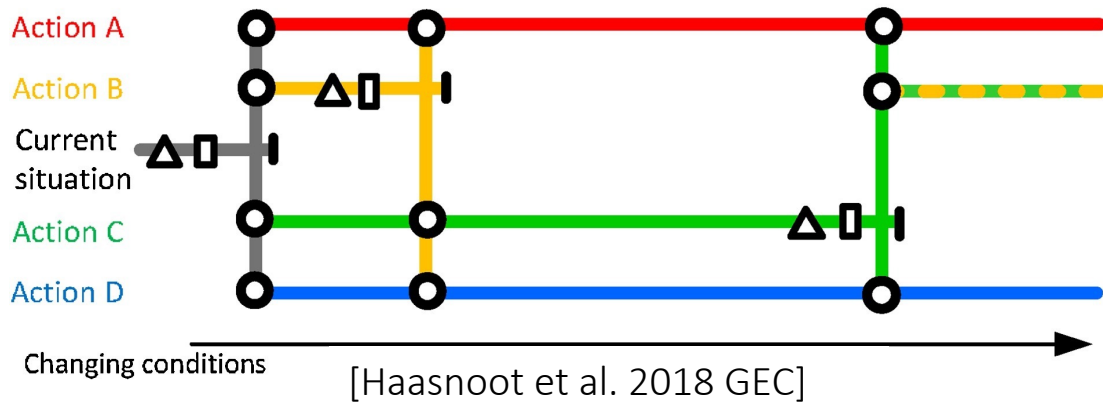
Image Credit: The Atlantic, Mar. 2014, Reuters/Robert Galbraith

Navigating uncertainty in future drought and flood risks



Under what conditions should adaptations be implemented?

Adaptive policy design supported by optimization methods



Solution Method

Dynamic Programming

Policy Search

Open Loop

Stochastic DP

Model Predictive Control

Stochastic LP/NLP

Enumeration

Time-based rules

if $t \geq t^*$:

action A_i

...

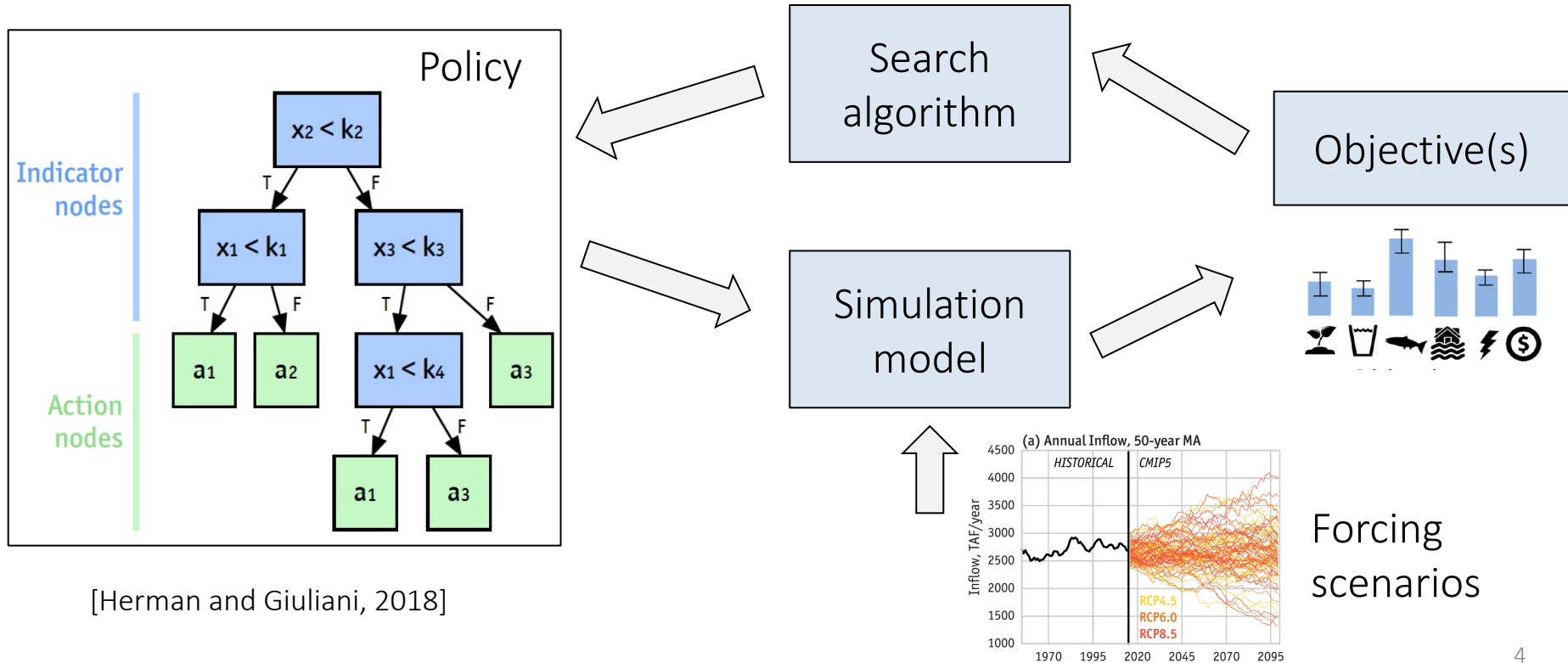
Indicator-based rules

if $I_t \geq k_t$:

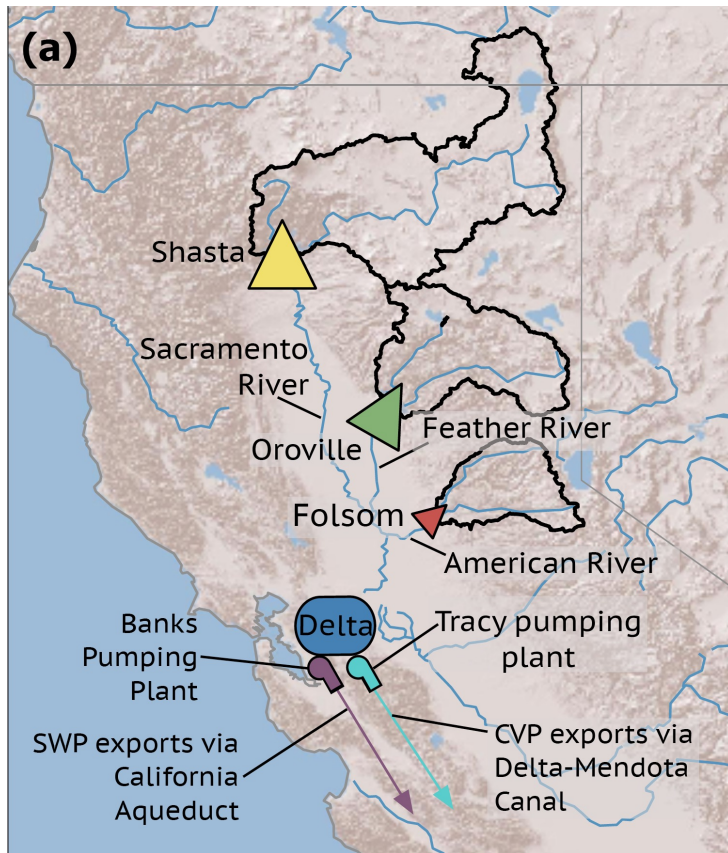
action A_i

...

Can we design adaptive policies by optimizing the choice of indicators, actions, and structure at the same time?



Experiment: Northern California reservoir system



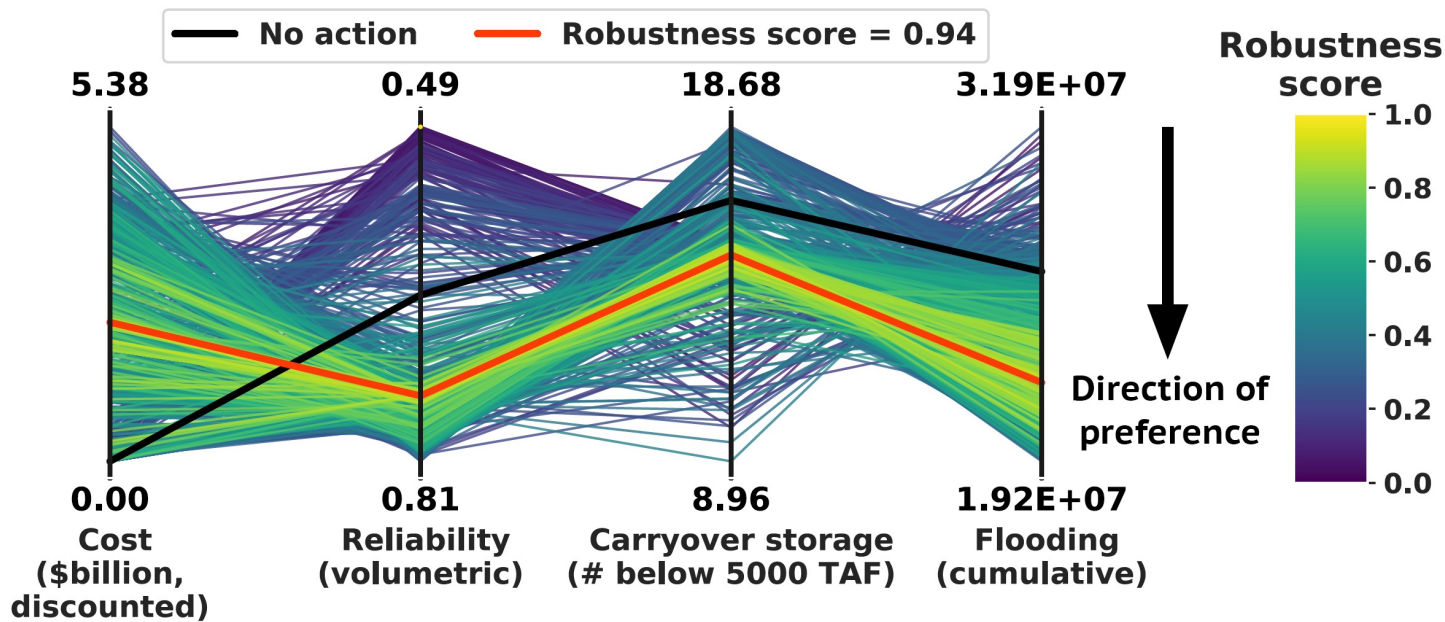
- Daily timestep simulation model
- **Actions:** infrastructure expansion, operating rules (22 total)
- **Objectives:** cost, water supply, carryover storage, flooding
- **Scenario ensemble:** climate and land use projections, 2020-2100 (~500 total, split into train/test)

Experiment: Indicators

Variable	Timescale	Window	Statistic
Streamflow (Q)	Annual (A)	5 years	Mean (μ)
Snow-water equivalent (SWE)	Monthly (M)	10 years	Standard deviation (σ)
Air temperature (TAS)	3 Months ($3M$)	20 years	Percentile, P (10,30,50,70,90)
Seasonal timing (T)	Daily (d)	30 years	Difference, Δ (5,10,20,30,50 years)
Water demand (D)	3 Days ($3d$)	50 years	

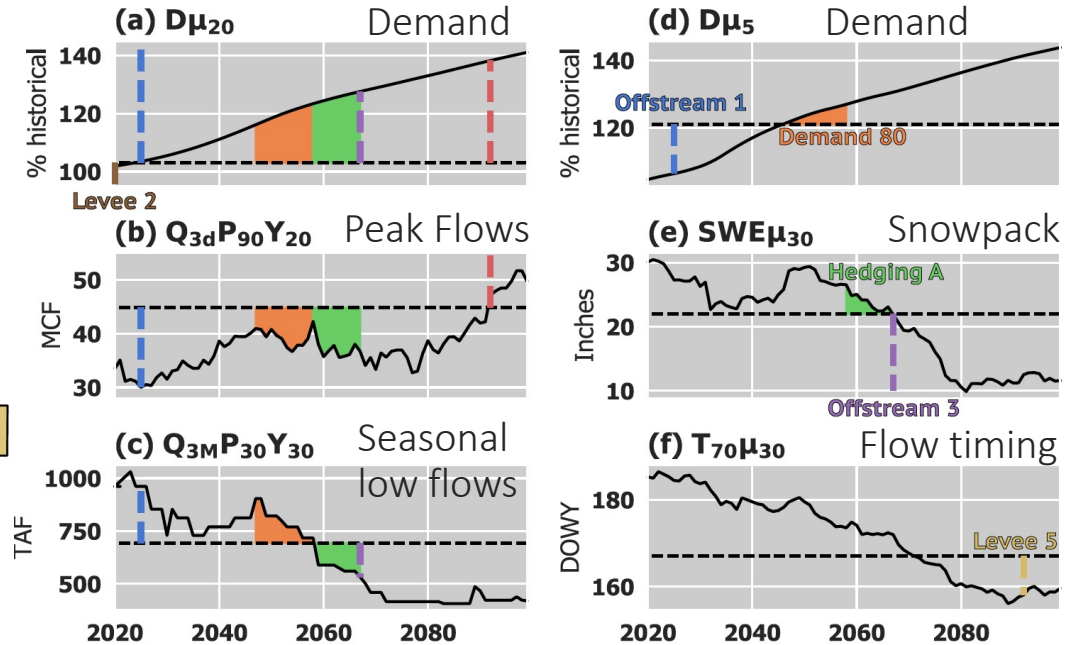
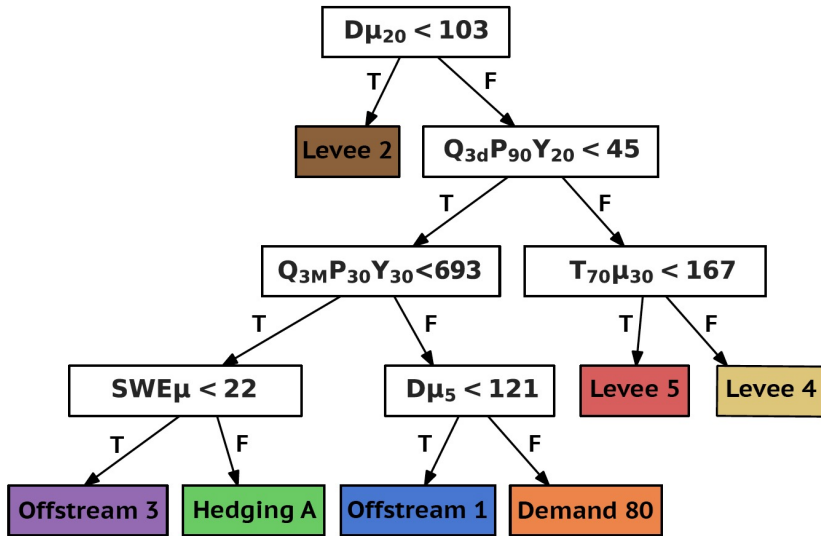
- Example $Q_A\mu_{30}$: 30-year mean annual streamflow
- 540 possible indicators, using combinations of above
- Tradeoff between adapting quickly vs. correctly

Results: which policies are robust to held-out test scenarios?



- Robustness score: % of test scenarios in which a policy dominates “No Action”
- Robust policies are not always the most costly—the sequence and timing of actions is important

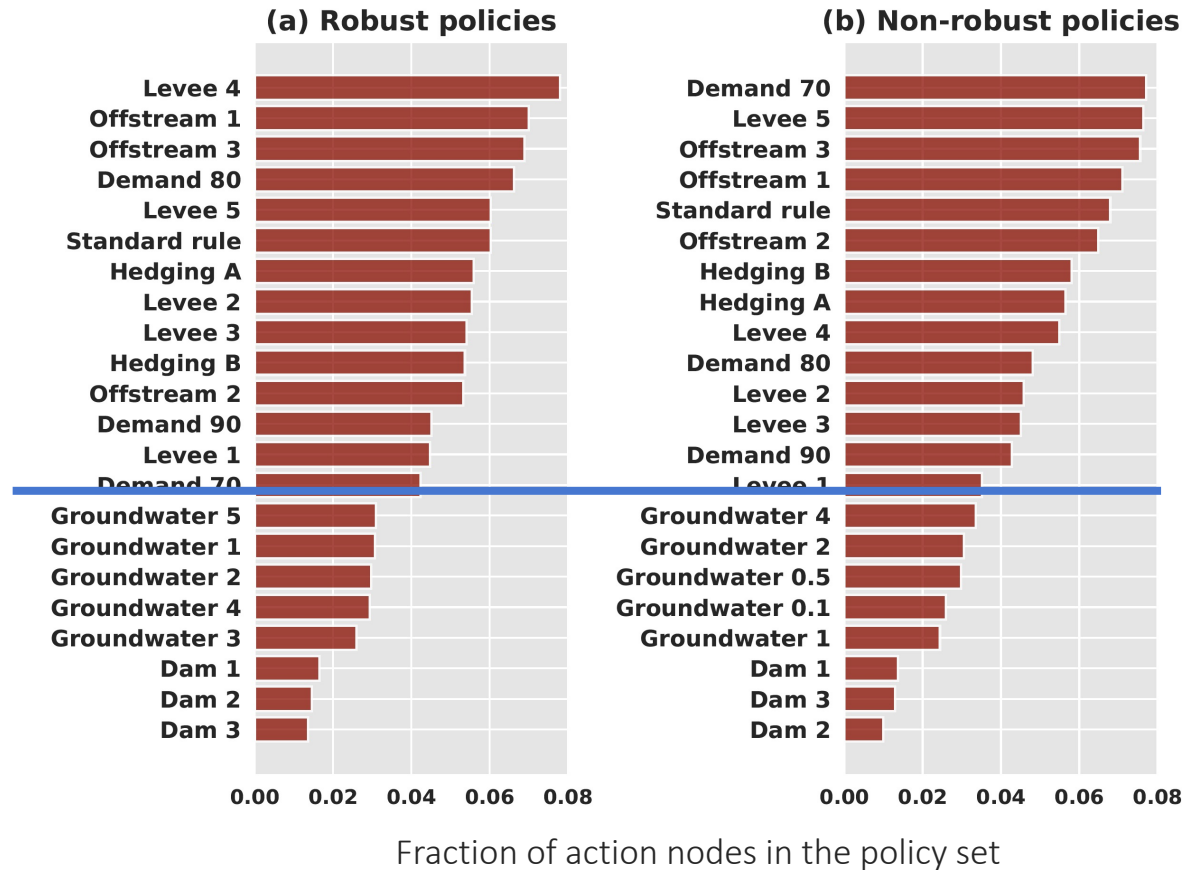
Example policy applied to test scenario (CESM RCP 8.5 + LUCAS BAU)



- Out of 540 indicators, 6 are selected to capture multi-scale trends.
- Moderate infrastructure triggered right away (**Levee2**, **Offstream1**)
- Large infrastructure triggered later by snowpack decline and flood extremes

What separates robust policies from others?

- The actions are similar across both sets of policies
- The least common actions are not cost-effective
- Differences must be due to dynamic components (indicators, timing)



What indicators are used?

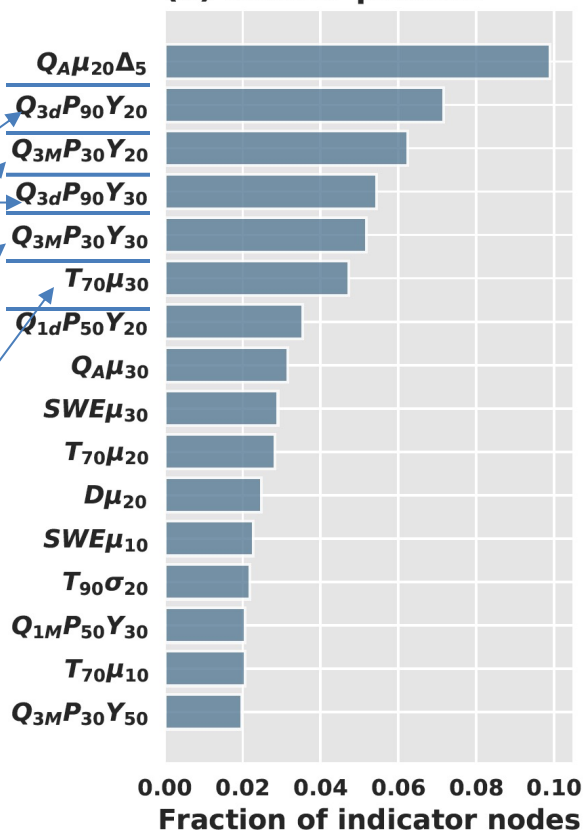
Change in long-term average annual flow

Peak flows (90th pctile over 20-year window)

Seasonal low flows (30th pctile over 20/30-year window)

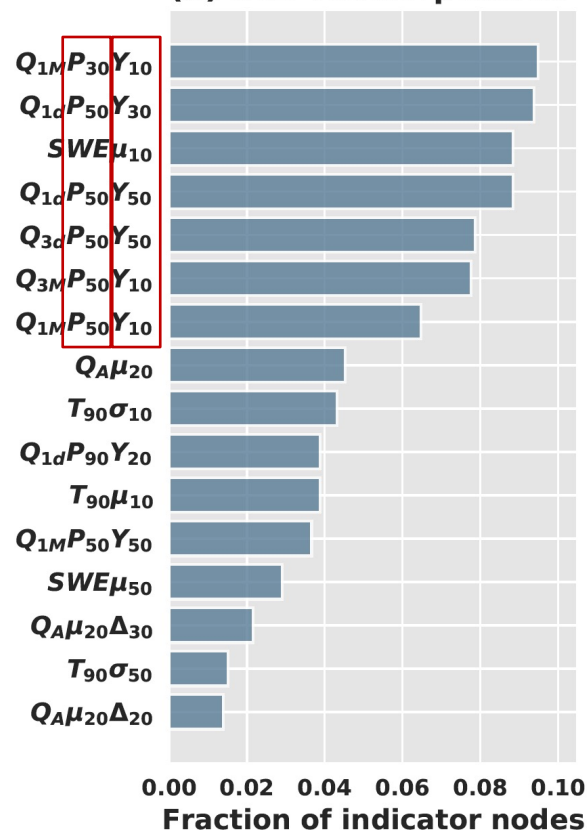
Seasonal flow timing (70%, 30-year window)

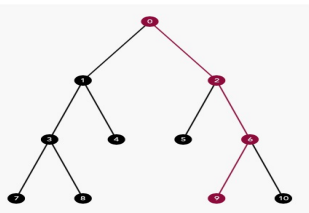
(a) Robust policies



Median instead of high/low percentiles
10/50 year windows instead of 20/30

(b) Non-robust policies



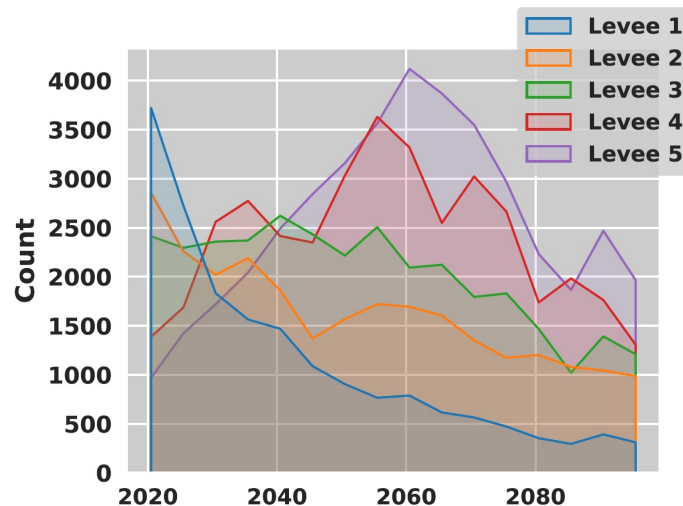
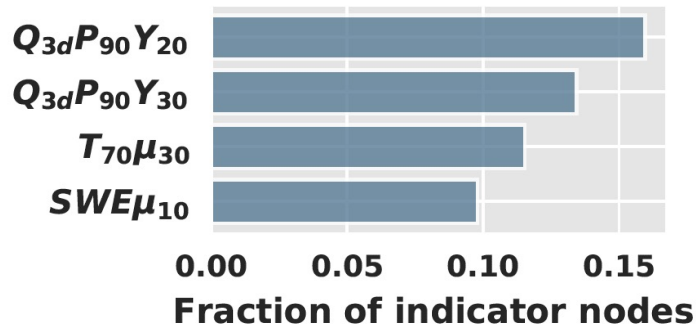


How and when are actions triggered?

← Fraction of indicators that are “ancestor” nodes to each action in the robust policies

Example: Levee expansion

Peak flows,
timing,
snowpack



- The indicators that trigger levee expansion are associated with flood risk
- Irreversible infrastructure actions are sequenced in order of magnitude, which was not constrained in the problem formulation

Policy trees for dynamic adaptation under uncertainty

- Optimization of policy structure: indicators, actions, thresholds
- Robust policies are not differentiated by actions, but by the indicators used to trigger them
- Indicators for robust policies balance adapting quickly vs. correctly, and can be interpreted in the context of physically-based hydrologic trends

References & Software



Research group
website

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Cohen, Zeff, and Herman (2020) “Adaptation of multi-objective reservoir operations to snowpack decline in the Western United States”. *Journal of Water Resources Planning and Management*.

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Robinson, Cohen, and Herman (2020) “Detecting early warning signals of long-term water supply vulnerability using machine learning”, *Env. Modelling & Software*.

Reservoir simulation model: <https://github.com/jscohen4/orca>

Policy tree optimization: <https://github.com/jdherman/ptreeopt>