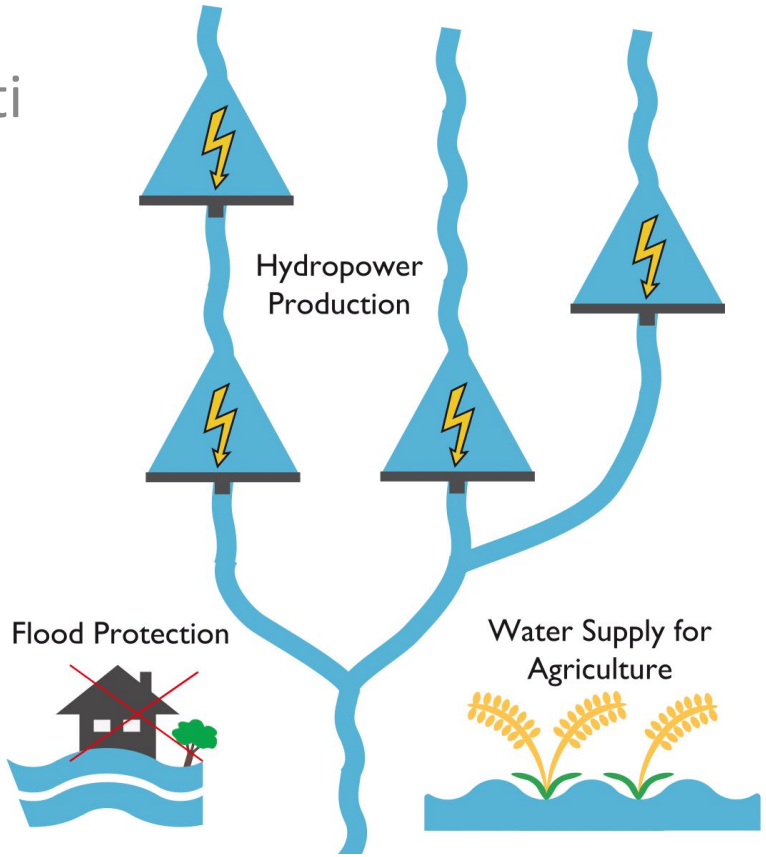
Conflict, Coordination, & Control:

Do we understand the actual rules used to balance flooding, energy, and ag tradeoffs?

Julianne Quinn, Patrick Reed*,

Matteo Giuliani and Andrea Castelletti



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1 November 2021


The New York Times
The Fight to Tame a Swelling River With Dams That May Be Outmatched by Climate Change
Along the Missouri, John Remus controls a network of dams that dictates the fate of millions. 'It was not designed to handle this.'
March 21, 2019

Key Points

Model-based understanding of the complex evolution of food-energy-water systems as well as their “risks” and “resilience”

1. Must be able to capture extremes and real failure modes.

2. Is heavily influenced by human preferences, tradeoffs in conflicting demands, and high-fidelity representations of candidate actions

3. Should create a platform for understanding *state-action-consequence feedbacks* as a function of the information available to the actual humans managing the systems

Red River Basin

Second largest river basin in Vietnam

Capital city of Hanoi sits in delta, threatened by floods

In 2002, UNDP estimated annual damages of 130M USD in the delta, 50M USD in Hanoi[1]

[1]Hansson, K., and Ekenberg, L. (2002). Flood Mitigation Strategies for the Red River Delta, in: International Conference on Environmental Engineering, An International Perspective on Environmental Engineering, Canada.

Red River Basin

To provide flood protection to Hanoi and the delta, the Vietnamese government has started constructing reservoirs

But how should they be coordinated to meet multi-sector demands?

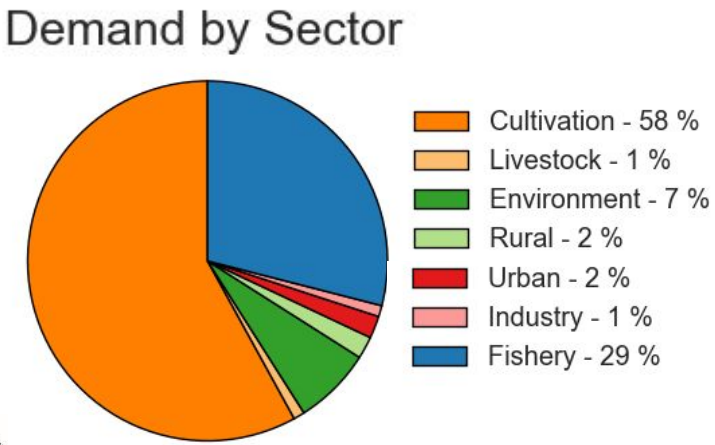
Multi-sector reservoir demands

Dams provide hydropower

Hydropower currently represents 46% of Vietnam's total installed electric power capacity

Reservoirs provide water supply

70% of Vietnamese population employed in agriculture,
76% of Vietnamese agriculture is irrigated



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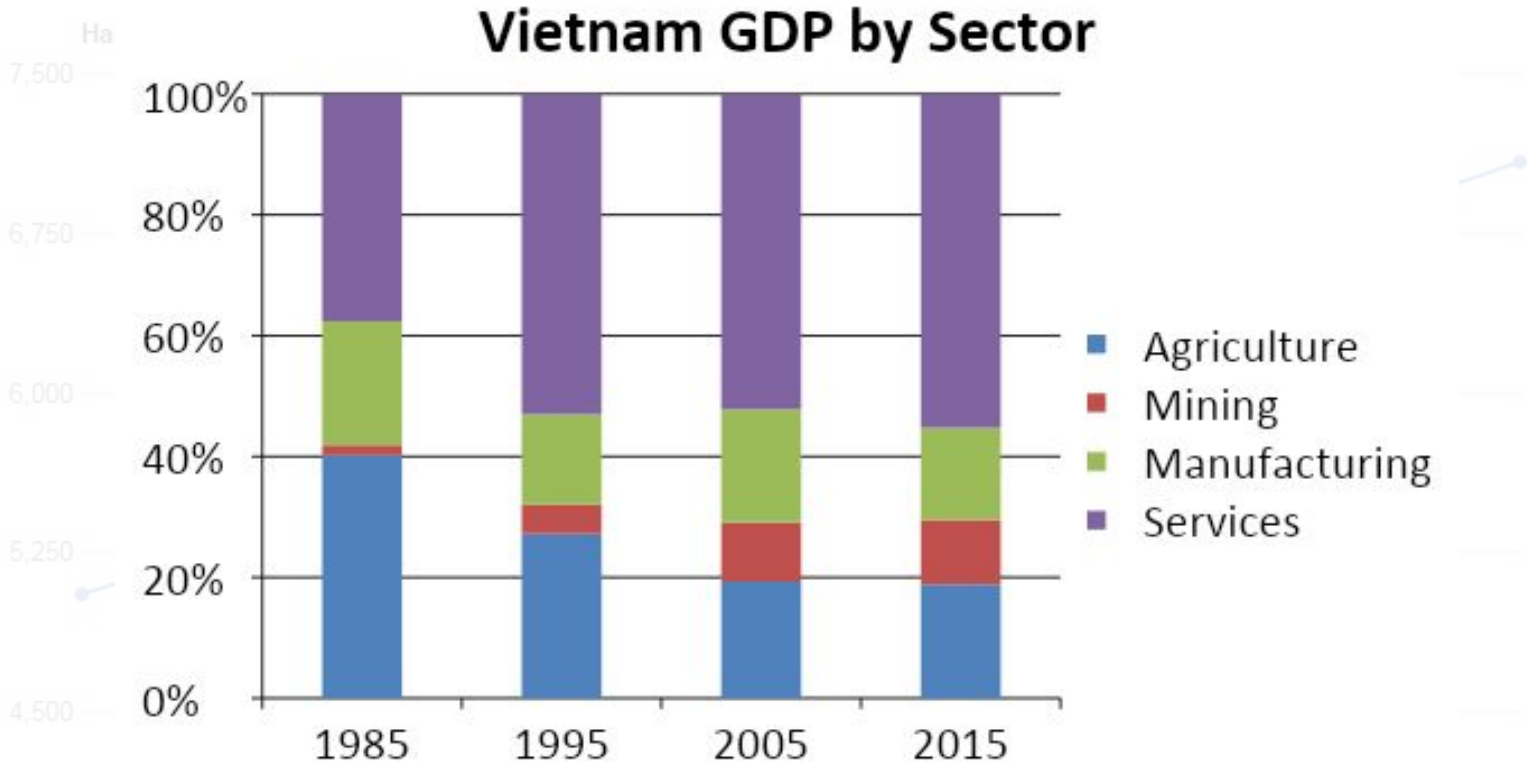
But will these demands change? How?



Population growth Urbanization Changing diets Increased demands

Will the climate change? How?

Vietnam Feels the Heat of a 100-Year Drought

TIME

By Martha Ann Overland / Hanoi | Thursday, Mar. 04, 2010

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Every year, even at the peak of Vietnam's dry season, when the Red River is at its lowest, Hanoi's skilled captains manage to negotiate their flat-bottomed boats through its shallow waters. But this year, with a drought gripping the entire country and water levels at record lows, the river is eerily quiet. What is normally a bustling waterway is becoming a winding river of sand, and farmers who depend upon the river for irrigation are watching the expanding sandbars as nervously as the boat captains. "If there is no water in the coming days," says 59-year-old farmer Vu Thi La, who just put in her spring rice seedlings, "it will all die."

Nguyen Huy Kham / Reuters

The dried-up bed of the Red River, near Long Bien Bridge in Hanoi on Dec. 1, 2009

ASIA PACIFIC

The New York Times

Drought and 'Rice First' Policy Imperil Vietnamese Farmers

By JANE PERLEZ MAY 28, 2016

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VIETNAM-IN-PHOTOS

Last update 11:17 | 25/07/2017

Red River rising

The water level of the Red River has been rising sharply in I discharge from the Hoa Binh Hydropower Plant reservoir.

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Red River System Goals

How should we translate and evaluate these narrative goals in our models?

Find operations for four largest reservoirs that

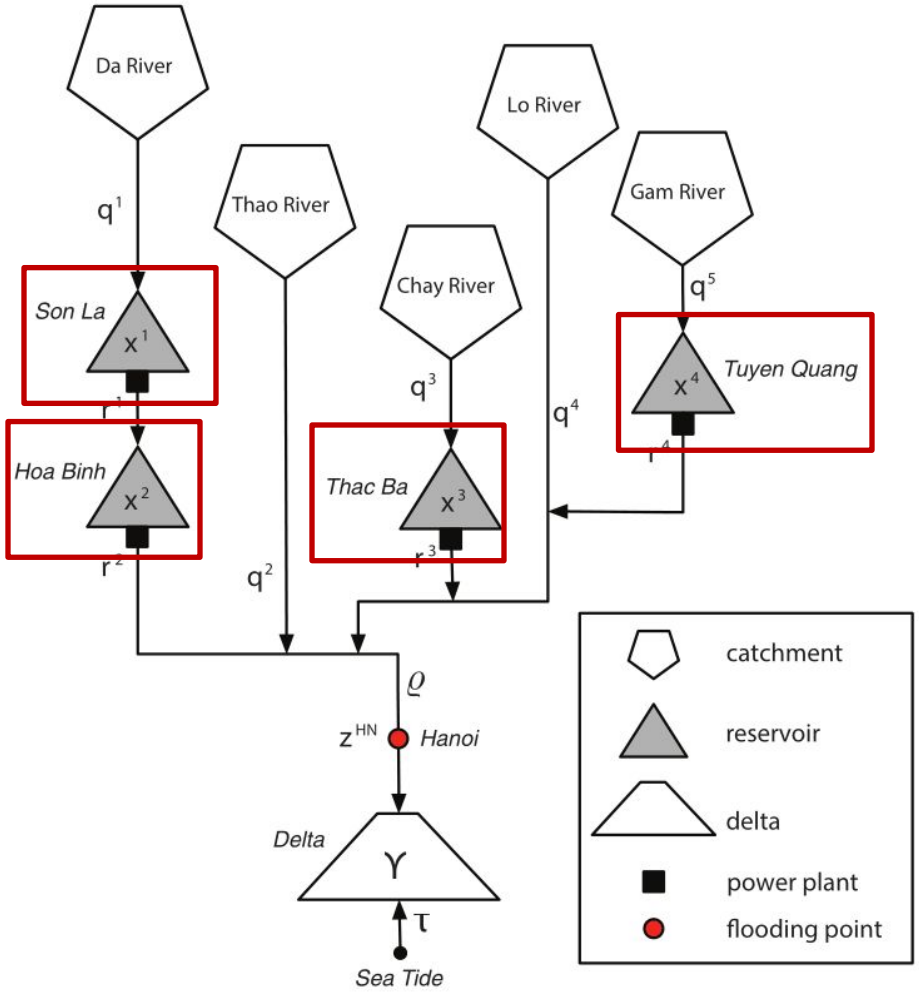
1) Maximize Hydropower Production

2) Minimize Water Supply Deficit

3) Minimize Flooding at Hanoi

and are robust to deep uncertainties

Red River System



Official Guidelines

Flood Season | **Dry Season** | **Between Seasons**

Determine SL release, u_t^{SL}

If/then/else statements that depend on:

$t, s_t^{SL}, s_t^{HB}, s_t^{TQ}, \tilde{z}_{t+1}^{HN}$

Determine HB release, u_t^{HB}

If/then/else statements that depend on:

$t, r_t^{SL}, s_t^{HB}, s_t^{TQ}, \tilde{z}_{t+1}^{HN}$

Determine TQ release, u_t^{TQ}

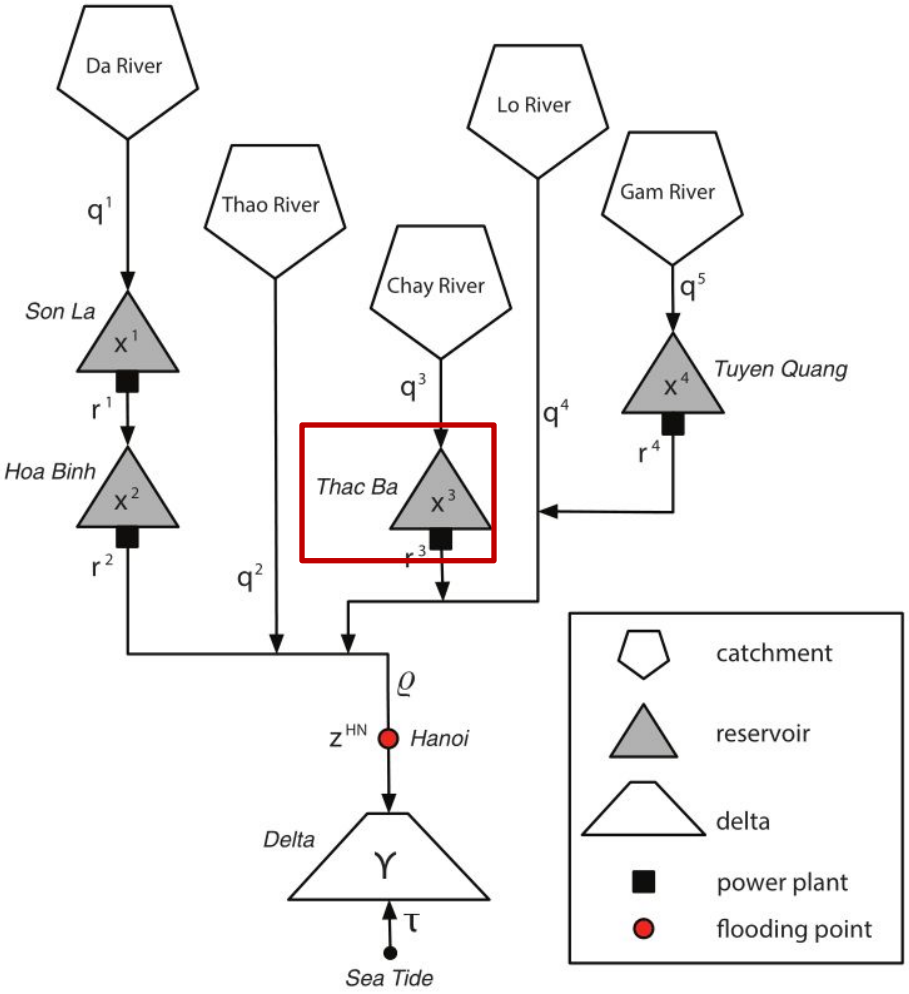
If/then/else statements that depend on:

$t, r_t^{HB}, s_t^{HB}, s_t^{TQ}, \tilde{z}_{t+1}^{HN}$

Determine TB release, u_t^{TB}

Unregulated. Use release from one of our optimized policies.

Red River System



Official Guidelines

Flood Season

Determine SL release, u_t^{SL}

Determine HB release, u_t^{HB}

Determine TQ release, u_t^{TQ}

Determine TB release, u_t^{TB}

Dry Season

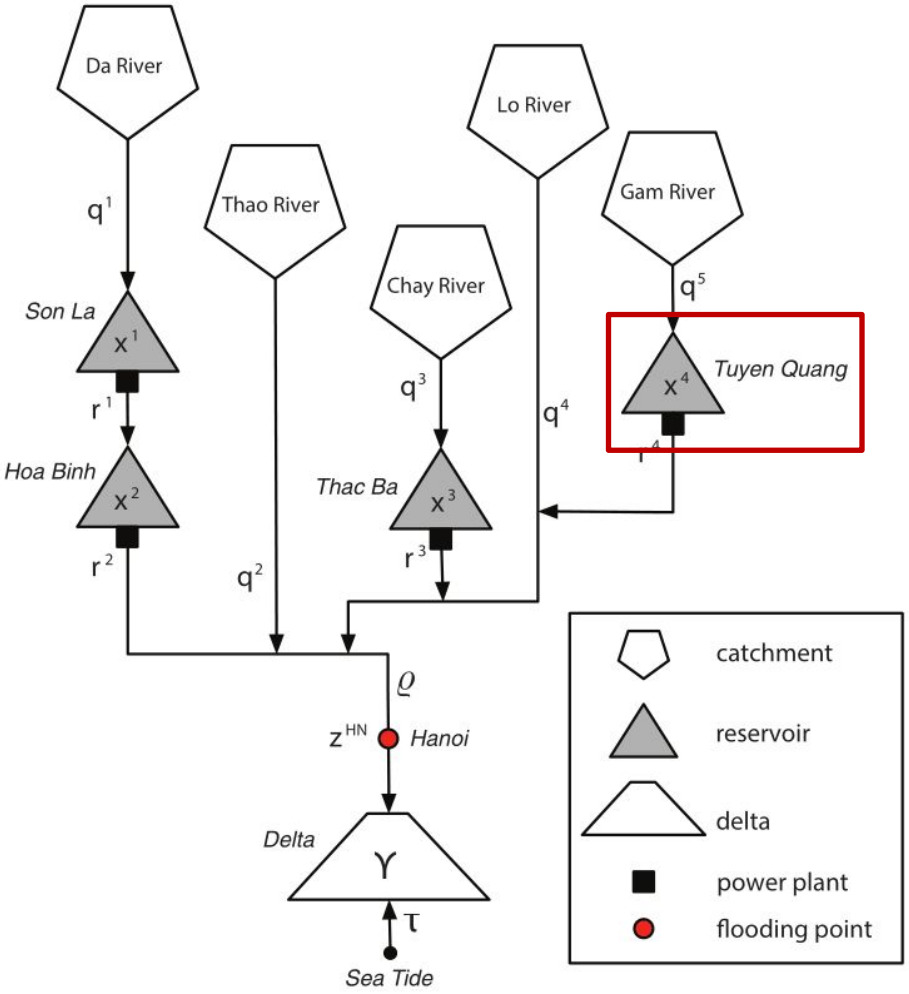
Determine TB release, u_t^{TB}

If $s_t^{TB} < s_t^{TB,\ lower\ target}$: $u_t^{TB} = 0$

Else: $u_t^{TB} = u_t^{TB,\ min}$

Between Seasons

Red River System



Official Guidelines

Flood Season

Determine SL release, u_t^{SL}

Determine HB release, u_t^{HB}

Determine TQ release, u_t^{TQ}

Determine TB release, u_t^{TB}

Dry Season

Determine TB release, u_t^{TB}

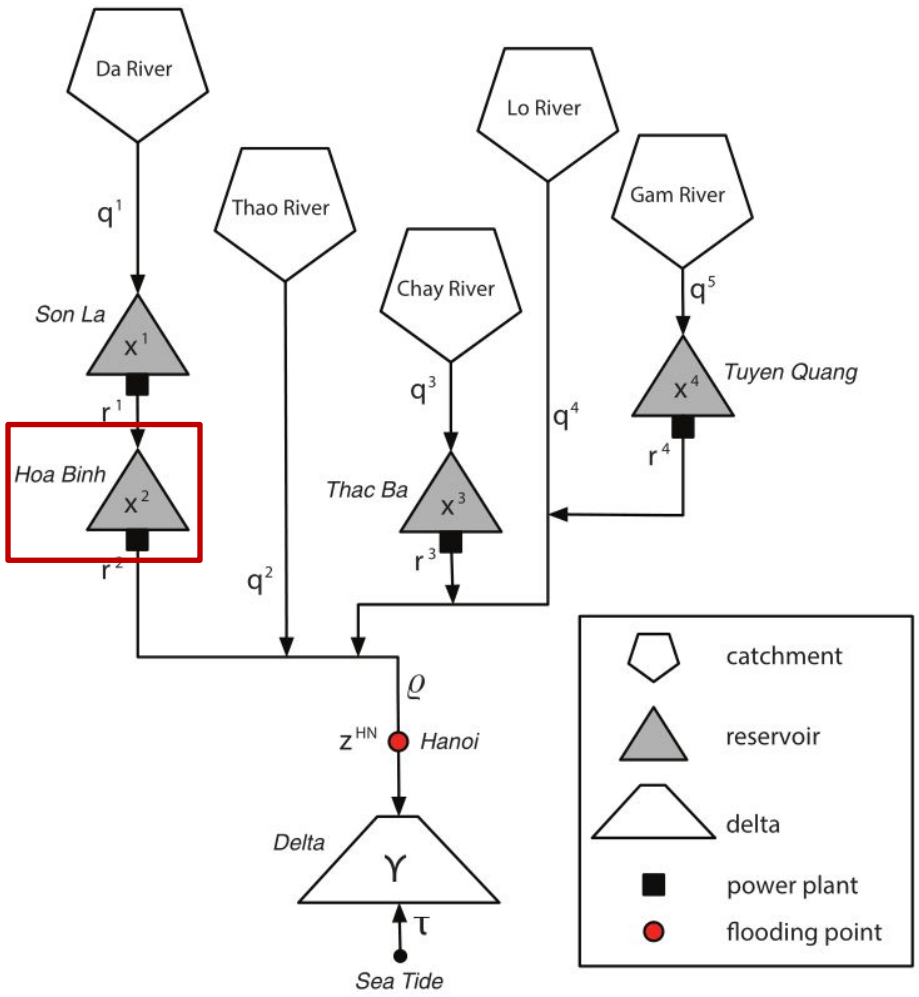
Determine TQ release, u_t^{TQ}

If $s_t^{TQ} < s_t^{TQ,\ lower\ target}$: $u_t^{TQ} = 0$

Else: $u_t^{TQ} = u_t^{TQ,\ min}$

Between Seasons

Red River System



Official Guidelines

Flood Season

Determine SL release, u_t^{SL}

Determine HB release, u_t^{HB}

Determine TQ release, u_t^{TQ}

Determine TB release, u_t^{TB}

Dry Season

Determine TB release, u_t^{TB}

Determine TQ release, u_t^{TQ}

Determine Preliminary HB release, u_t^{HB}

If t!=(27,28,41,42,55,56)

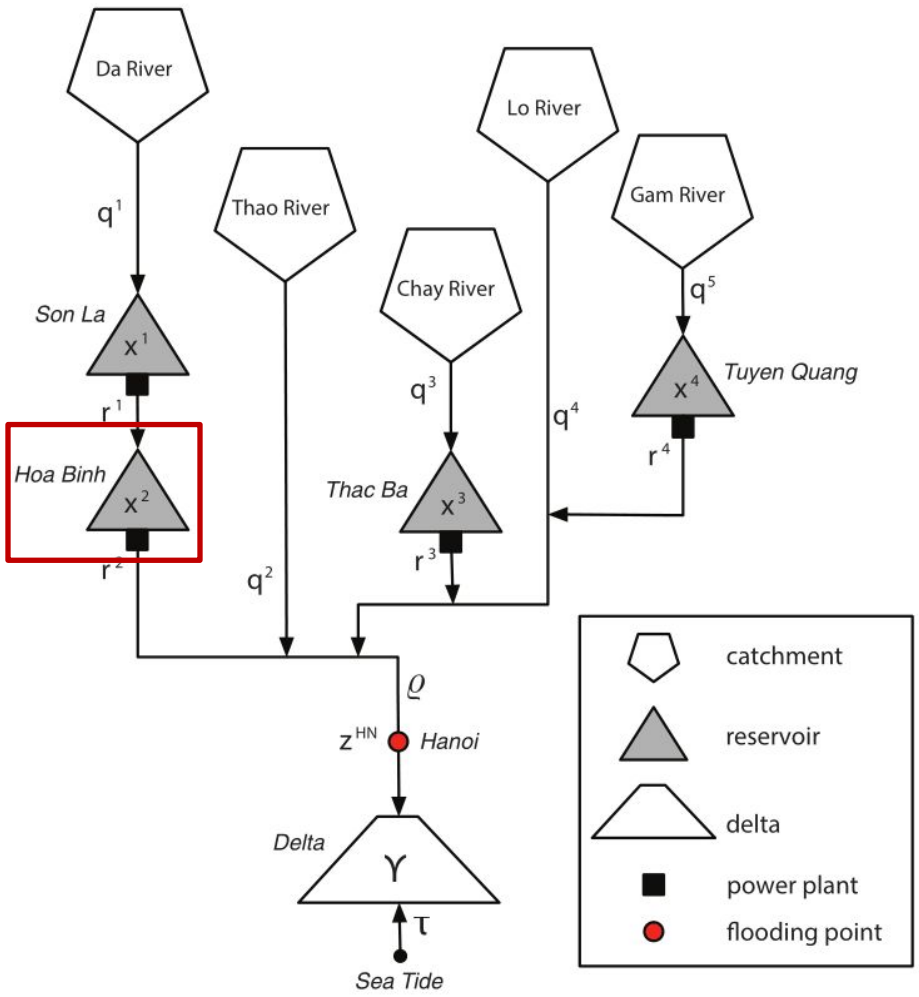
If $s_t^{HB} < s_t^{HB,\ lower\ target}$ Else

$u_t^{HB} = 0$

$u_t^{HB} = u_t^{HB,\ min}$

Between Seasons

Red River System



Official Guidelines

Flood Season

Determine SL release, u_t^{SL}

Determine HB release, u_t^{HB}

Determine TQ release, u_t^{TQ}

Determine TB release, u_t^{TB}

Dry Season

Determine TB release, u_t^{TB}

Determine TQ release, u_t^{TQ}

Determine Preliminary HB release, u_t^{HB}

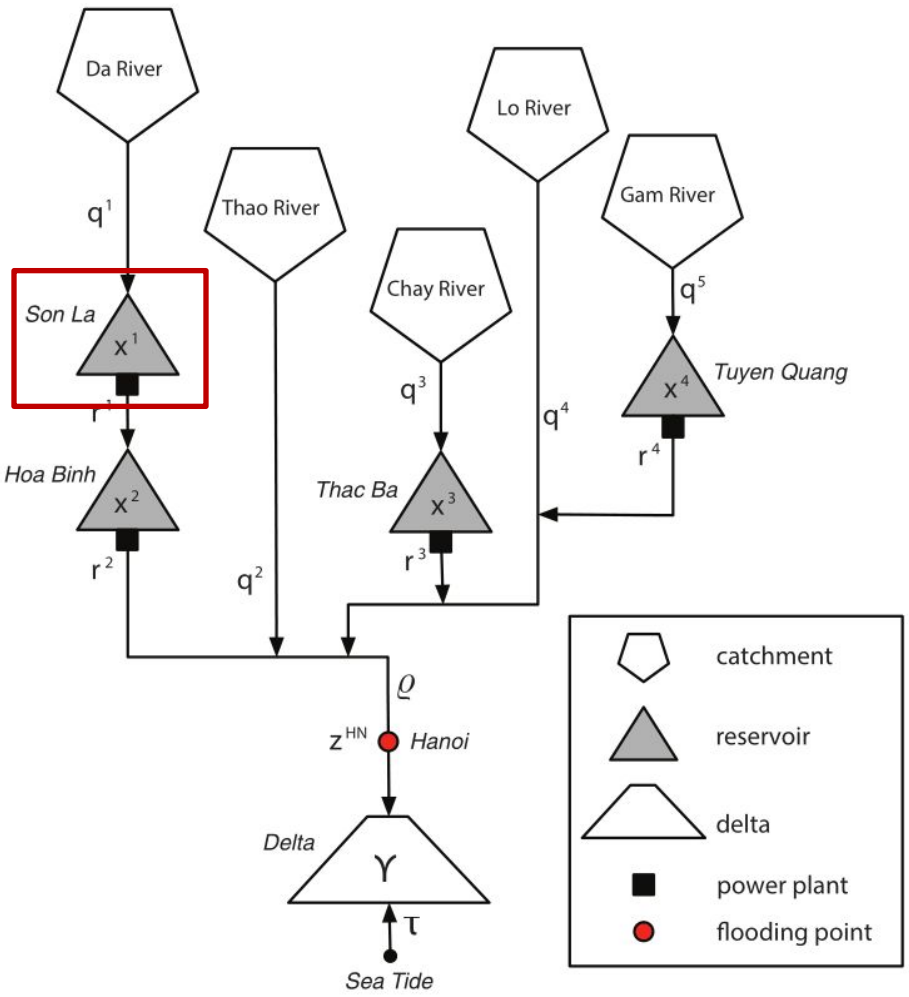
If t=(27,28,41,42,55,56)

If $Q^{dry,lim} - q_{t+1}^{TOT} < 0$ Else

$u_t^{HB} = 0$ $u_t^{HB} = Q^{dry,lim} - q_{t+1}^{TOT}$

Between Seasons

Red River System



Official Guidelines

Flood Season

Determine SL release, u_t^{SL}

Determine HB release, u_t^{HB}

Determine TQ release, u_t^{TQ}

Determine TB release, u_t^{TB}

Dry Season

Determine TB release, u_t^{TB}

Determine TQ release, u_t^{TQ}

Determine Preliminary HB release, u_t^{HB}

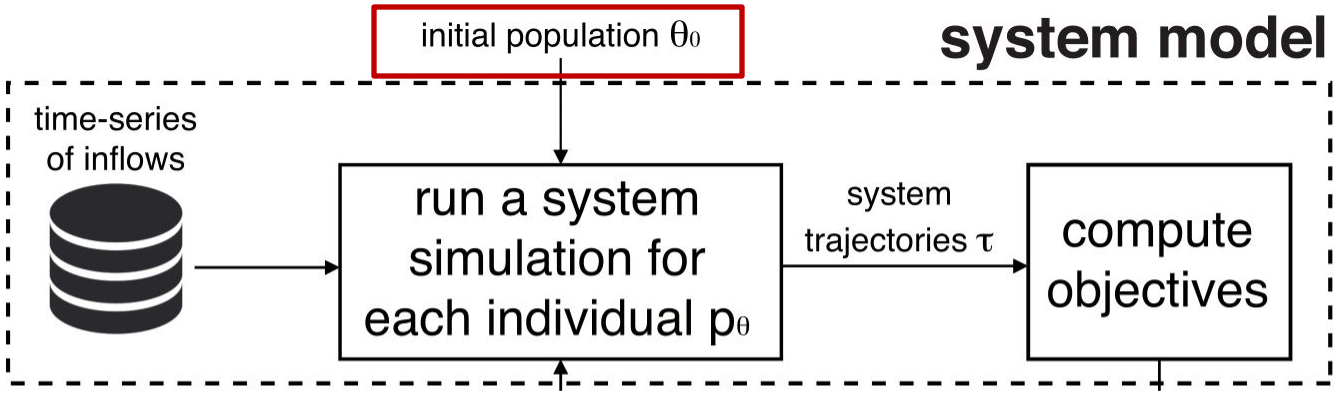
Determine SL release, u_t^{SL}

u_t^{SL} = max(0,q needed to raise s_t^{HB} to $s_t^{HB,\ lower\ target}$)

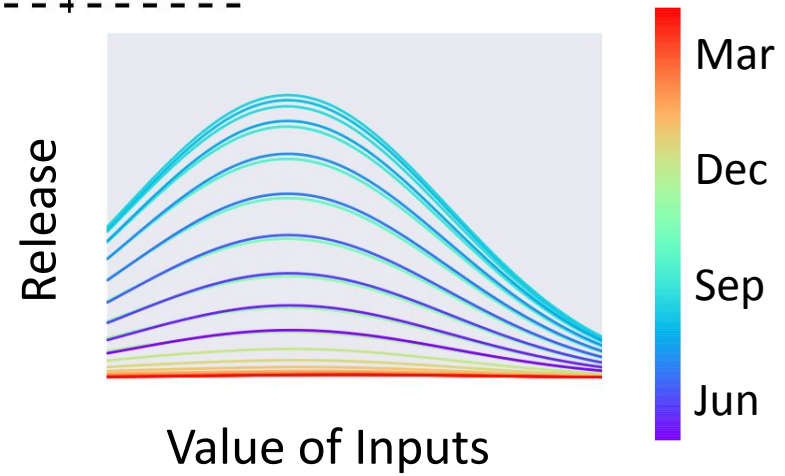
Between Seasons

Evolutionary Multi-Objective Direct Policy Search (EMODPS)

Computationally efficient method for solving high-dimensional, multi-objective control problems

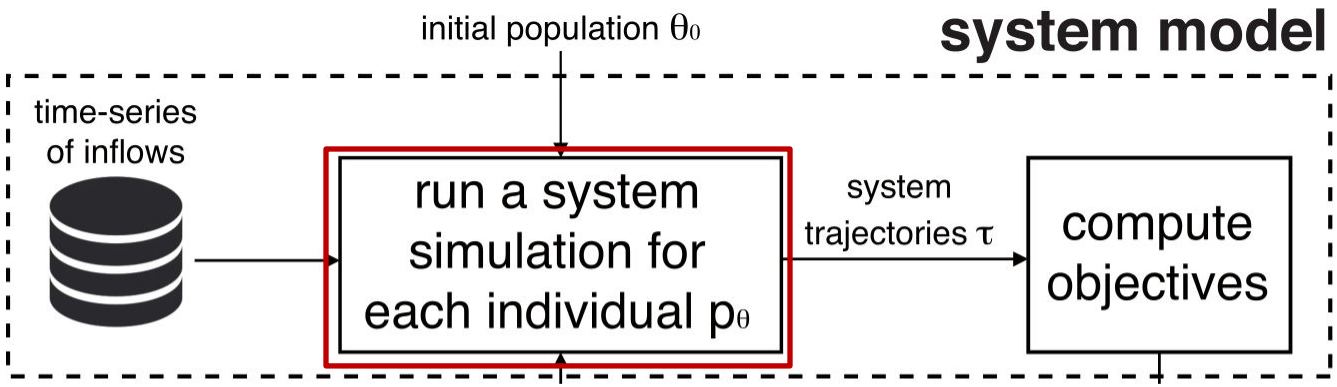


Step 1: Parameterization

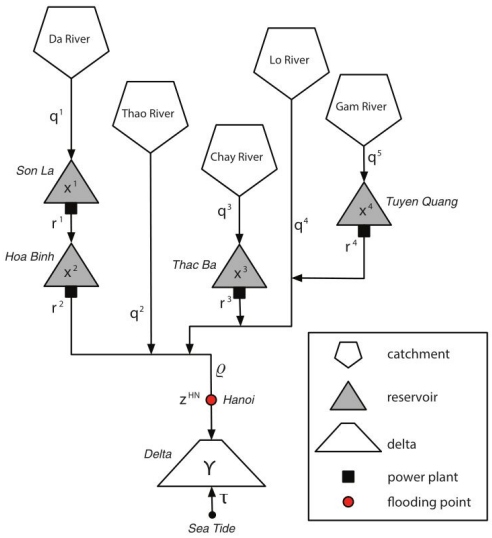


Evolutionary Multi-Objective Direct Policy Search (EMODPS)

Computationally efficient method for solving high-dimensional, multi-objective control problems



Step 2: Simulation



Evolutionary Multi-Objective Direct Policy Search (EMODPS)

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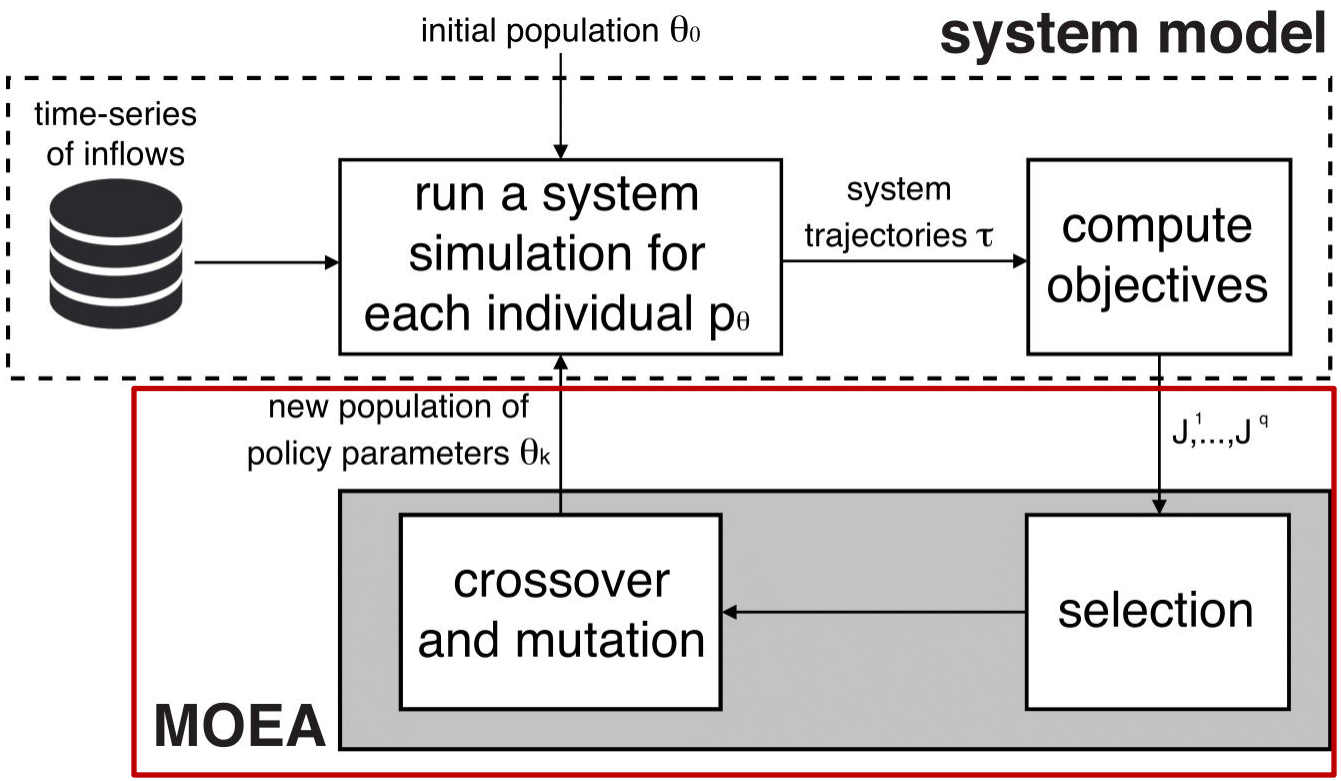
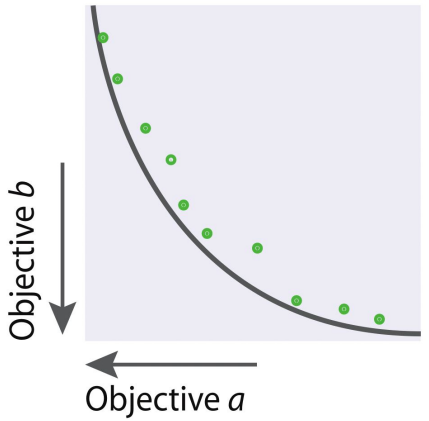
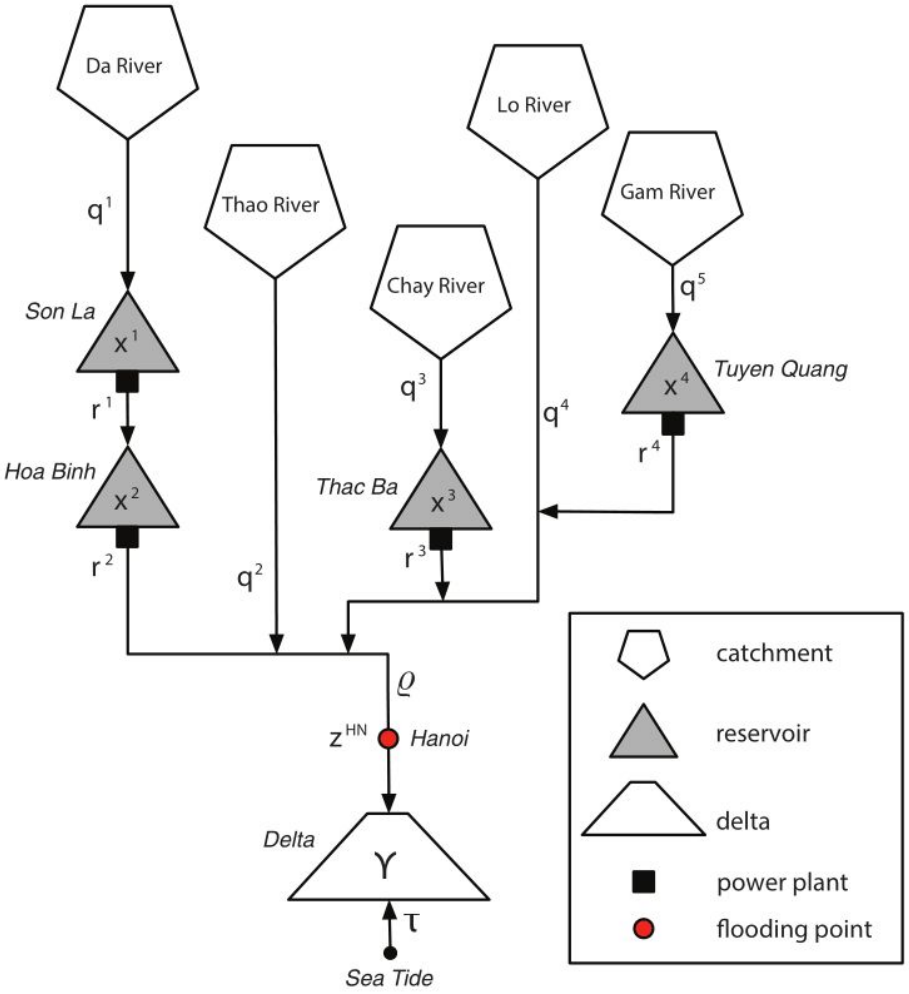


Step 3: Optimization



Red River System

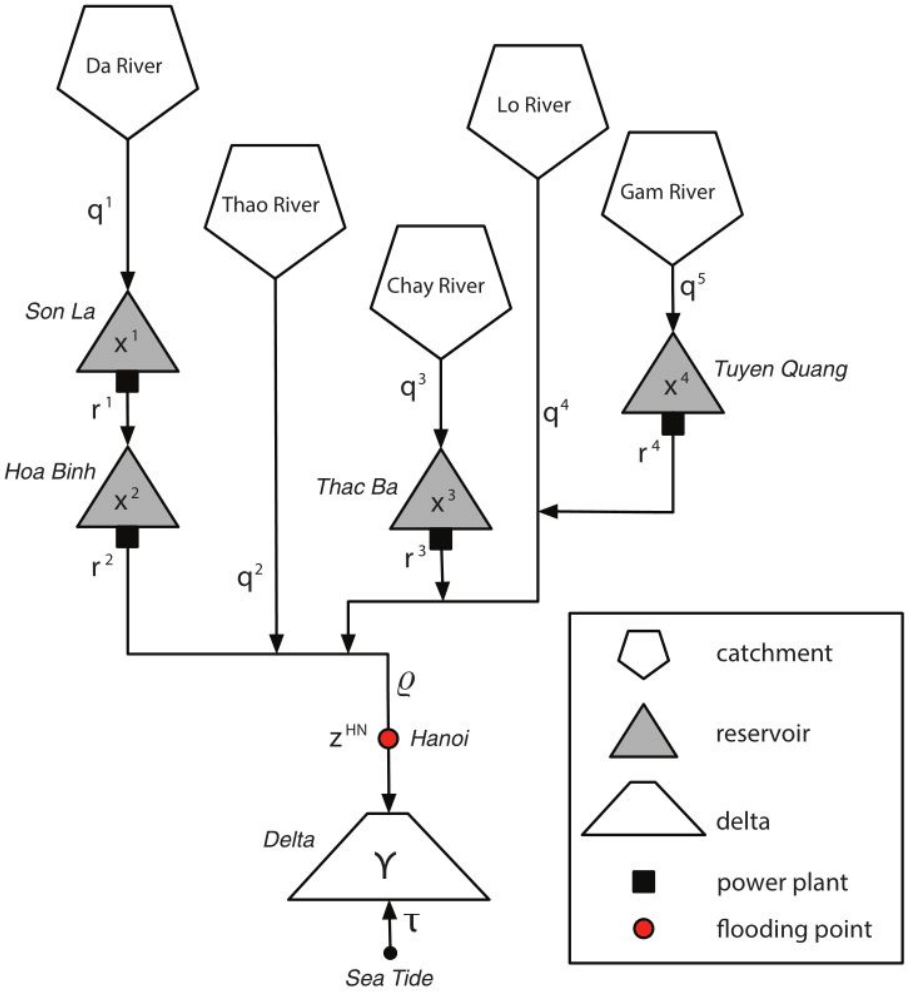


EMODPS Policies

$$u_t^k = \sum_{i=1}^{n} w_i^k \exp\left(-\sum_{j=1}^{M} \left(\frac{(x_t)_j - c_{i,j}}{b_{i,j}} \right)^2 \right)$$

$$u_t = \text{outputs} = \left\{ u_t^{SL}, u_t^{HB}, u_t^{TQ}, u_t^{TB} \right\}$$

Red River System



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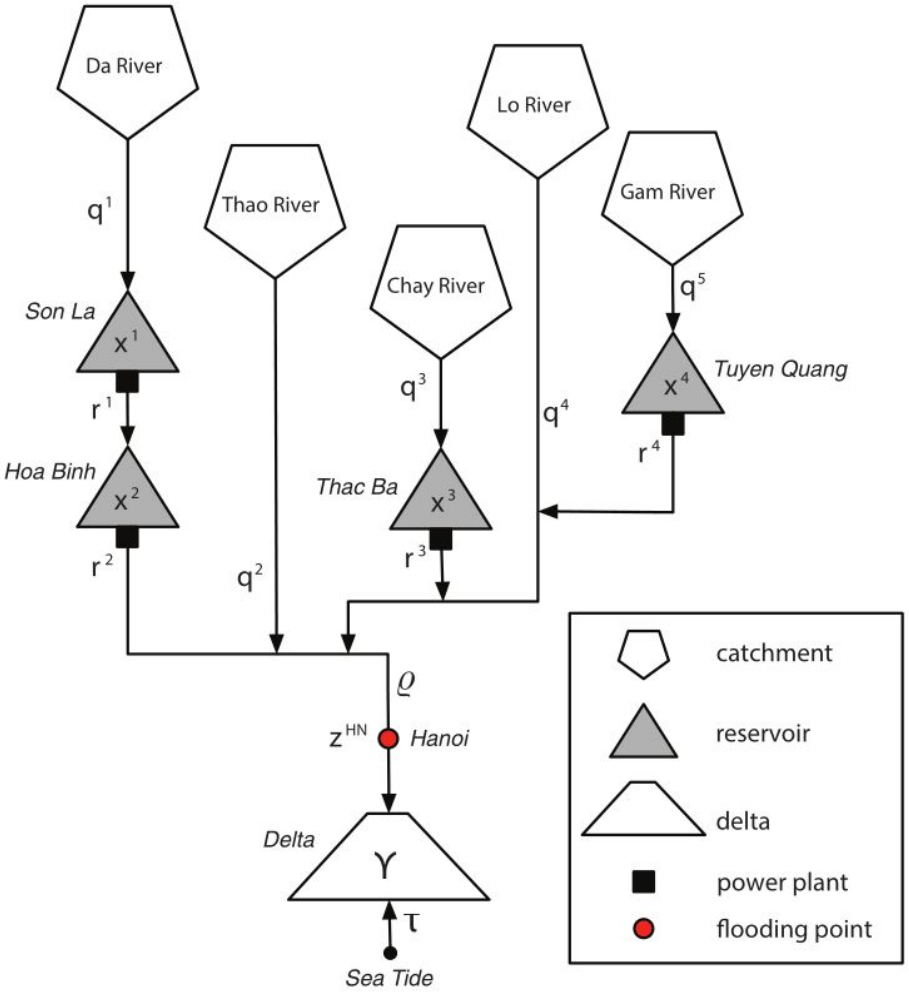
u_t = outputs = $\left\{u_t^{SL}, u_t^{HB}, u_t^{TQ}, u_t^{TB}\right\}$

x_t = inputs = $\left\{\begin{matrix} s_t^{SL}, s_t^{HB}, s_t^{TQ}, s_t^{TB}, \tilde{z}_{t+1}^{HN}, \\ \sin\left(\frac{2\pi t}{365} - \varphi_1\right), \cos\left(\frac{2\pi t}{365} - \varphi_2\right) \end{matrix}\right\}$

Red River System



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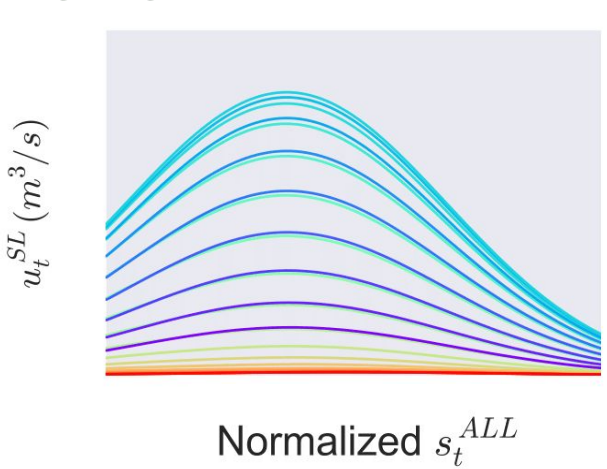
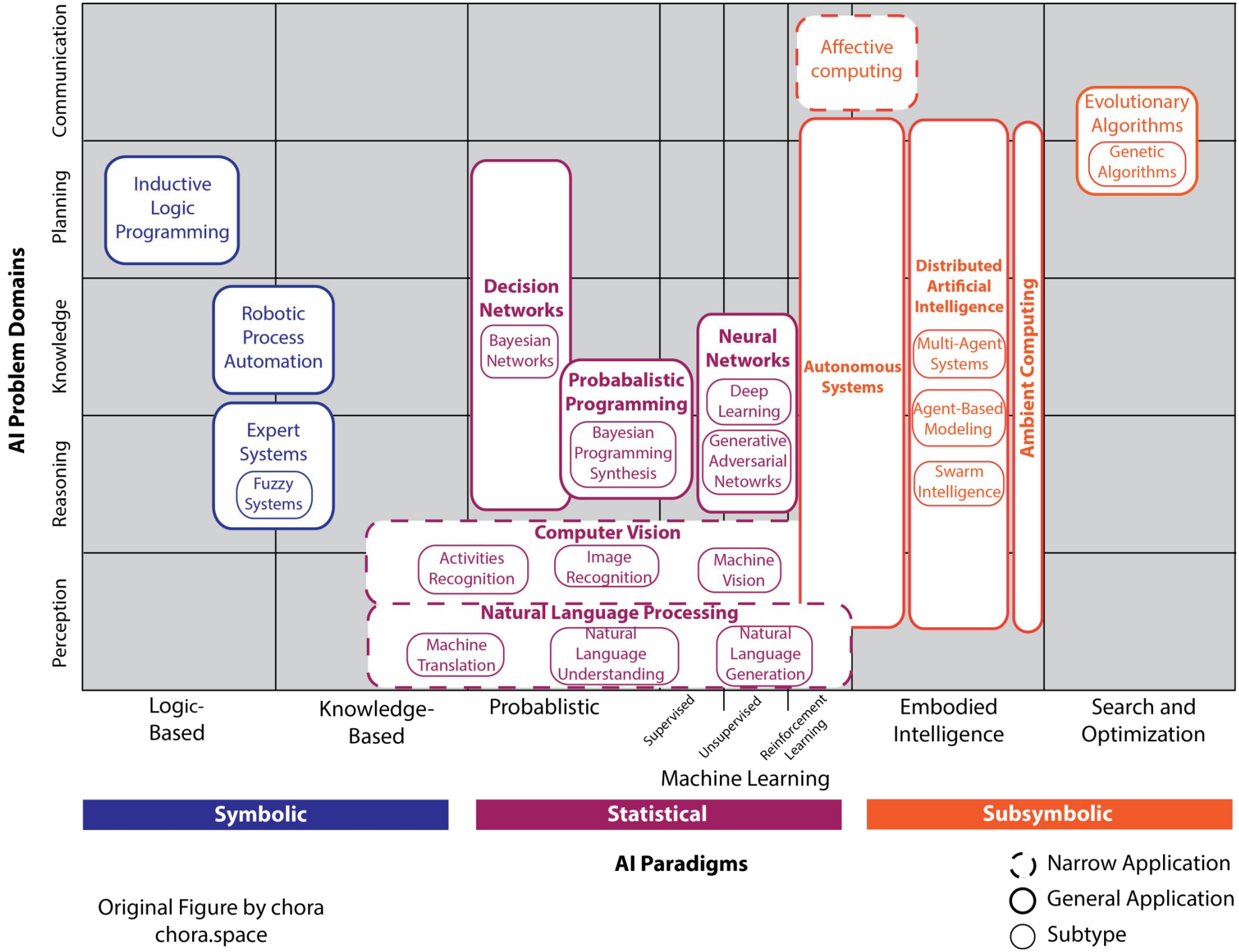
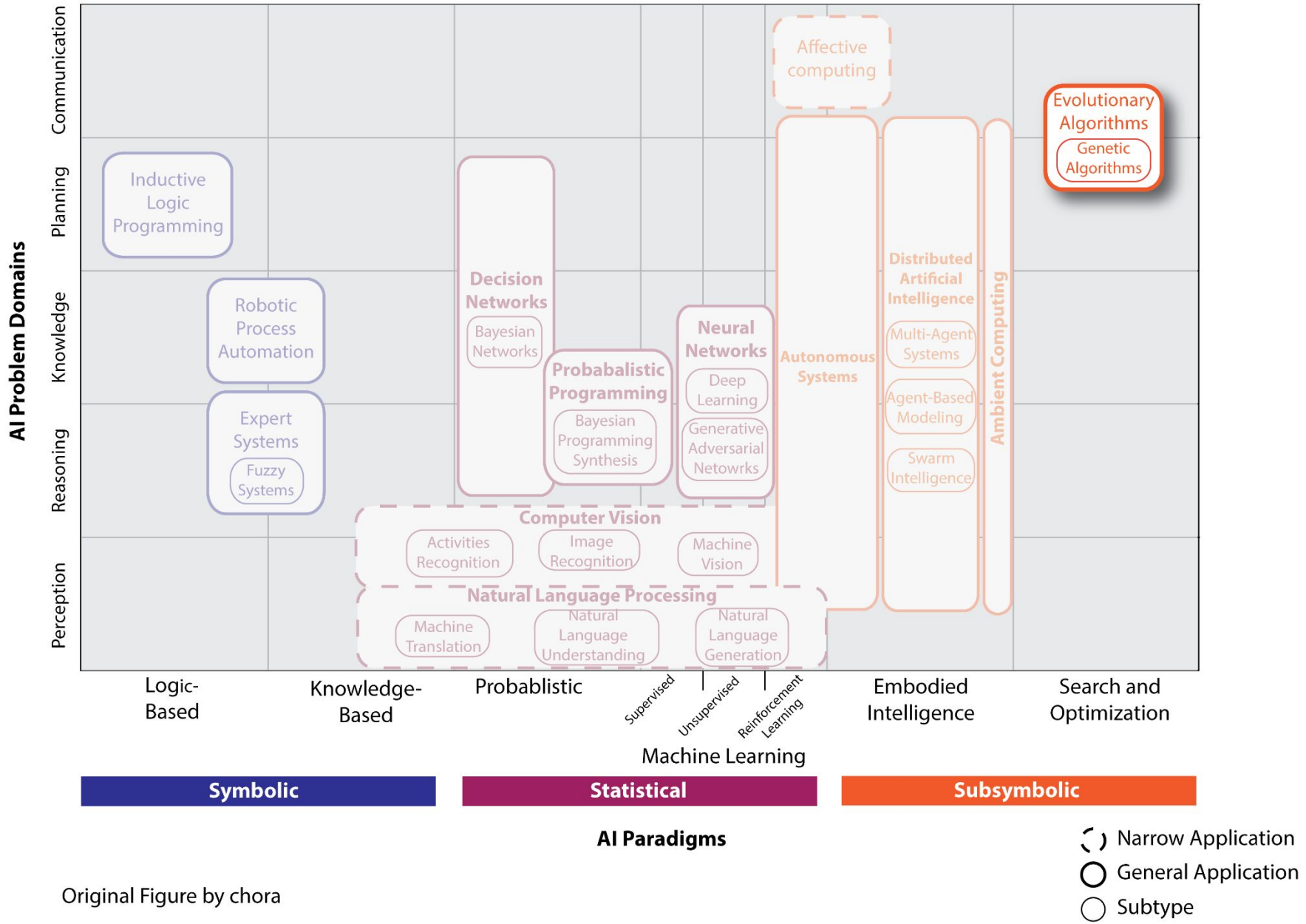
w_i^k, $c_{i,j}$, $b_{i,j}$, φ_1, φ_2 = decision variables




AI Problem Domains
Communication
Planning
Knowledge
Reasoning
Perception
Inductive Logic Programming
Robotic Process Automation
Expert Systems
Fuzzy Systems
Decision Networks
Bayesian Networks
Probabalistic Programming
Bayesian Programming Synthesis
Neural Networks
Deep Learning
Generative Adversarial Netowrks
Affective computing
Autonomous Systems
Distributed Artificial Intelligence
Multi-Agent Systems
Agent-Based Modeling
Swarm Intelligence
Ambient Computing
Evolutionary Algorithms
Genetic Algorithms
Computer Vision
Activities Recognition
Image Recognition
Machine Vision
Natural Language Processing
Machine Translation
Natural Language Understanding
Natural Language Generation
Logic-Based
Knowledge-Based
Probablistic
Supervised
Unsupervised
Reinforcement Learning
Embodied Intelligence
Search and Optimization
Machine Learning
Symbolic
Statistical
Subsymbolic
AI Paradigms
Narrow Application
General Application
Subtype
Original Figure by chora
chora.space



Original Figure by chora

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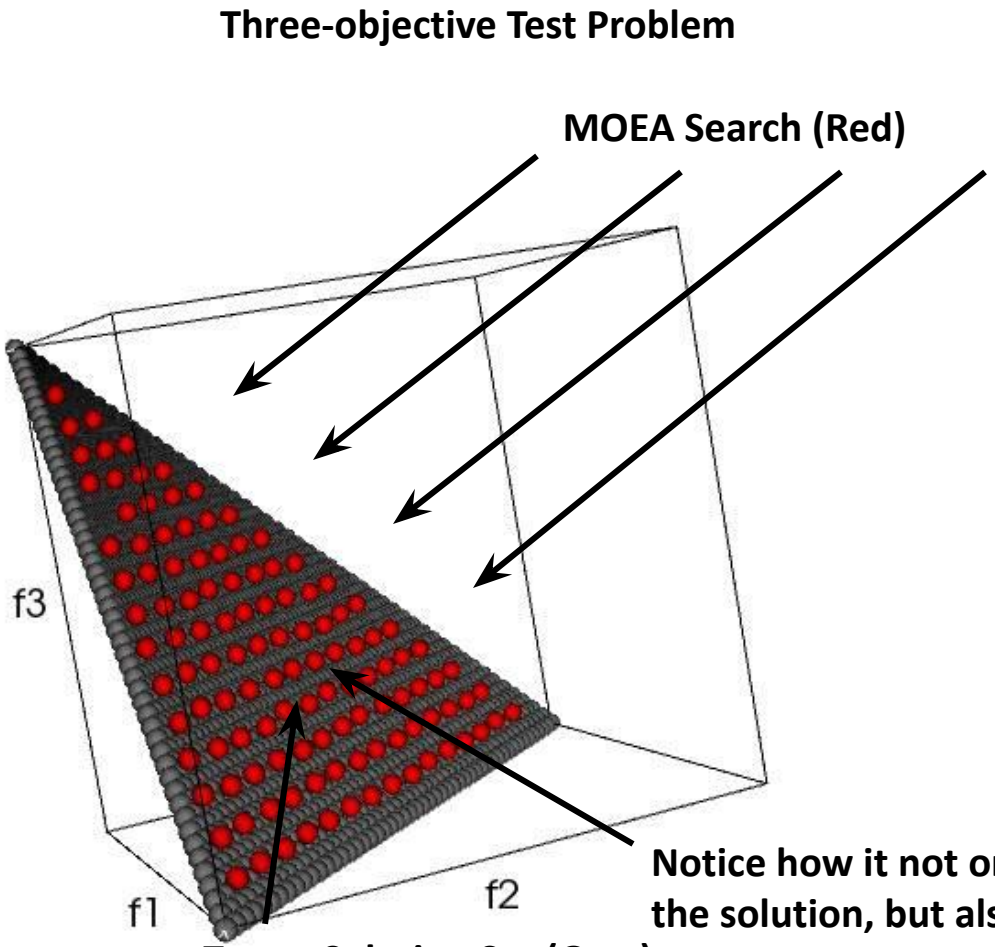
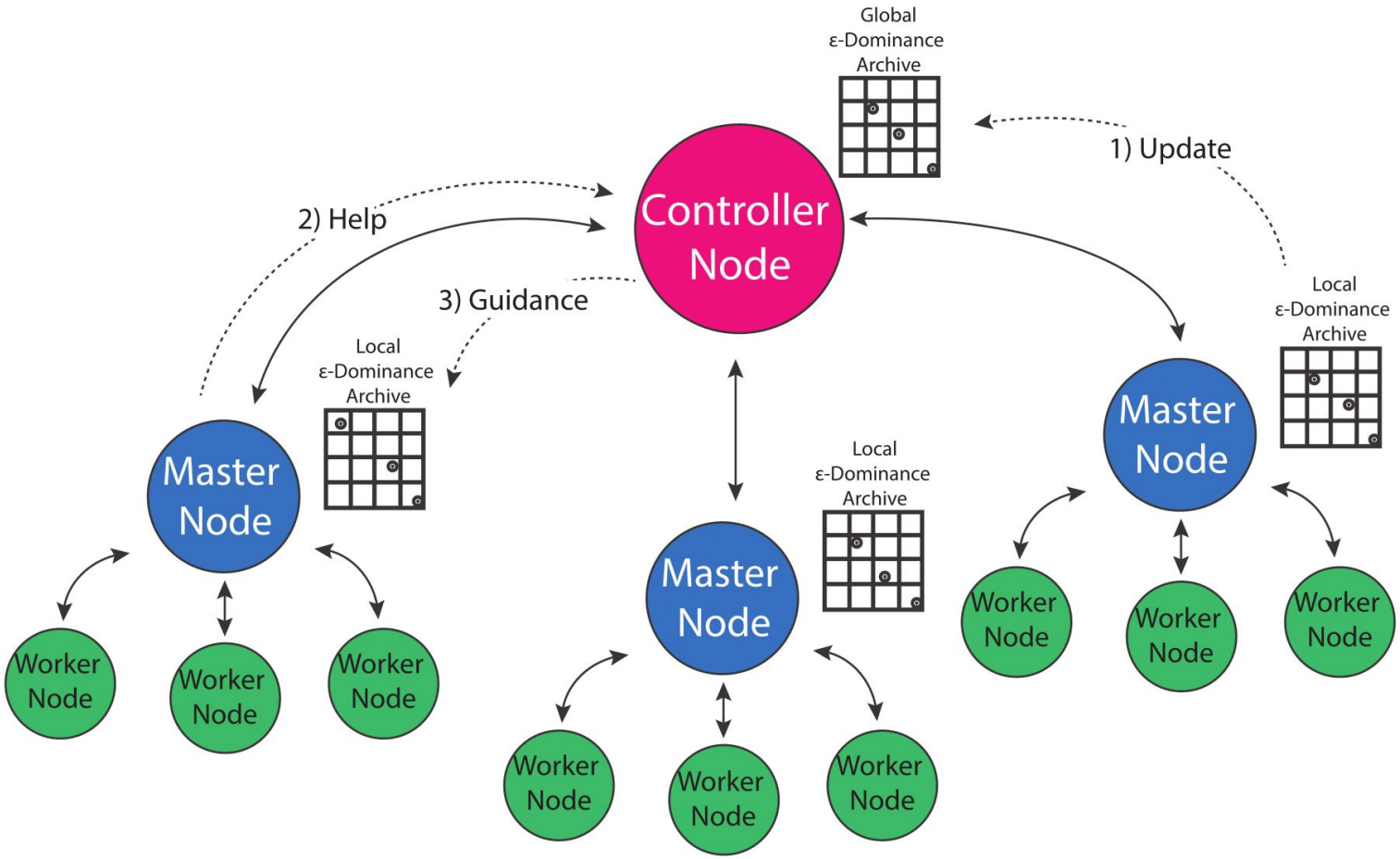
Many-Objective Tradeoffs



Visual analytics:

- *Understand* search
- *Avoid errors* or *wasted effort* due to arbitrary termination choices
- Provide *meaningfully comparisons* of formulations/algorithms
- Allow stakeholders to see the *full context* of what was gained

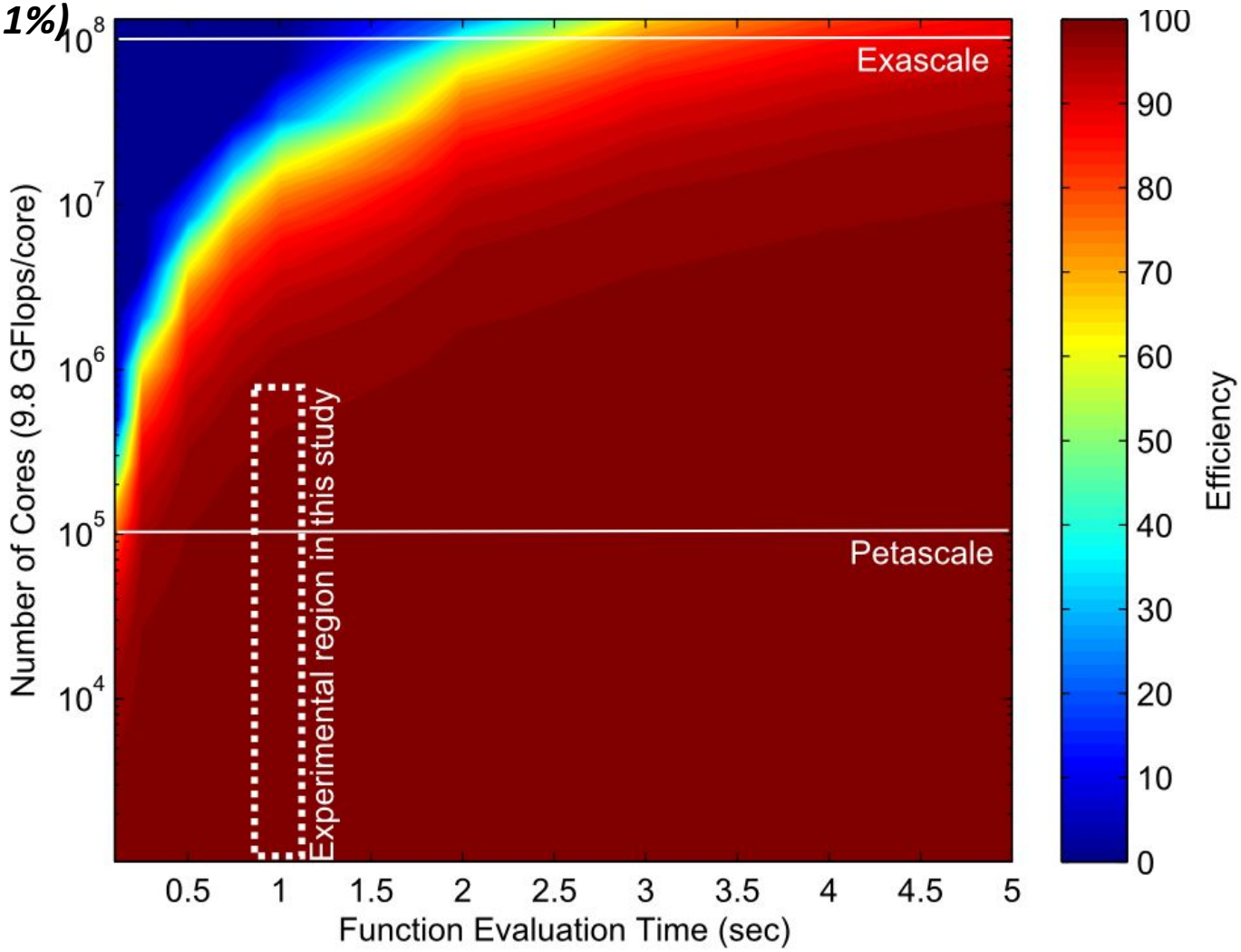
Borg MOEA Parallelization



Hadka, D., and Reed, P.M., "Large-scale Parallelization of the Borg MOEA for Many-Objective Optimization of Complex Environmental Systems", Environmental Modelling & Software, v69, 353-369, 2015.

Monte Carlo Simulation of Scalability of Search

Theoretical Scaling from Discrete Event Simulation (accurate to within 0.1%)



Reed, P.M. and Hadka, D., "Evolving Many-Objective Water Management to Exploit Exascale Computing", Water Resources Research, v50, n10, 8367–8373, 2014.

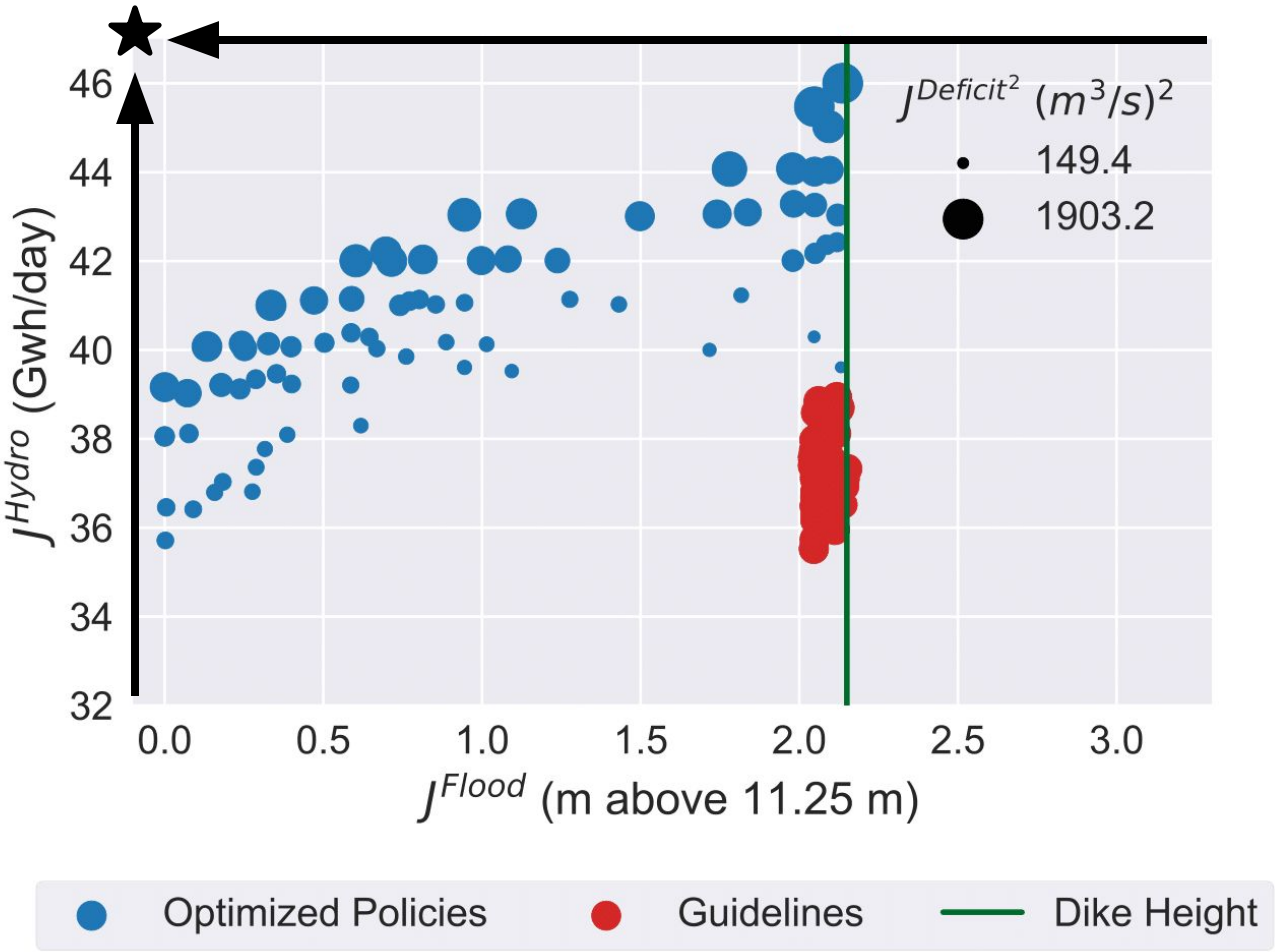
Official Control Rules vs. EMODPS Polices

So, how do these approaches compare?

Objective Comparison

Guidelines are fully dominated, and domination should increase with # of reservoirs

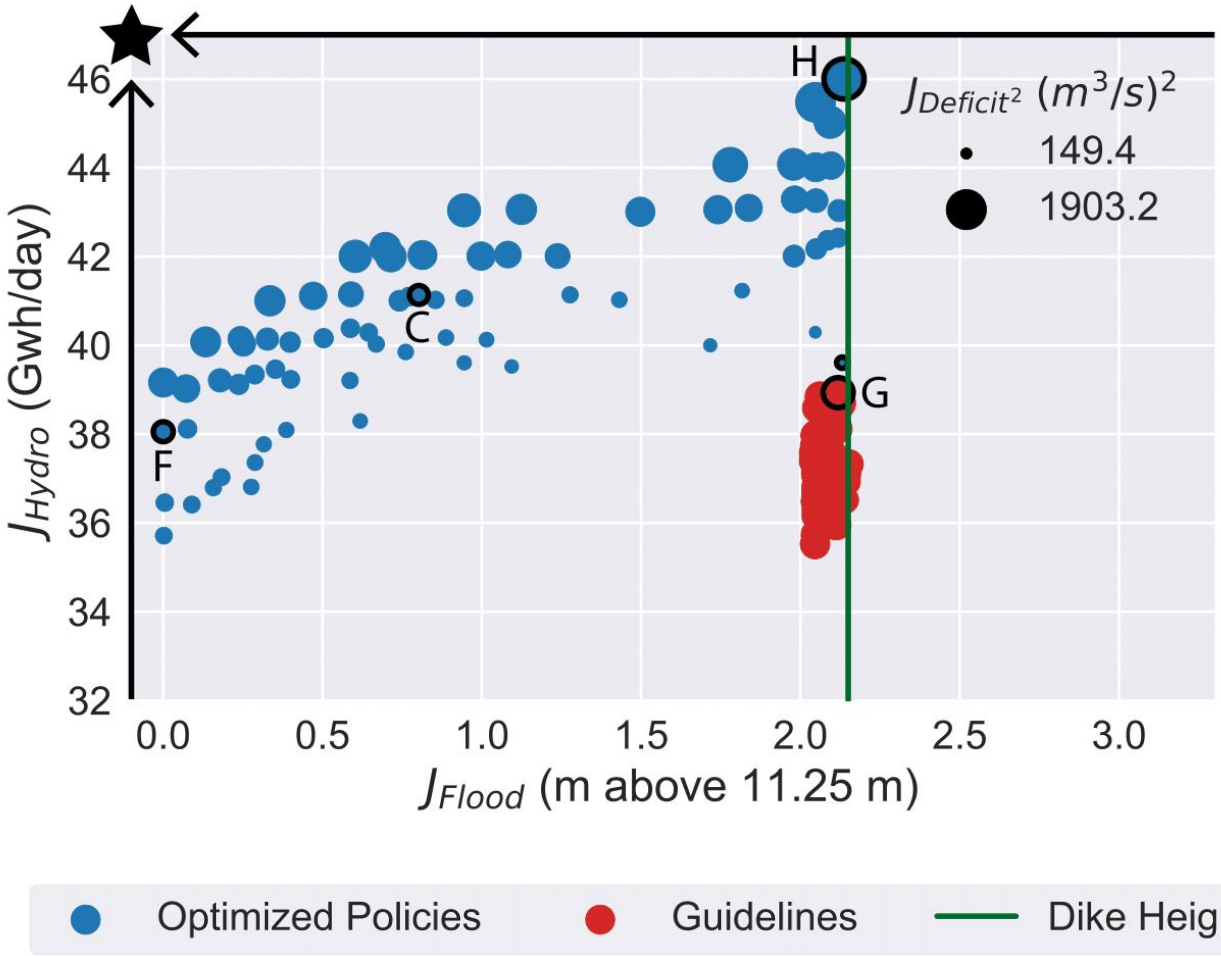
Barely provide protection to the 100-yr flood



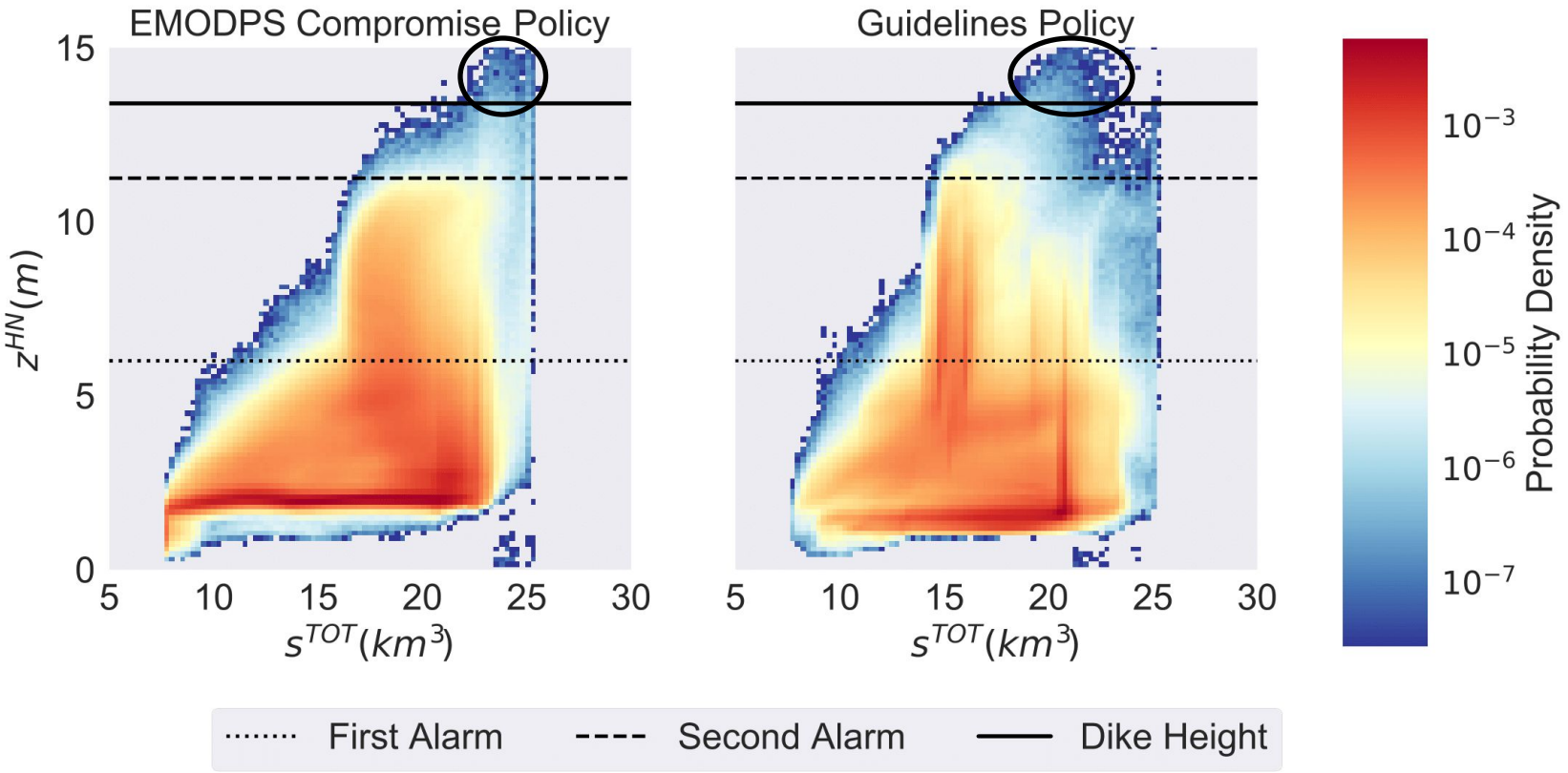
Let's pick a few to highlight

Guidelines are fully dominated, and domination should increase with # of reservoirs

Barely provide protection to the 100-yr flood



Let's look in more detail…100,000 simulated years



Guidelines do not effectively coordinate operations to make use of reservoir storage for flood protection

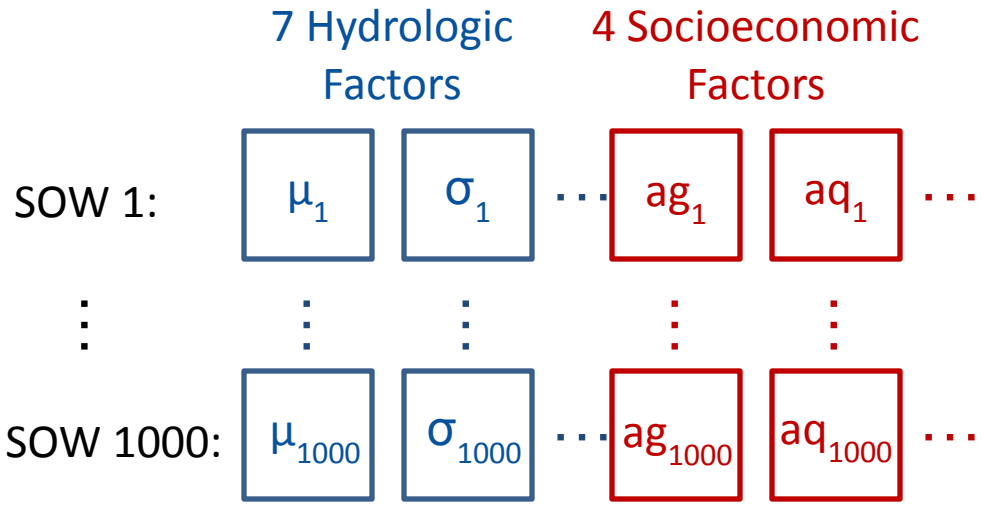
Guidelines are not coordinating operations well

This is troubling given we have only looked at stationary hydrologic uncertainty.

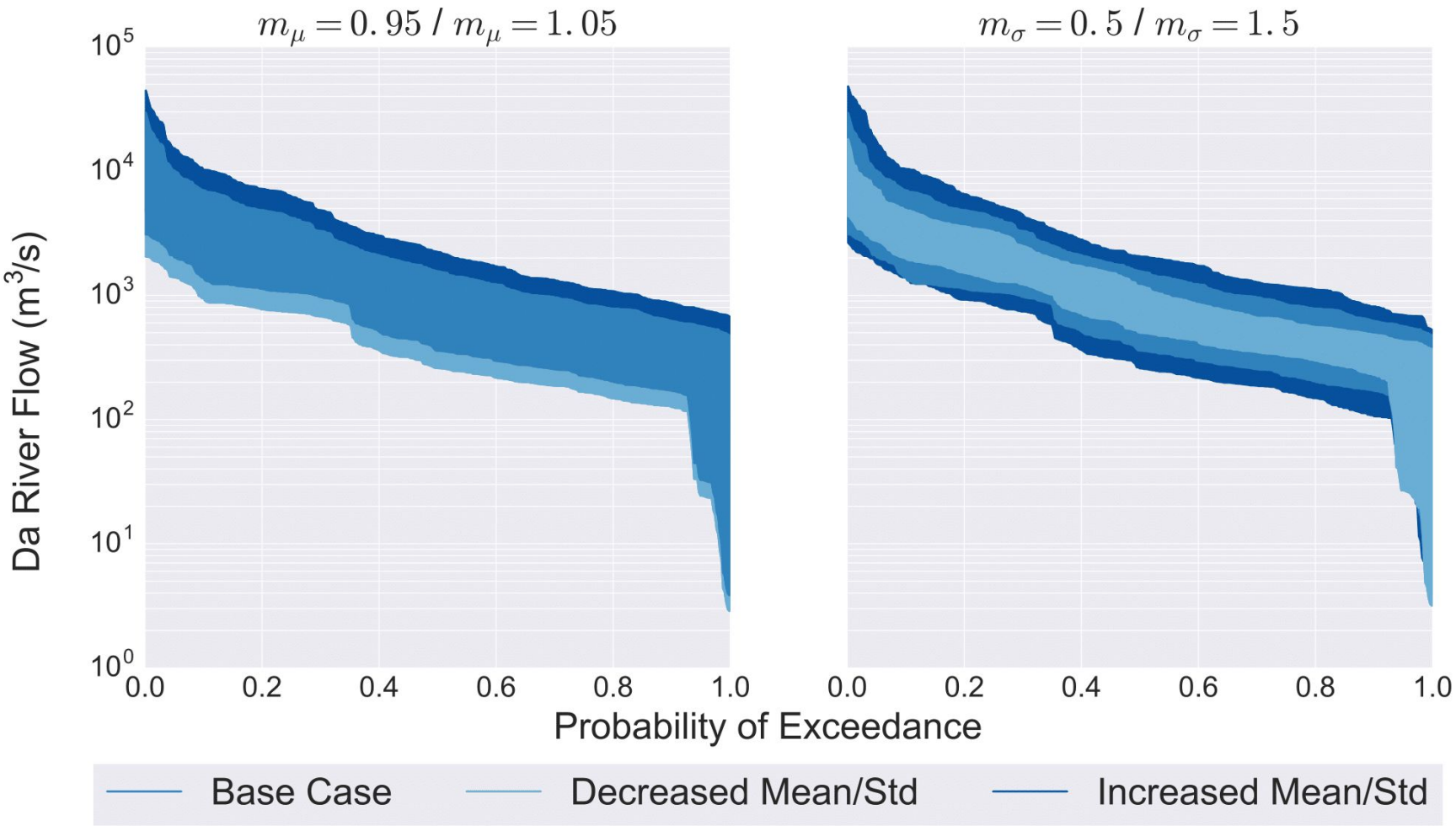
What if we experience major changes in human demands or monsoonal extremes?

Generating alternative states of the world

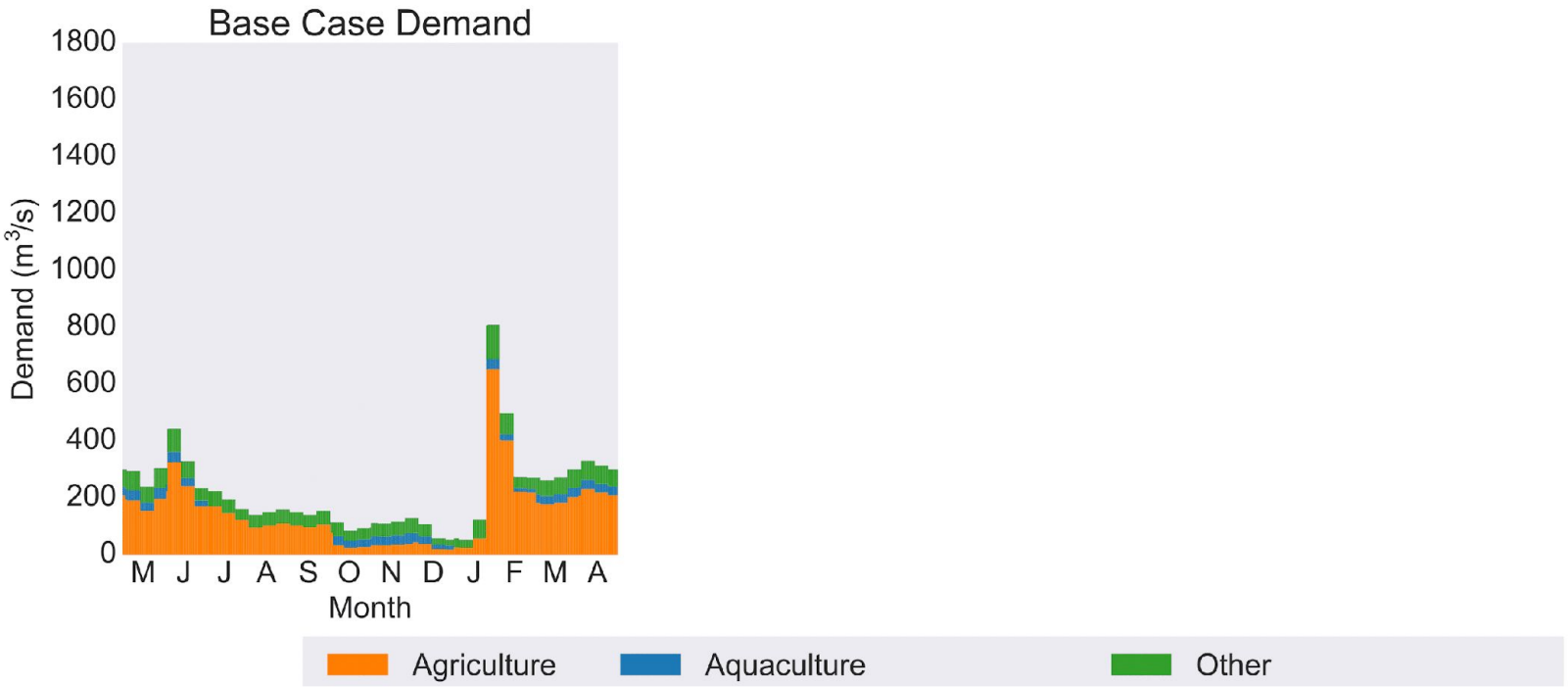
Goal: Sample broad range of hydrologic and socio-economic factors to discover, *a posteriori*, the most important drivers of system dynamics and performance



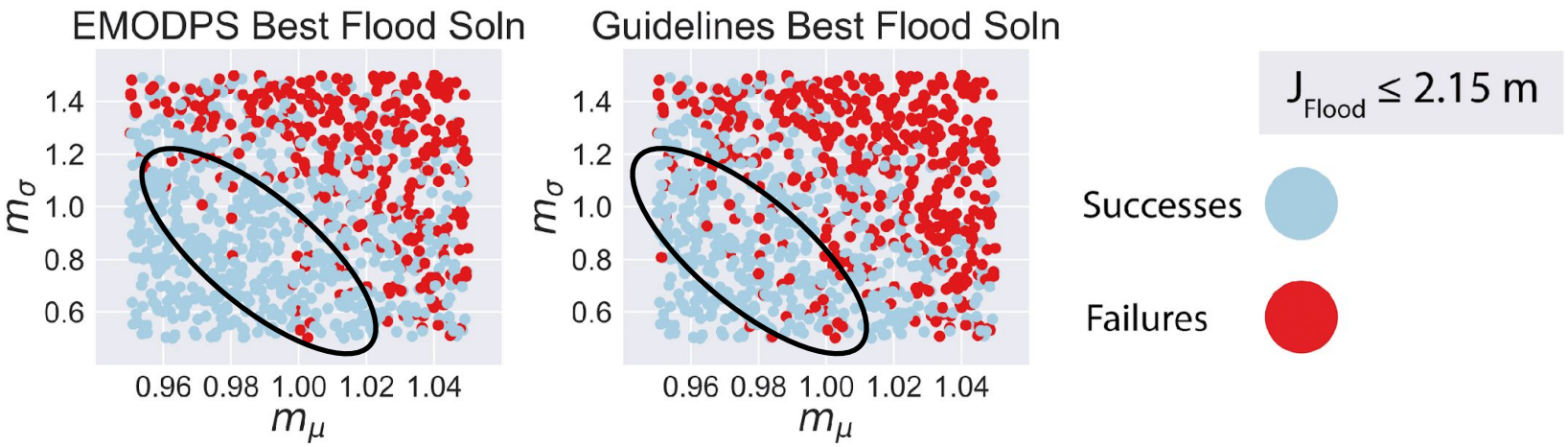
Annual mean flow and inter-annual variability



Demand changes

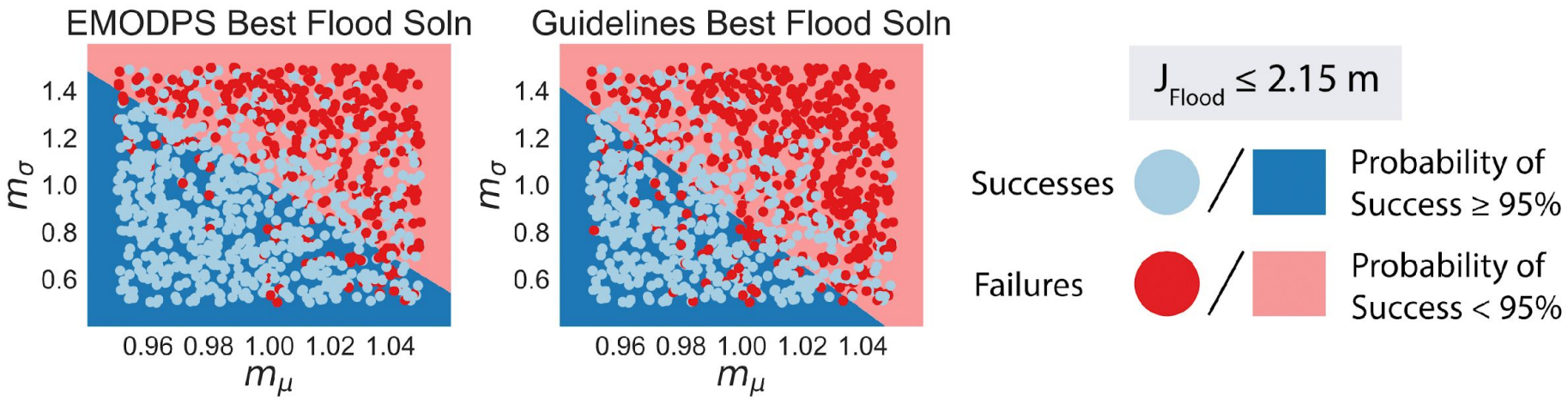


Factors influencing flood failures



Guidelines have more failures

Factors influencing flood failures

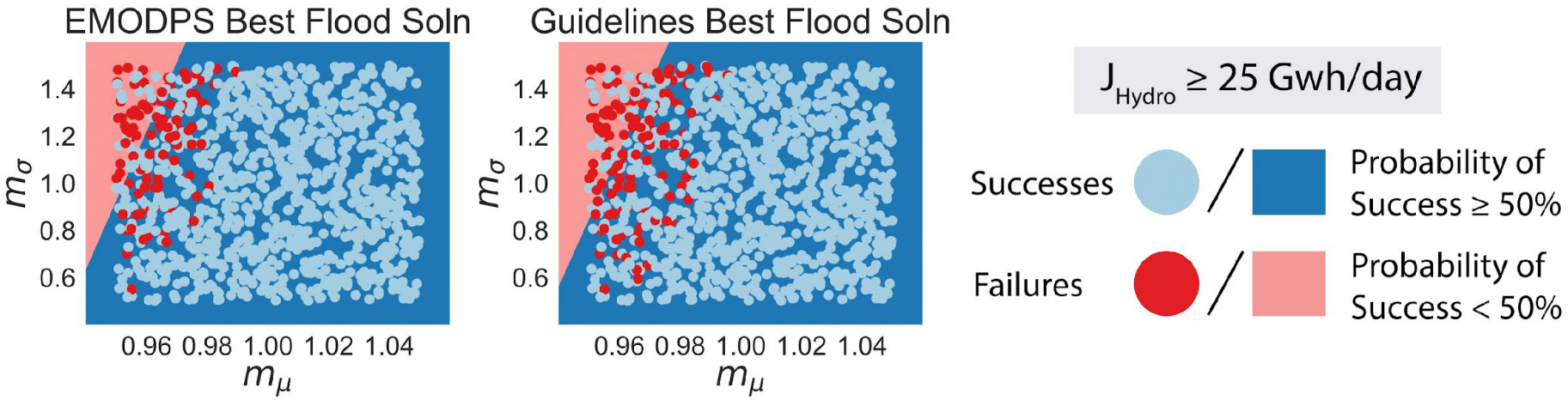


Guidelines have more failures

Failures explained by 2 major factors:

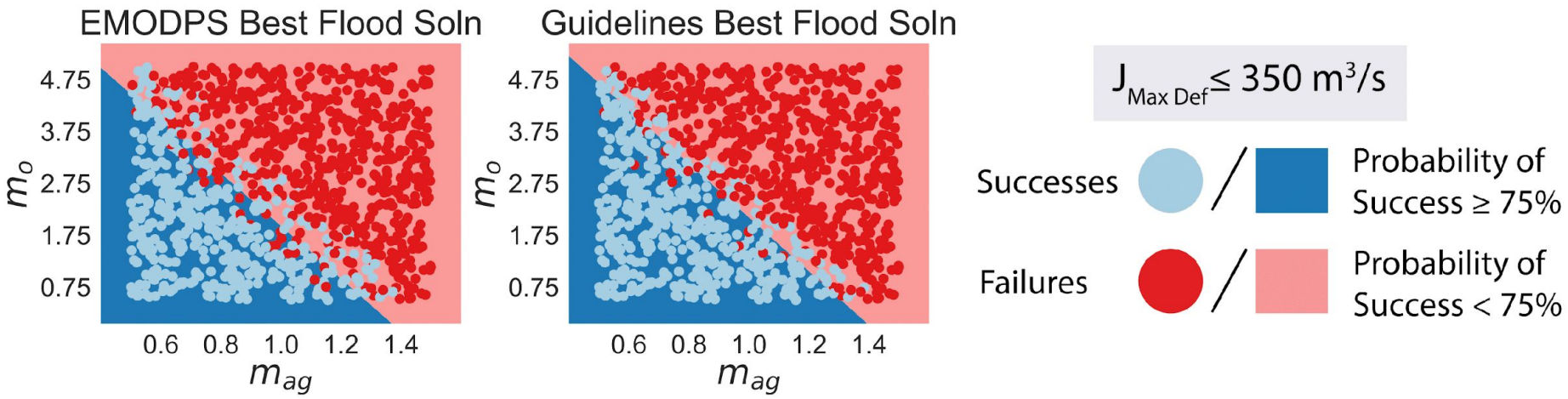
- Mean flow, μ
- Inter-annual variability, σ

Factors influencing hydropower failures



Same controlling factors, but failure regions are opposite

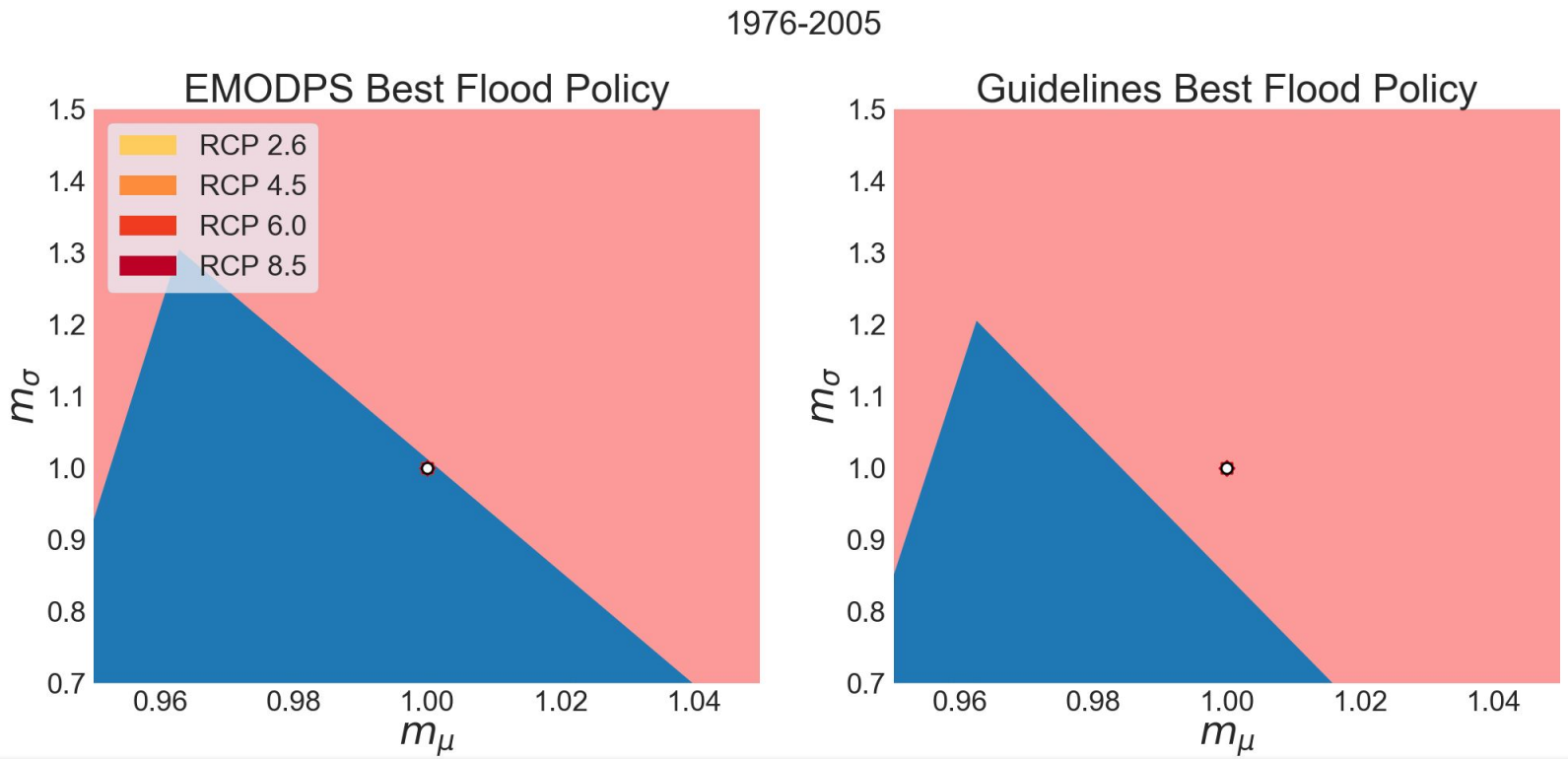
Factors influencing deficit failures



Controlled predominantly by socio-economic factors:

- Agricultural demand, *ag*
- Other demand, *o*

Defining a safe operating space (SOS)



SOS does not encompass base SOW
Cannot provide protection to 100-yr flood with 95% reliability

Frequently Ignored Issues in Climate Assessments

1. Simple discrete if/then/else-based human systems abstractions lack fidelity and likely to inadvertently ignore major failures modes

2. Deterministic model "fits" to historical observations do not reflect rare events or the extrapolation of how they are changing. This is not a regression problem…it's an extrapolation problem

3. Poor abstractions of sequential decision-making, coordination failures, sectoral conflicts, and poor use of information will cause severe errors in projecting candidate future pathways

4. Human institutions, land rights/competition, economic and technology transitions, infrastructure investments, etc. all can have huge landscape effects with small changes

Thanks! Any questions?

Acknowledgements

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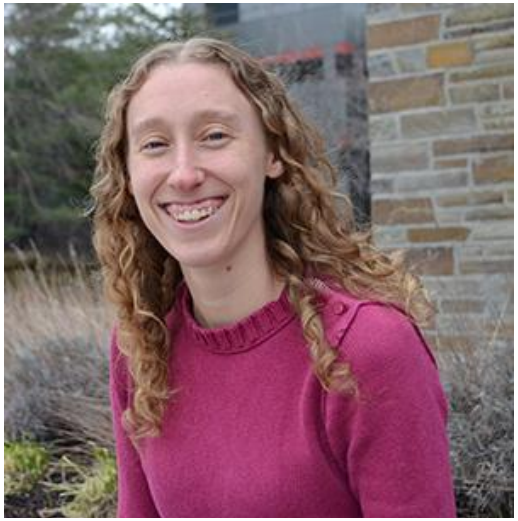
TACC
TEXAS ADVANCED COMPUTING CENTER

SCRiM
an NSF-sponsored research network for
Sustainable Climate Risk Management



Julie Quinn

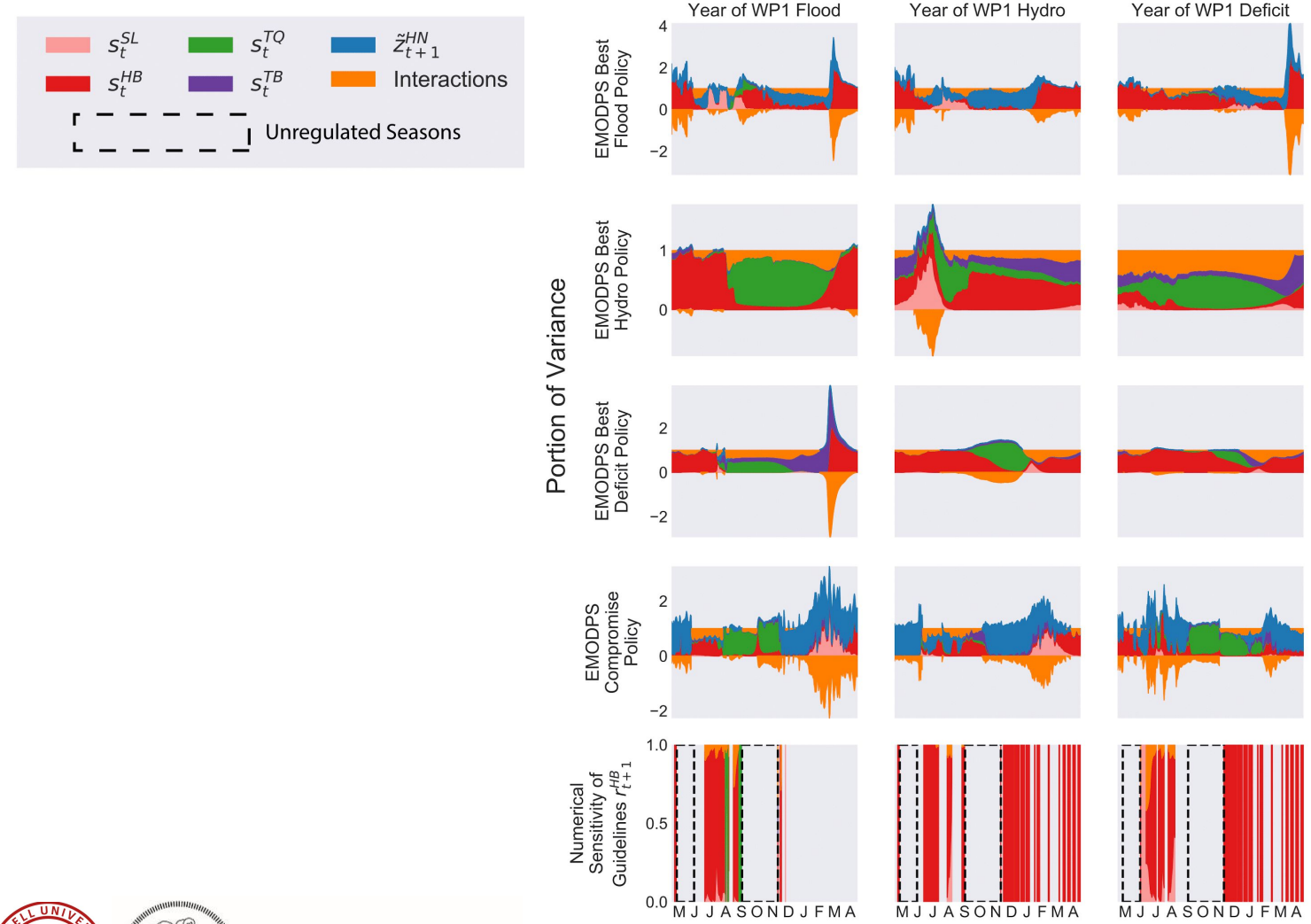
Matteo Giuliani

Andrea Castelletti

POLITECNICO
MILANO 1863

Appendix

Sensitivity of u_t^{HB} with Different Policies



POLITECNICO MILANO 1863