

Advancing the science of complex adaptive human-Earth systems through MultiSector Dynamics

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Escuela de Gobierno y
Transformación Pública del
Tecnológico de Monterrey
February 2022





**Navigating climate risks and transitions
in an increasingly interconnected and
rapidly changing world requires deep
interdisciplinary integration and new
modes of scientific inquiry**

A recent example...

The temperature extremes and energy demands during the event were equivalent to past winter storms in Texas¹ but caused \$195 billion and 246 deaths in Texas alone.

Winter Storm Uri
February 13–17, 2021

AUSTIN, TEXAS · February 16, 2021





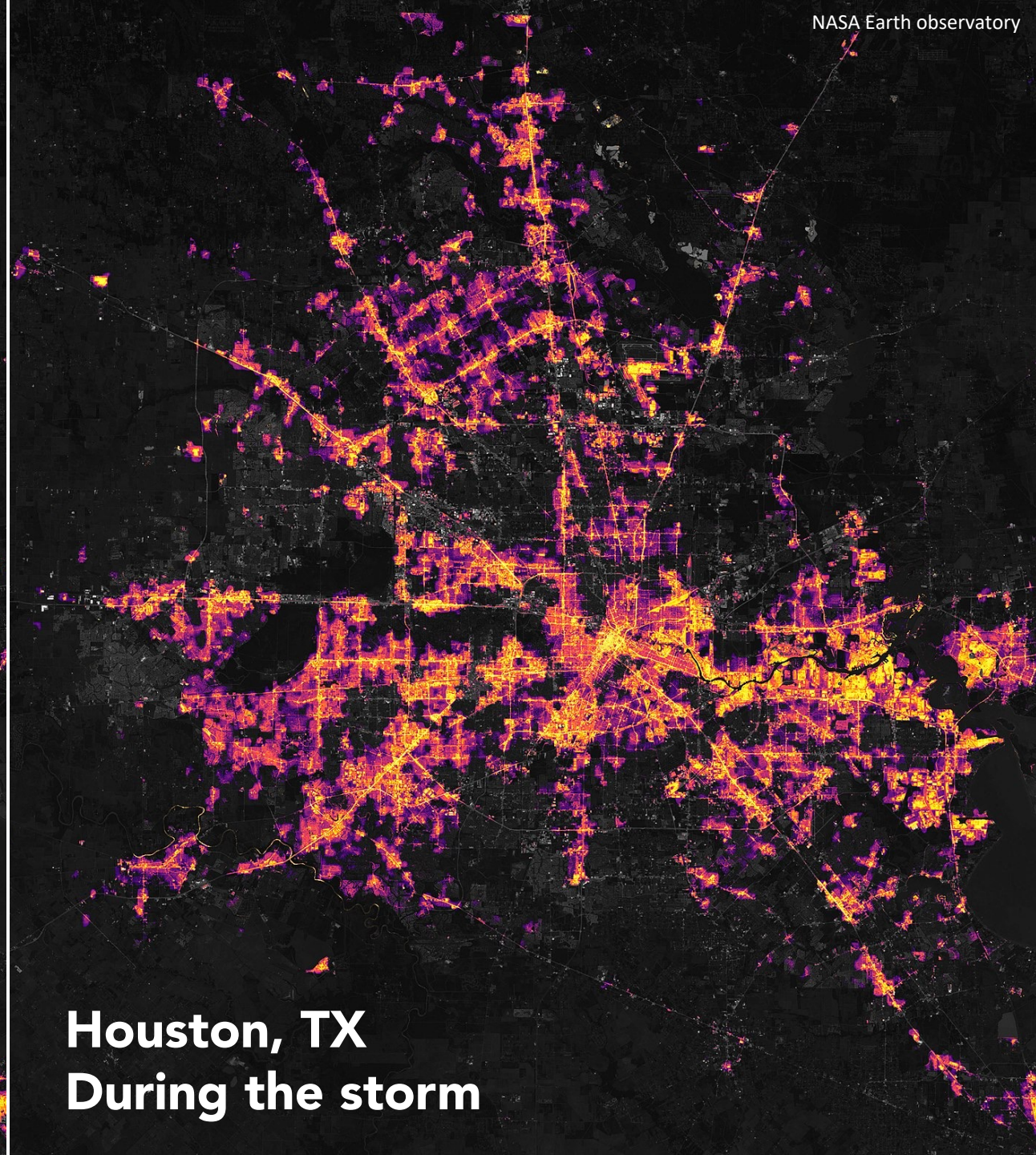
Besides the environmental hazard, these impacts were due to several institutional, infrastructural and socio-economic reasons:

- Texas operates on an isolated power grid
- Power generation systems were not sufficiently weatherized
- Insufficient planning for high demands

Rolling blackouts across the state left millions without electricity, water or food



**Houston, TX
Before the storm**



**Houston, TX
During the storm**

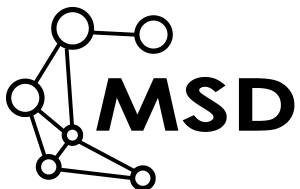
Human response:

- Increased energy demands
- Buying additional fuel and generators
- Storing food and water
- Electricity scarcity pricing



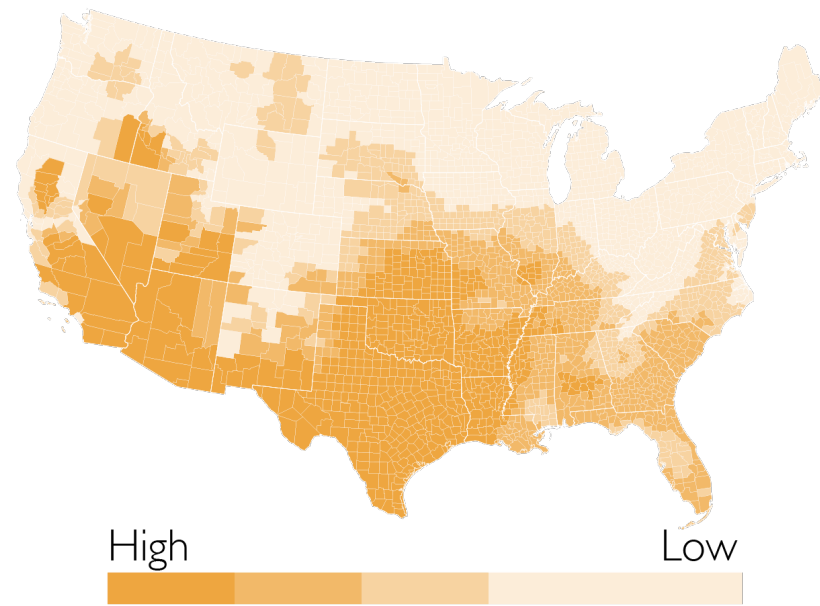
Propane tanks are placed in a line as people wait for the power to turn on to fill their tanks in Houston. (Mark Felix for The Washington Post)

Risk emerged as a result of many **dynamic processes** and actions across many **systems** and across different **scales**

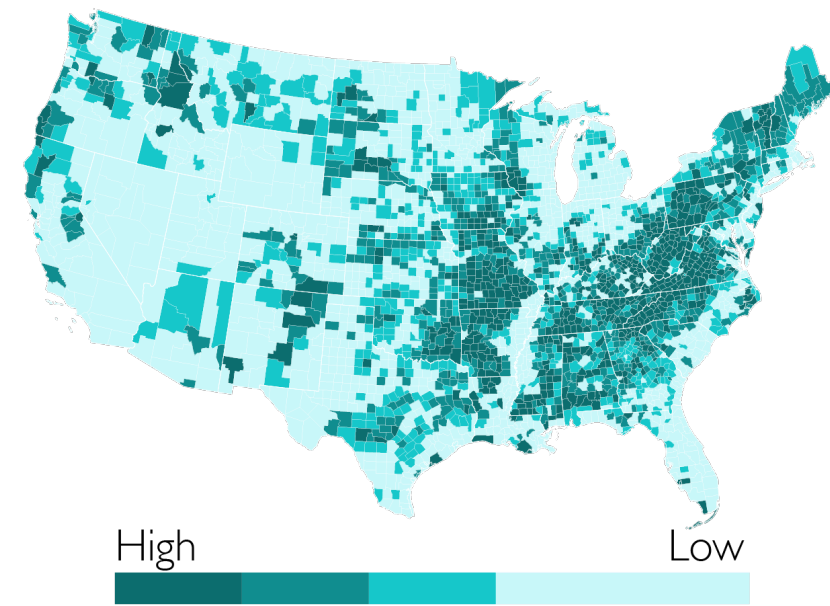


Winter storms are only one type of hazard potentially facing a region

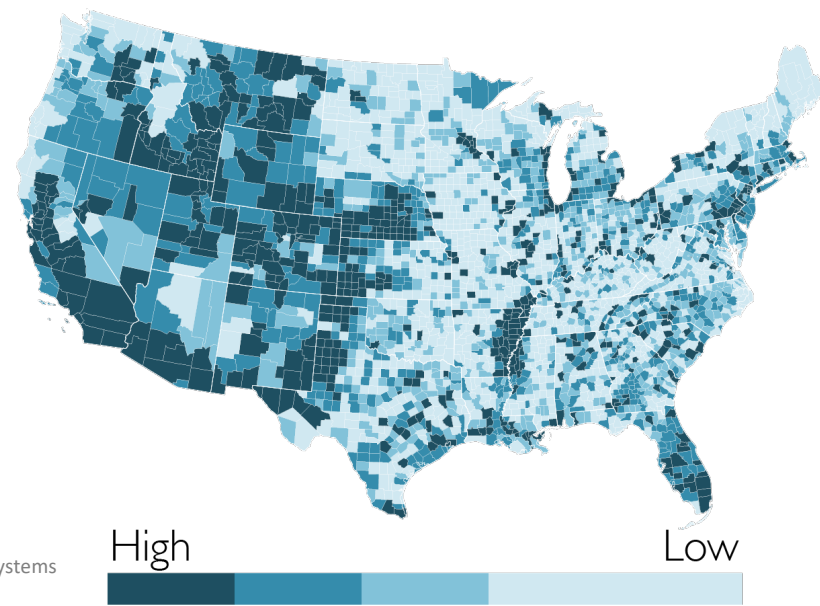
Temperature Stress



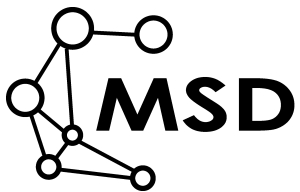
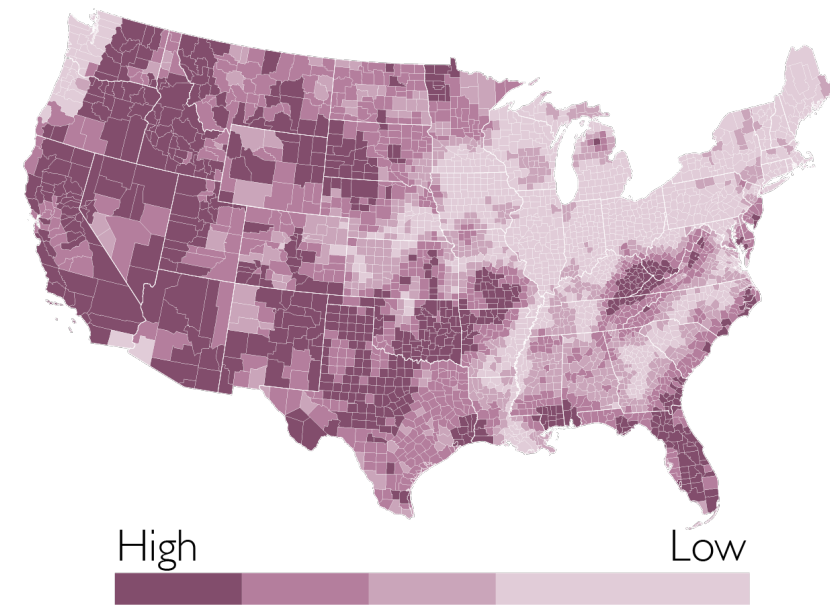
Flood Risk



Water Stress



Wildfire risk



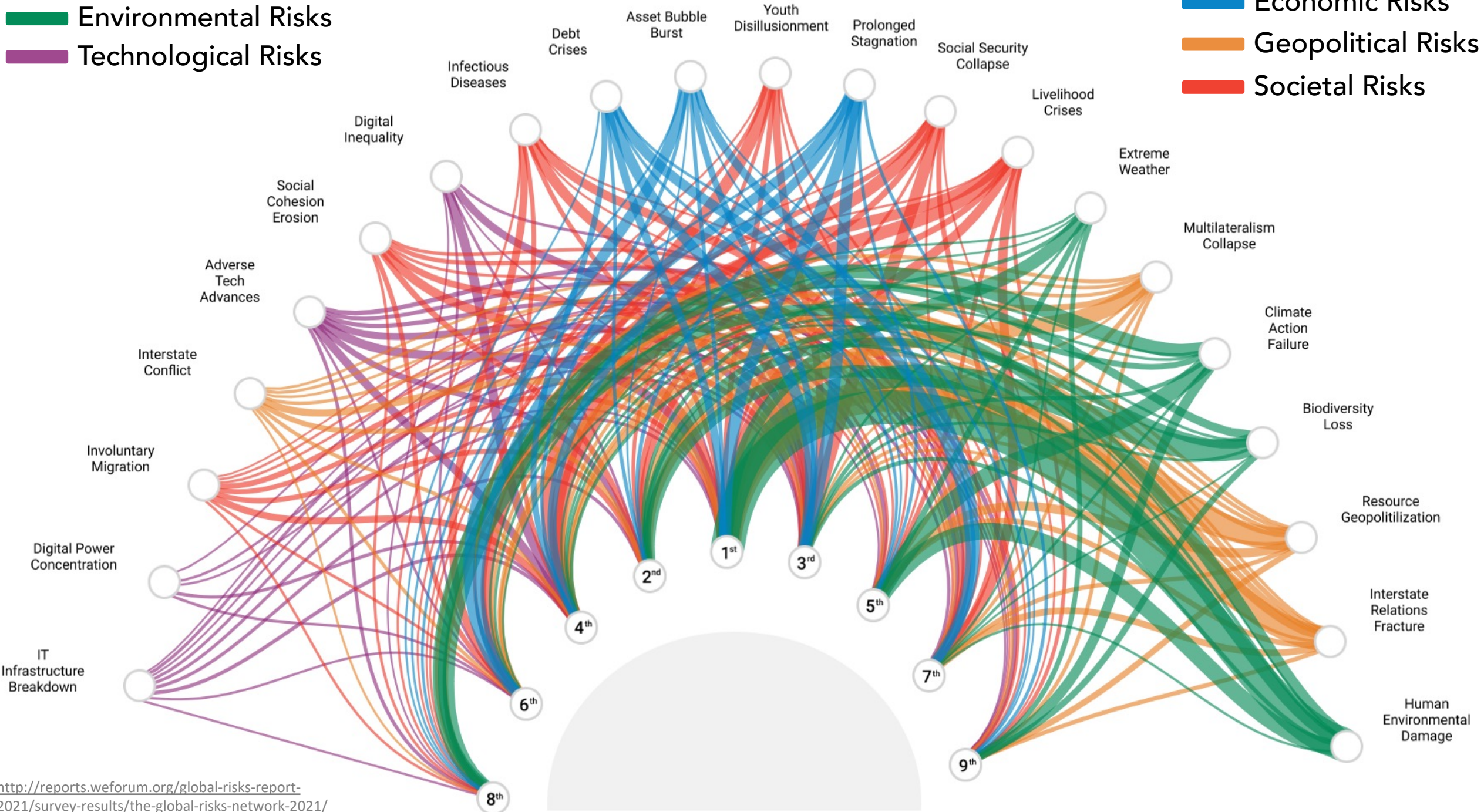
Globally, we are facing interconnected, multisectoral risks.



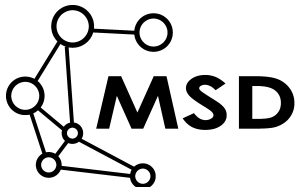
A group of refugees and migrants walk towards the border of Greece and North Macedonia. Credit: UNHCR

█ Environmental Risks
█ Technological Risks

█ Economic Risks
█ Geopolitical Risks
█ Societal Risks



There are several promising frameworks to help us understand these interactions.



A framework for complex climate change risk assessment

Systemic failures, extreme events and 'hyper-risks' emerge as a result of the **highly complex and highly interconnected** human-Earth systems

Dynamic relationships between agents, systems and sectors transmit risk for one to another

Drivers can amplify or buffer existing threats

Need for **fundamental innovations** in risk assessment





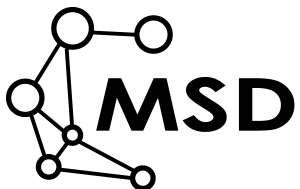
Besides risks we must navigate:

- important transitions in energy and other sectors,
- fundamental transformations to place ourselves in sustainable future pathways

A scientific grand challenge:

Better understand how interdependent global-to-local challenges are shaping critical pathways of societal change

Deep integration of diverse perspectives and technical capabilities



These challenges have been articulated by several communities

Contents lists available at [ScienceDirect](#)

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

ELSEVIER

Commentary

The role of inter-sectoral dynamics in sustainability transitions: A comment on the transitions research agenda

Allan Dahl Andersen^{a,*}, Markus Steen^b, Tuukka Mäkitie^a, Jens Hanson^a, Taran M. Thune^a, Birthe Soppe^{c,d}

Check for updates

Contents lists available at [ScienceDirect](#)

Environmental Modelling and Software

journal homepage: <http://www.elsevier.com/locate/envsoft>

ELSEVIER

Socio-technical scales in socio-environmental modeling: Managing a system-of-systems modeling approach

Takuya Iwanaga^{a,*}, Hsiao-Hsuan Wang^b, Serena H. Hamilton^{a,c}, Volker Grimm^{d,e}, Tomasz E. Koralewski^b, Alejandro Salado^f, Sondoss Elsawah^{a,g}, Saman Razavi^h, Jing Yangⁱ, Pierre Glynn^j, Jennifer Badham^k, Alexey Voinov^{l,m}, Min Chenⁿ, William E. Grant^b, Tarla Rai Peterson^o, Karin Frank^d, Gary Shenk^p, C. Michael Barton^q, Anthony J. Jakeman^a, John C. Little^r

Check for updates

One Earth

Perspective

Gold Standard for the Global Goals
1 ton of CO₂ offset

CellPress

Societal Transformations in Models for Energy and Climate Policy: The Ambitious Next Step

Evelina Trutnevyte,^{1,*} Léon F. Hirt,¹ Nico Bauer,² Aleh Cherp,^{3,4} Adam Hawkes,⁵ Oreane Y. Edelenbosch,^{6,7} Simona Pedde,⁸ and Detlef P. van Vuuren^{9,10}

Understanding Dynamics and Resilience in Complex Interdependent Systems
Prospects for a Multi-Model Framework and Community of Practice

Report of a workshop held under the auspices of the U.S. Global Change Research Program
Interpreting Science on Integrative Modeling with support from the U.S. Department of Energy

U.S. Global Change Research Program

nature

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Published: 01 May 2013

Globally networked risks and how to respond

Dirk Helbing

Nature 497, 51–59 (2013) | [Cite this article](#)

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Vincent A. W. J. Marchau
Warren E. Walker
Pieter J. T. M. Bloemen
Steven W. Popper *Editors*

Decision Making under Deep Uncertainty
From Theory to Practice

DMDU

OPEN Springer

Routledge Studies in Sustainability Transitions

MODELLING TRANSITIONS
VIRTUES, VICES, VISIONS OF THE FUTURE

Edited by
Enayat A. Moallemi and Fjalar J. de Haan

Routledge

Panarchy

UNDERSTANDING TRANSFORMATIONS IN HUMAN AND NATURAL SYSTEMS

EDITED BY
Lance H. Gunderson
C. S. Holling

Convergence

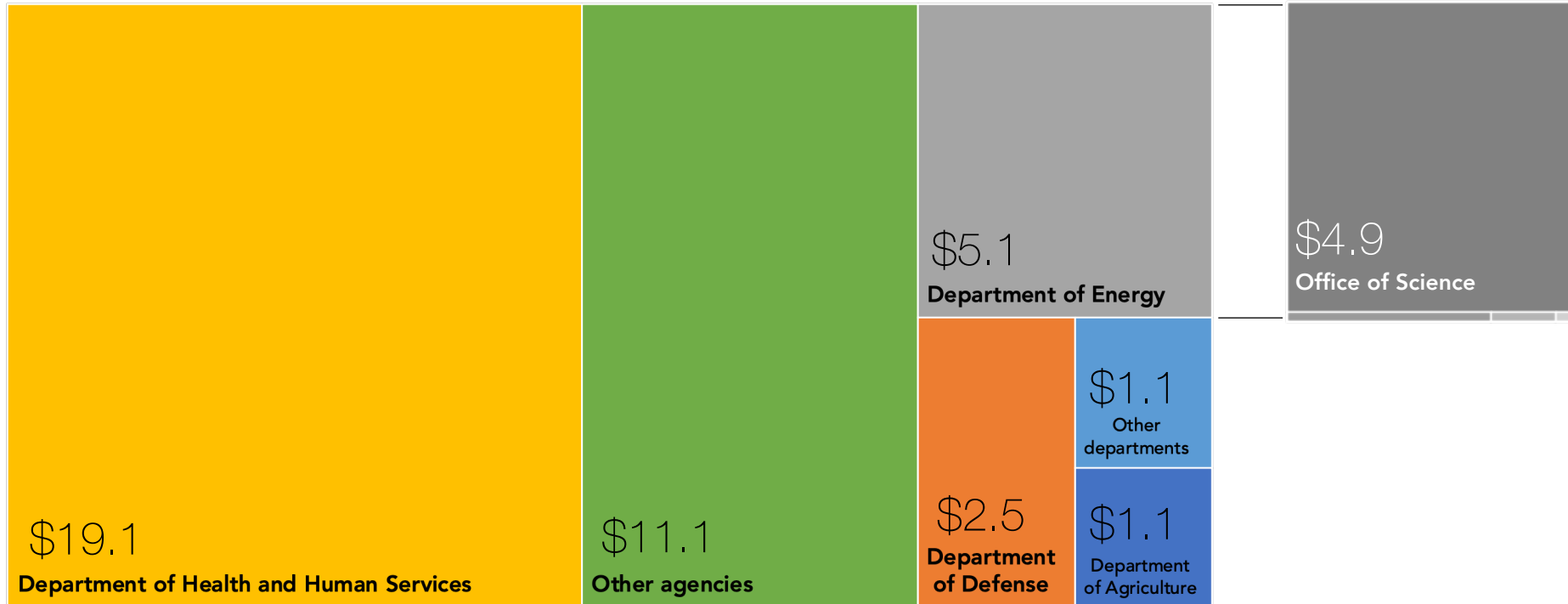
Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond

NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMIES

Opportunity for this research to coalesce

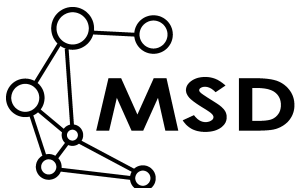
Federal obligations for basic research, by agency (FY 2019)

US Dollars in Billions



Department of Energy Office of Science has created the *Multisector Dynamics* research program to fund research in this area

They have committed initial and sustained funding to create a **Community of Practice** around this challenge



Source: National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FYs 2019–20.

CoP goal and activities

Communication

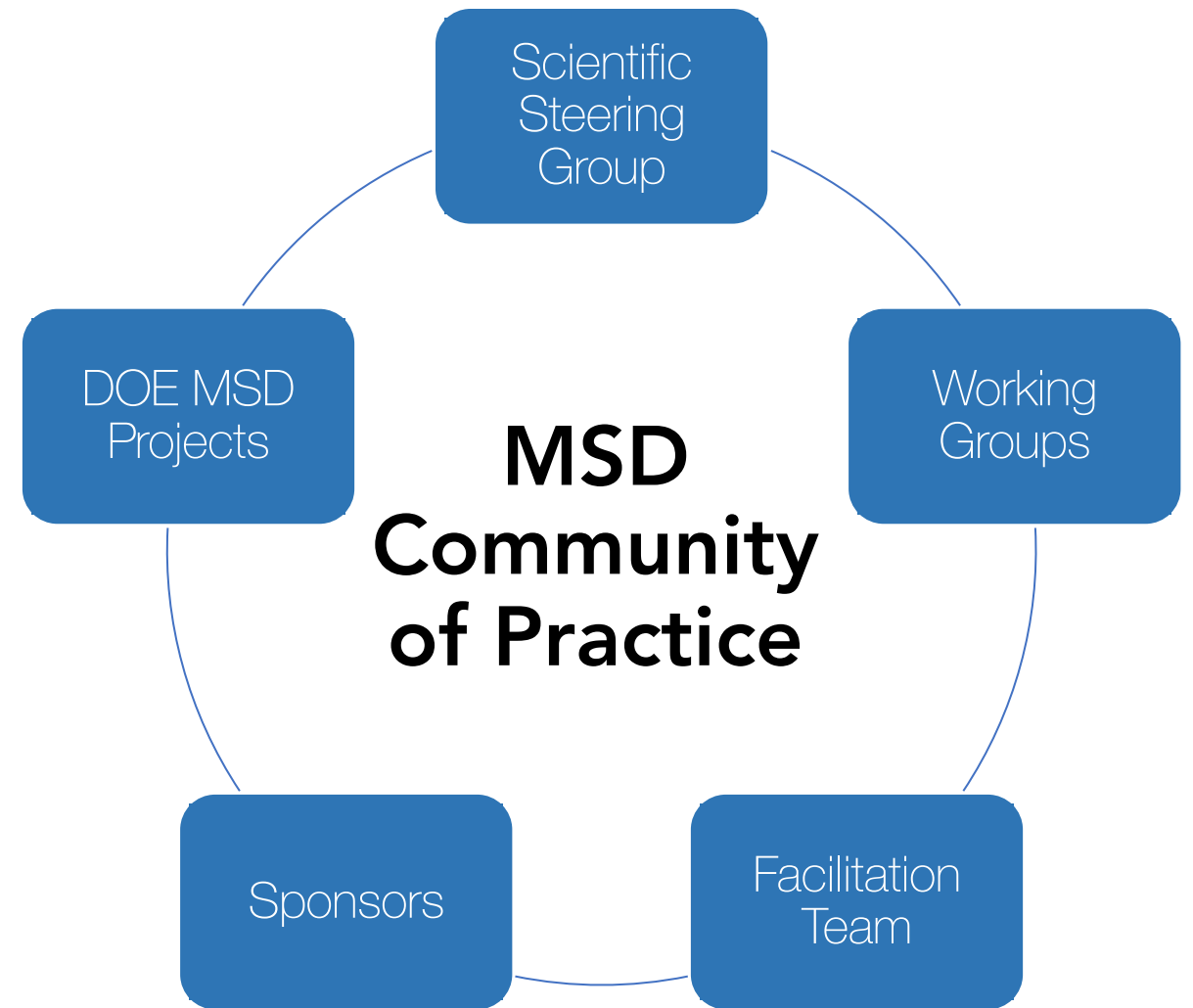
- Website
- Newsletter
- Webinars
- Outreach

Conceptual Framework

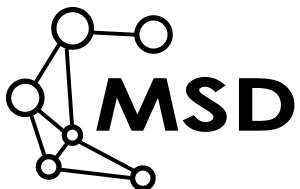
- Vision report and journal article
- Review process

Technical coordination

- Working groups



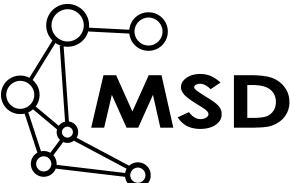
Goal: Bring together currently dispersed research teams and communities that are working on related challenges, both nationally and internationally. Establish mechanisms for collaboration and synthesis to accelerate discovery and add value to individuals and projects.



Facilitation Team



Richard Moss, PNNL
Patrick Reed, Cornell University
Erwan Monier, UC Davis
Antonia Hadjimichael, Penn State University



Scientific Steering Group



Nathalie Voisin,
PNNL



Klaus Keller,
Dartmouth



Megan Konar,
UIUC



Jen Morris, MIT



Jim Yoon, PNNL



Christa Brelsford,
ORNL



Stuart Cohen,
NREL



Ana Dyreson,
MTU



Casey Burleyson,
PNNL

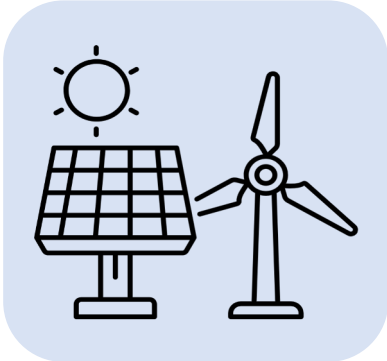


Vivek Srikrishnan,
Cornell



Jordan
Macknick, NREL

Current Working Groups



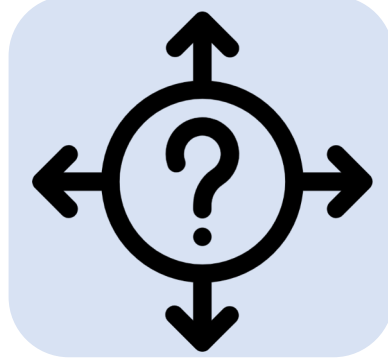
MultiSector
Impacts of
Energy
Transitions



Urban
Systems



Human
System
Modeling



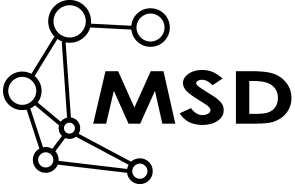
Uncertainty
Quantification
and Scenario
Development



Education and
Professional
Development



Facilitating
FAIR Data

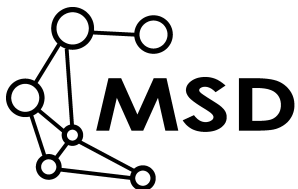


MSD Vision Report

Outline a vision for MSD as an emerging transdisciplinary field

Clarify core definitions, share research questions, highlight scientific opportunities, and provide steps for improving our community's capacity to support needed scientific progress.

<https://multisectordynamics.org/vision>



MULTISECTOR DYNAMICS

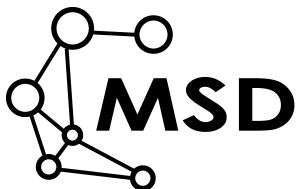
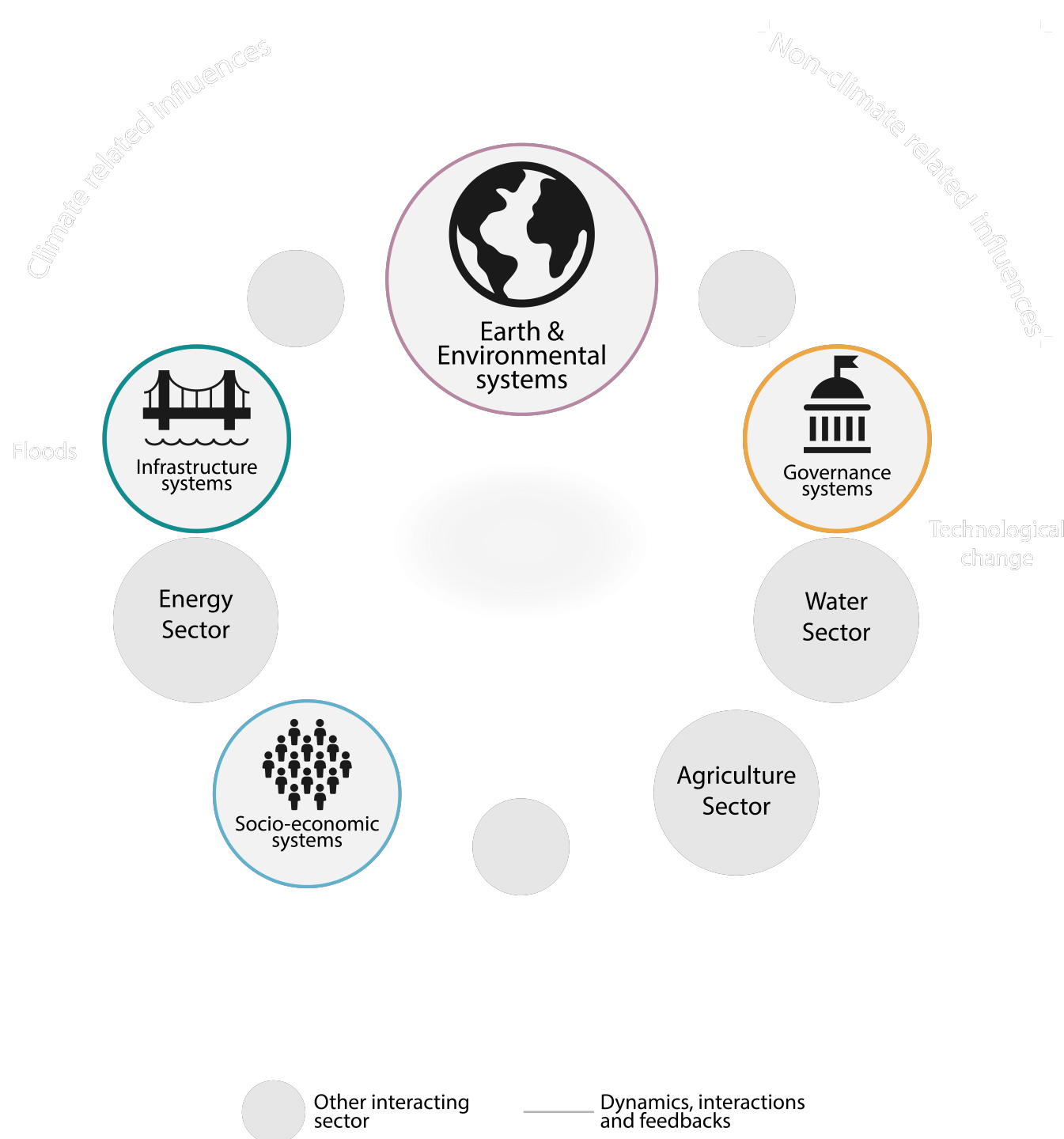
Scientific Challenges
and a Research
Vision for 2030



What is MSD?

Sector:

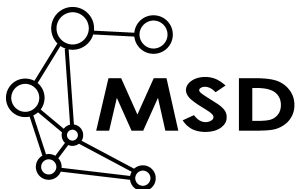
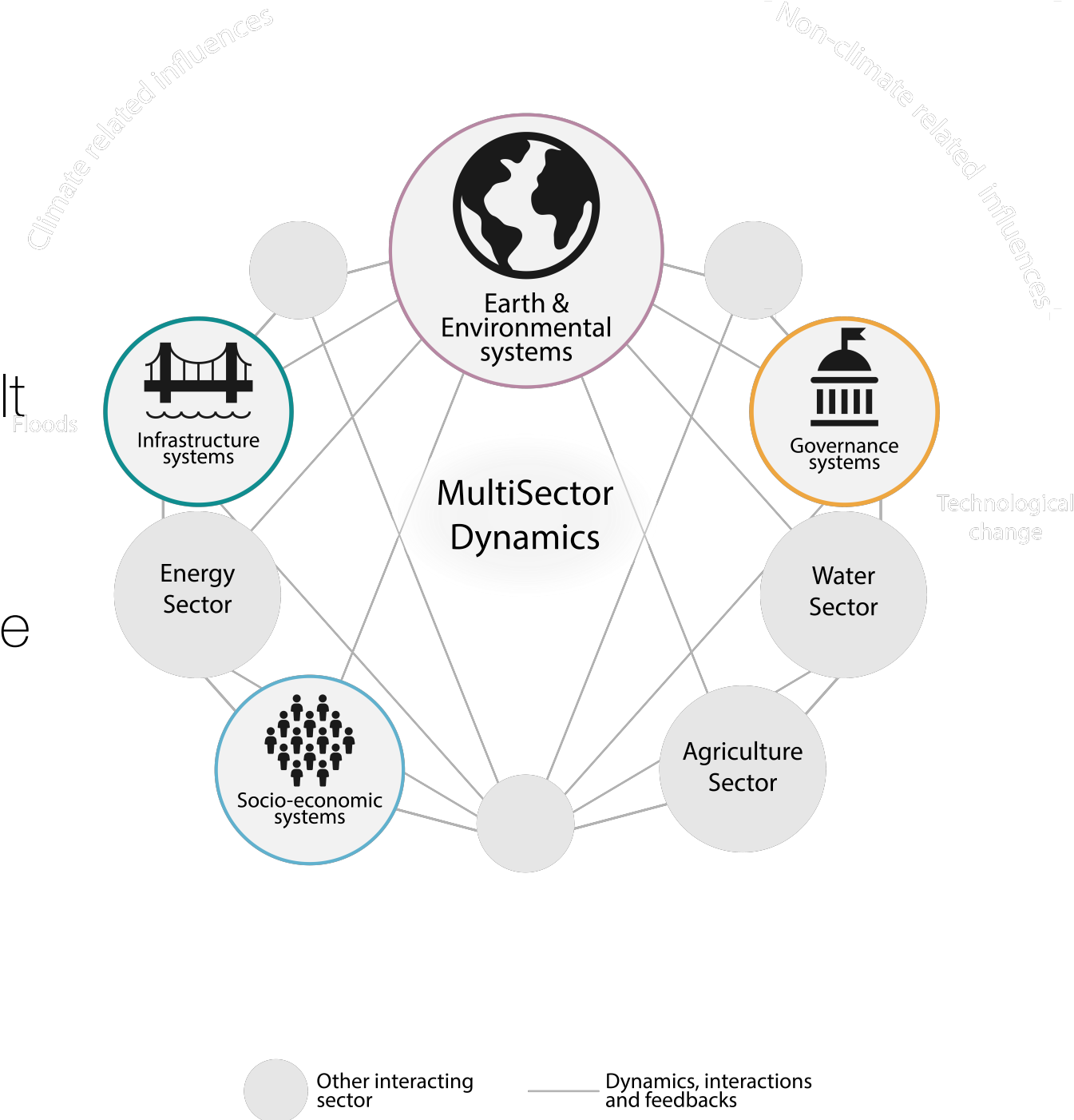
“ Complex **systems of systems** that deliver services, amenities, and products critical to society. ”



What is MSD?

Dynamics:

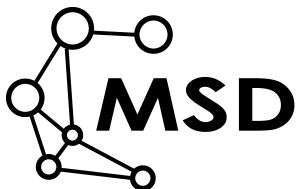
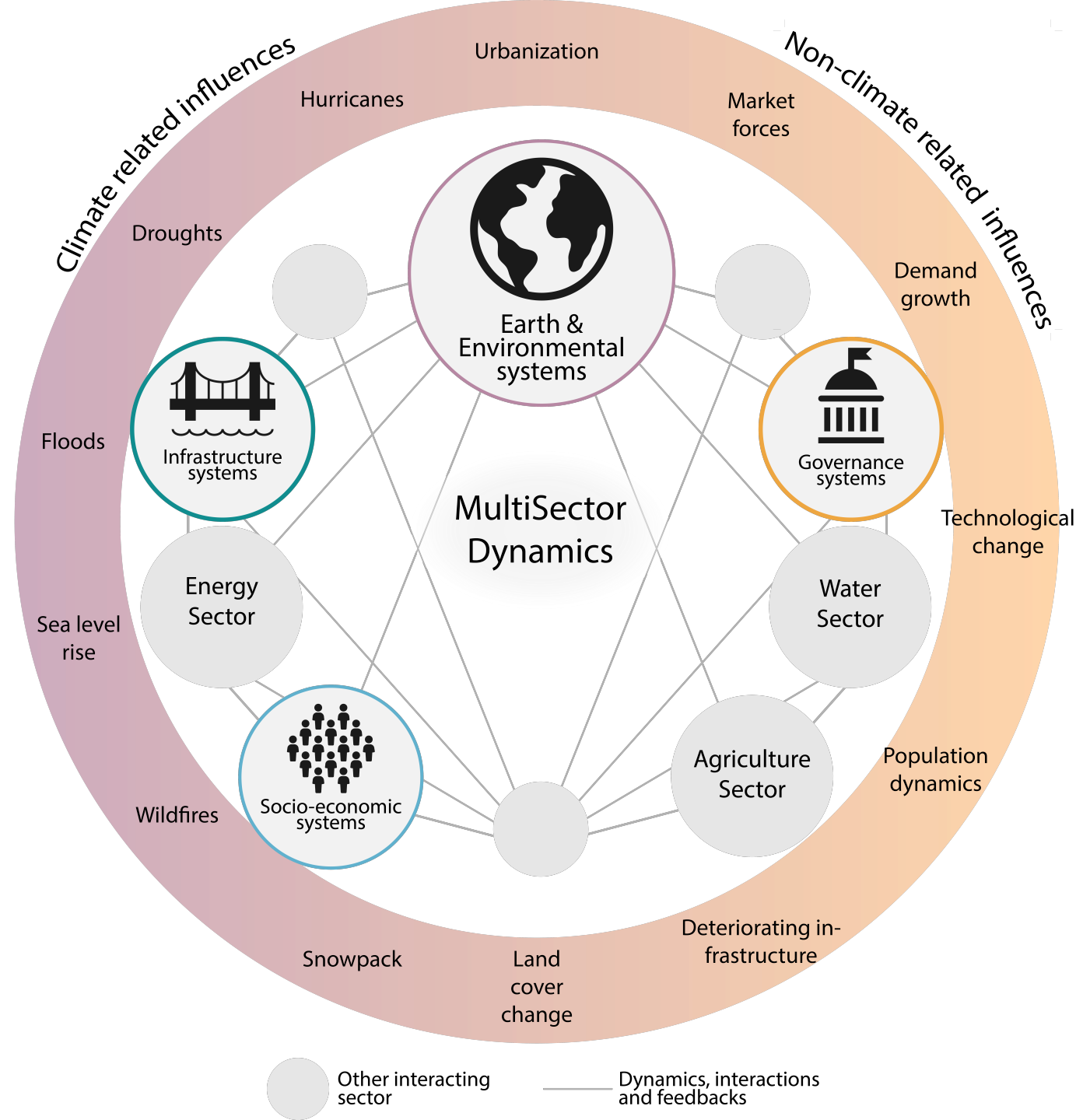
“ Pathways of change that result from transitions and shocks. Shaped by **interconnectedness**, alternative perspectives, cross-scale influences, and deep uncertainties.”



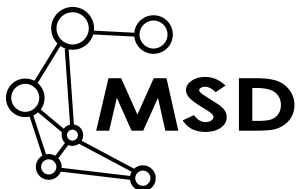
What is MSD?

The study of how complex built, natural, and socio-economic systems **co-evolve in response to change**.

A transdisciplinary research area that seeks to advance our understanding of how **human-Earth systems and feedbacks shape pathways of change across scales and uncertainties**.

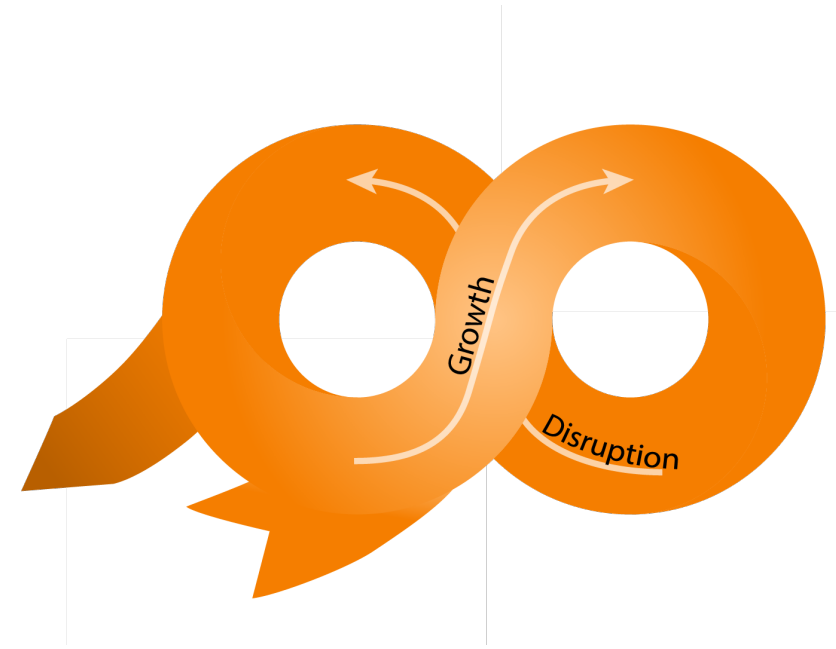


This framing is not entirely new but draws inspiration from several disciplines



Multisector dynamics emerge from complex adaptive systems of systems

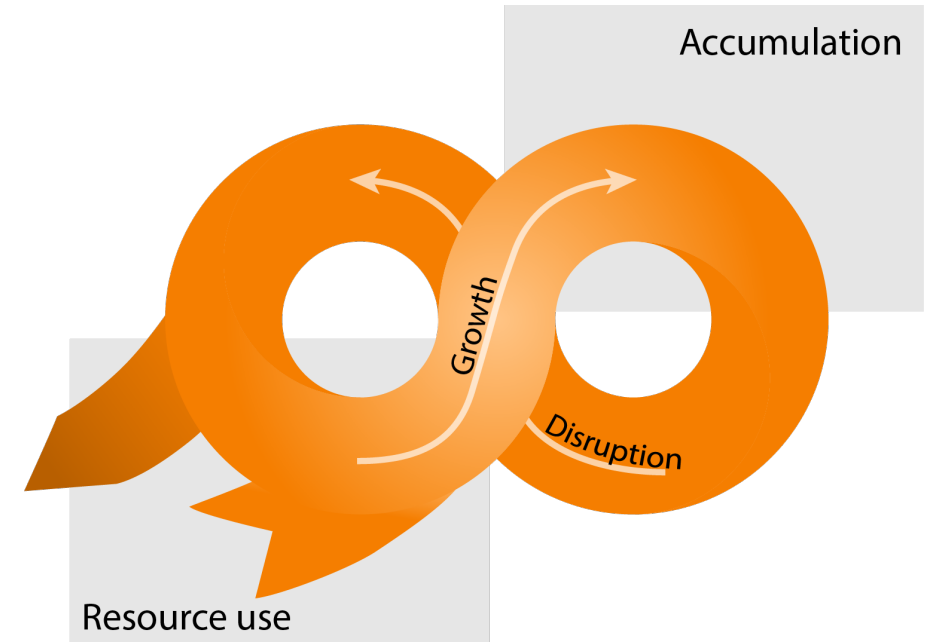
Complex adaptive systems can be conceptualized in terms of **cycles of growth and disruption**



Multisector dynamics emerge from complex adaptive systems of systems

Complex adaptive systems can be conceptualized in terms of **cycles of growth and disruption**

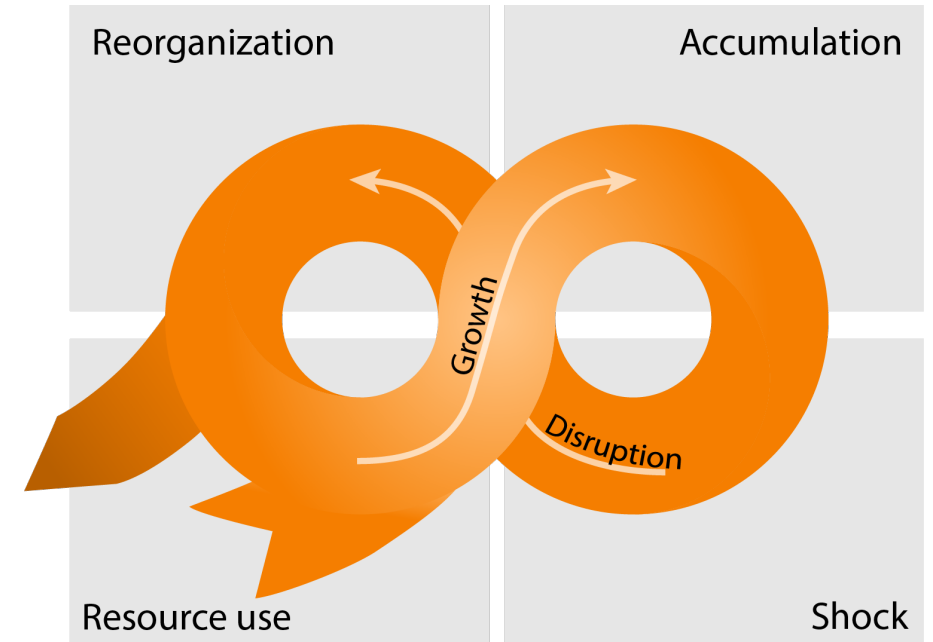
1. **Growth phase** – accumulation of resources and capital



Multisector dynamics emerge from complex adaptive systems of systems

Complex adaptive systems can be conceptualized in terms of **cycles of growth and disruption**

1. **Growth phase** – accumulation of resources and capital
2. **Disruption phase** – occurrence of system shock, subsequent reorganization

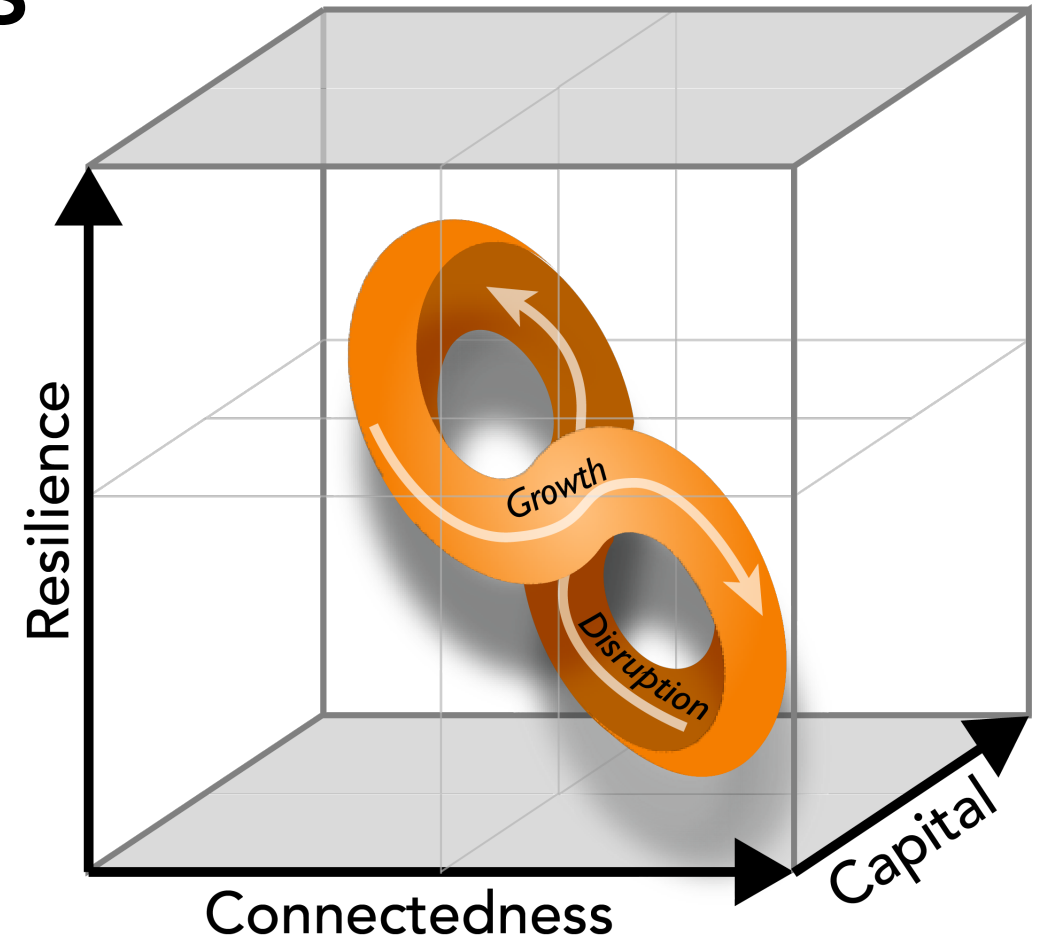


Key system properties

Connectedness: Increases as the system grows, becomes more aggregated and organized

Capital: system potential, reflects monetary assets or natural or human capacities that accumulate as the system develops

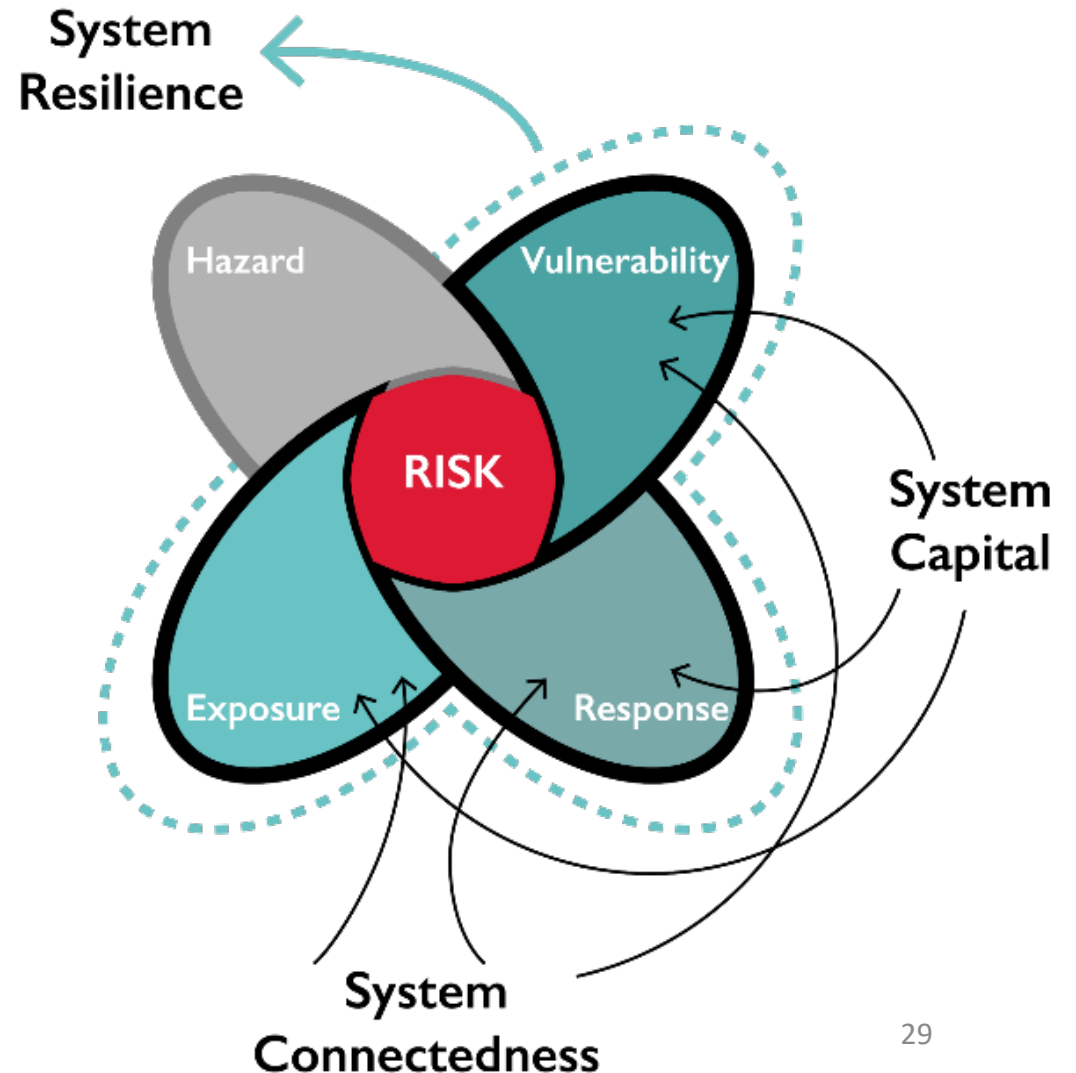
Resilience: the capacity of a system to absorb a shock and adapt to maintain essentially the same function and identity



Bridging Risk and Resilience

Hazards can **cascade** between systems and **interact** with drivers of **vulnerability**, **exposure** and **response**.

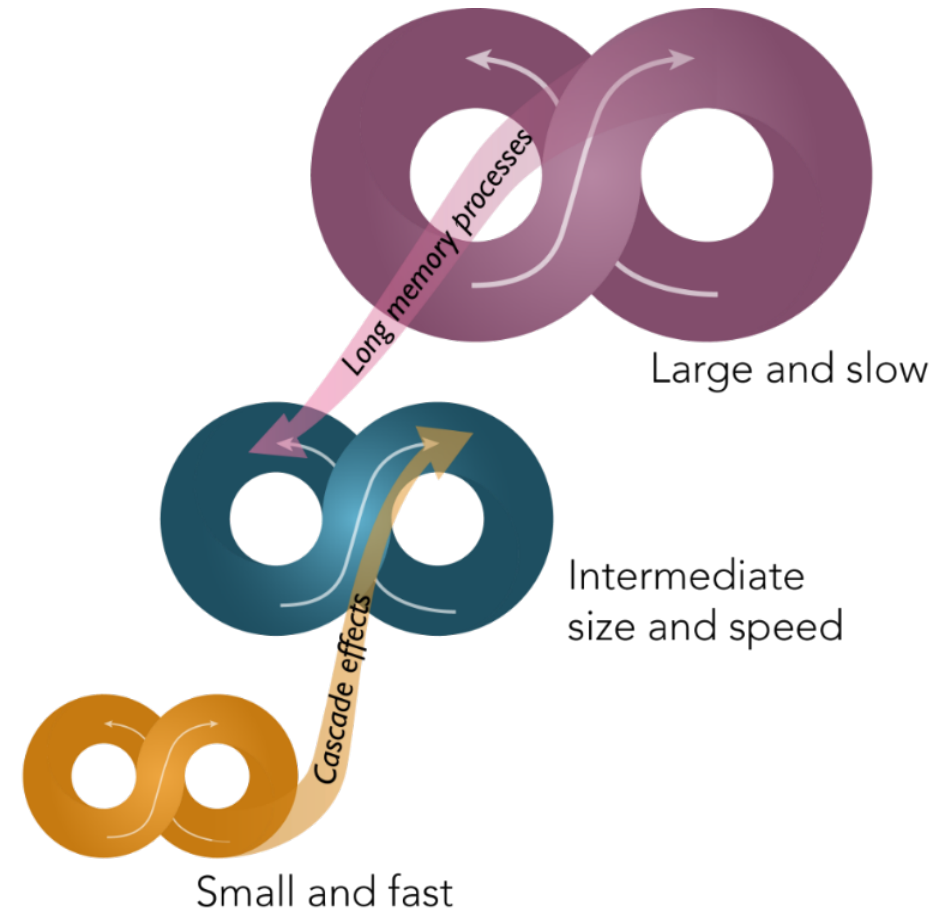
System **organization** and **aggregation** can **shape resilience** to hazards in both positive and negative ways through the presence of **drivers** and their **interactions**



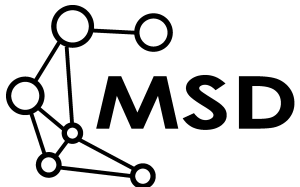
Adaptive system cycles across scales

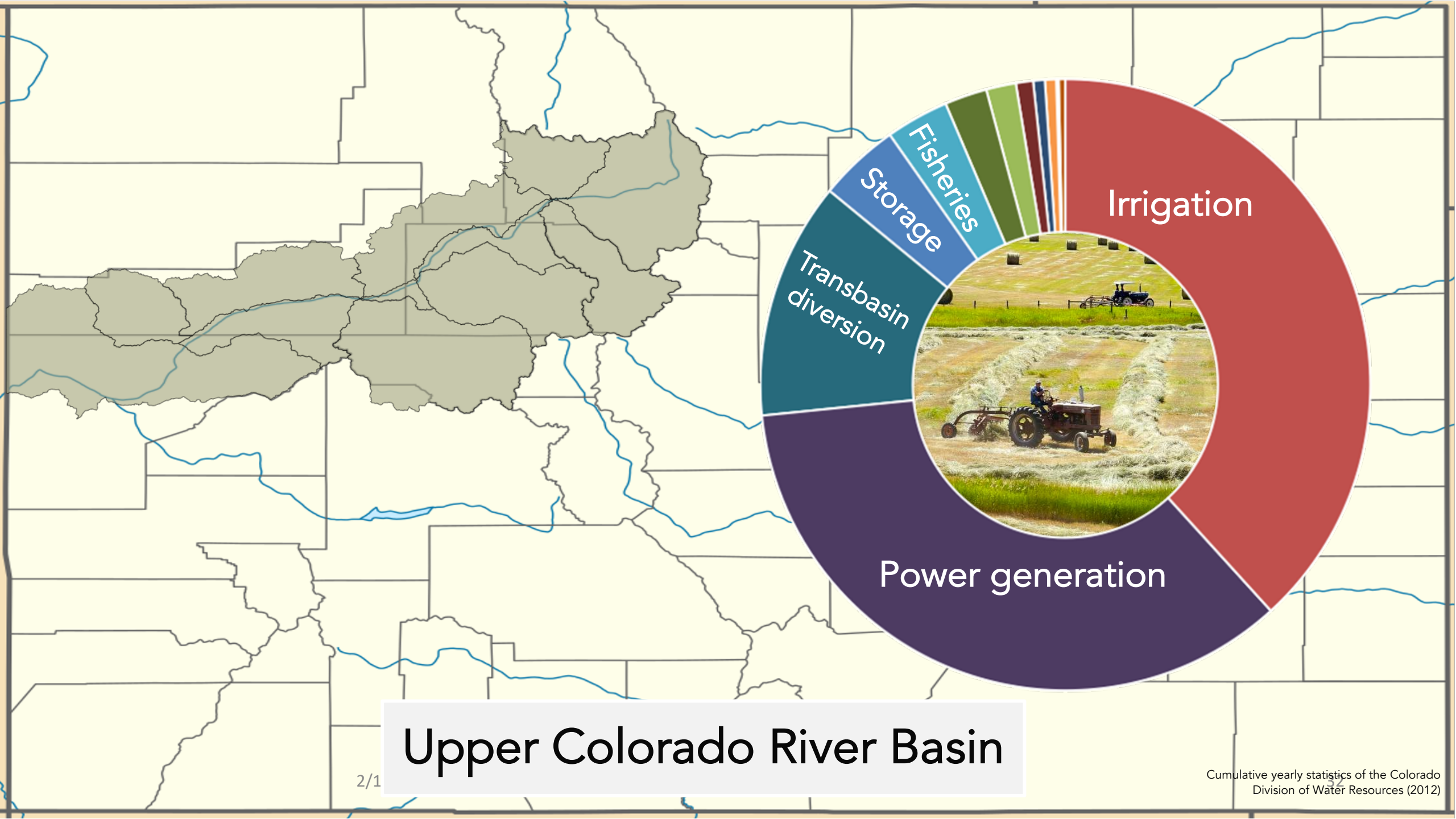
Multi-scale feedbacks are critical for understanding how systems co-evolve to:

- Shape path dependencies
- Amplify or dampen dynamics
- Lead to emergent behaviors



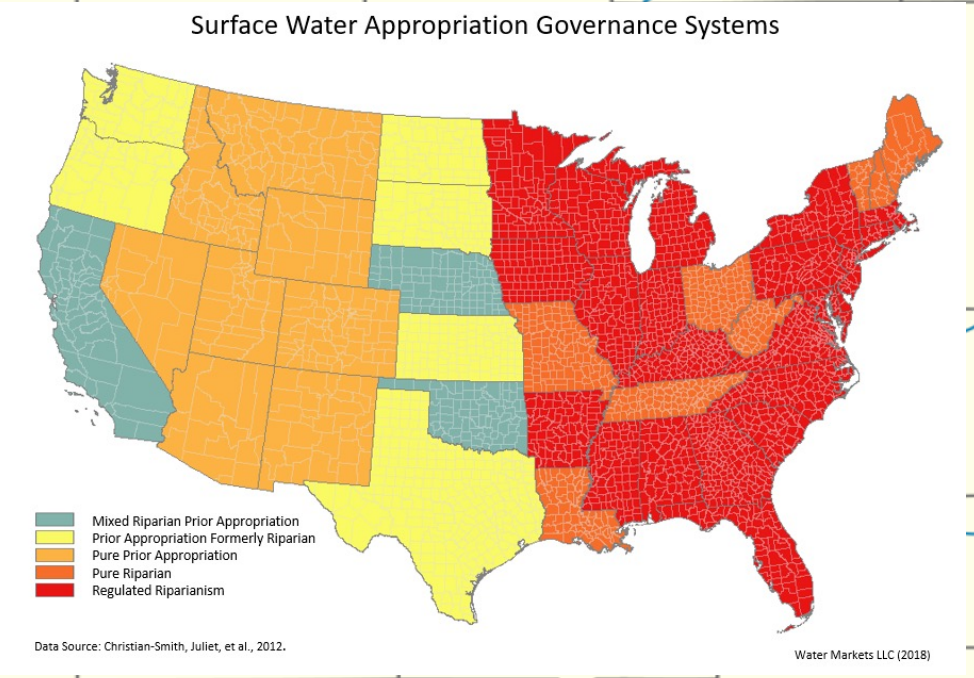
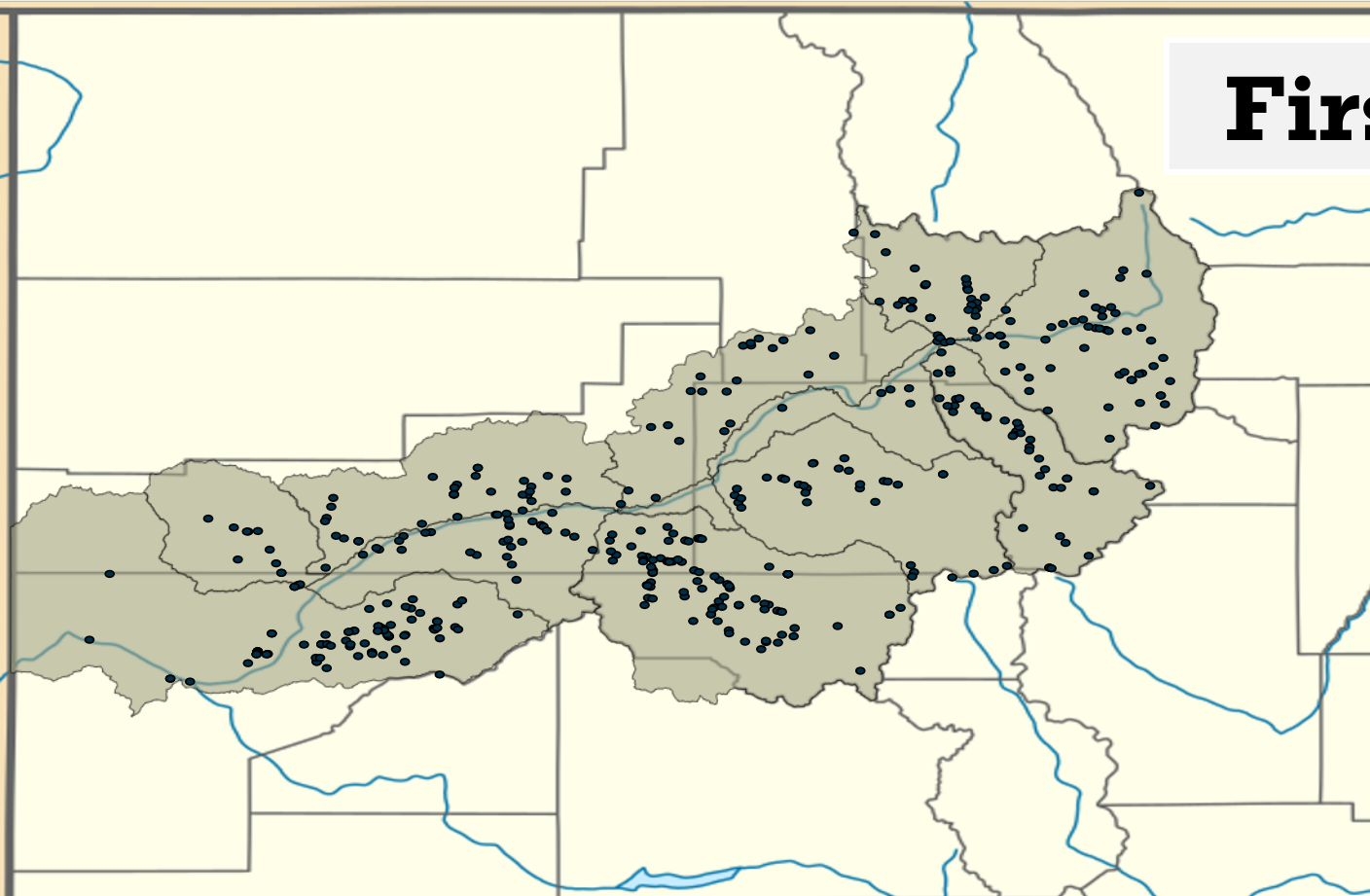
A research example...



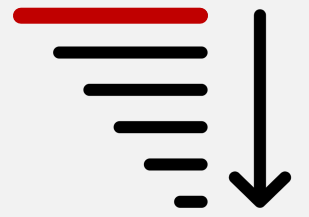


Upper Colorado River Basin

First in time, first in right



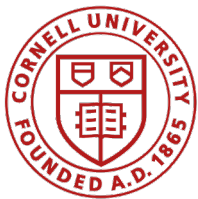
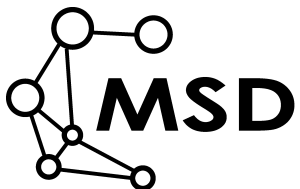
*Gets **all** water demands met before others*



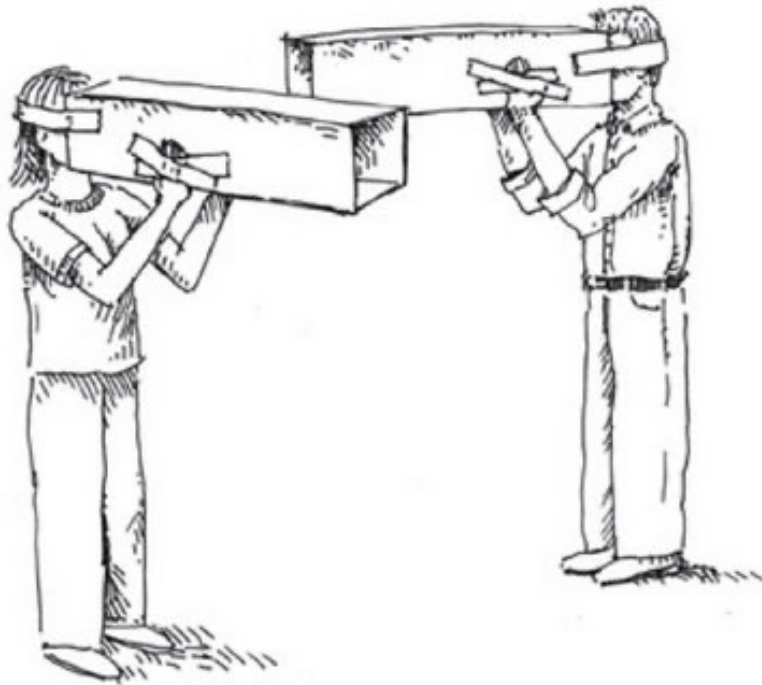
Prior-appropriation doctrine:
Each diversion with level of seniority and decreed flow

Upper Colorado River Basin

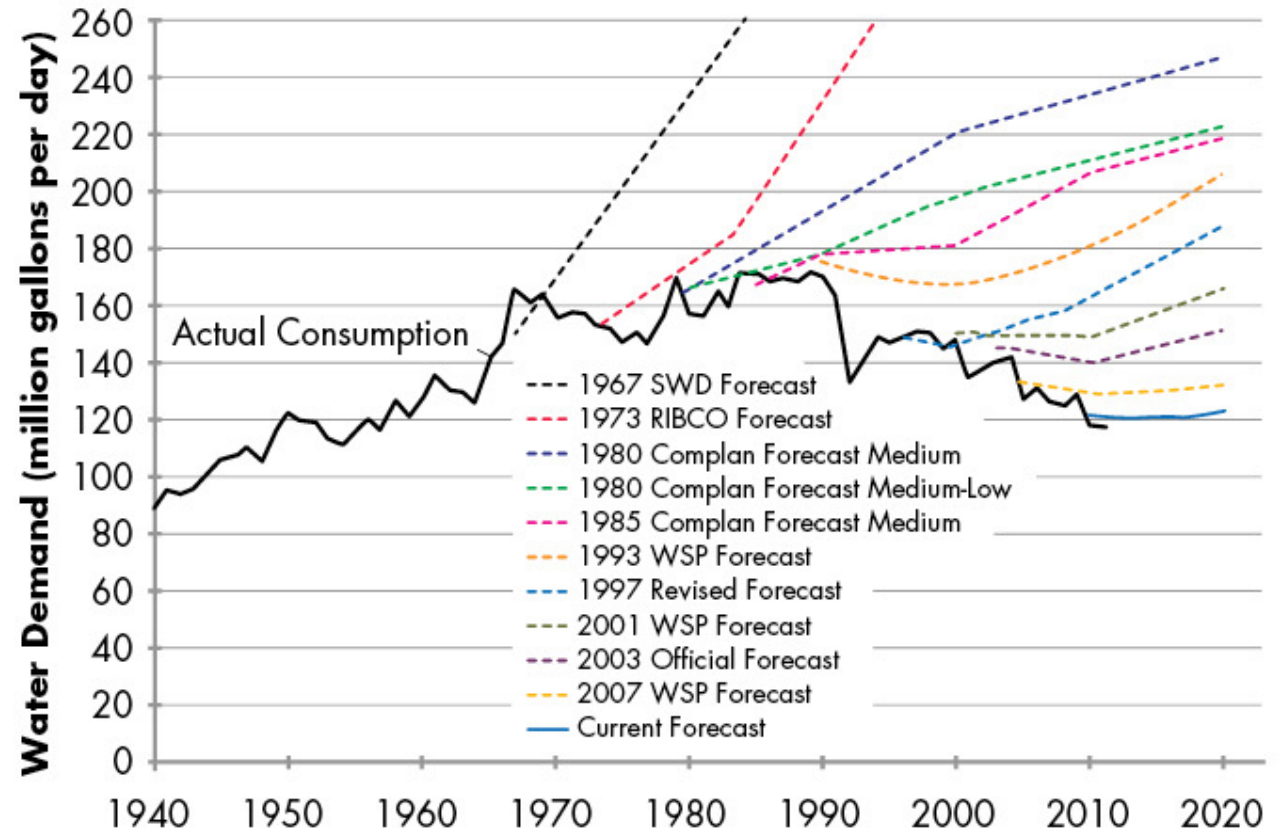
- How **vulnerable** are these water users to **future** climatic stress, increasing water demands and other uncertain drivers?
- Can we identify which stressors are most **consequential** for these users and under what conditions?
- Are there **asymmetries** in impacts across users?



Assessing future impacts: are 4 2 5 10 possible futures representative?



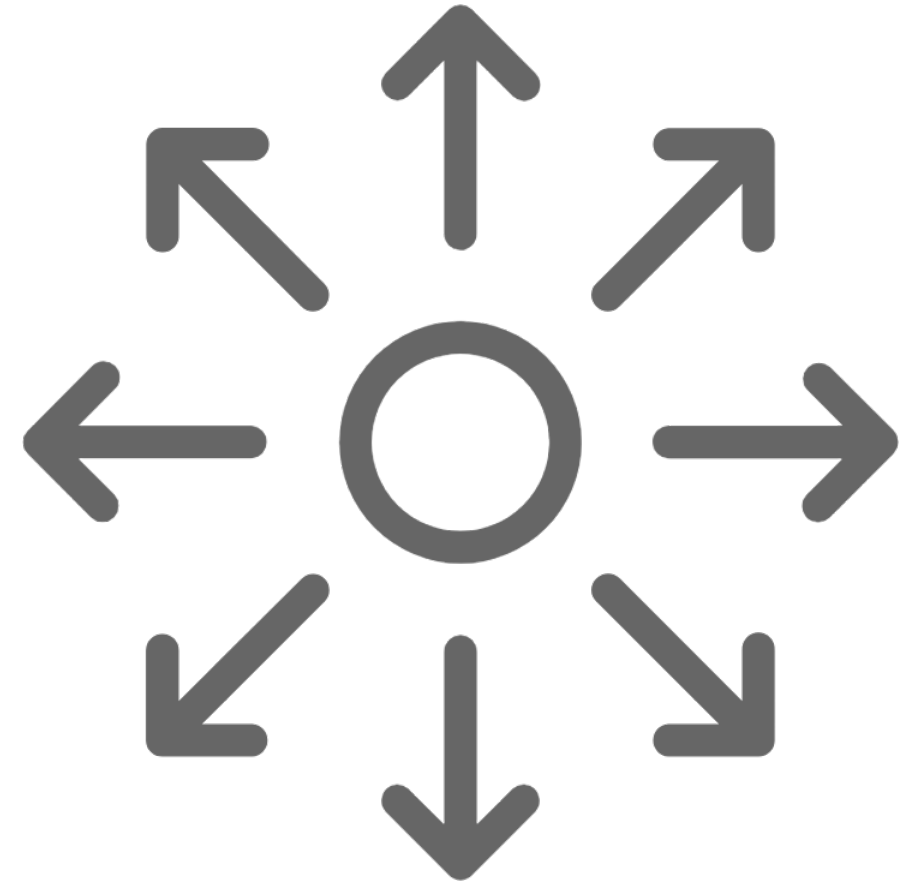
Water demand forecasts for Seattle, Washington



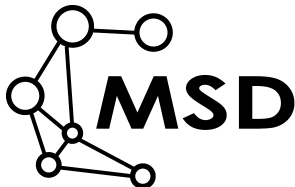
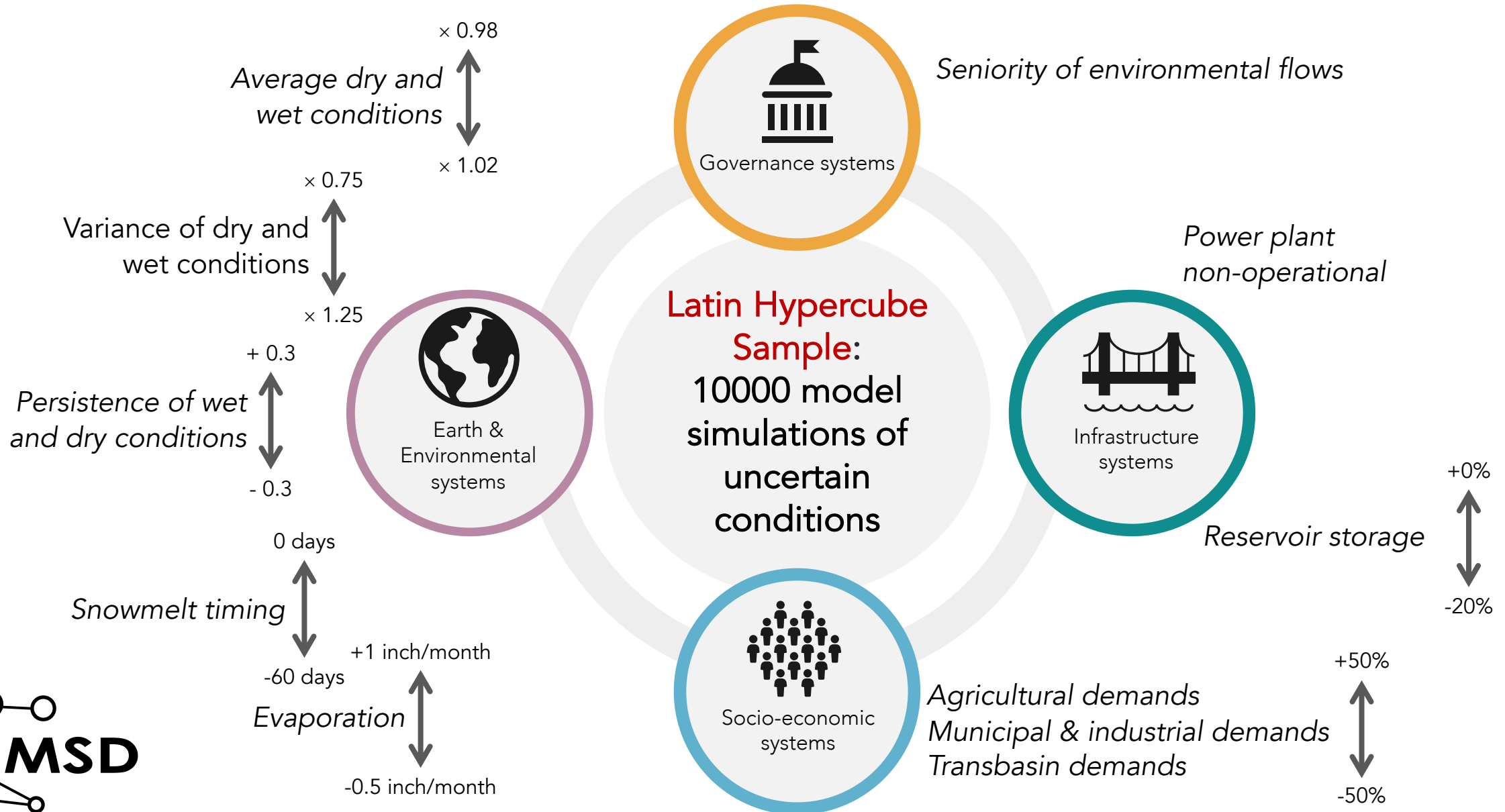
A Community Guide for Evaluating Future Urban
Water Demand (2016). Pacific Institute

Exploratory modeling

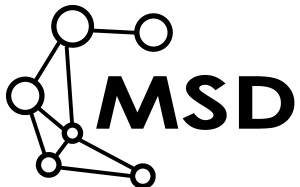
Sampling over ensembles of computational experiments that represent a **large number of plausible assumptions** about the future.



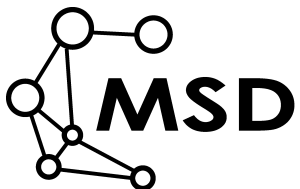
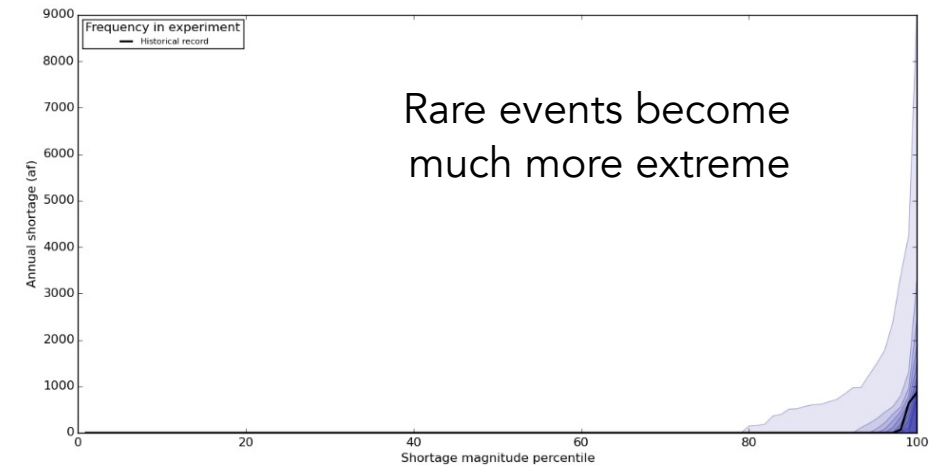
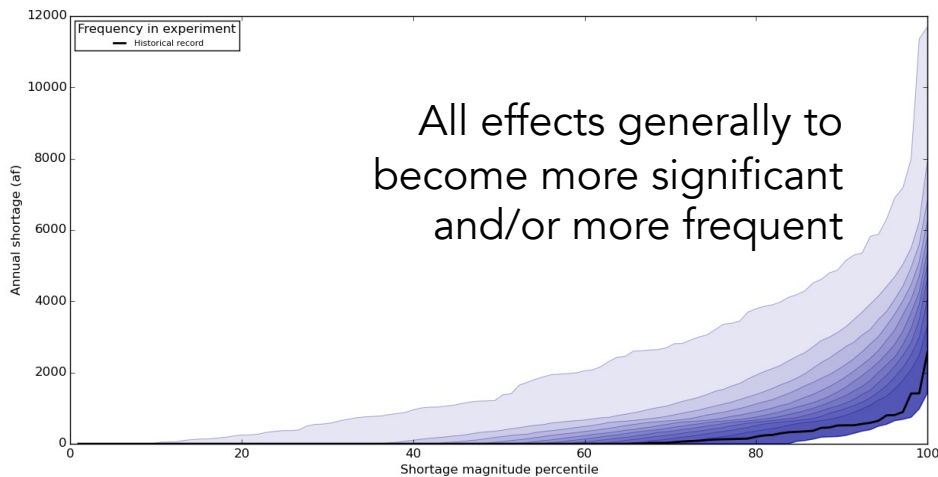
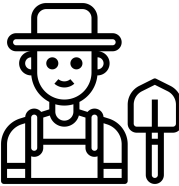
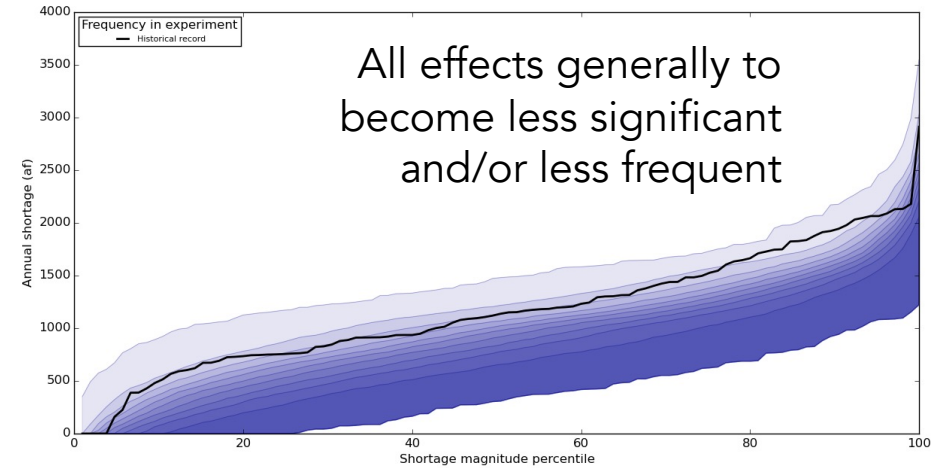
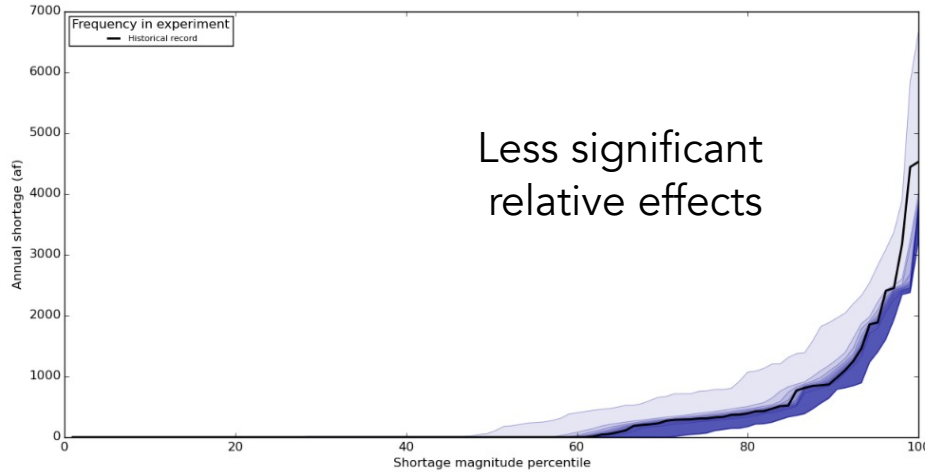
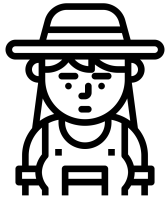
Exploratory experiment



How does this experiment
affect water users?

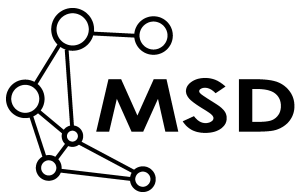
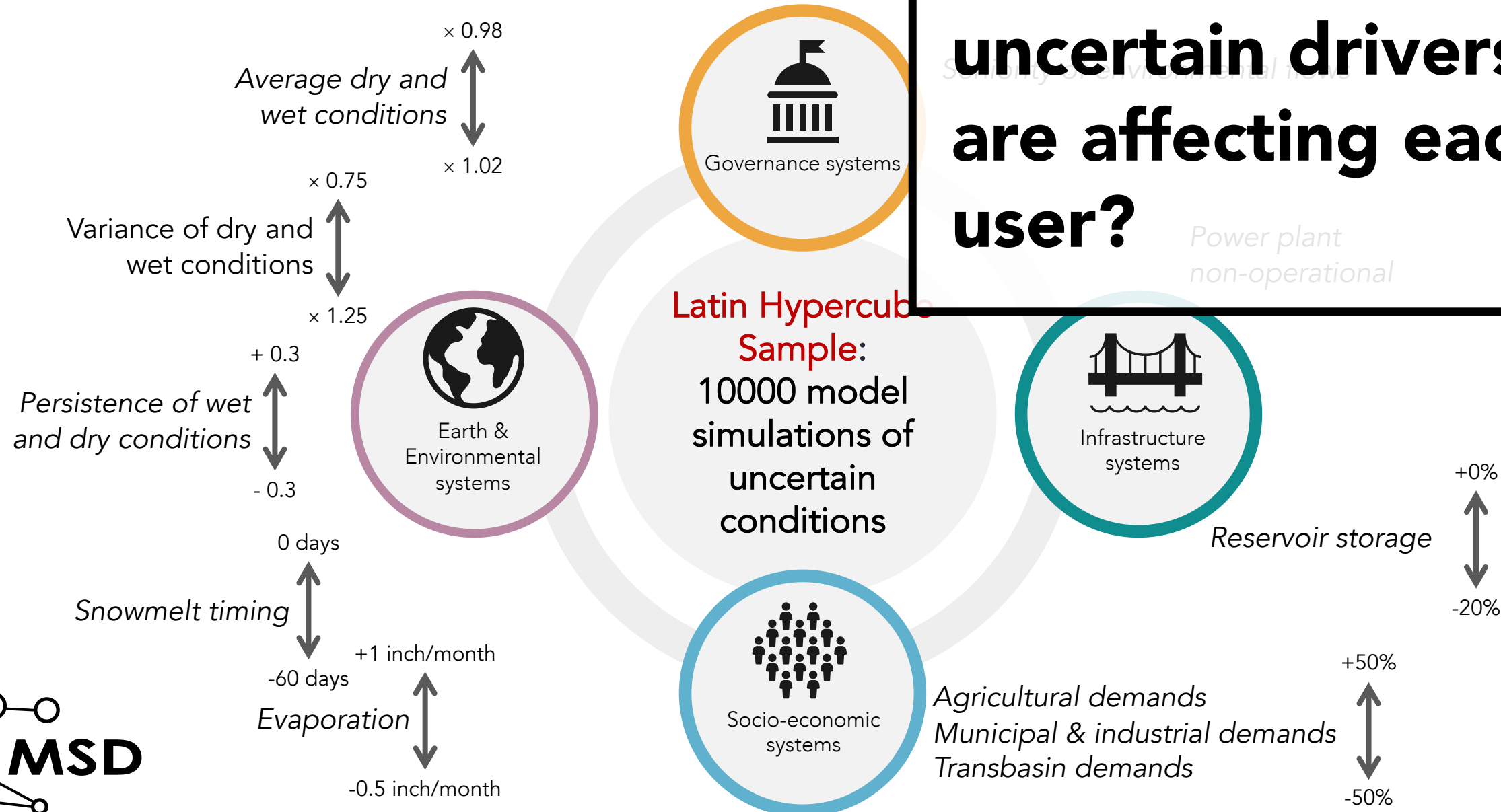


Different users experience different impacts

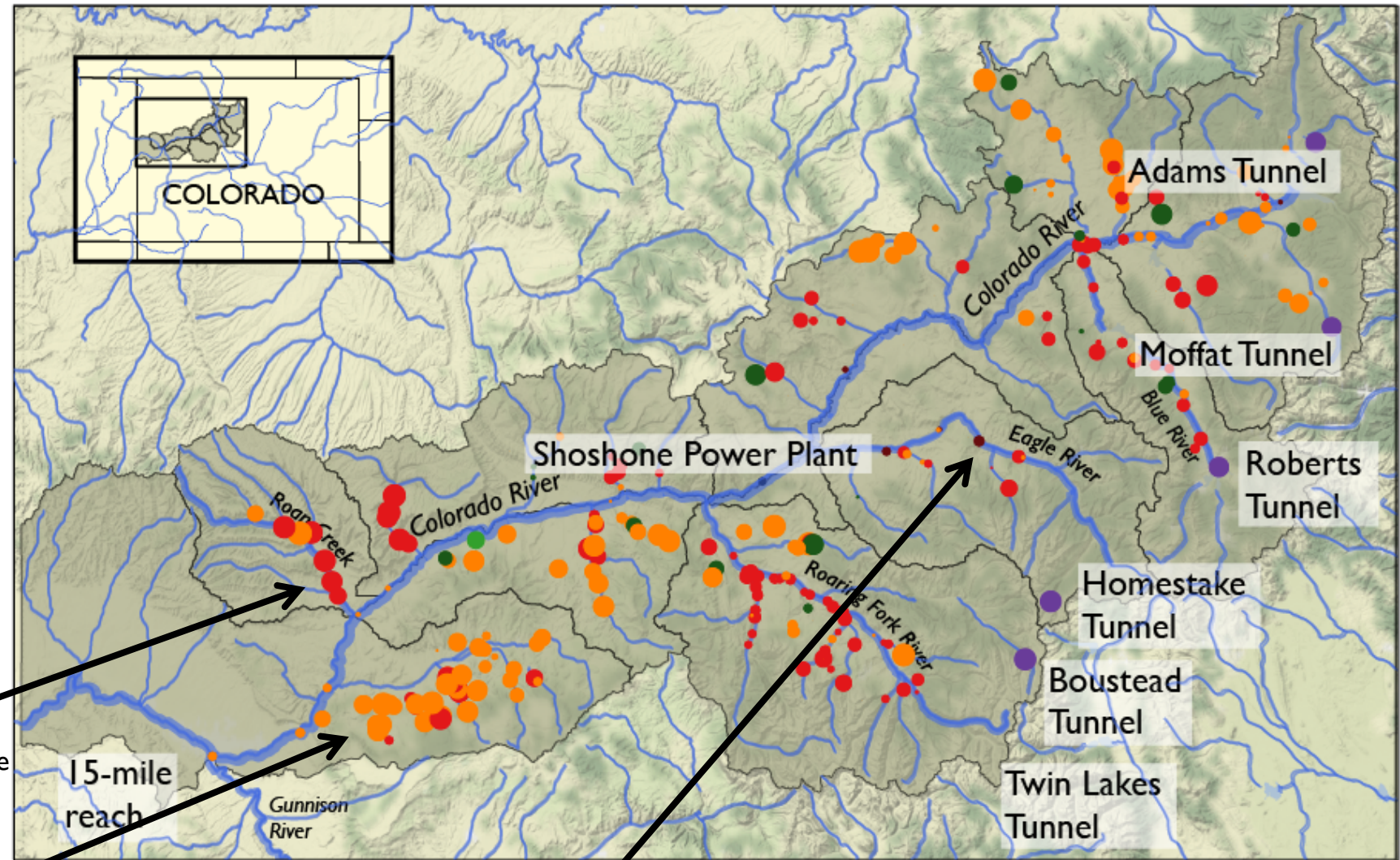


Exploratory experiment

Which of these uncertain drivers are affecting each user?



Different kinds of drivers shape impacts



- Dry flow variance
- Evaporation
- Wet flow variance
- Dry flow persistence

- Mean wet flow
- Mean dry flow
- Wet flow persistence
- Snowmelt timing



- Irrigation demand
- Transbasin demand
- M&I demand



- Power plant operational
- Reservoir loss

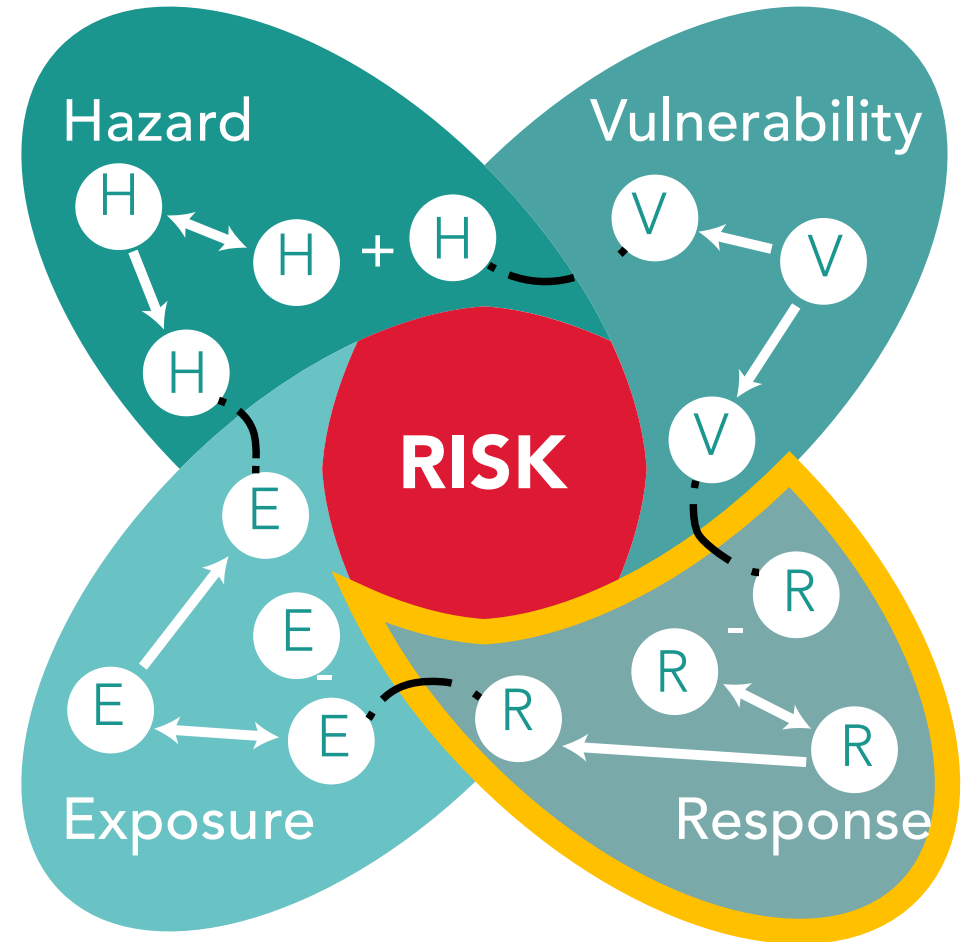


- Environmental right seniority

Currently expanding...

Previous work has focused more on impacts, by accounting for (some) drivers of hazard, vulnerability and exposure.

But what about **human response**?



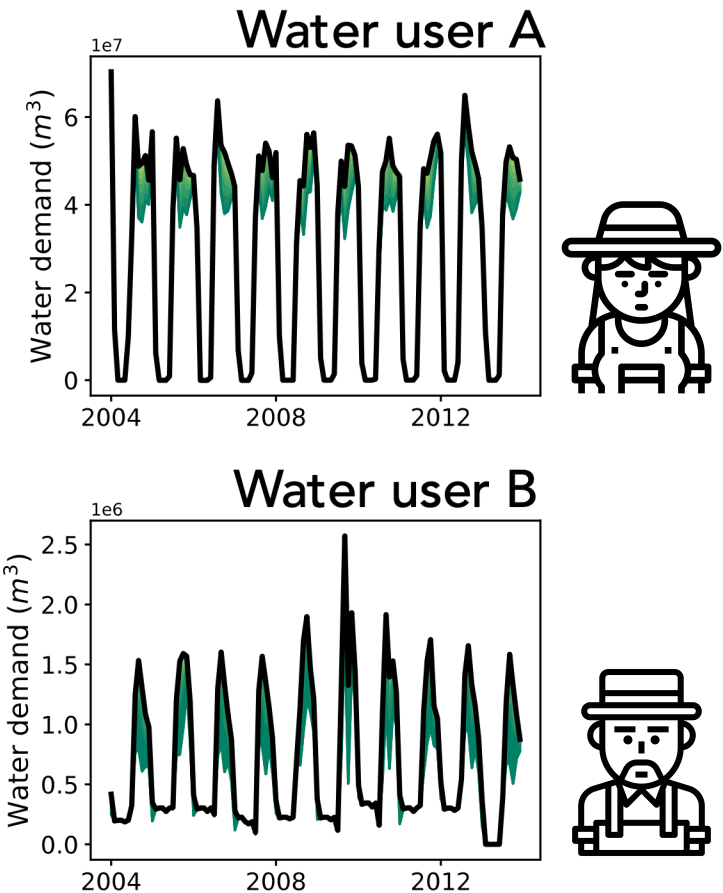
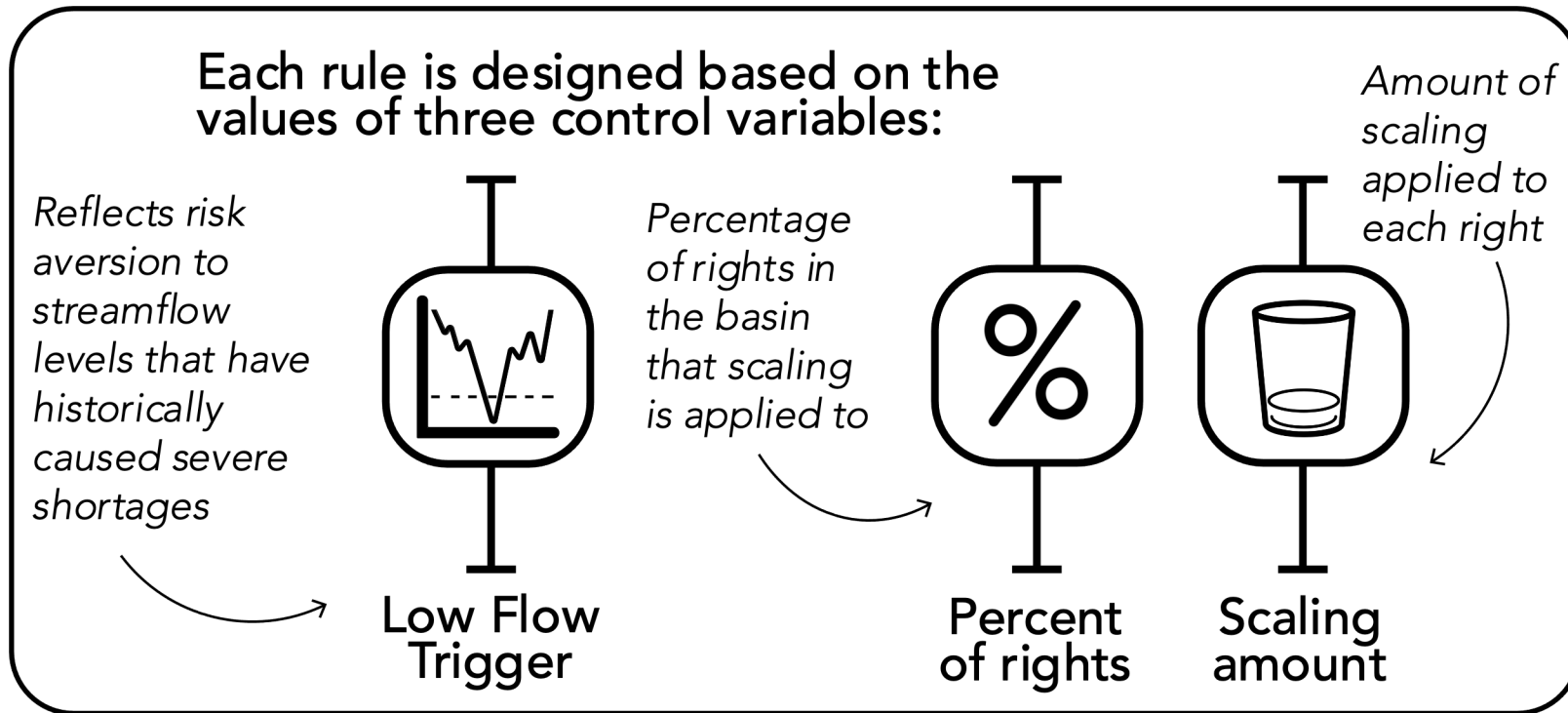
Adapting to changing conditions

Water utilities and individuals have been buying water rights to safeguard their supply

Water conservation efforts are reducing demands



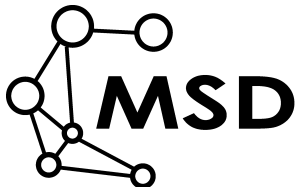
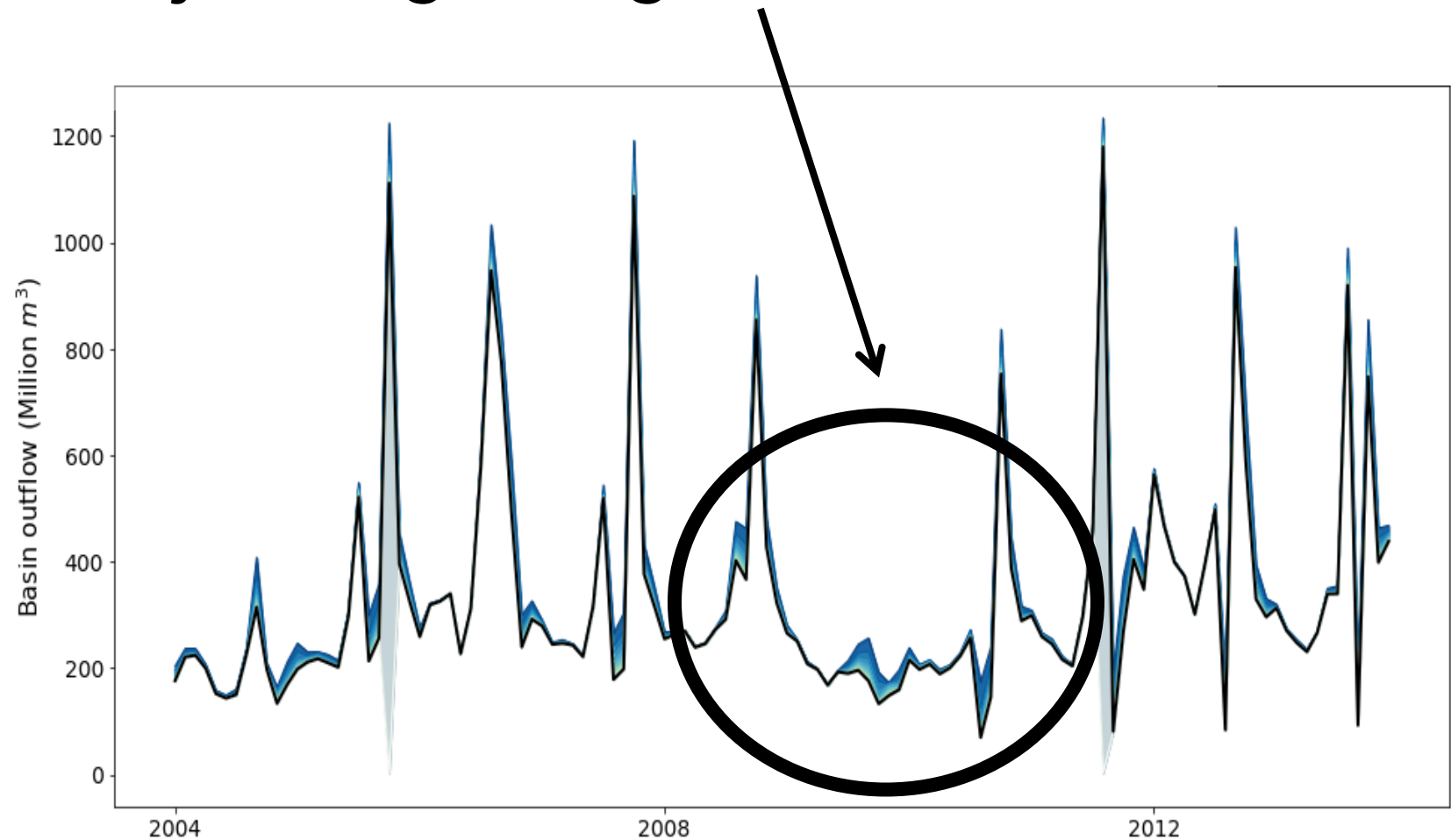
Create 600 exploratory adaptive demand scaling rules tailored to each user



Effects on water availability

Preliminary results show positive effect on increasing available water, especially during droughts

Effect is limited under increasingly stressed conditions

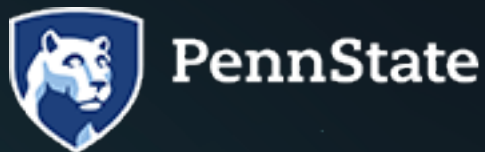


Thank you for your attention!

**MultiSector Dynamics
Community Building Webinar
February 22nd 12-2PM CST**

Registration and info:

<https://multisectordynamics.org/community-webinar/>



www.hadjimichael.info/



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