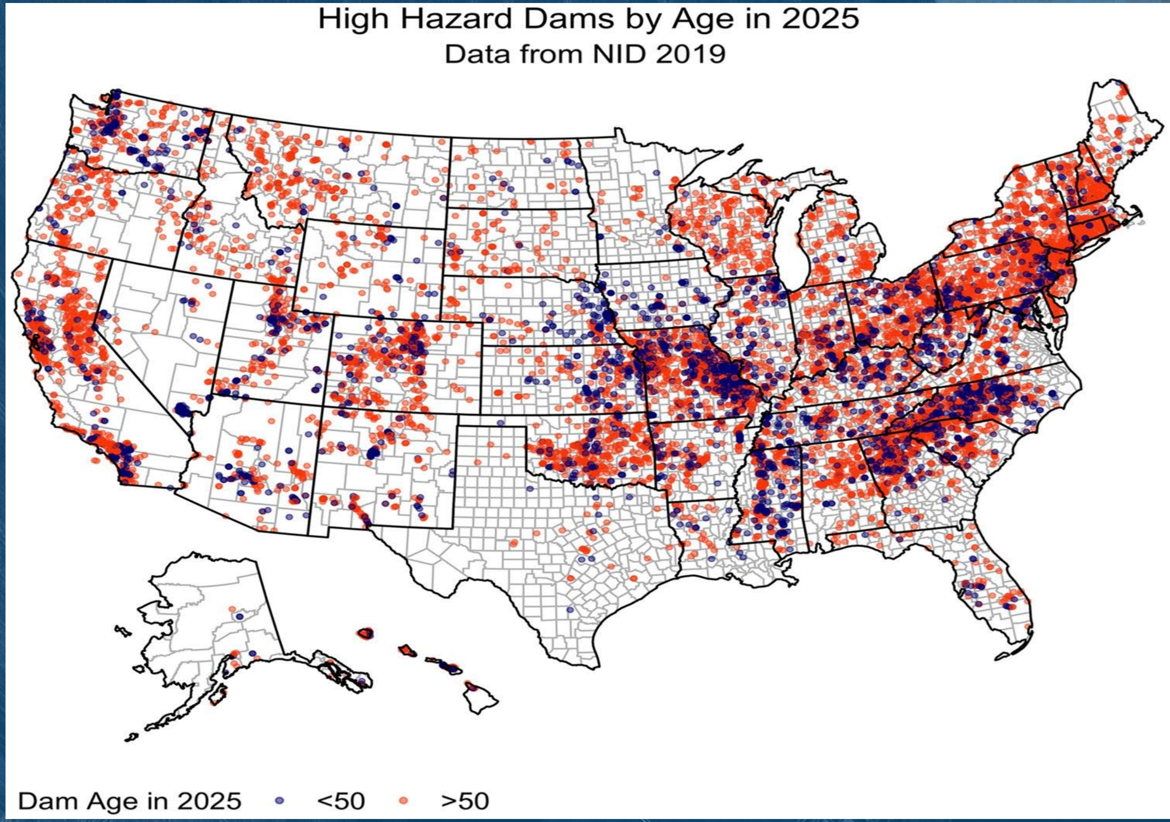
Data informed strategies for portfolio risk assessment of 90,000 US dams

National Dam Safety Program Technical Seminar | Upmanu Lall, Columbia Univ.



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Concha Larrauri, P., Lall, U., & Hariri-Ardebili, M. A. (2023). Needs for Portfolio Risk Assessment of Aging Dams in the United States. *Journal of Water Resources Planning and Management*, *149*(3), 04022083.

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Team Members (NSF-HDR IGuide Project)

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- Michigan State University
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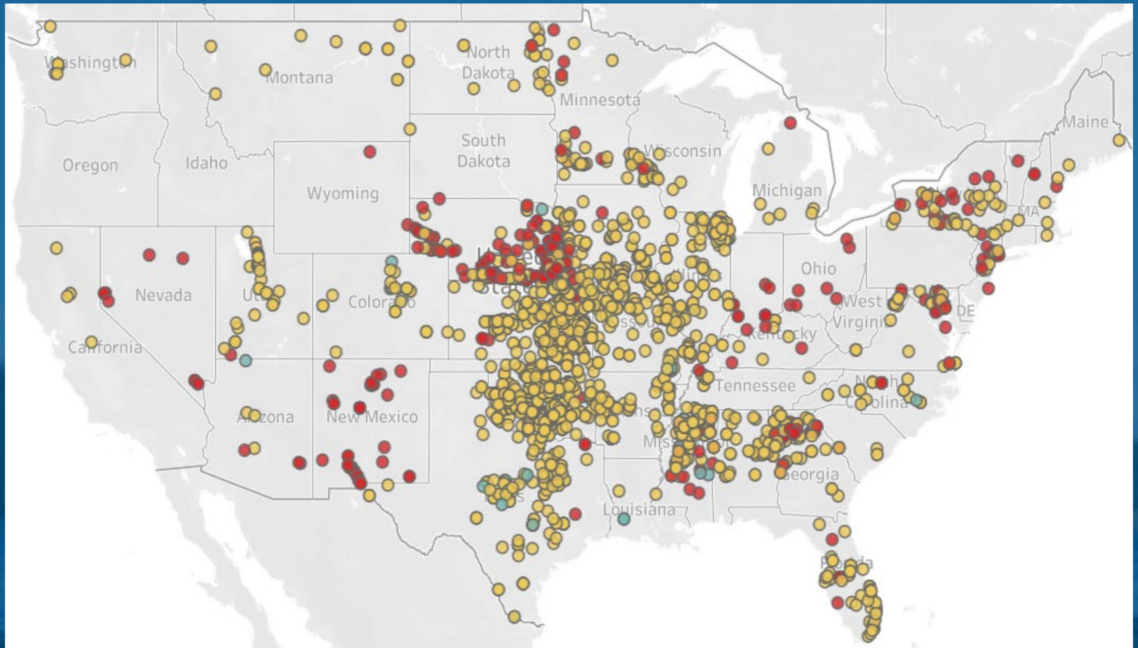
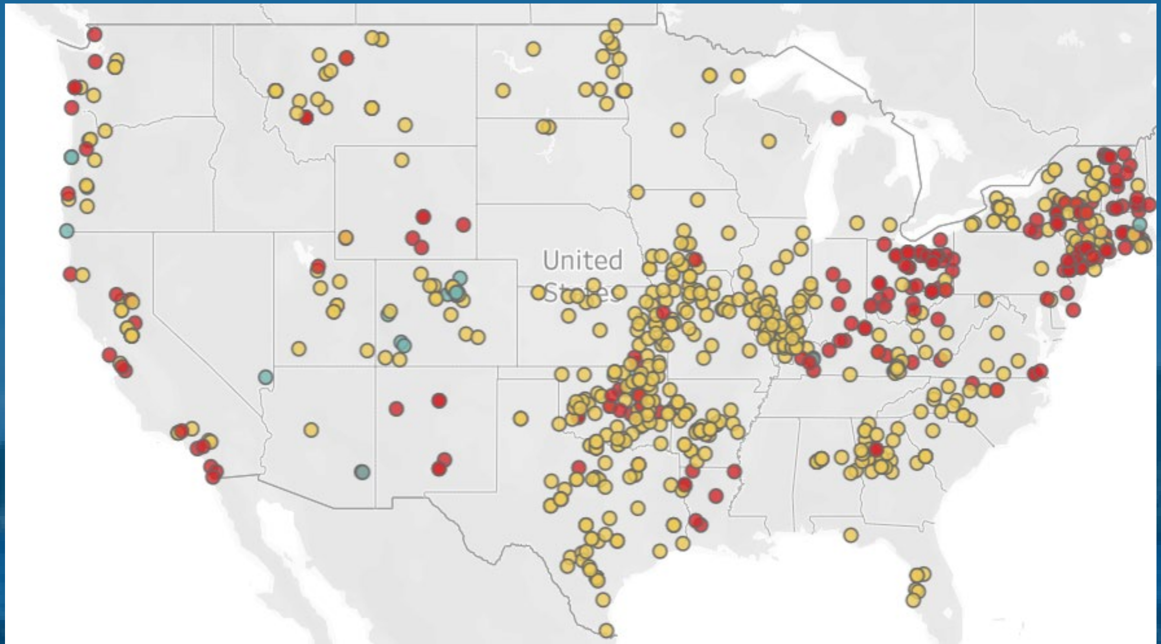
State of US Flood Control Dams



State of US Water Supply Dams



Condition Assessment

- Not Available
- Not Rated
- Poor
- Unsatisfactory

Nearly 2/3rds of dams are rated poor, unsatisfactory or unrated

92000+ dams total

>80000 non-federal dams

Failure consequences largely unknown

18657 Total high and significant hazard ratings with poor, fair unsatisfactory or not rated

74% of dams in these 2 categories of concern!!

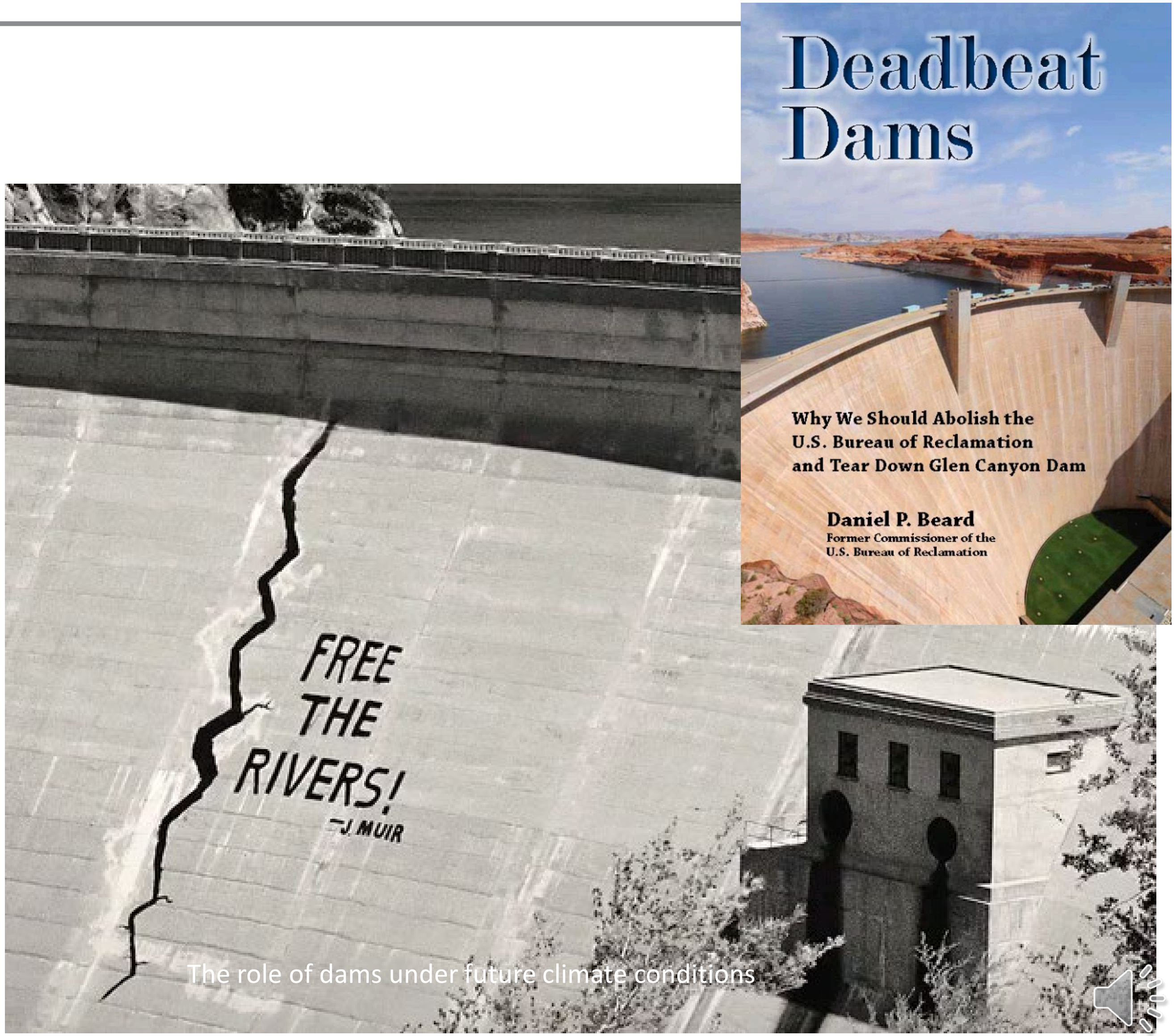
Based on data from National Inventory of Dams

Outline

- The context: State of Systems and Changing Perceptions
- The challenge
  - What is the likelihood of a dam failing, especially under a changing climate?
  - What would be the impacts: on other dams; critical infrastructure; people; ecosystems; other regions, short and long run economics, services impacted?
  - Hot spots? Prioritization? Opportunities?
  - Investment Analysis – role of climate change adaptation; removal vs restoration or expansion?
- The approach
- Examples
- Invitation for collaboration

Attitude towards dams

- Environment:
  - Downstream estuaries
  - Sediment trapping and changes in downstream sediment gradient
  - Fish migration
  - Greenhouse gas emissions
- Economic/social
  - Poor financial returns
  - Distribution of benefit



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Emerging attitudes towards dams

- Changing Climate :
  - Need more storage, raise or add dams
  - Pumped storage hydro
  - Augment low flow for ecology
- Economic/social
  - Public Private Partnerships (Public good and impact, private owners?)
  - Energy interest
  - Failure could lead to catastrophic impacts through cascading failure of downstream critical infrastructure and pollution

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Energy as a driver

1. ~10% of the dams currently have hydropower installation
2. They are spatially distributed over the country
3. Floating solar panels on reservoirs are a possibility
4. lower costs to connect to the grid – transmission

How can this legacy infrastructure be de-risked or repurposed most effectively, given increasing fragility and changes in possible use cases?

How could we inform a national investment strategy, especially for non-federal dams?

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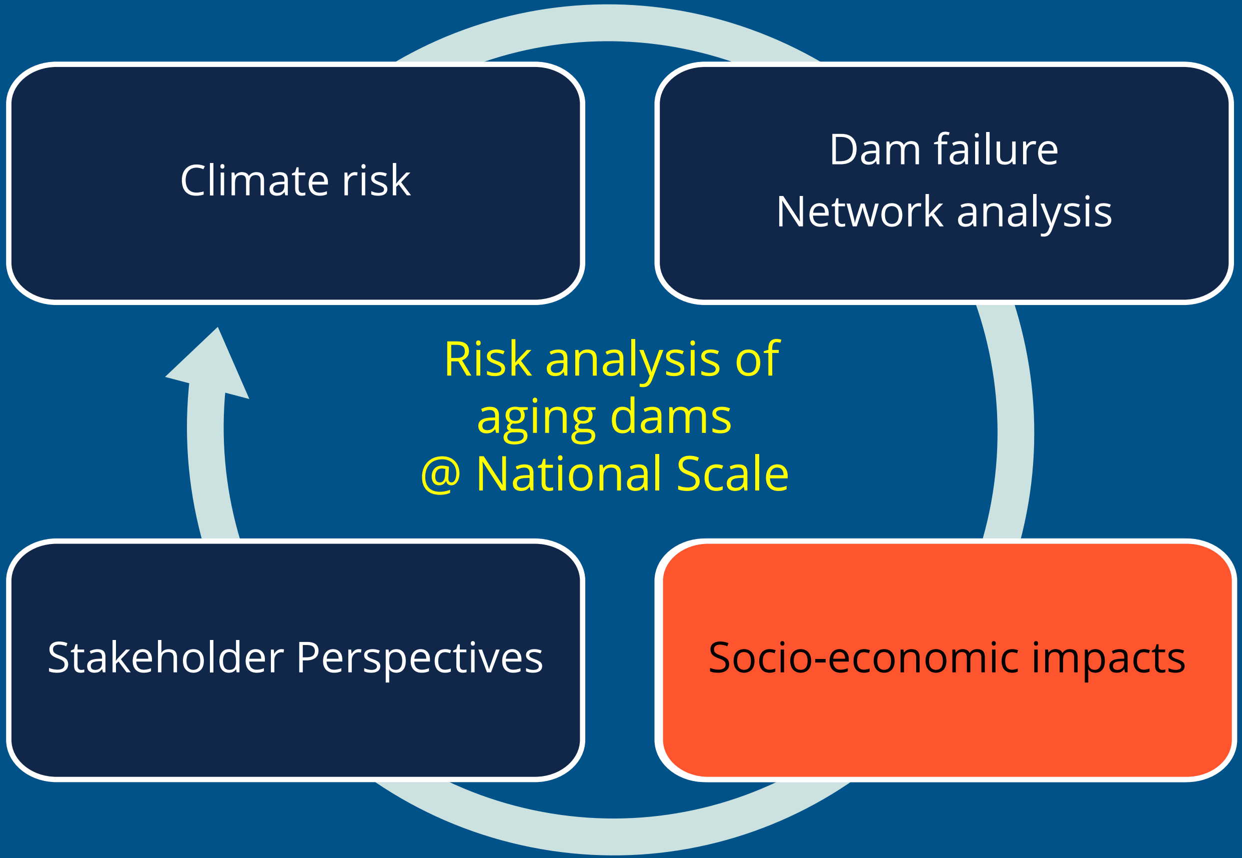
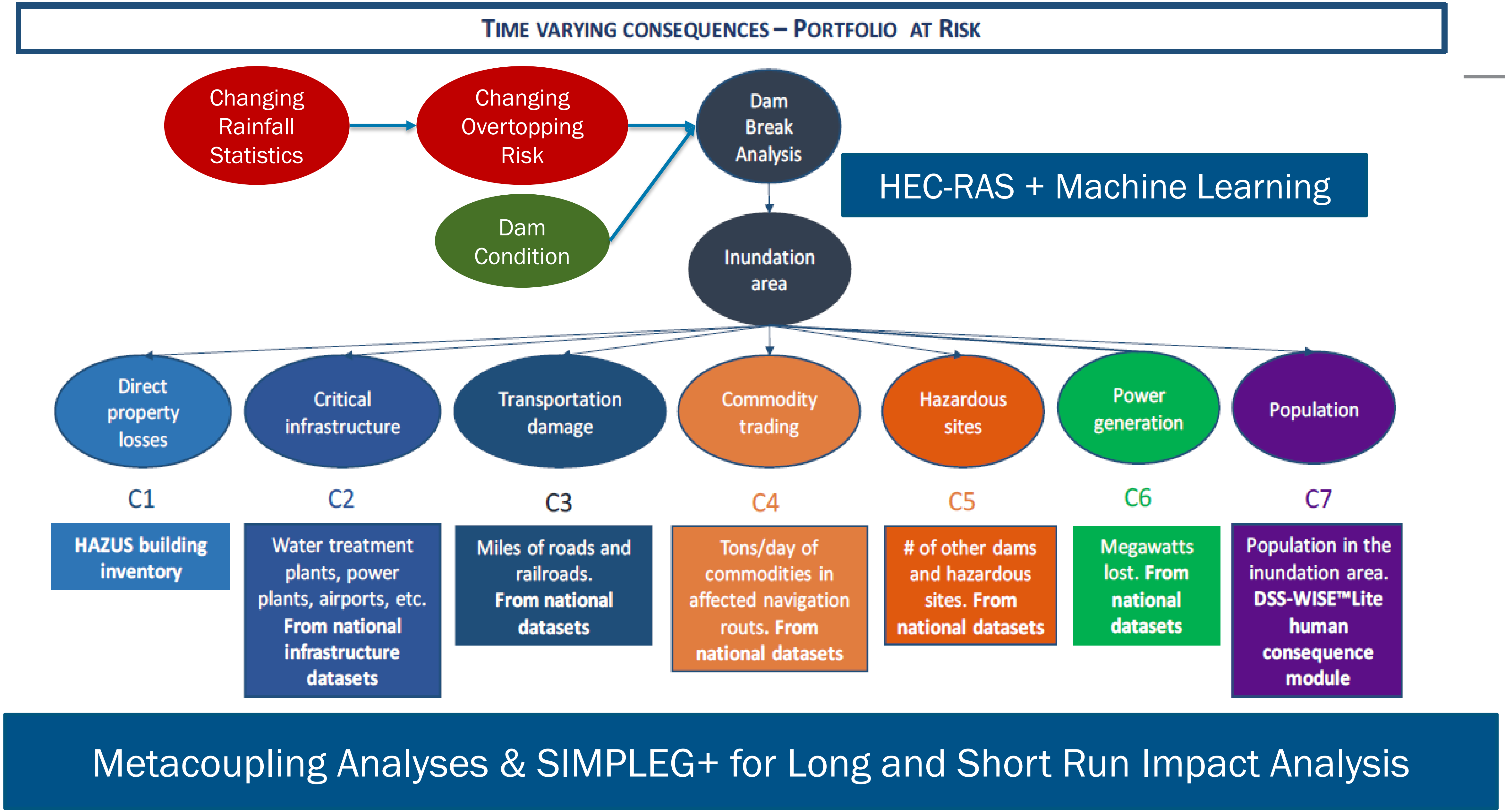
Risk Analysis

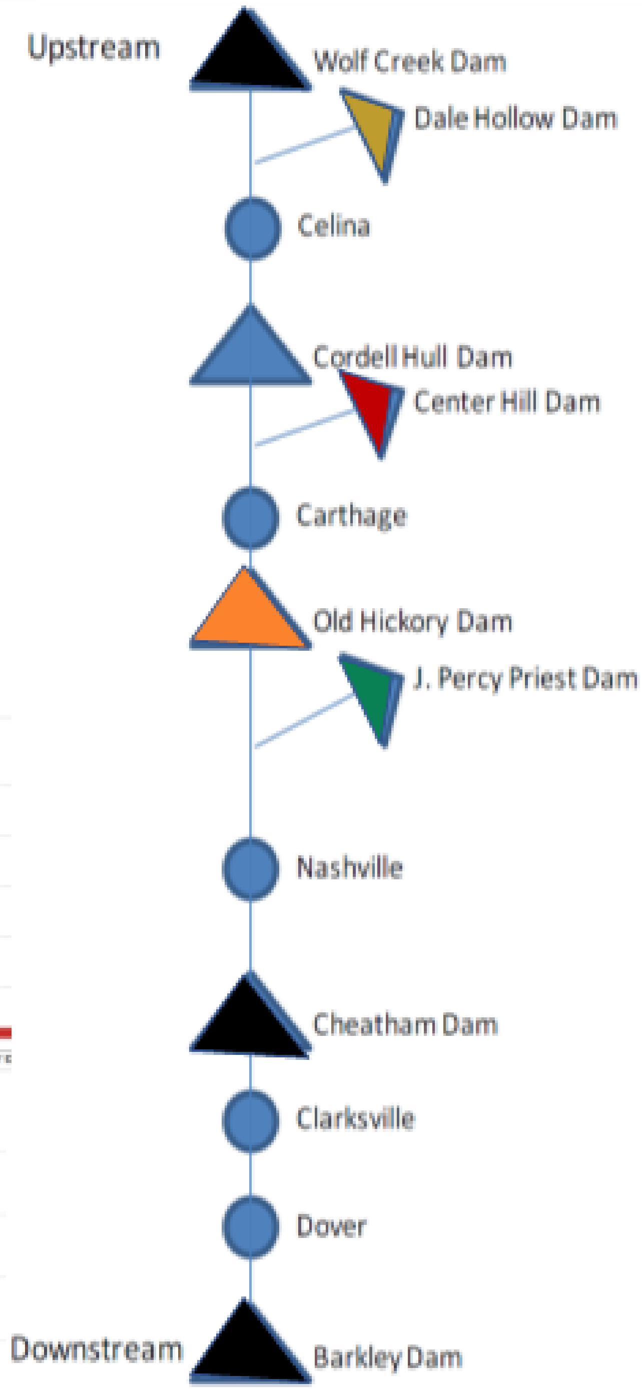


A Scalable Machine Learning and Artificial Intelligence Platform

Dam by Dam analysis vs National Screening Tool
Prioritizing Inspection & Investment based on Risk

Time Varying Consequences





Impact Analysis from Potential Dam Failures in the Ohio River Basin

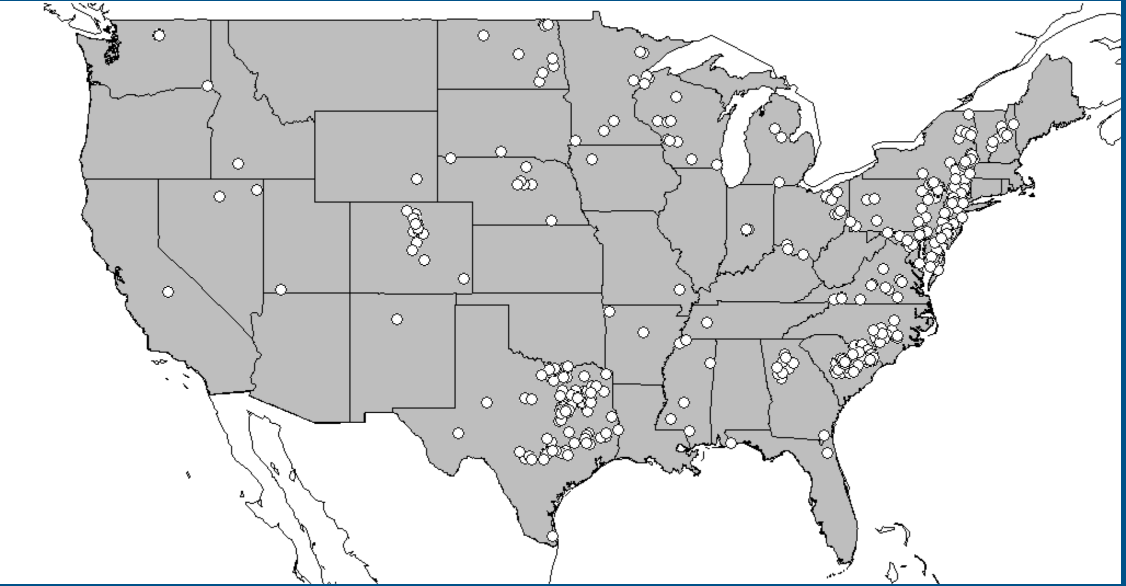
The climate question

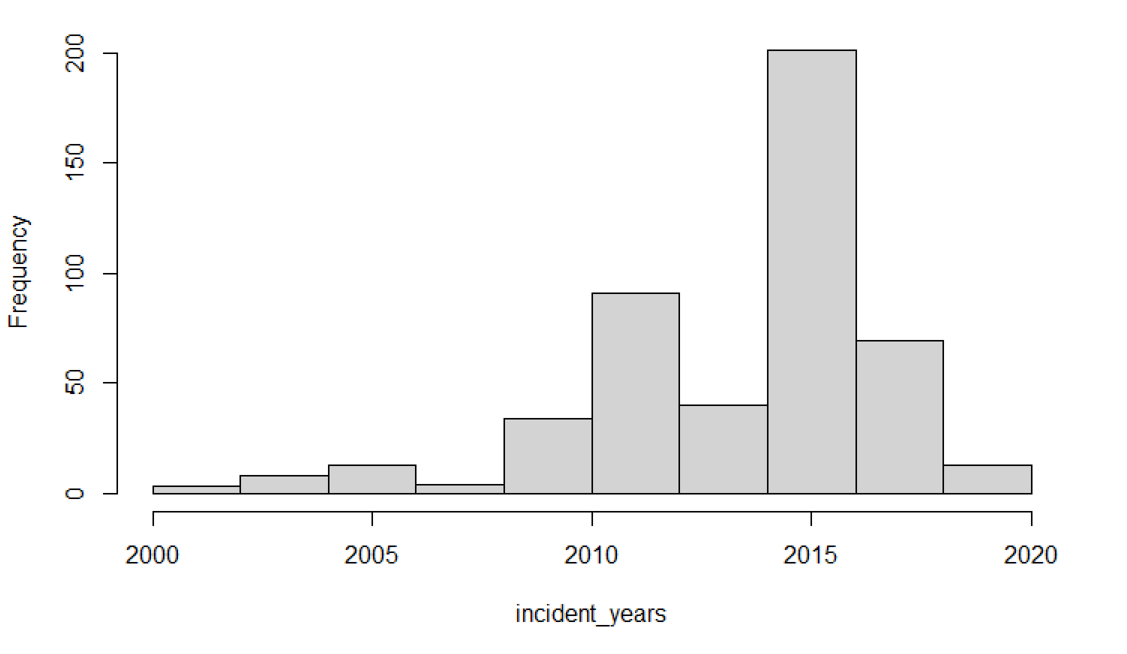
- Overtopping = 1/3rd of all dam failures
- "Dam spillways are designed for 10k year flood"
- Drought concerns motivate keeping reservoir full
- Overtopping likelier if extreme storm when reservoir full

- **Did dams that failed due to hydroclimatic factors experience a very extreme flood or a modest flood after a wet period?**
- **How are the risks of an extreme rainfall event following a wet period changing across the country?**

What was the climate like during actual hydrologic dam failures?

Dam Failure Data:
- ASDSO
- Failures due to hydrologic/flooding since year 2000
- Data: 569 failures





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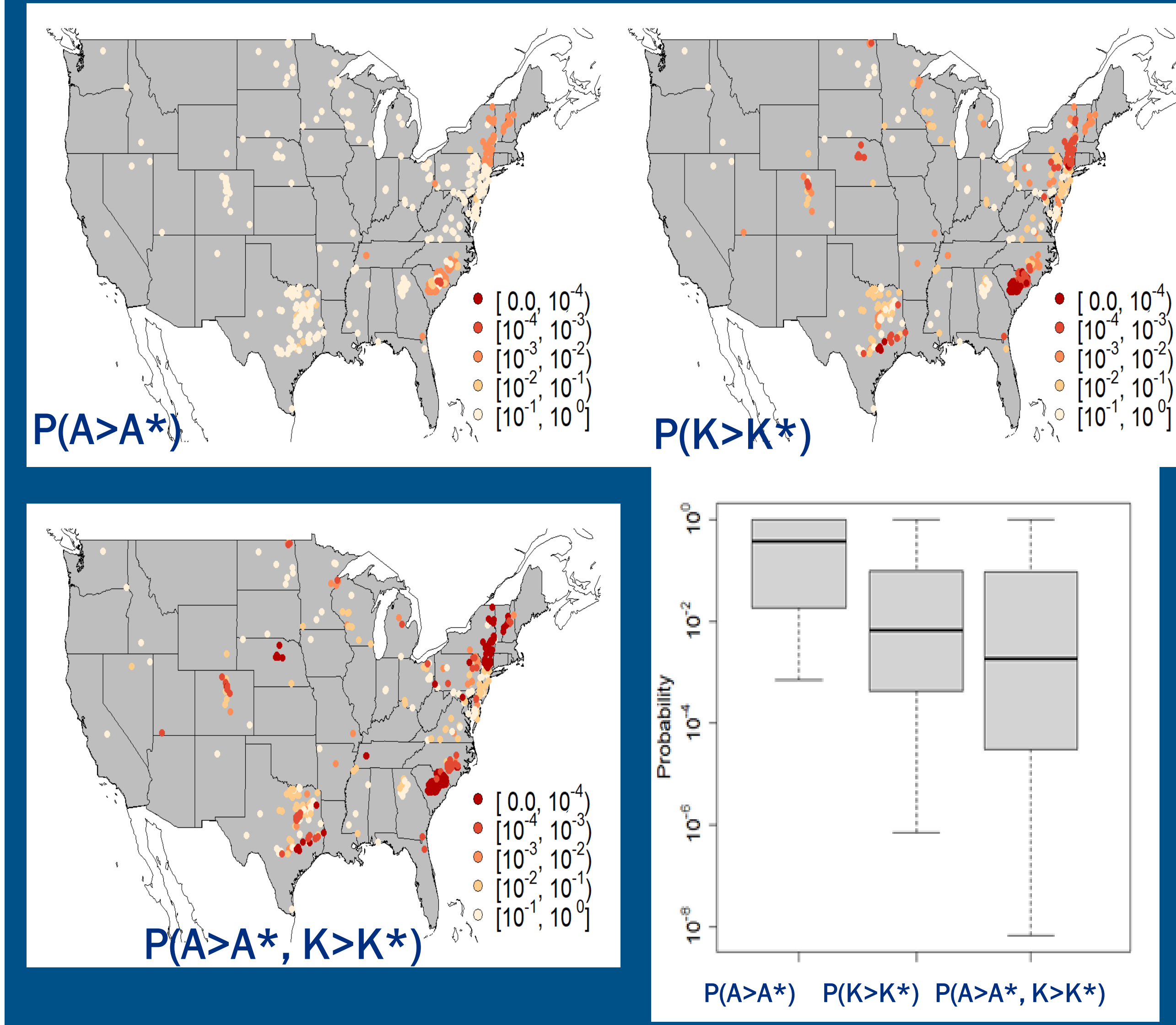
Jeongwoo Hwang, N C State University

Hydrologic Dam Failures often correspond to “moderately extreme” wet period + high rain

- A = Annual Daily Maxima
- K = Preceding 30 day rainfall
- A*= Max Daily Rain associated with failure
- K*=Preceding 30 day rainfall w/failure
- J* = Joint, both A* and K*

Median return period of *A: ~4 years**
Median return period of *K: ~29 years**
Median return period of *J: ~52 years**



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Edenville Dam Failure (2020)
A – 8.5 years
K – 21 years
Joint – 181 years

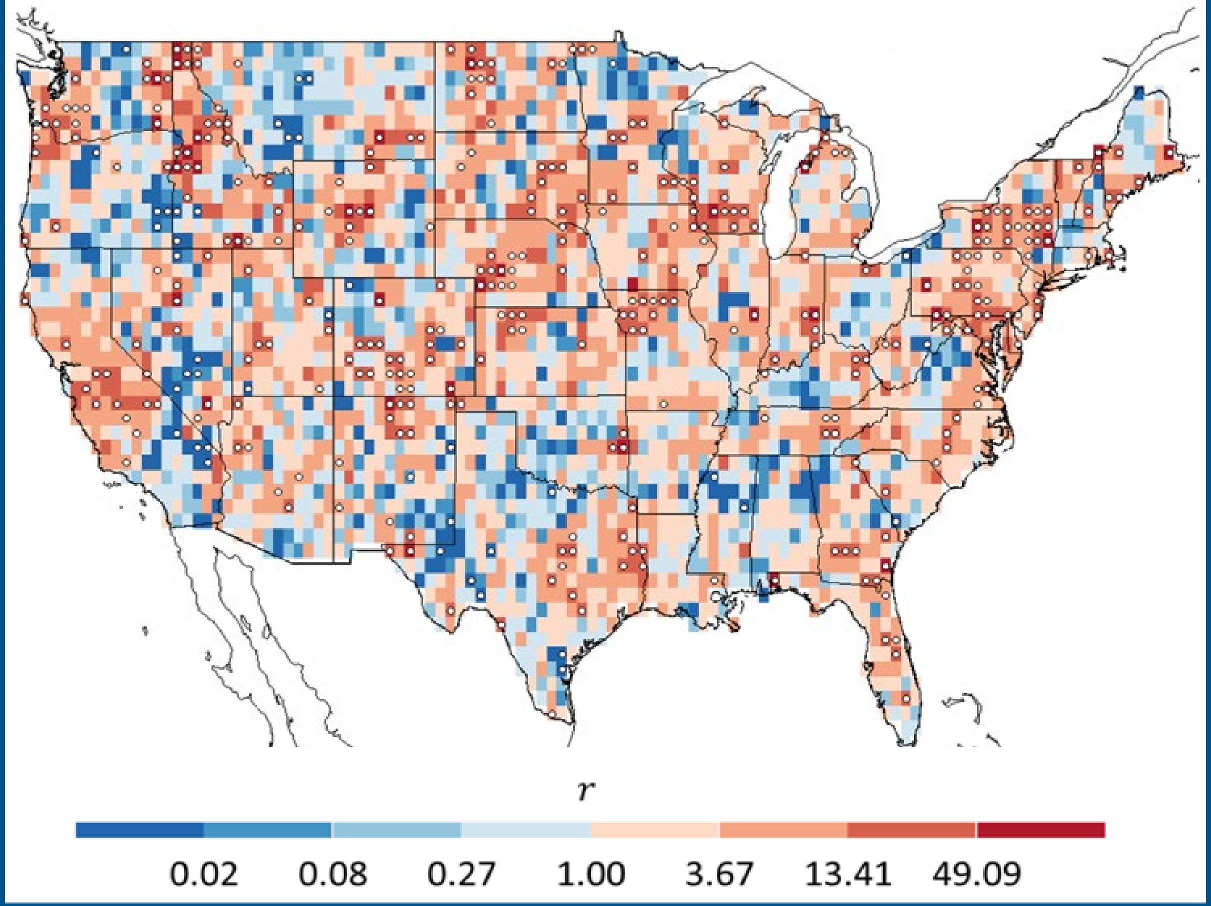
Are there statistically significant rainfall trends that amplify the risk of aging dam failure?

Changes in the **joint exceedance probability**;
P(A>A*, K>K*)
(A* = 100-year event, K* = 10-year event)

$$Nonstationary\ Model\ with\ A \sim GEV, K \sim Gamma$$
$$and\ (A, K) \sim best\ copula$$

Over much of the country the probability of the annual daily maximum rainfall > 100 year event and the preceding 30 day rainfall >10 year event are going up

Risk of overtopping or hydrologic failure amplified



Ratio of the joint exceedance probability in 2022 to the joint exceedance probability in 1979.

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The Dam Failure Flood Wave question

- Is there an automatic and scalable way to predict inundation areas for the NID dams consequent to dam failure?

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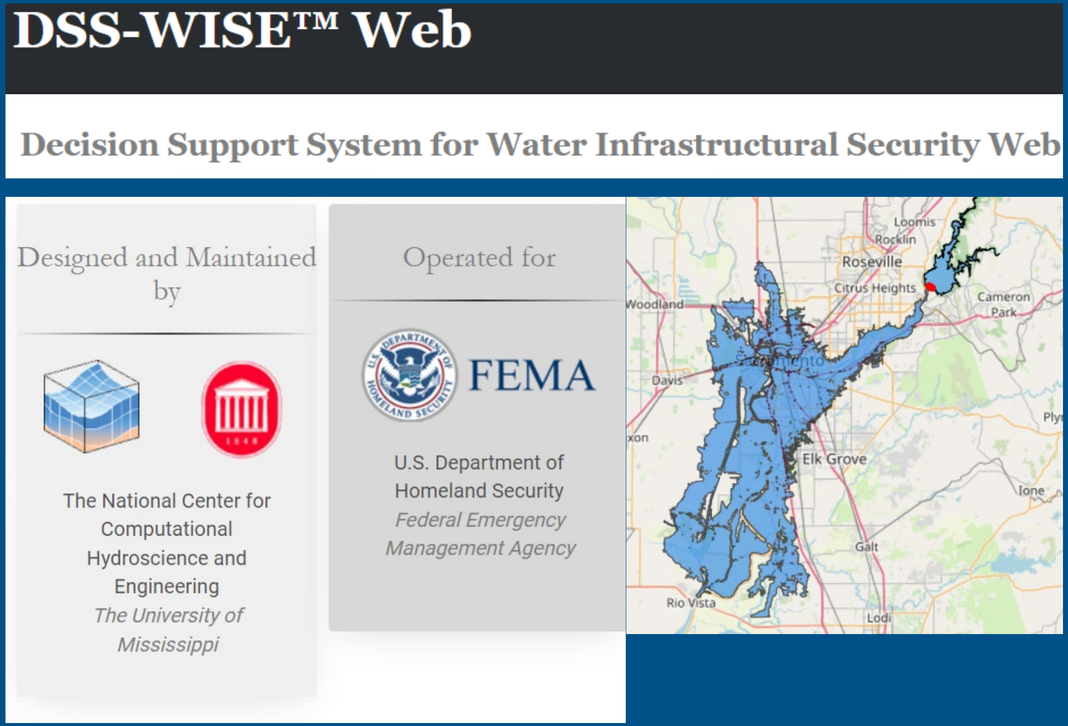
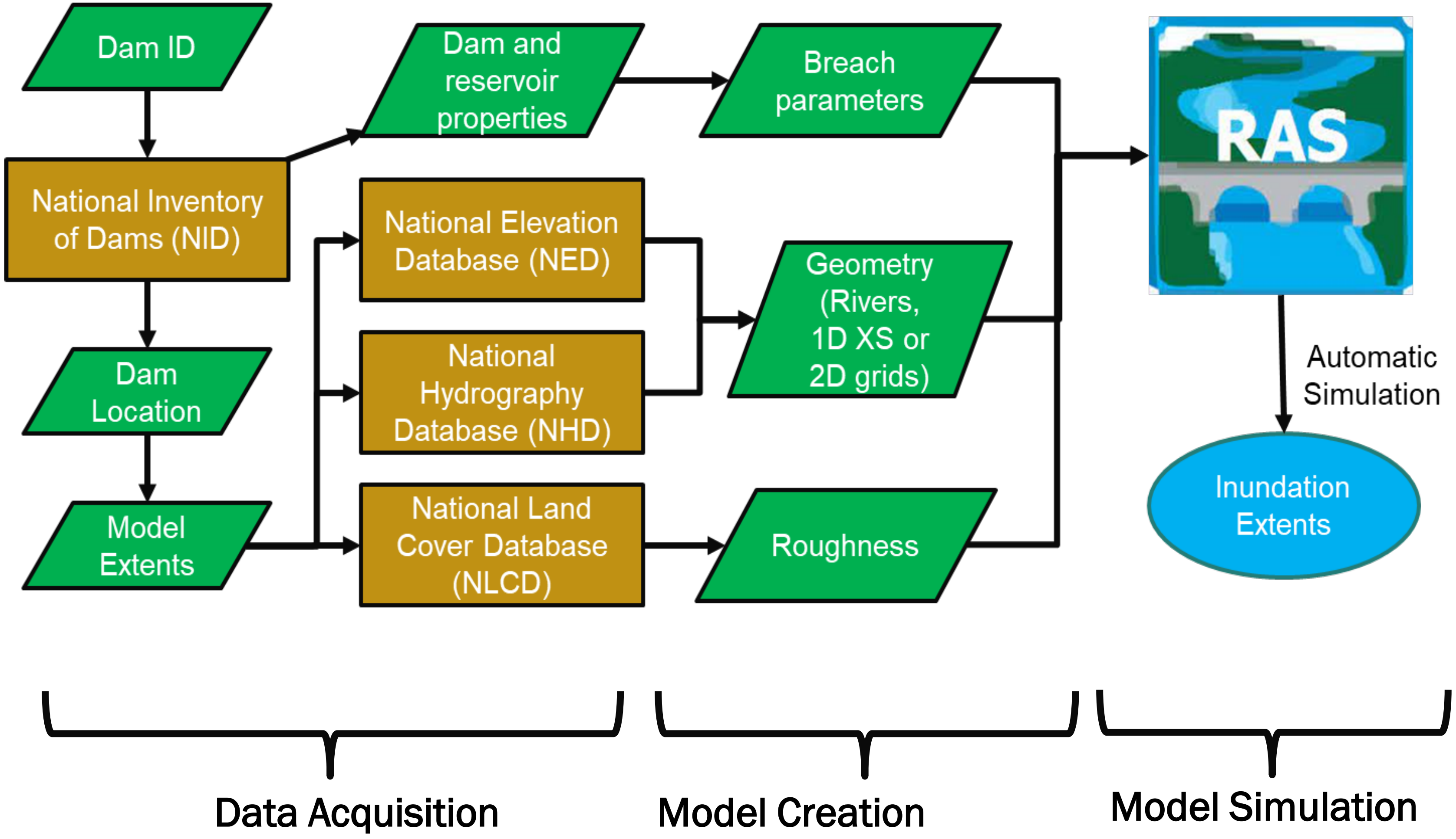
2D hydrodynamic modelling: DSS-WISE



- Connects to databases to import relevant data
- Outputs: Inundation maps, time of arrival, human consequences analysis
- Can NOT be automated

Automated Model Building: HEC-RAS

- Goal is to quantify hazard associated with ~5000 dams, possibly 90,000 dams!
- Automate HEC-RAS with reasonable accuracy using Python based framework
- Use previous dambreak and model run results to predict for all 90000 dams



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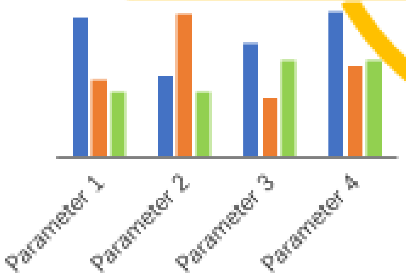
Sayan Dey, Purdue University

Validation and Uncertainty Analysis

- Model structures (dam breach types & 1D or 2D flood models)
- Model parameters (roughness)
- Model input (spatial & temporal boundaries)

Uncertainty Sources

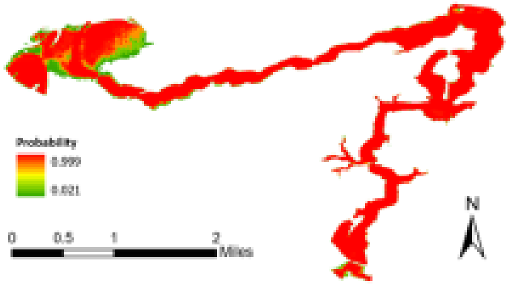


Flood Modeling

- Automating data preparation
- Automating HEC-RAS model set-up and hydraulic simulations

- Probabilistic flood inundation extents accounting for various uncertainty sources in dam breaches
- Flood risk indicators

Probabilistic Flood Inundation Maps



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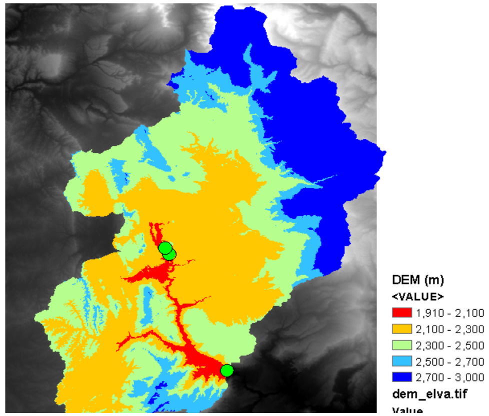
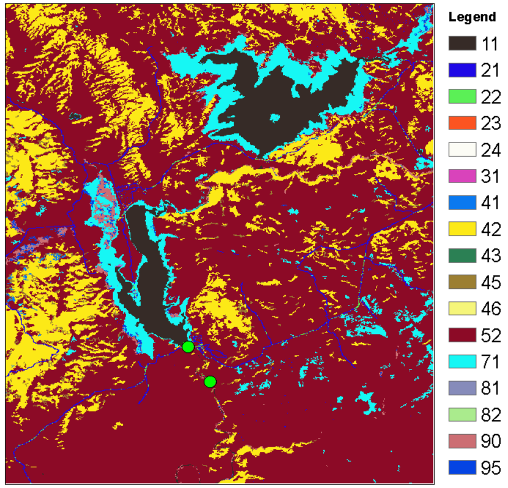
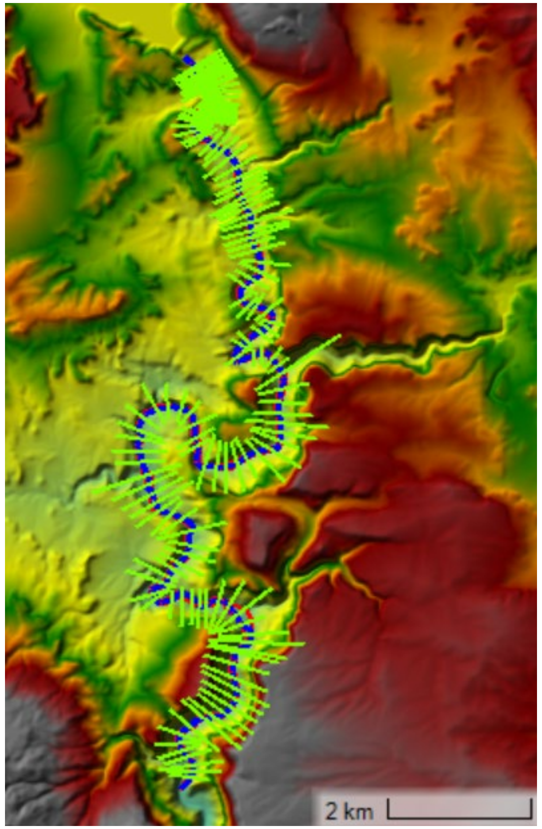
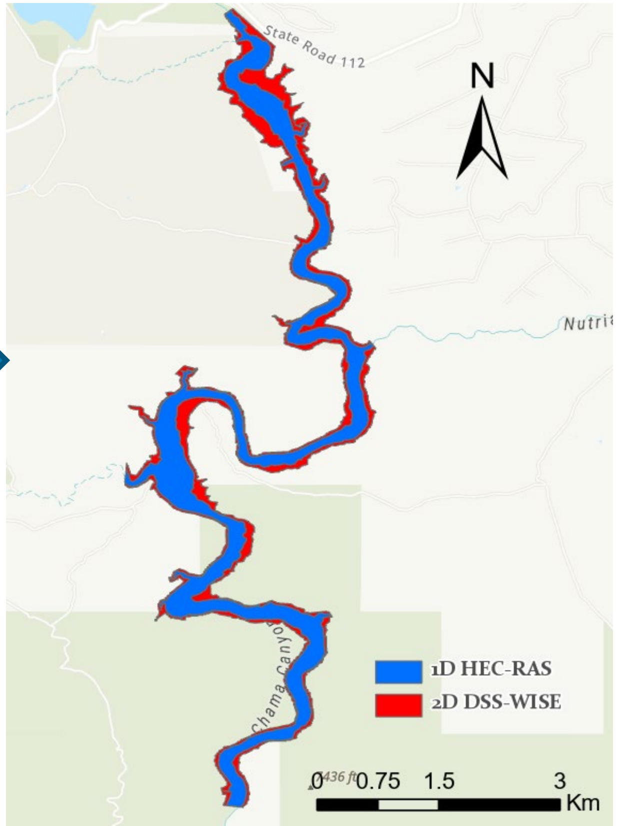
Case Study (El Vado Dam), New Mexico







1D HEC-RAS model



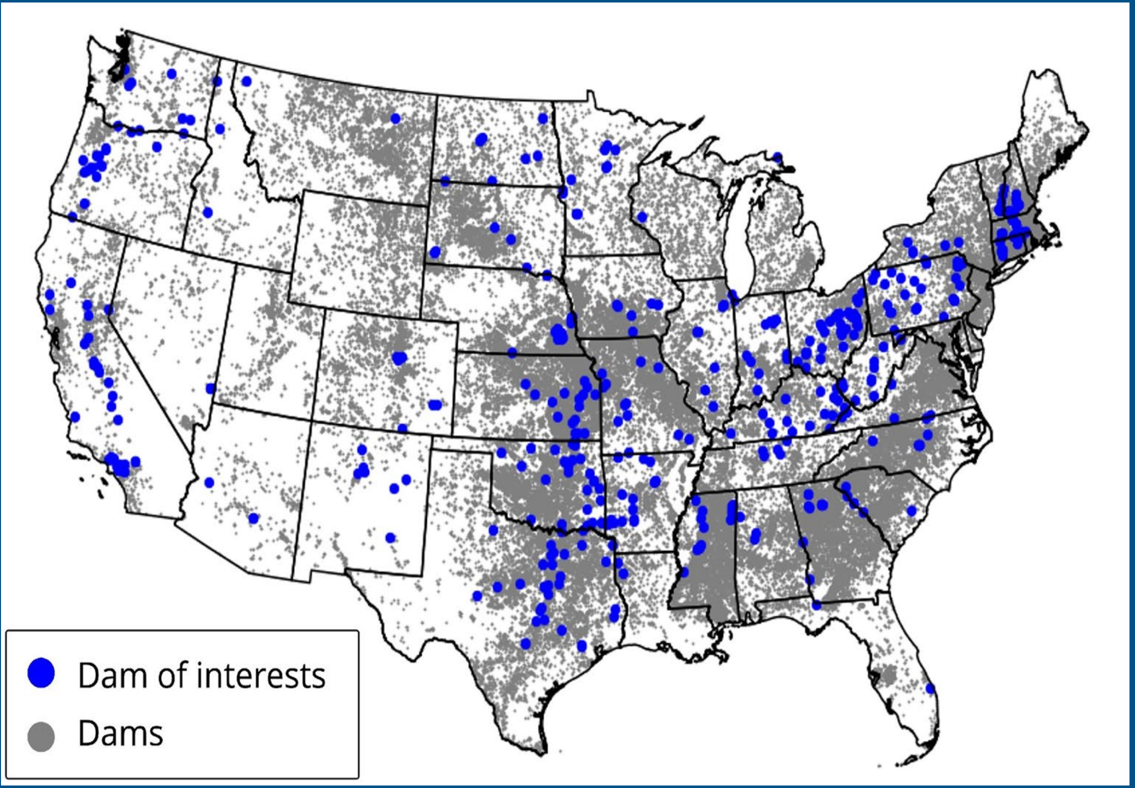
Comparison of inundation extents

Source: National Inventory of Dams (https://nid.usace.army.mil/#/)

The Dam Failure Impact Question(s)

- Can impacts of dam failure on different attributes be computed using network properties?
- Can short and long term economic impacts be assessed?

427 dams in CONUS



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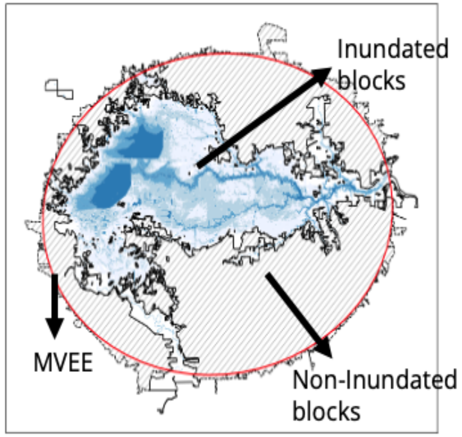
Analytical workflow

- Identify population characteristics vulnerable to dam failures

Flooded area identification



Social Vulnerability related census :
(~ 17 variables)

Education level	Poverty
Ethnicity	Car ownership

Spatial correlation

Bivariate Moran's I (+1 ~ -1):
a global index of spatial relationship

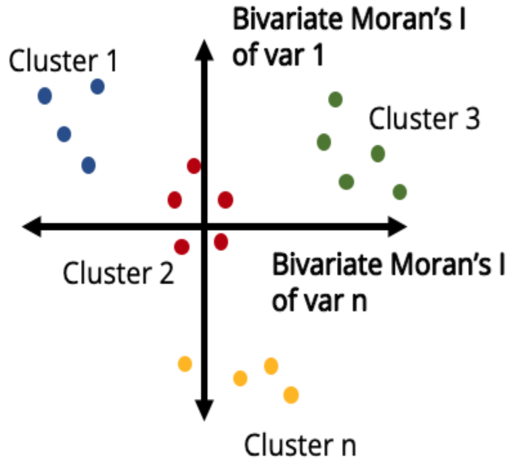
Bivariate Local Moran's I:
spatial cluster between inundated areas and census data

Social Vulnerability

Inundation	High	Low
High	HH	HL
Low	LH	LL

Rank dams per risk

K-means clustering :
group dams with their Moran's Index.



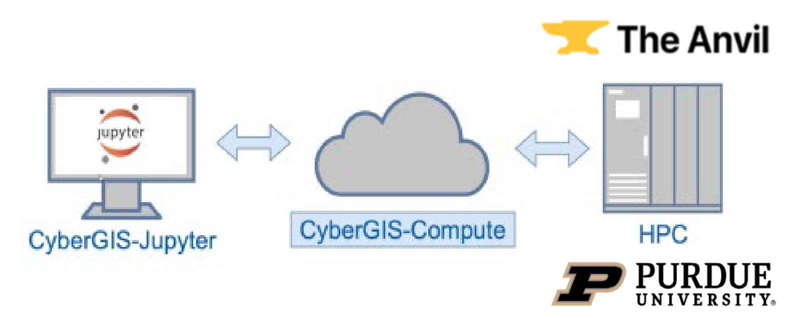
Jinwoo Park, University of Illinois @ Urbana-Champaign

Computation configuration

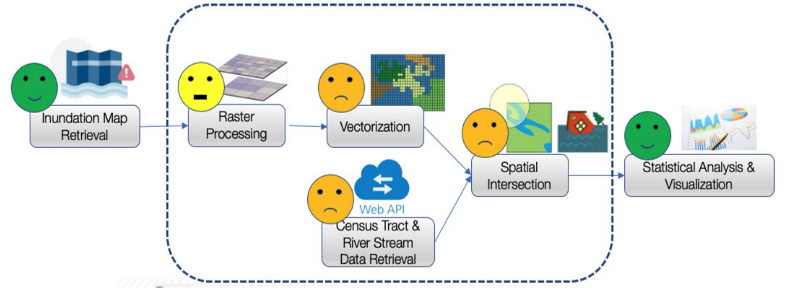
- HPC resources are used to address computational and data intensity due to the large-scale analysis.

- Modularized steps to improve reproducibility and replicability of the analysis.

Computing platform



Modularized step
(Flooded area identification)



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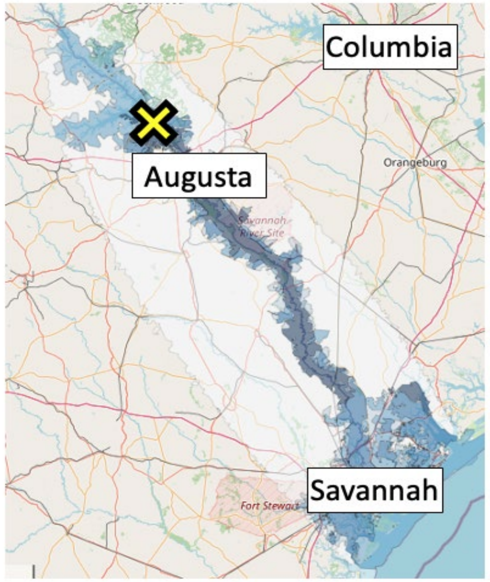
Preliminary result - local

J. Strom Thurmond Dam



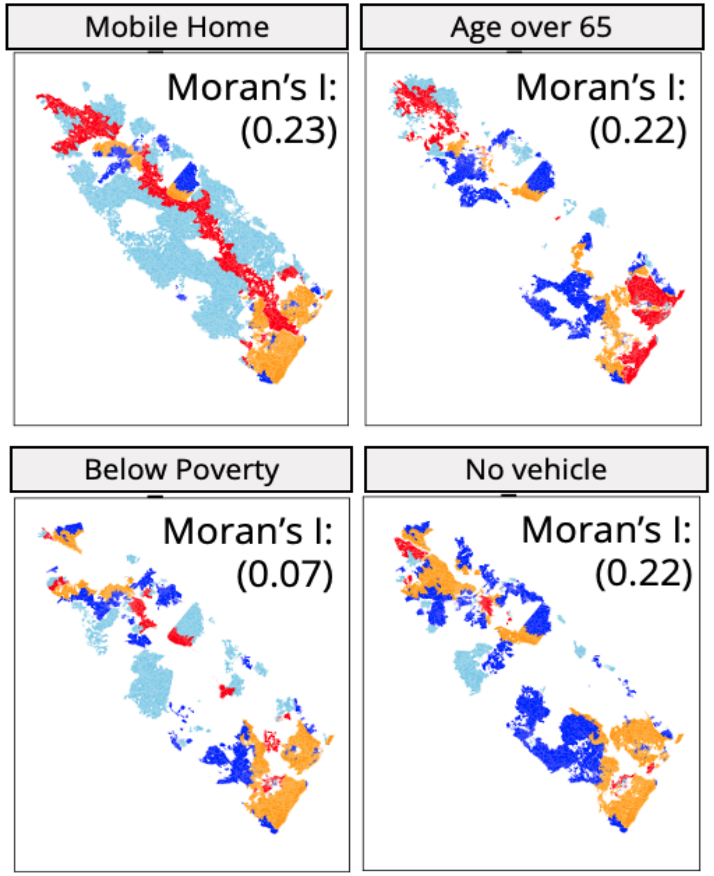
Built-in: 1954
Populations at risk: 53,050
Economic impact: $4 billion

Strong relationship:
mobile home,
age over 65,
no vehicle.

Weak relationship:
below poverty

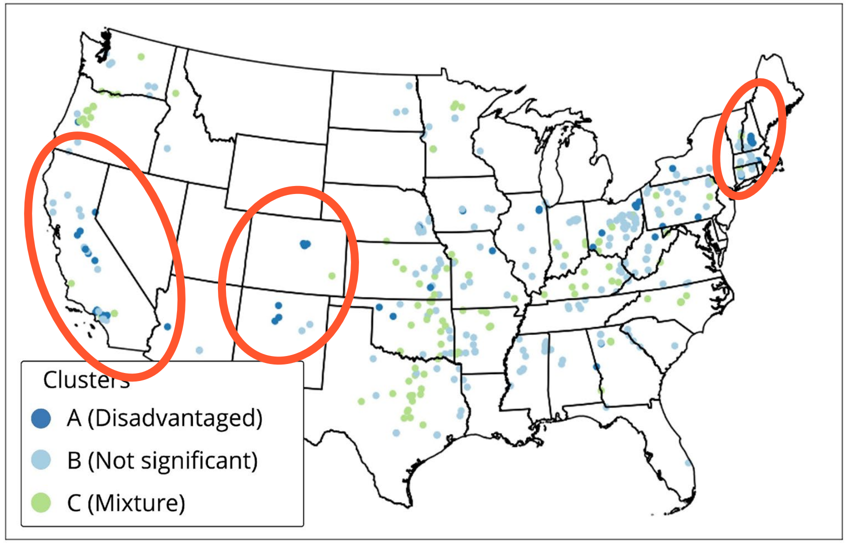
Social Vulnerability

Inundation	High	Low
High	HH	HL
Low	LH	LL

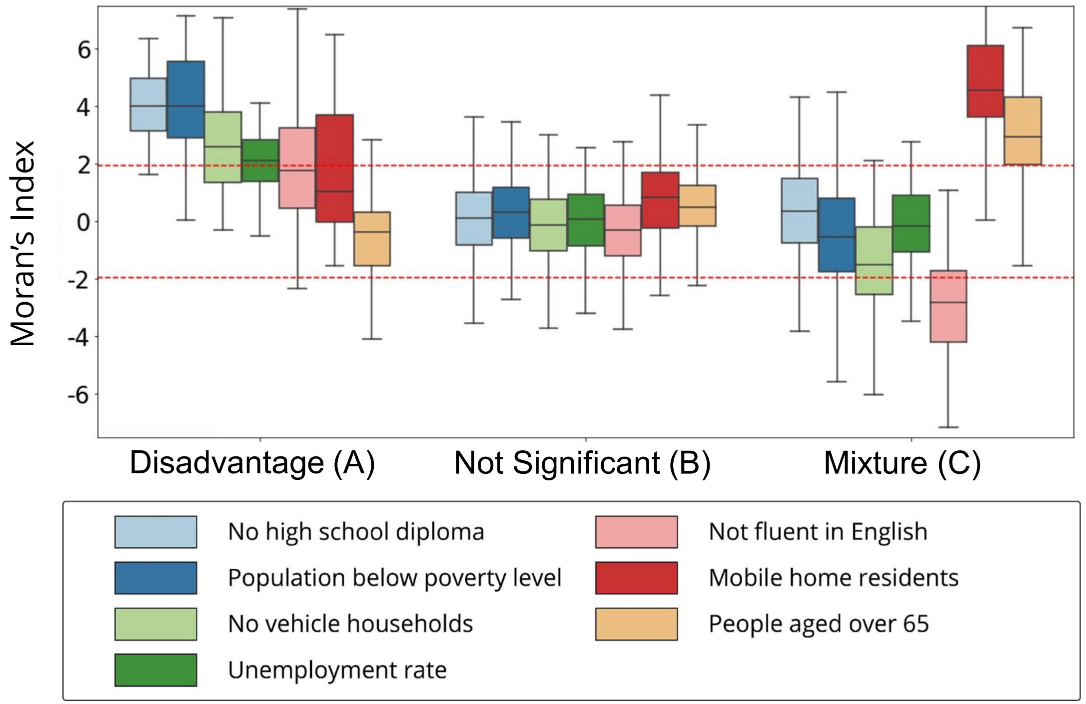


Preliminary result - national

Dams impacting socio-economically disadvantaged people (Cluster A) are in California, Colorado, New Mexico, New Hampshire, and Massachusetts.



At-risk population characteristics (SVI-related census) per dam cluster



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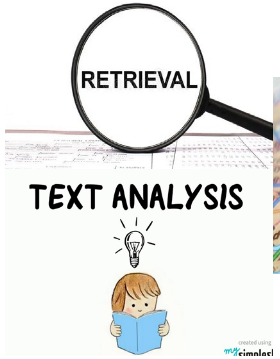
Hypercube

Text Data

Hypercube



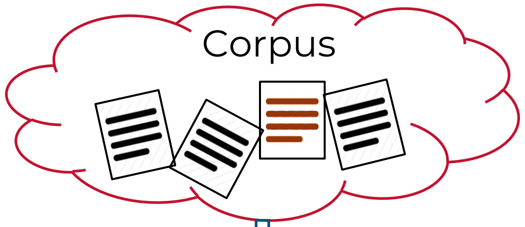
Downstream Tasks

- Multiple sources: news, research papers, social media, etc.
- Diverse, dynamic, massive, and unstructured

- Structured knowledge representation
- Avoid heavy human labeling work

- Text analysis
- Information retrieval
- Mapping

Aging Dams Hypercube

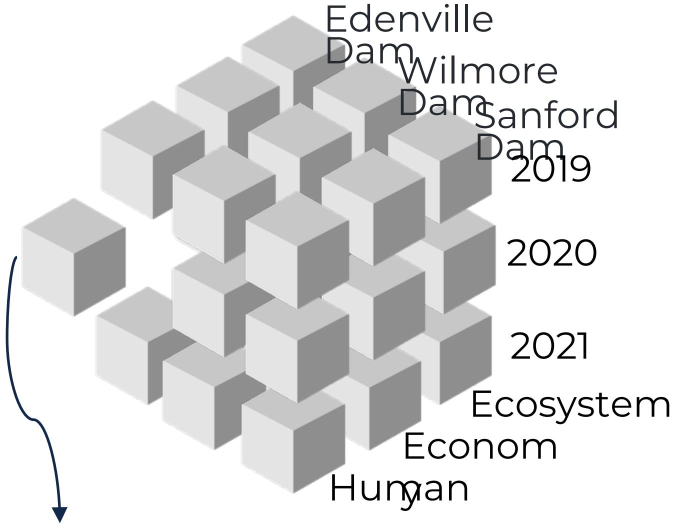


ID	Document Content
1	Midland-area residents evacuate to high school after dam failure threatens city … on May 19, 2020 … Midland-area residents gathered to seek refuge within the walls of Midland High School Tuesday night after the Edenville Dam failed to hold back a deluge of water …
2	…

+ Weakly supervised input (domain knowledge) → Aging Dams Hypercube

1. Pre-defined cube **dimensions**:
<ID, dam, year, impact, …>

2. Impact taxonomy:
Human, Economy, Ecosystem, Infrastructure



Cell: < 1, Human, Edenville Dam, 2020, …>

Understanding Dam Failures with the Metacoupling Framework

	Causes	Effects	Flows	Agents associated
Types	construction quality, dam age, weather, management, financial, human errors, etc.	demographic, economy, ecosystem, infrastructure, etc.	movement of information, water, goods, services, people, organisms, sediments, etc.	residents, NGOs, dam managers and owners, government agencies, etc.
At the dam site	dam age, construction quality, rainfall, human errors, etc.	infrastructure collapse, water loss, economic loss, etc.	movement of water, sediment, organisms, etc.	dam managers and owners
Near the dam site	rainfall flow to reservoir, etc.	deaths, injuries, flooding, damage to land, crops, livestock, roads, etc.	movement of information, financial capital, organisms, goods, services, people, etc.	farmers, residents, workers, teachers, students, etc.
Far away from the dam site	rainfall flow to reservoir, financial support, etc.	support for rescue and recovery, species invasion, economic production, etc.	movement of information, water, financial capital, sediment, people, etc.	government agencies, factories producing goods and products, etc.

Goals

- Complete Development of End-to-End Analytical Capability
  - Climate → Hydrology; Fragility → Failure; Inundation → Impacts→ Economics→ Stakeholders
- Develop a “Current State” Risk & Impacts (Stratified) National Risk Assessment
  - Patterns, Hot Spots, Cascading Failure, Specific Impacts – e.g., Environmental Justice
- Integrate Future Climate Projections – 10 years and 50 years
- Integrate Opportunity and Services Analytics
- Portfolio Risk and Opportunity Investment Prioritization and Optimization Tools

Invitation

- Our goal is to create a public resource to highlight the need and to facilitate strategic planning and investment
- This is a significant challenge
- We welcome collaboration to help build the platform and to keep us inspired.

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Thank You

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