



California

DRIP Collaborative

Drought Indicators & Metrics Workshop #2

Drought Resilience Interagency & Partners (DRIP) Collaborative

Friday, June 5, 2026
10:00AM - 12:00PM PT
Remote Participation (via Zoom)

Meeting Information

1. This meeting is being recorded for notetaking purposes only.
2. This is a working meeting:
 - Your participation is important for our successful collaboration
 - This meeting does not require following BKA rules, but we are adhering to best practices
3. All participants are encouraged to keep their cameras on during the meeting to promote collaboration and discussion.
4. Please practice electronics courtesy and mute when not speaking.

Purpose and Agenda

Meeting Purpose: Discuss potential gaps and opportunities to advance DI&M, based on current California efforts and an extended list of current indicators.

Meeting Topics:

- Review CA specific context on DI&M
- Discuss the approach to the user-centric needs assessment process
- Identify initial thinking on gaps and opportunities that should be prioritized

...and we'll start our meeting with a quick process recap, so we're all in the same conversation together

Ongoing Commitment for Our Joint Work

Opening remarks from Paul Gosselin

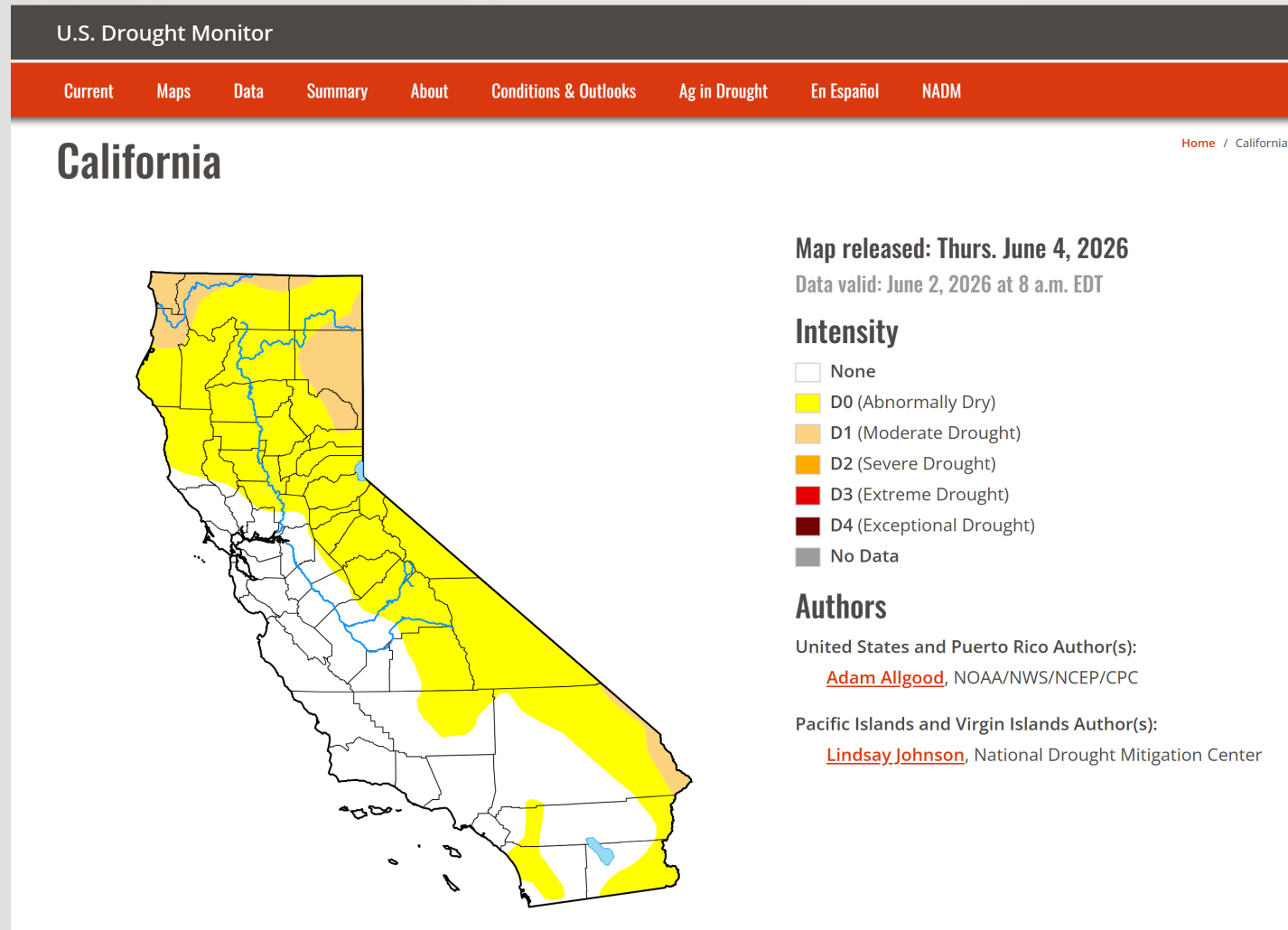
Chair of the DRIP Collaborative



Please introduce yourself in the zoom chat:

- 1) Your name and organization.
- 2) What was the most recent river or lake that you visited.

Opening Question: Is California in a snow drought right now?



Where would you look for info?
What risk indicators to use?
What thresholds to use?
What actions to take?

CA snow drought: What's happening

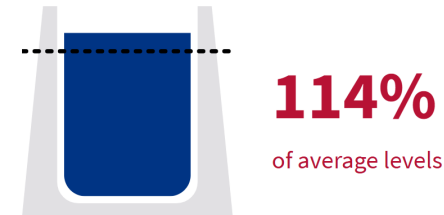
Do we have enough water stored?

In drier seasons, we rely on other sources of water. These include reservoirs and melted snowpack. But climate change is causing extreme weather and changing the amount of rain and snow we get, impacting how we are able to capture and distribute water.

Californians must adapt to this new normal and adopt conservation as a way of life to make the most out of our limited water supplies across the state.

Major reservoir levels

Reservoirs get us through the dry months



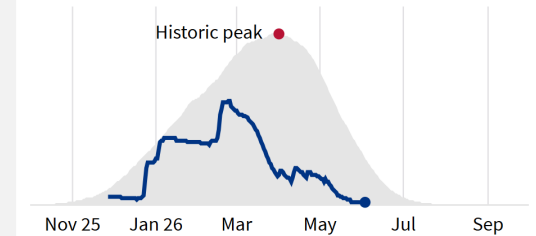
Updated daily

[More about reservoirs](#)

Statewide snowpack levels

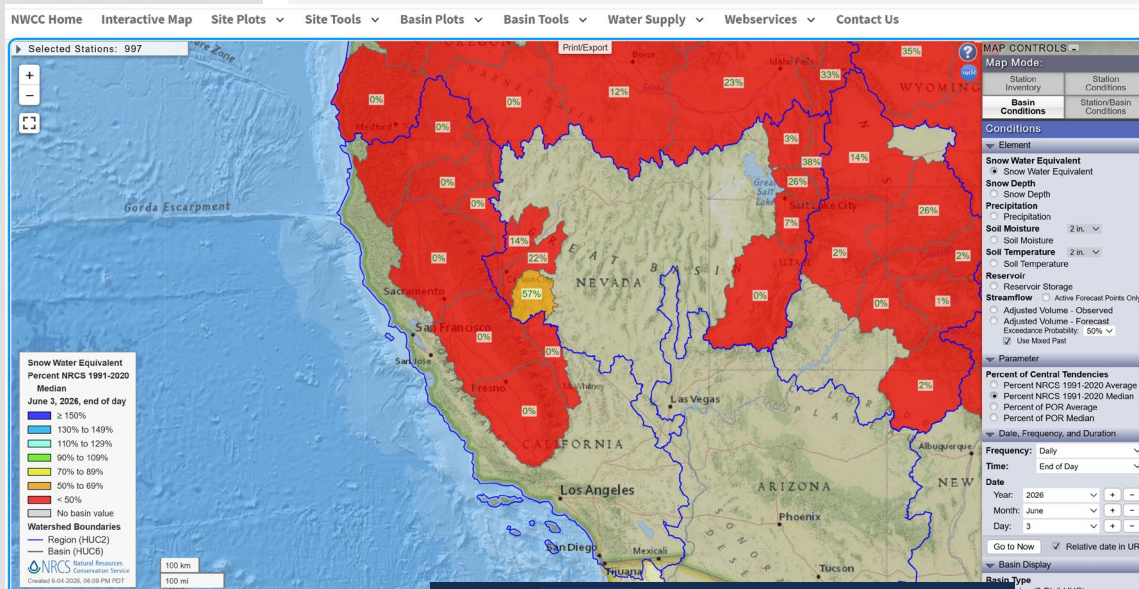
Snow melt feeds our reservoirs & rivers

2% of average peak snowpack



Updated daily

[More about snowpack levels](#)



Risk Indicator: SWE (snow water equivalent)

Threshold: SWE below 20th percentile

Actions: SWP allocations, DWR reservoir carryover rules, Delta pumping mandates

Impacts: Wildfire risk (Live Fuel Moisture LFM), aquatic ecosystems (anoxic streamflow days), # of dry wells (more gw pumping, due to less sw)

PROGRESS TO DATE

Purpose: Brief review of the white paper development process and key learnings from the April 1st DI&M Workshop #1 and the April 17th DRIP Collaborative meeting.

Drought Indicator & Metrics

Problem Statement: As California faces a hotter, drier future, **the absence of clearly defined, actionable drought metrics and indicators** poses a significant challenge to prioritize **drought actions** effectively and understand their **full impacts**. To ensure adaptive and localized strategies through all phases of the water lifecycle, it is crucial to bridge data gaps, ensure data accessibility and interoperability, and support modeling for climate-ready decision making across the state.



2024 DRIP Collaborative Recommendation: Develop a practical drought early warning system to improve information to inform local and state drought management actions and increase overall drought resilience.

This analysis should include:

- **Implementation Considerations:** Need to develop a partnership between state agencies and other interested parties, possibly via steering workgroup and advisory committee. Conduct research activities and set-up hosting/maintenance.
- **Equity Considerations:** Address limited resources and data to small communities, domestic well owners, tribal nations, and those most vulnerable to droughts.
- **Alignment with Other Initiatives:** Ensure complementarity and value add with other existing efforts, including SB 552 (Water Shortage Vulnerability Tool), SAFER, NIDIS, US Drought Monitor and CWDC (Consortium) efforts.

DRIP White Paper Development Process 2026



PREPLANNING

- Identify individuals, organizations, and information resources to support topic development.
- Develop a draft vision and white paper outline to guide workshops discussions.



I. VISION FOR THE FUTURE

- Define the desired end state and the key questions to be addressed in the white paper.
Framing the Vision - Key Questions to Explore - White Paper Scope and Outline



II. UNDERSTANDING WHERE WE'RE AT

- Establish a shared understanding of the current situation, experience, and capacity.
Current Conditions - Experience and Capacity



III. GAP ANALYSIS

- Identify discrepancies between the current situation and the desired future vision.
Comparing Vision and Reality - Underlying Causes of Identified Gaps - Prioritizing Gaps

IV. LOOKING AHEAD

- Identify practical pathways to move from current conditions toward the desired vision.
Opportunities for Progress - Barriers and Challenges - Proposed Next Steps



V. PUTTING IT ALL TOGETHER

- Draft the white paper to document discussions, findings, and suggested next steps.

DI&M WHITE PAPER: KEY QUESTIONS TO ANSWER



1. **Vision.** What is the appropriate DI&M vision for California?
2. **Current Conditions (and Audience).** What is the current landscape of drought tools and portals? Who are the various intended end users and what are their needs?
3. **Inventory.** What are the existing indicators? Can we create a master inventory list of indicators, identify key gaps, and plan out the path forward to ensure sufficient (spatial / temporal) coverage?
4. **Datasets.** What datasets are needed to achieve those indicators? Which ones exist already? What additional data needs to be gathered?
5. **Roadmap.** What defines success in 1 year (immediate)? 3 years (short-term)? Next 5 years (medium-term)?
6. **Funding/Resources.** What type of investment is needed to achieve the roadmap? What types of resources and expertise is needed?
7. **Organizations and Hosting.** What organizations need to be involved? Who should lead the effort? Who will play what role in hosting and being authoritative sources for indicators? Will there always be many tools/efforts?

DI&M Development Timeline



Framing the Vision for Drought Indicator & Metrics

Proposed vision statement:

All California **audiences** have access to the **current, historical, and upcoming risks and impacts** of drought. This includes knowledge at a **sector-specific level** via a Drought Early Warning System (**DEWS**), that can help inform what **actions** are required to most effectively achieve drought resilience.

Needs to start with **audiences**, to ensure we're "**user centric**"



Agriculture/Farmers



Water Agencies



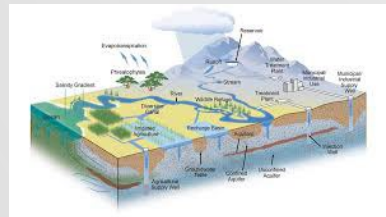
Cities



Tribal/Vulnerable Communities



State Agencies



Academics/Researchers



Counties



NGOs/Environment



Media

...plus others including Federal Agencies, Finance/Insurance, Recreation/Tourism, and Public Health

Recap: April 1st DI&M Workshop #1

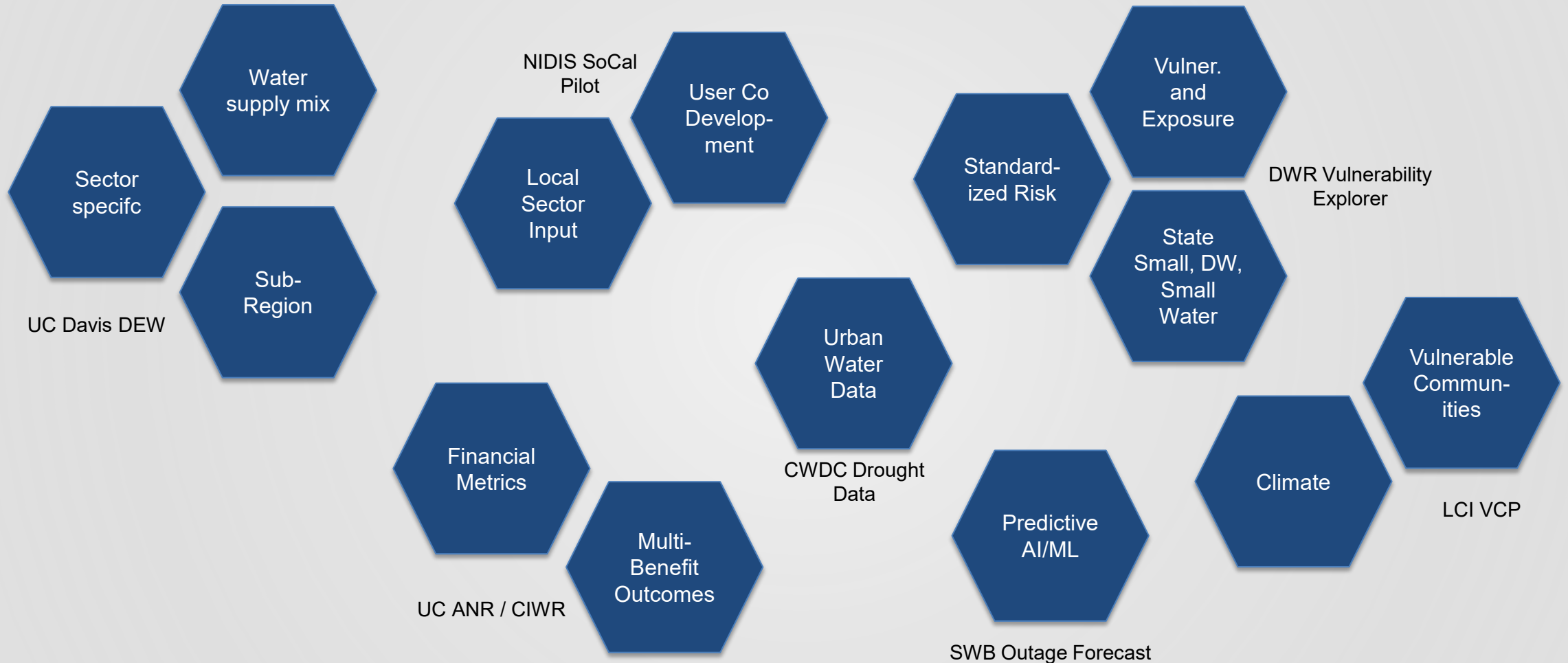
Participation: DRIP Collaborative members and 30+ participants included diverse perspectives

- Agencies: Department of Water Resources, State Water Board, Governor's Office LCI, CDPH, EPA
- Academics/Researchers: UC Davis, NOAA NIDIS, CA Water Data Consortium

Project	Presenter	Description	Audience
UC Davis Drought Early Warning	Alvar	Project to establish a CA centric, higher resolution drought early warning system and dashboard	State/regional/local Researchers
NOAA NIDIS SoCal Pilot	Amanda/Andy	Pilot to modernize DEW by improving sector specific response and move to proactive	Local health officials, farmers, water utilities
CWDC Drought Data	Robyn	Project making drought data more accessible, especially those from urban water agencies	Water data stakeholders, including water agencies
UC ANR / CIWR	Erik P	Research to assess drought response and impacts, including financial effect on water utility finances	State/regional/local Researchers
CA Water Watch & DWR Water Shortage Vulnerability Explorer	Julie	Tools to communicate key info, assess risk of small water systems, DWs, and state smalls	Small Water Systems, DWs, State Small WS, Counties
SWB Outage Forecast Predictor	Eric Z	Program to forecast community water system outages using drought indices	Div of Drinking Water, CalOES, Water System staff
LCI Drought and VCP	Ben	Effort to use drought indices in climate work and Vulnerable Communities Platform	VCP: NGOs, locals, and policy makers

Innovations Highlighted in Workshop #1

Biggest Takeaway: Complementary innovations highlighted by the seven presentations

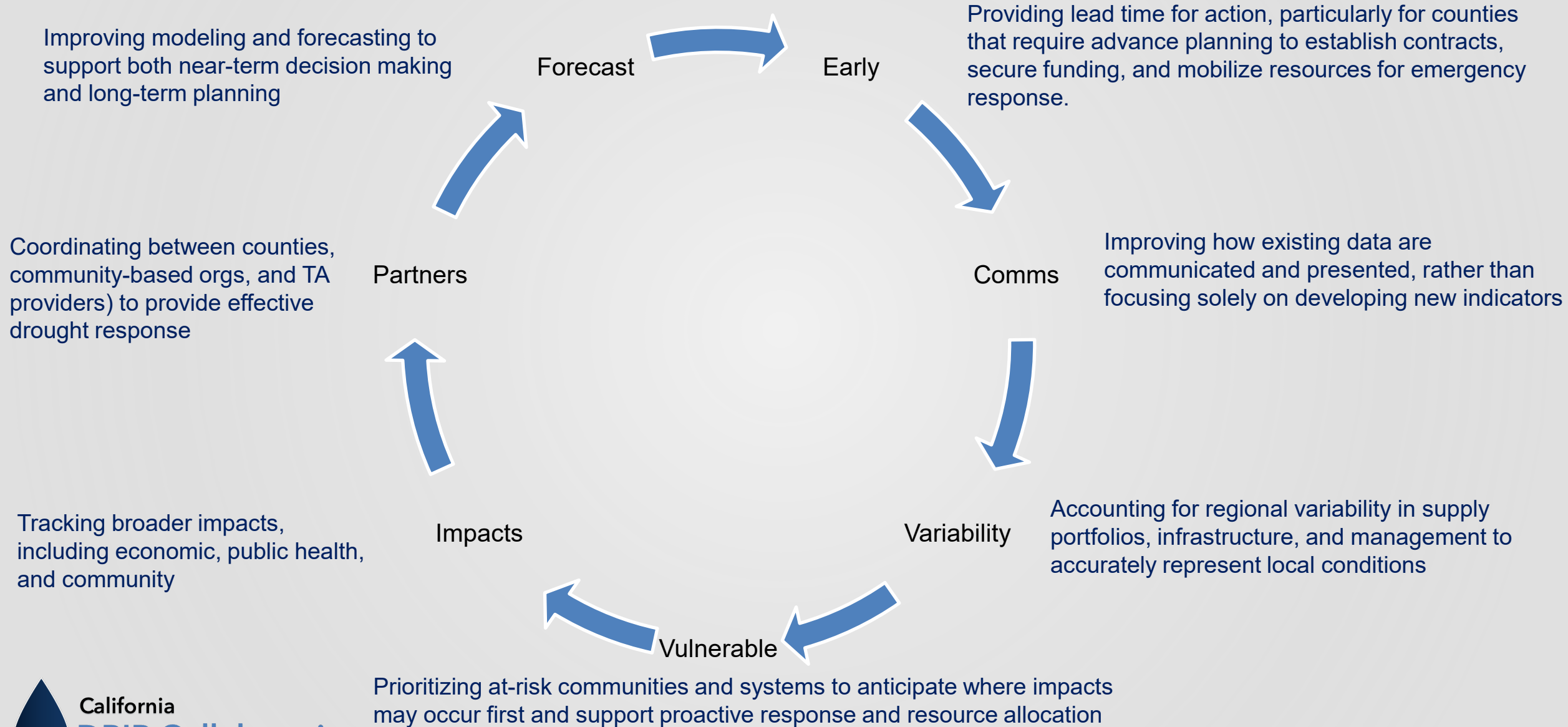


So many possible combinations!

More impact metrics? Use of AI/ML, user/sector engagement?

Predictive, climate, at various spatial/temporal scales?

DI&M: APRIL 17 KEY COMMENTS



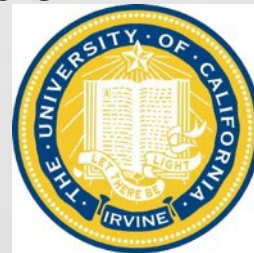


UCI CHRS **Drought** Monitoring and Prediction System

Amir AghaKouchak, Debora de Oliveira, Phu Nguyen, Tu Thanh Ung, Annika Hjelmstad, Charlotte Love, David Feldman, Ali Mirchi, Daniel Placht, Dalal Najib

***Center for Hydrometeorology & Remote Sensing (CHRS)
University of California, Irvine***

With contributions from: *Laurie Huning, Yue Qin, Yannis Markonis, Baoxiang Pan, Ali Mehran, Steven J Davis, Moji Sadegh, Felicia Chiang, Shahrbanou Madadgar, Alireza Farahmand, Ali Nazemi, and many more...*



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 : [@AmirAghaKouchak](https://twitter.com/AmirAghaKouchak)



Map Layers

- ☐ Country
- ☐ Pol. Division
- ☐ Cont. Basin
- ☐ Major River
- ☐ Tributary
- ☐ Watershed

Realtime Data

Image Time: 16 Oct 2025 16:00 GMT

Current Lagtime: 0 Hours and 14 Minutes

Rain Layers

- ☒ PUnet Legend: ☒ ON
- ☐ PDIRnow
- ☐ Radar (US only)
- ☐ Crowdsourced
- ☐ Rain Gauge Filter By:

Rain Totals (Hrs)

3 6 12 24 48 72

3 Hourly Rain Animation

0 - 72 past hours

◀ ▶ ⏮ ⏭

Spatial Query

Query By:

Search Place



Sponsors



(Hsu et al., 1997; Hong et al., 2005, Ashoori et al., 2015; Nguyen et al., 2020, 2026)



- Map Layers
- ☐ Country
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- Rain Layers
- ☒ PUnet
 - ☐ PDIRnow
 - ☐ Radar (US only)
 - ☐ Crowdsourced
 - ☐ Rain Gauge
- Filter By: Rain

Rain Totals (Hrs) Extreme Events
☐ 3 ☐ 6 ☐ 12 ☒ 24 ☐ 48 ☐ 72

3 Hourly Rain Animation
0 - 72 past hours

Spatial Query
Query By: Location

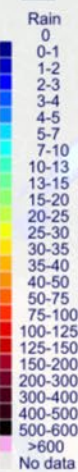
Realtime Data

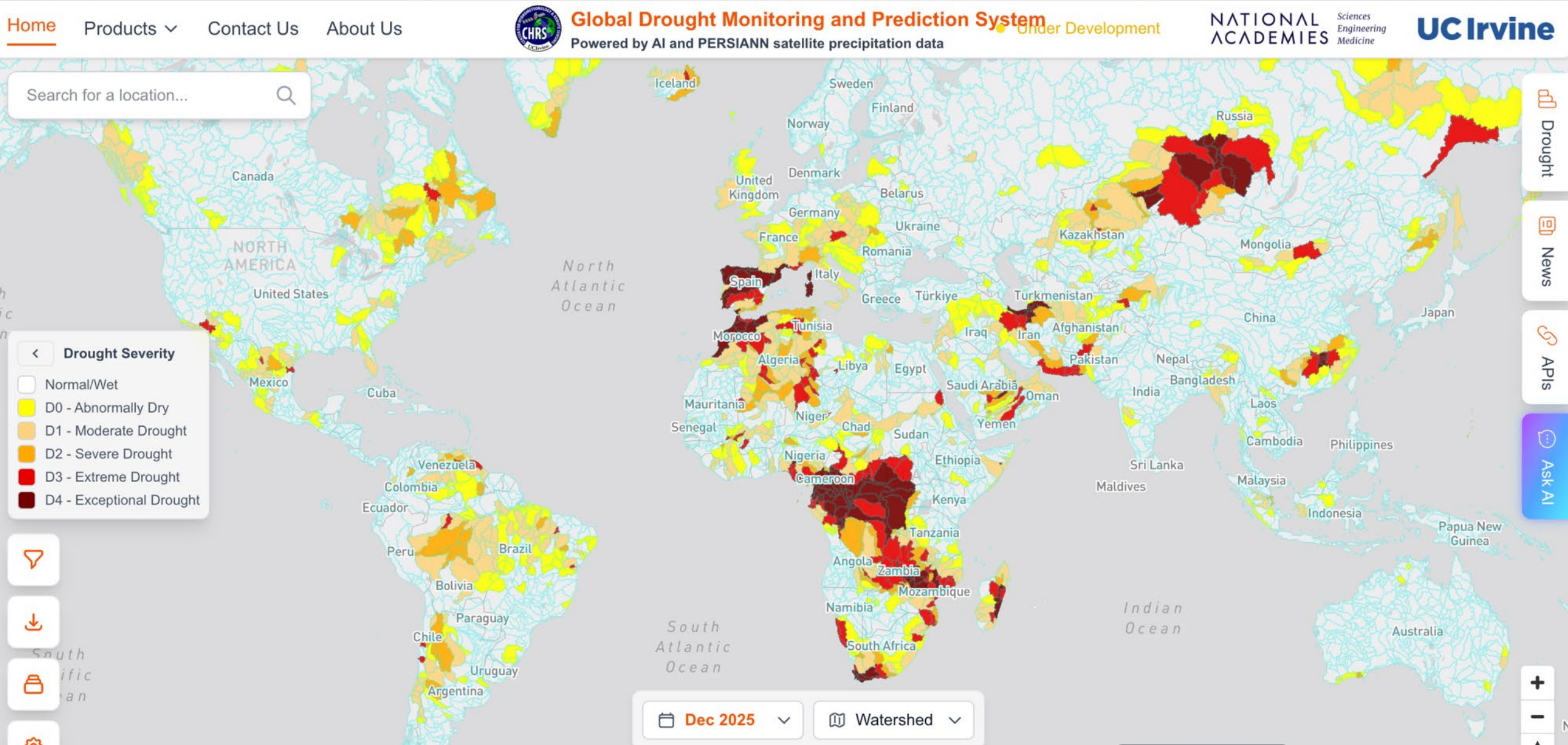
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Current Lagtime: 0 Hours and 14 Minutes

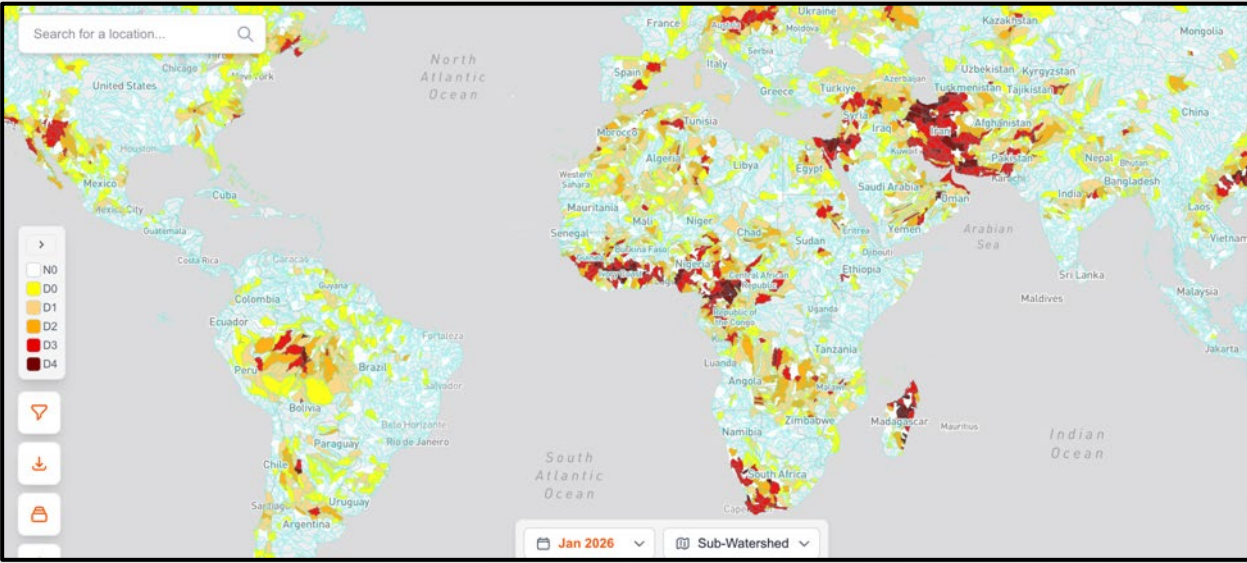
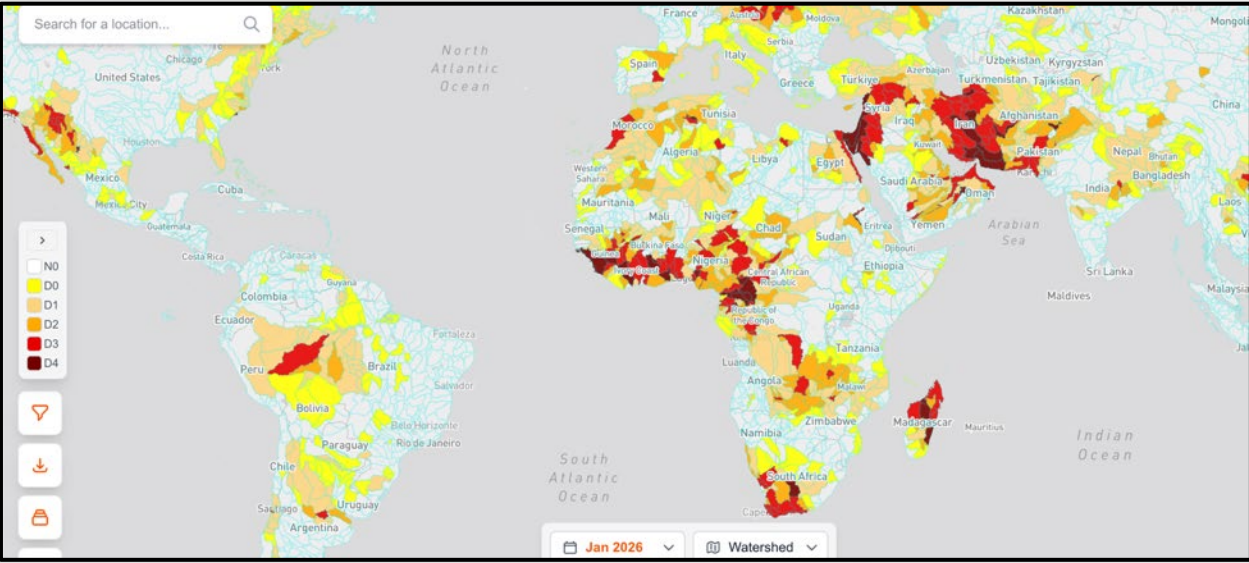
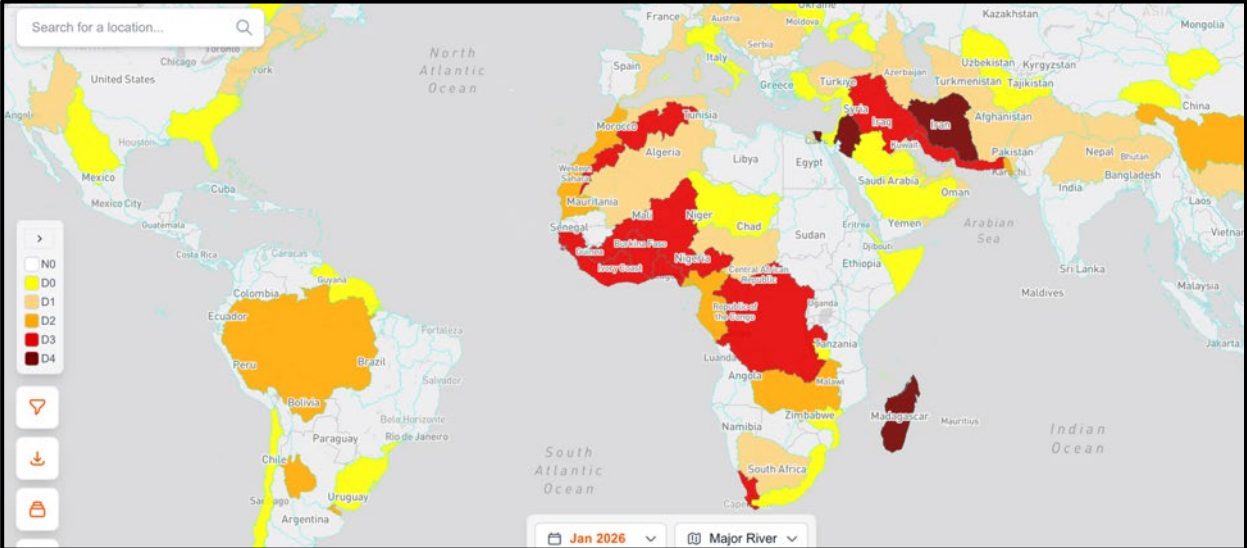
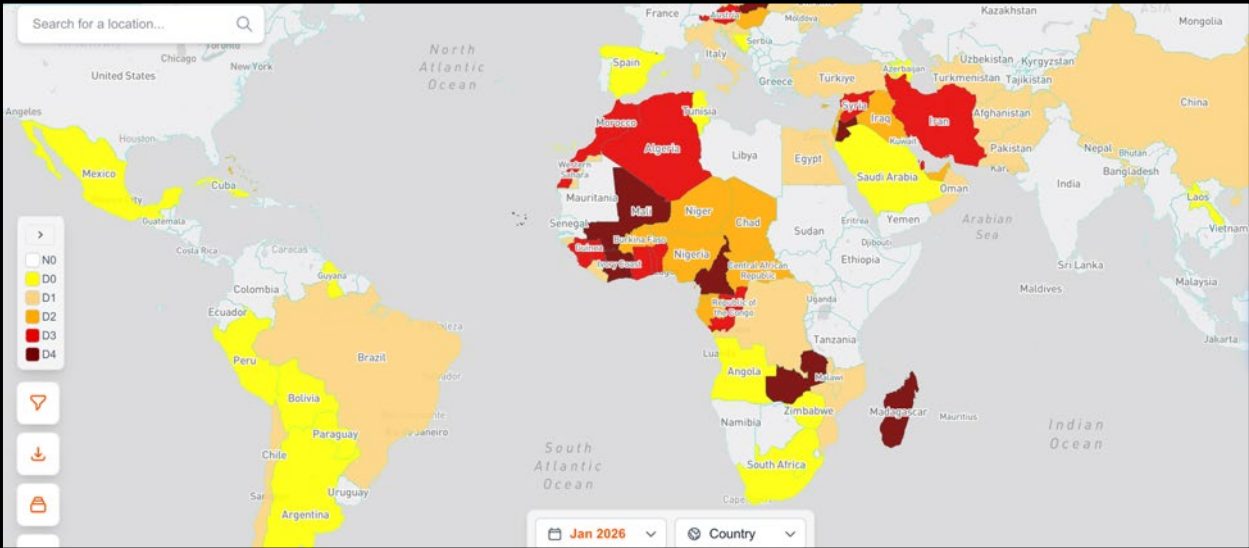
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Search Place



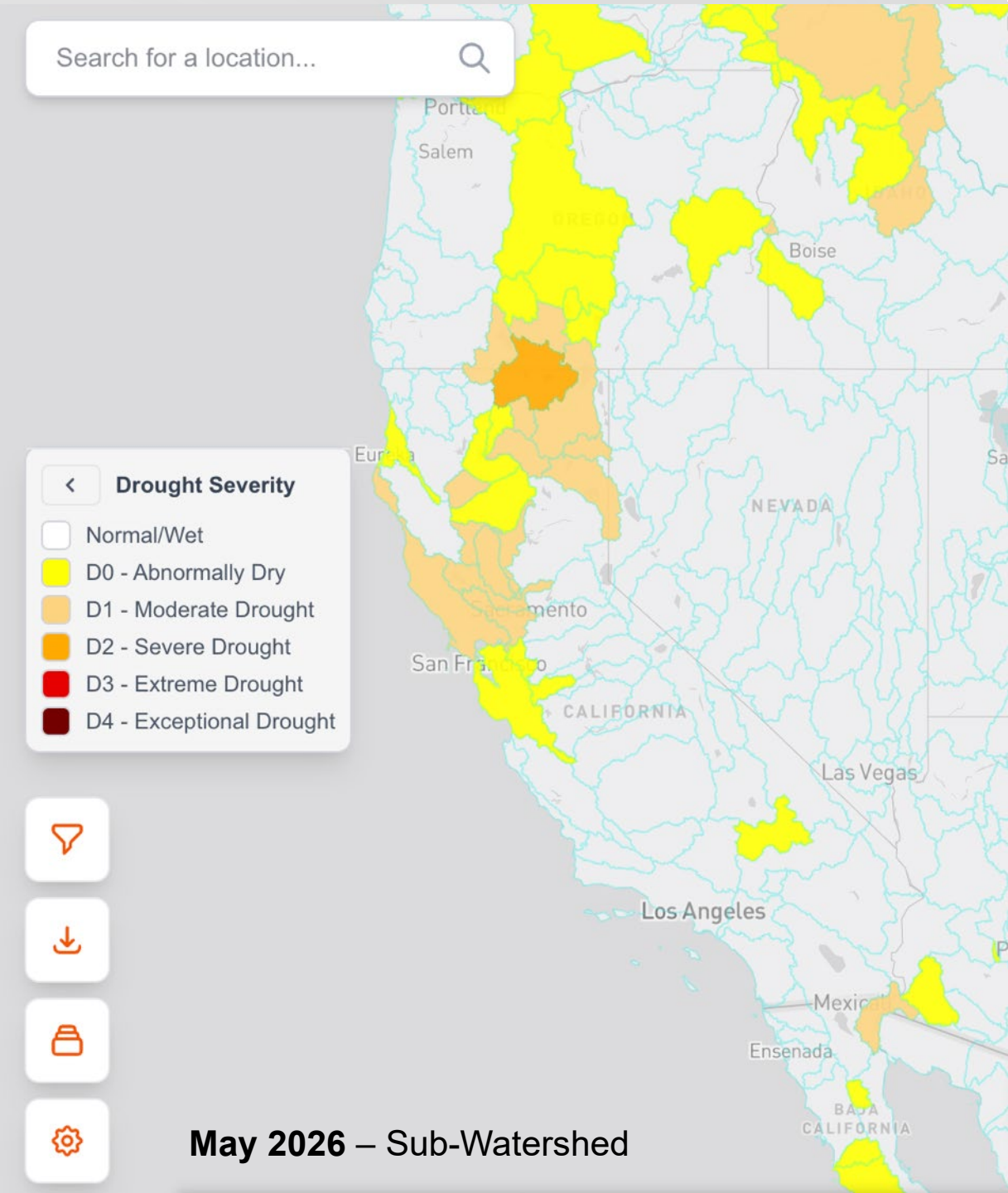
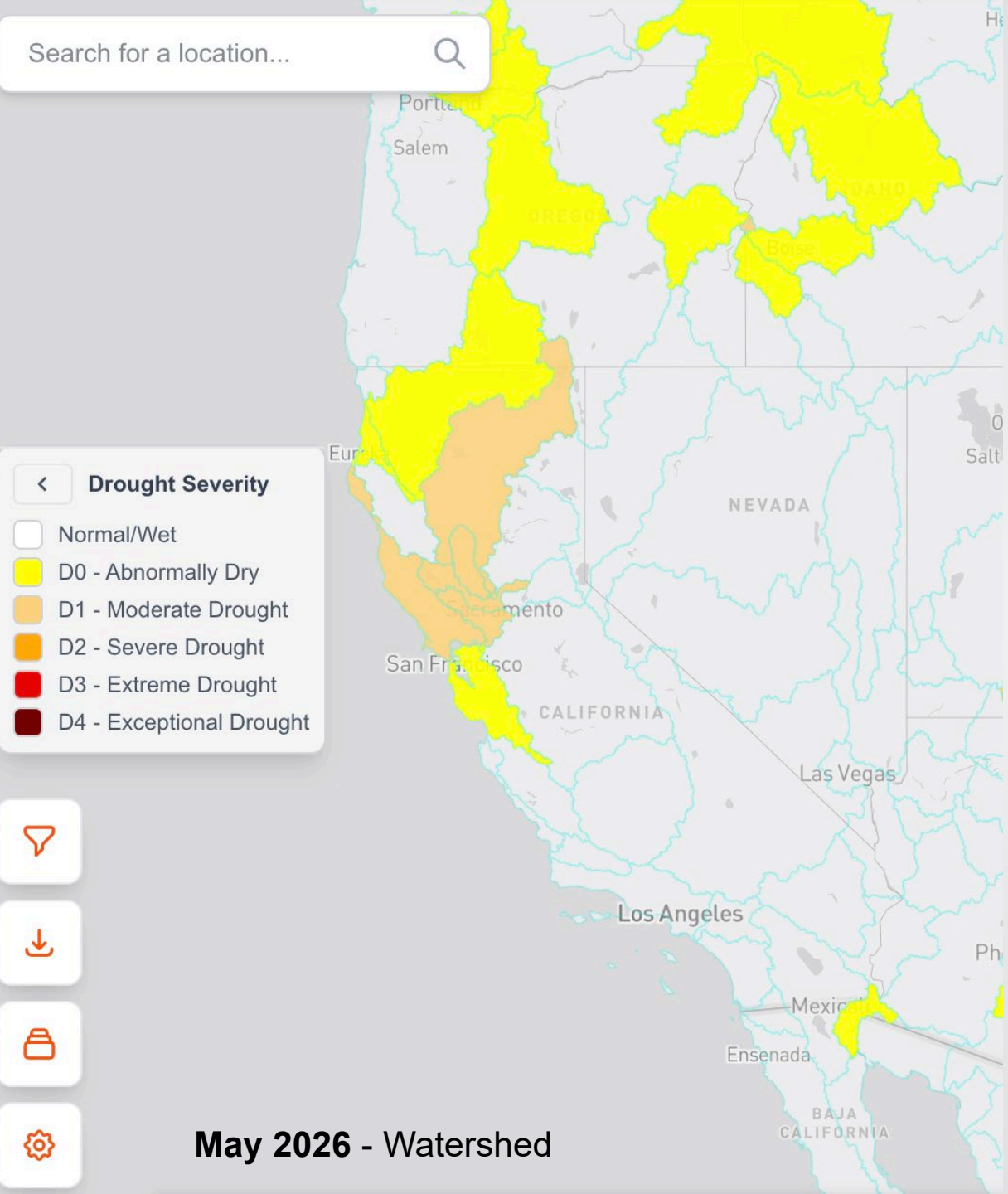


<https://drought.eng.uci.edu/>



CALIFORNIA DEPARTMENT OF
WATER RESOURCES

<https://drought.eng.uci.edu/>



Search for a location... 

 **Drought Severity**



 Normal/Wet



 D0 - Abnormally Dry



 D1 - Moderate Drought



 D2 - Severe Drought



 D3 - Extreme Drought



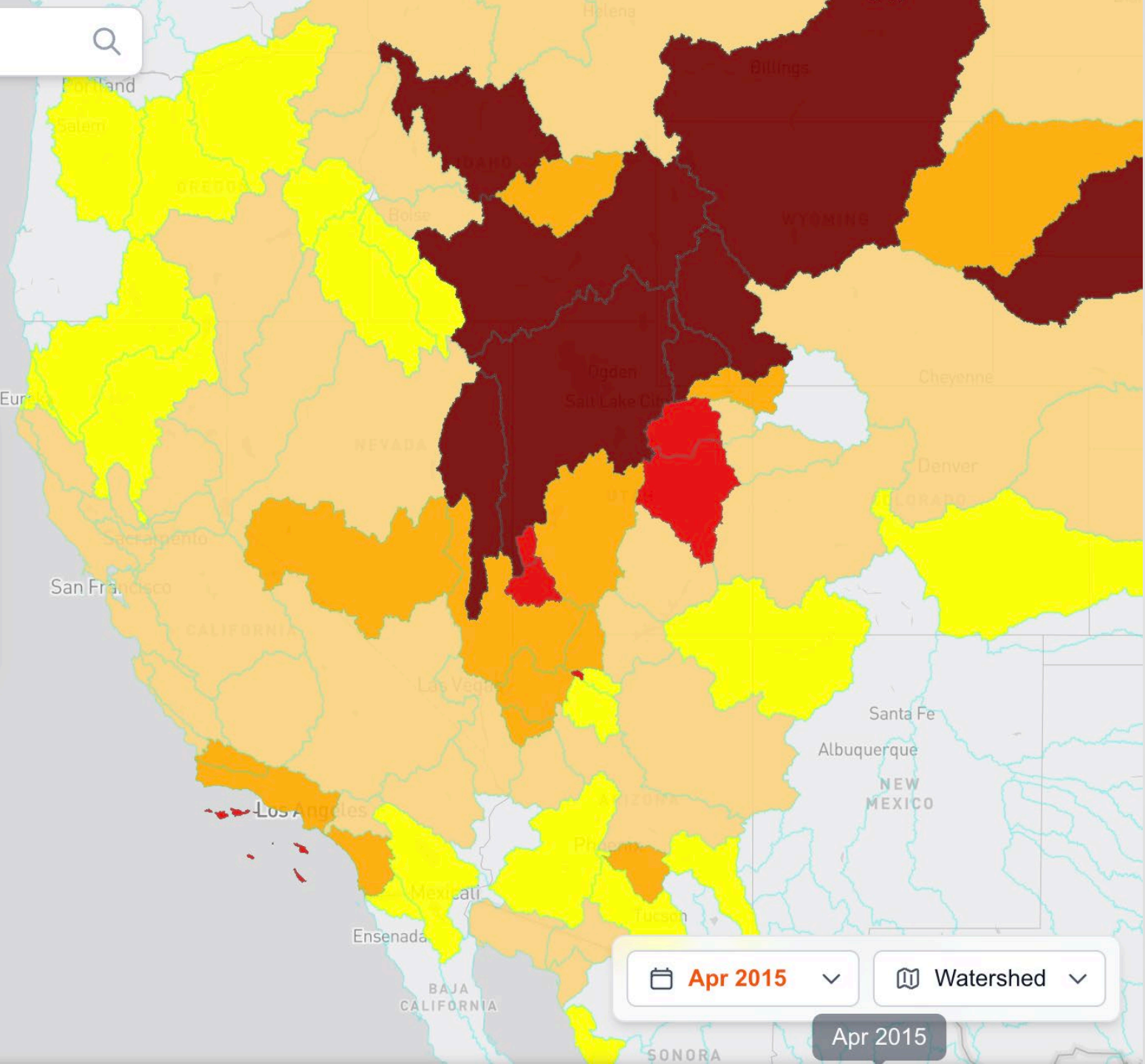
 D4 - Exceptional Drought







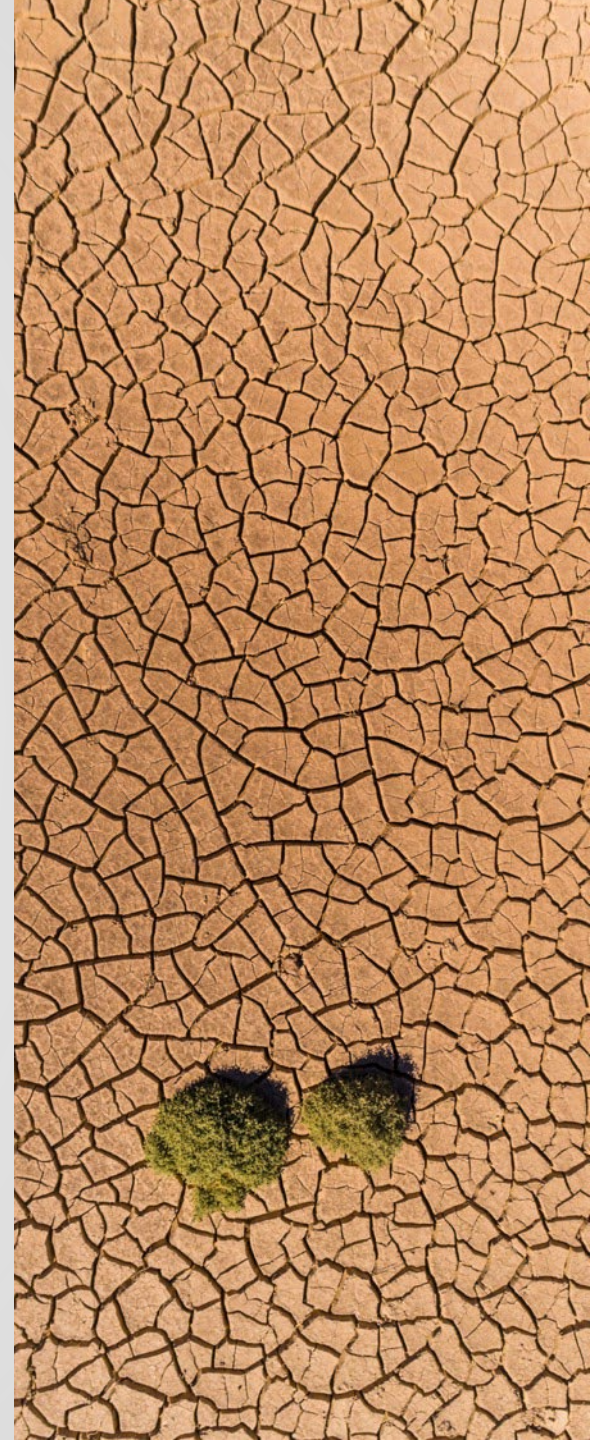




 **Apr 2015** 

 Watershed 

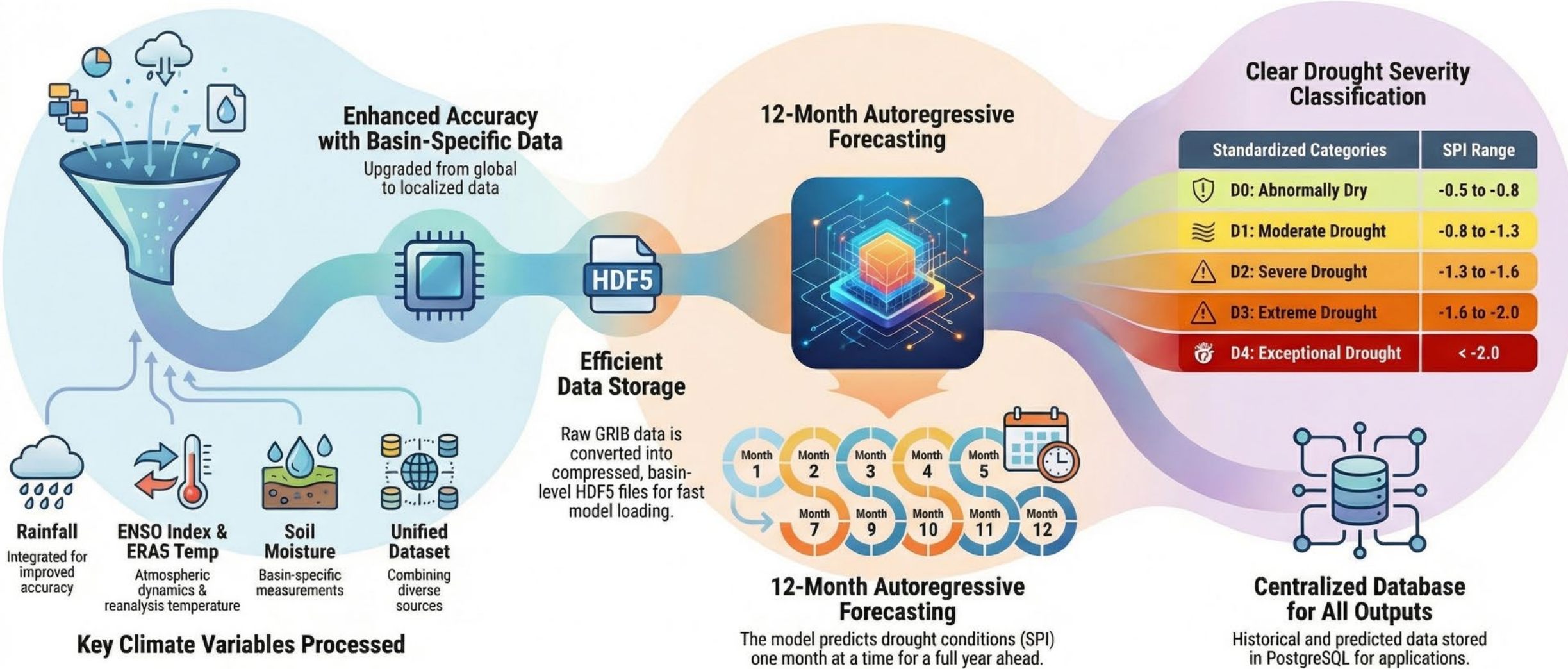
Apr 2015



Data Processing & Integration

Prediction & Analysis

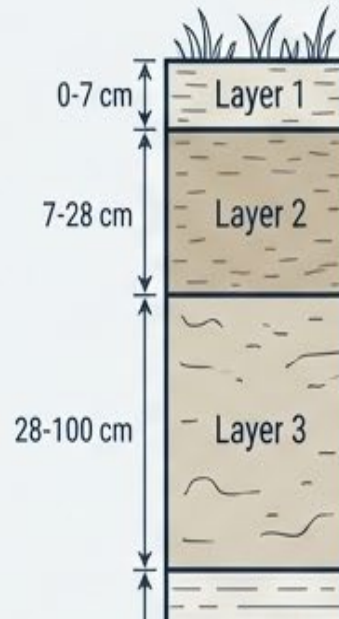
Output & Actionable Insights



We Integrated Soil Moisture, Selecting the Optimal Root Zone Layer for SPI Forecasting

The Scientific Rationale

1. **Root Zone Coverage:** Captures water available to most crops and vegetation.
2. **Temporal Response:** Responds to rainfall on a 1-3 month scale, matching the target SPI-6 timeframe.



Layer	Depth	Best For	Response Time
1	0-7 cm	Surface conditions	Days to weeks
2	7-28 cm	SPI forecasting	1-3 months
3	28-100 cm	Long-term drought	3-6 months

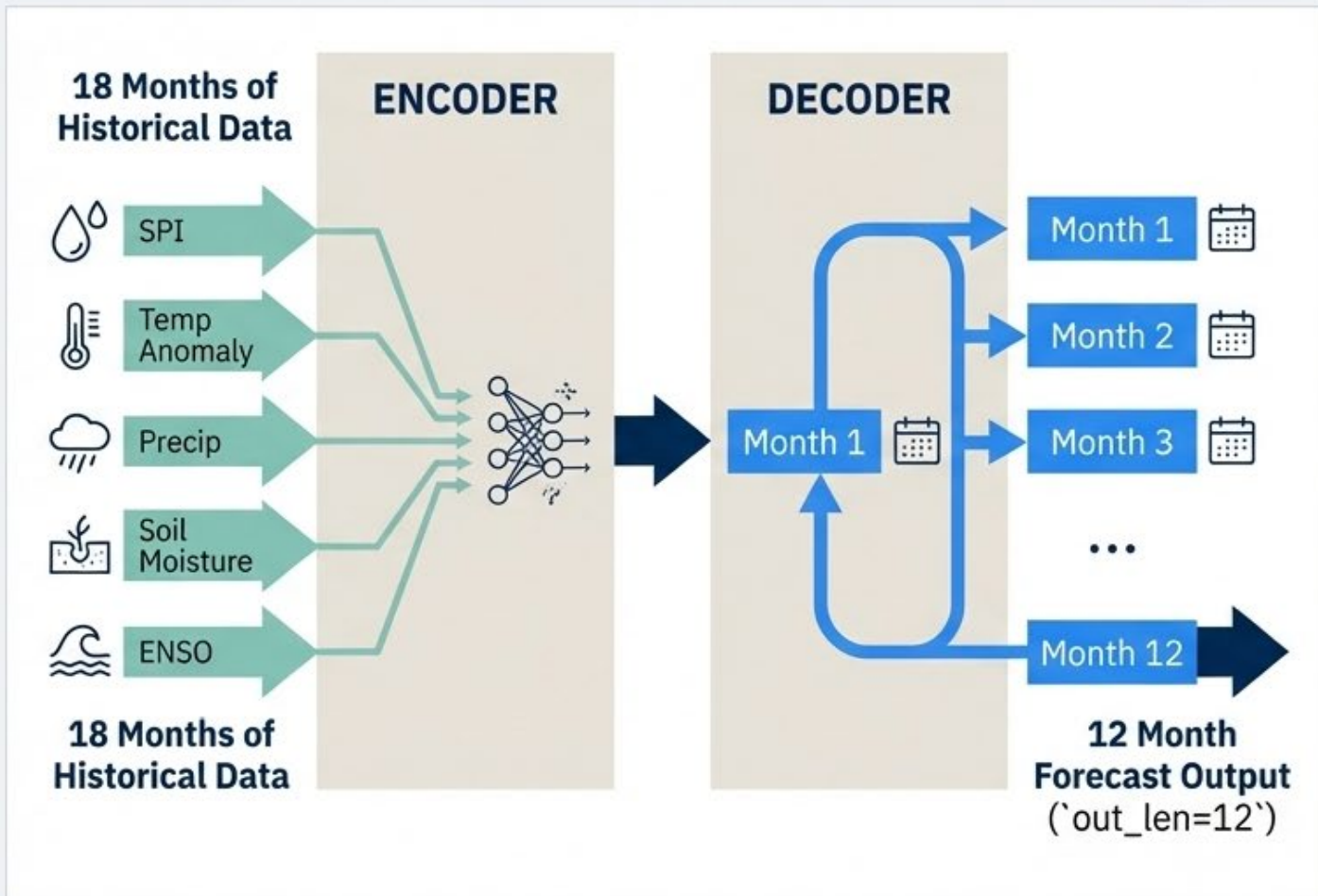
Our Model Uses a Sequence-to-Sequence Architecture to Forecast 12 Months Ahead Autoregressively

The Architecture

The model uses an Encoder-Decoder approach (supporting LSTM, TCN, and Transformer backbones).

Encoder

Processes the last 18 months ('in_len=18') of historical data. This includes SPI, temperature anomaly, precipitation, soil moisture, and ENSO index.



How it Works

Decoder

Generates predictions for the next 12 months ('out_len=12') one step at a time.

1. Predicts Month 1 using the 18 months of history.
2. Uses the Month 1 prediction as an input to help predict Month 2.
3. Continues this autoregressive process for all 12 months.



Search for a location...

Drought Severity

Normal/Wet

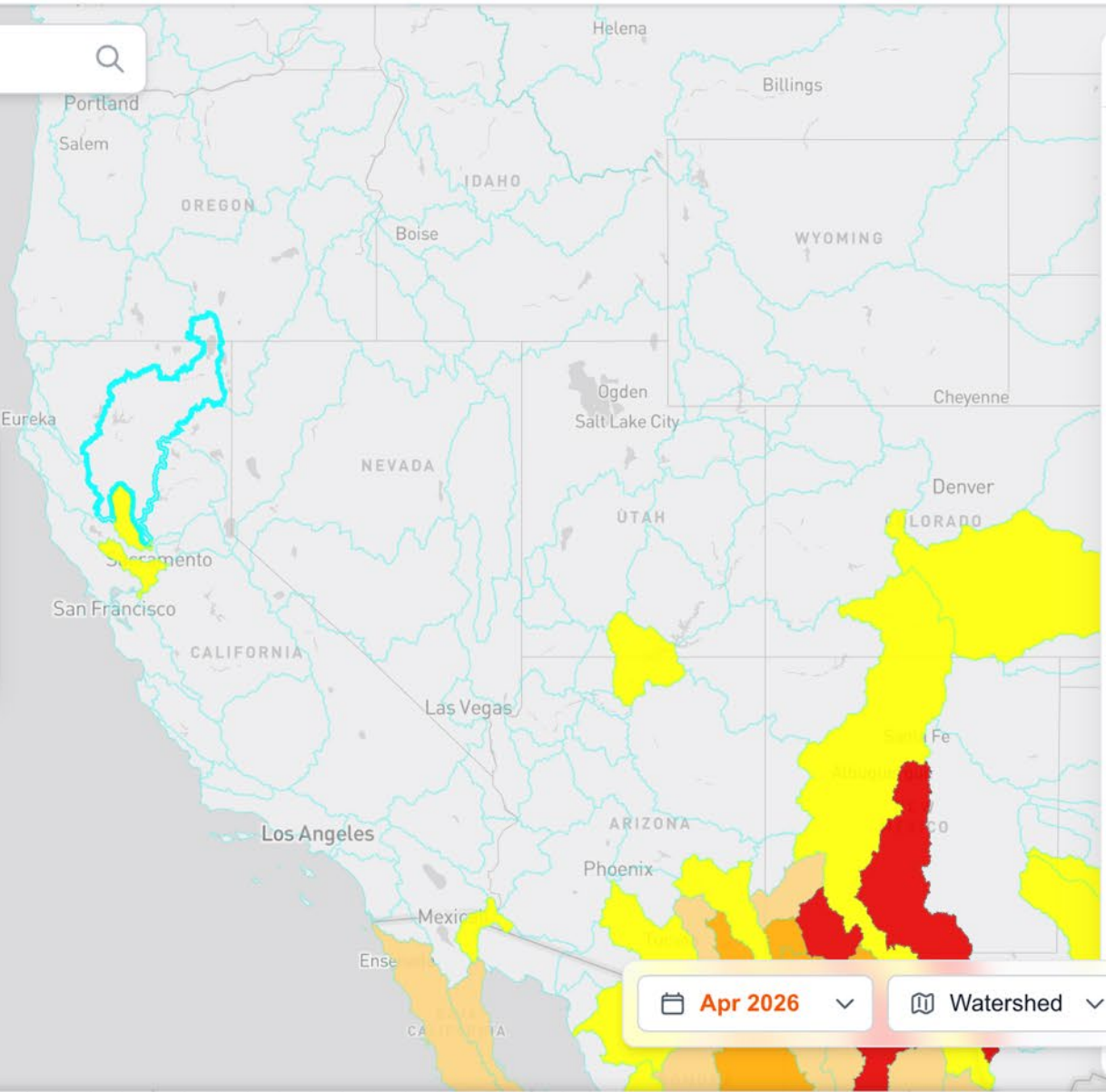
D0 - Abnormally Dry

D1 - Moderate Drought

D2 - Severe Drought

D3 - Extreme Drought

D4 - Exceptional Drought



Drought - Apr 2026

Time Series

Click on data points to select a time period. Use the toolbox to zoom, restore, or save the chart.

Trend Analysis

Decreasing Trend (Drier)

Kendall's τ
-0.115

P-value
<0.001

Sen's Slope
-0.0011/yr

Statistically significant trend ($p < 0.05$)

Apr 2026 (Predicted)

Drought

News

APIs

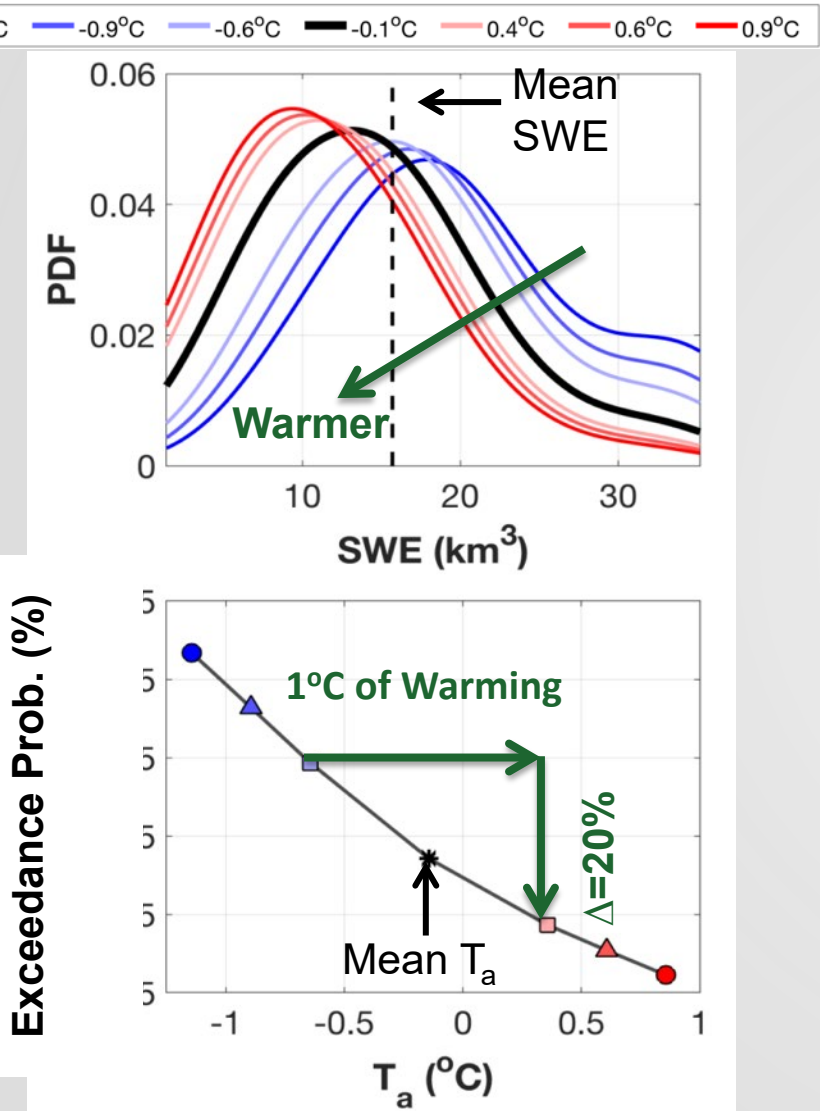
Ask AI

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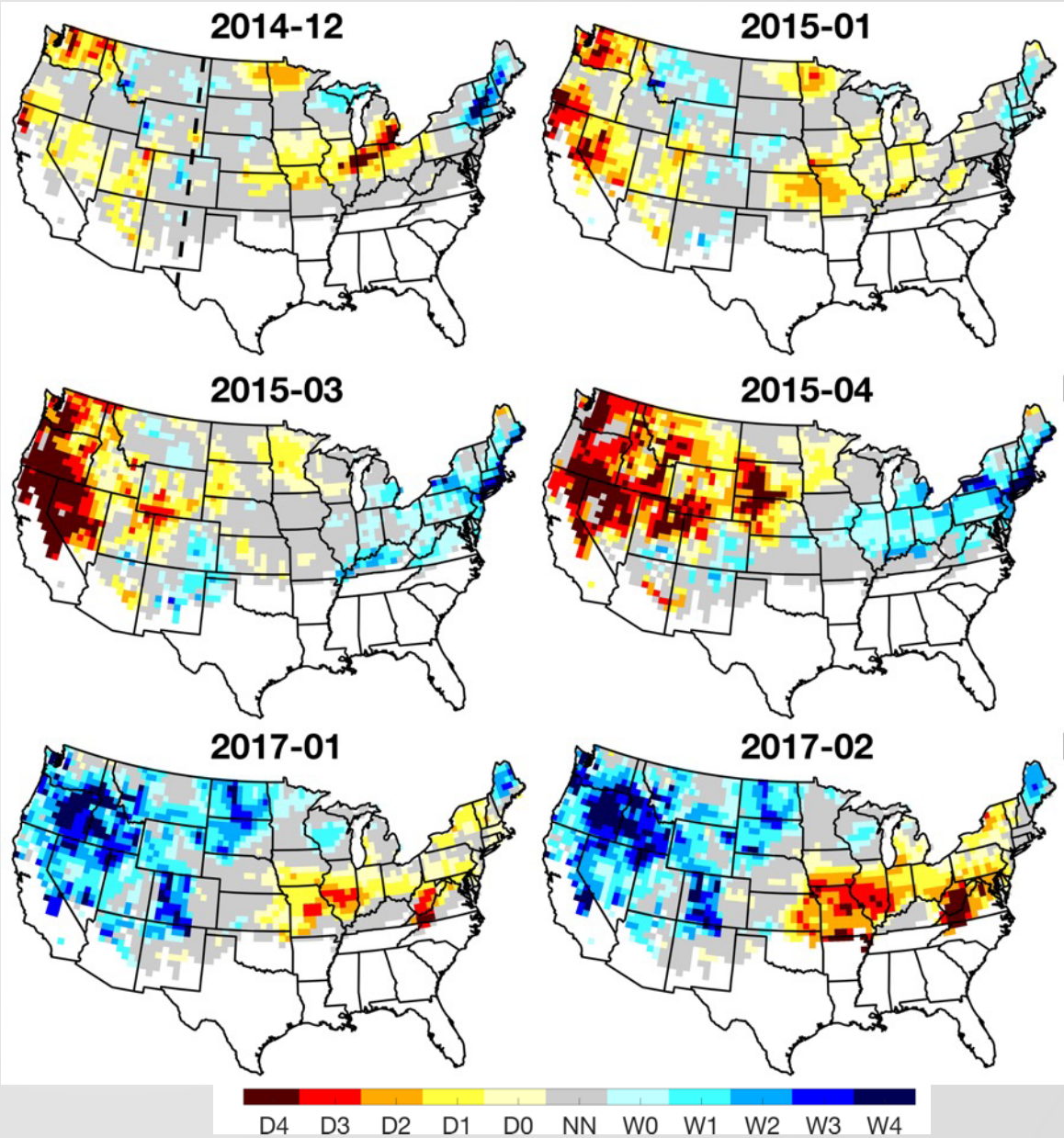
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Mountain Snowpack Response to Different Levels of Warming

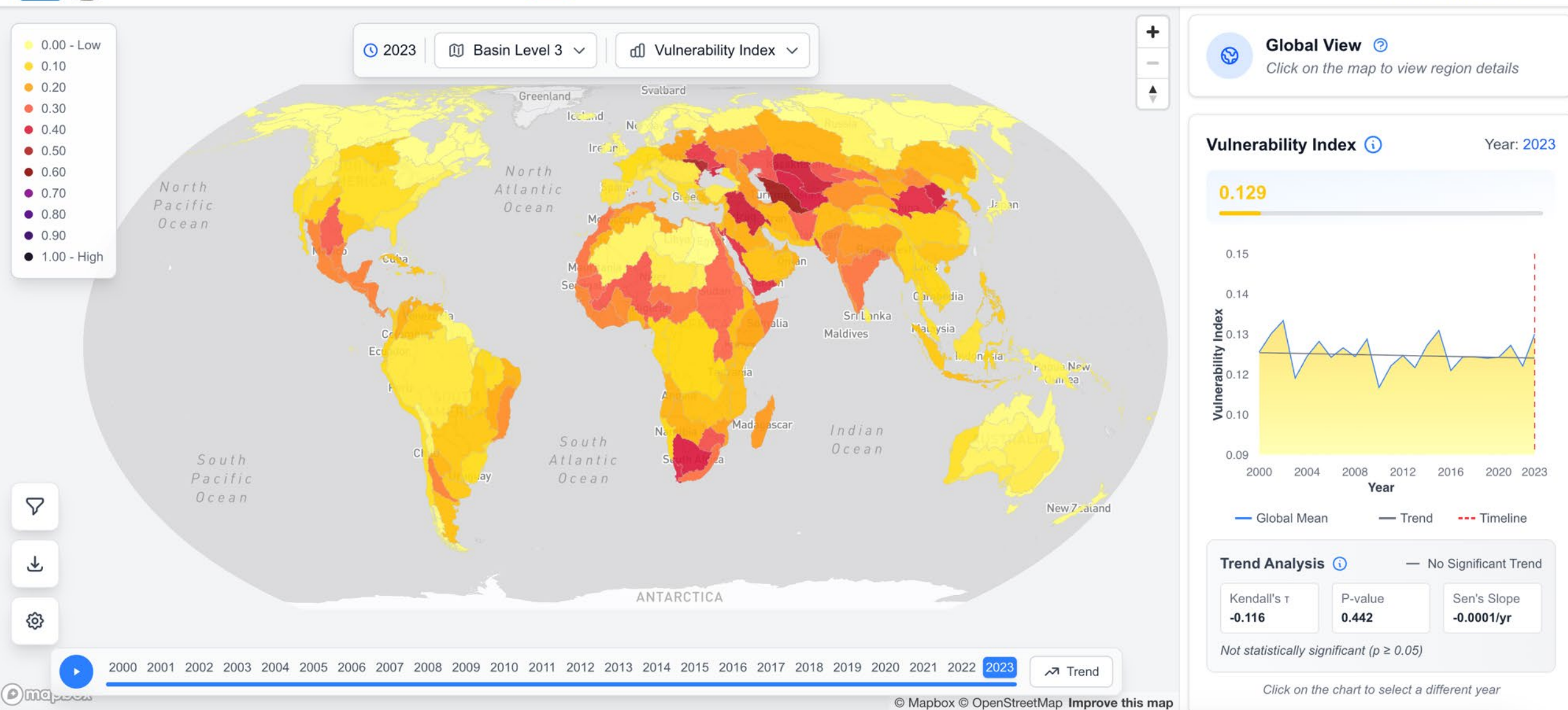


Huning & AghaKouchak, 2018, *PNAS*

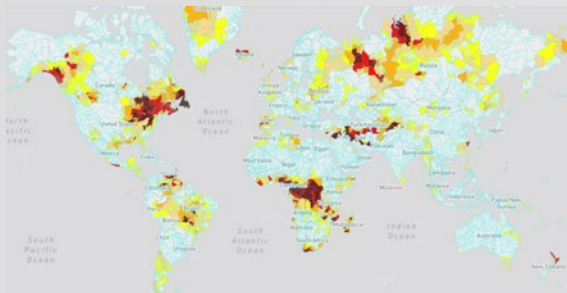
Snow Drought



Huning & AghaKouchak, 2020, *PNAS*

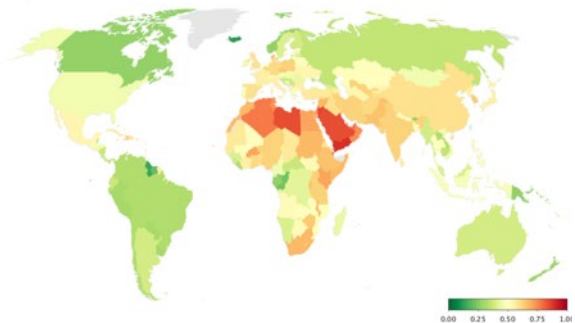


Water Availability



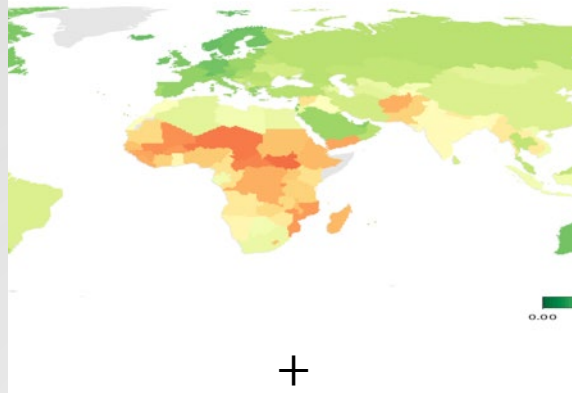
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Water Demand



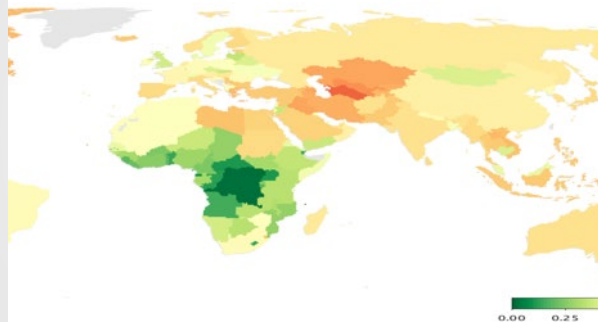
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GPD per Capita



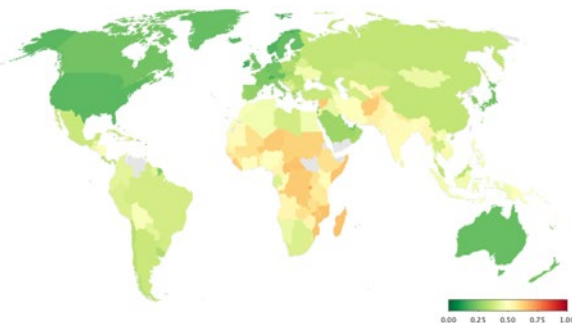
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Human Development Index (HDI)



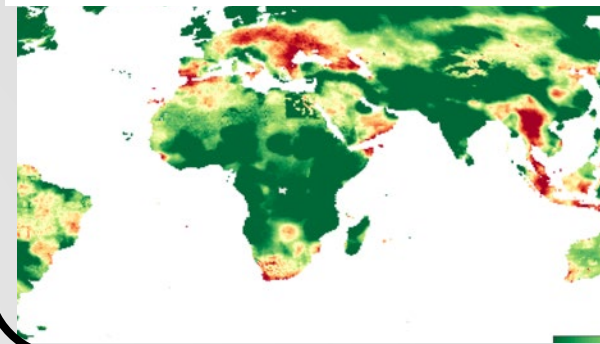
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Government Effectiveness

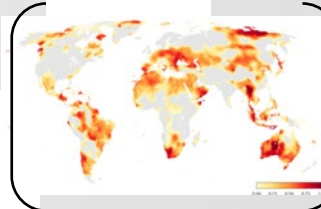


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Exposure (Population & Industry)



Hazard

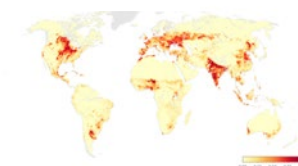


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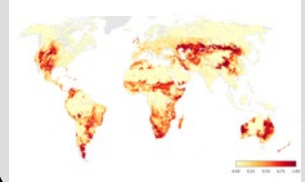
Population



Croplands



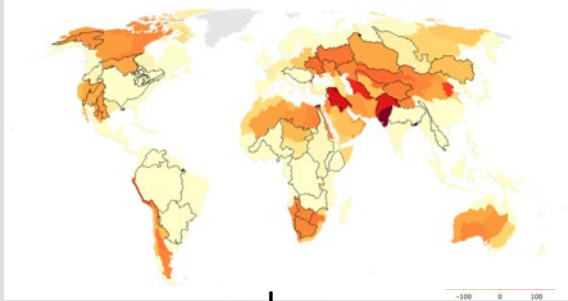
Pasture



Water Resource Vulnerability and Coping Capacity (VCC) Assessment Framework

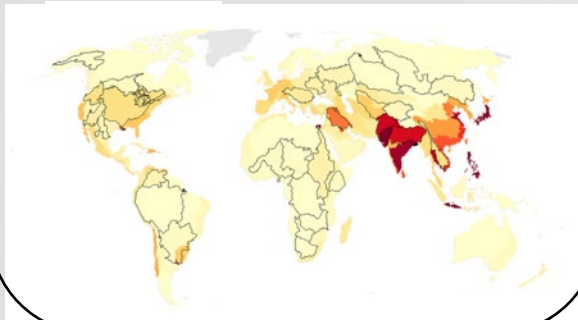
Water stress indicators

Water availability



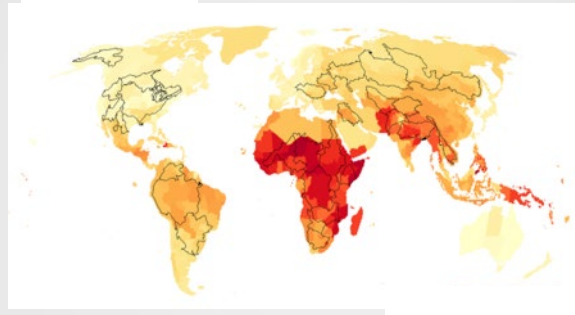
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Water demand



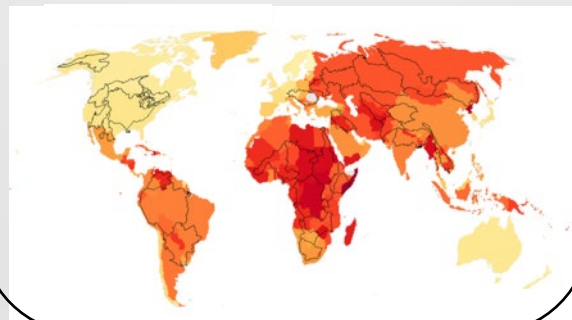
Management capacity indicators

HDI



+

Government effectiveness



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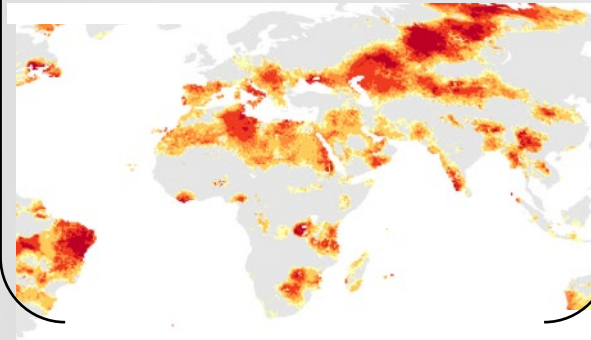
Coping capacity

$$VCC = (WS + MC) \times HE$$

Water Resource Vulnerability and Coping Capacity (VCC) Assessment Framework

Hazard indicators

SPEI

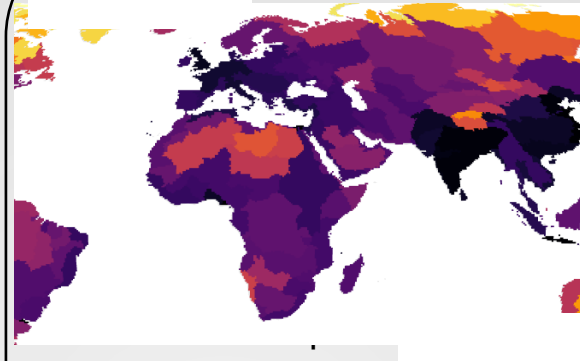


SPEI Standardized Precipitation
Evapotranspiration Index

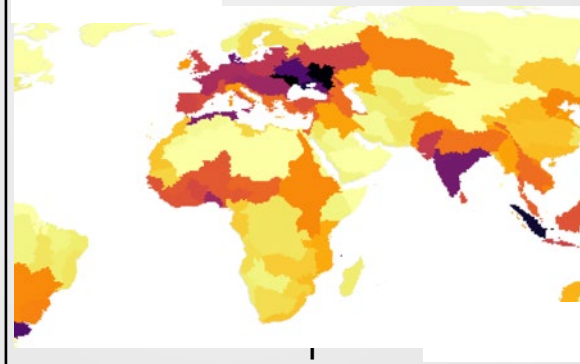
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Exposure indicators

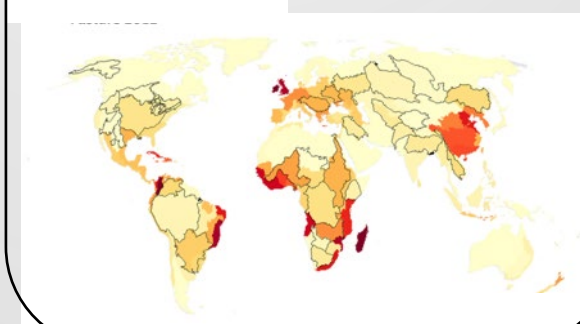
Population



Cropland



Pasture



= Hazard x exposure

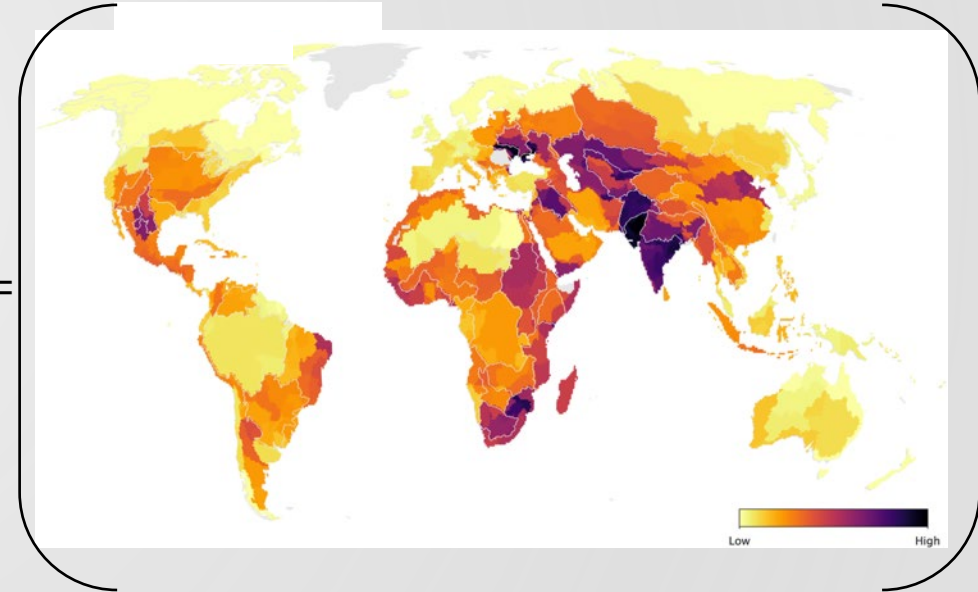
$$VCC = (WS + MC) \times HE$$

Water Resource Vulnerability and Coping Capacity (VCC) Assessment Framework

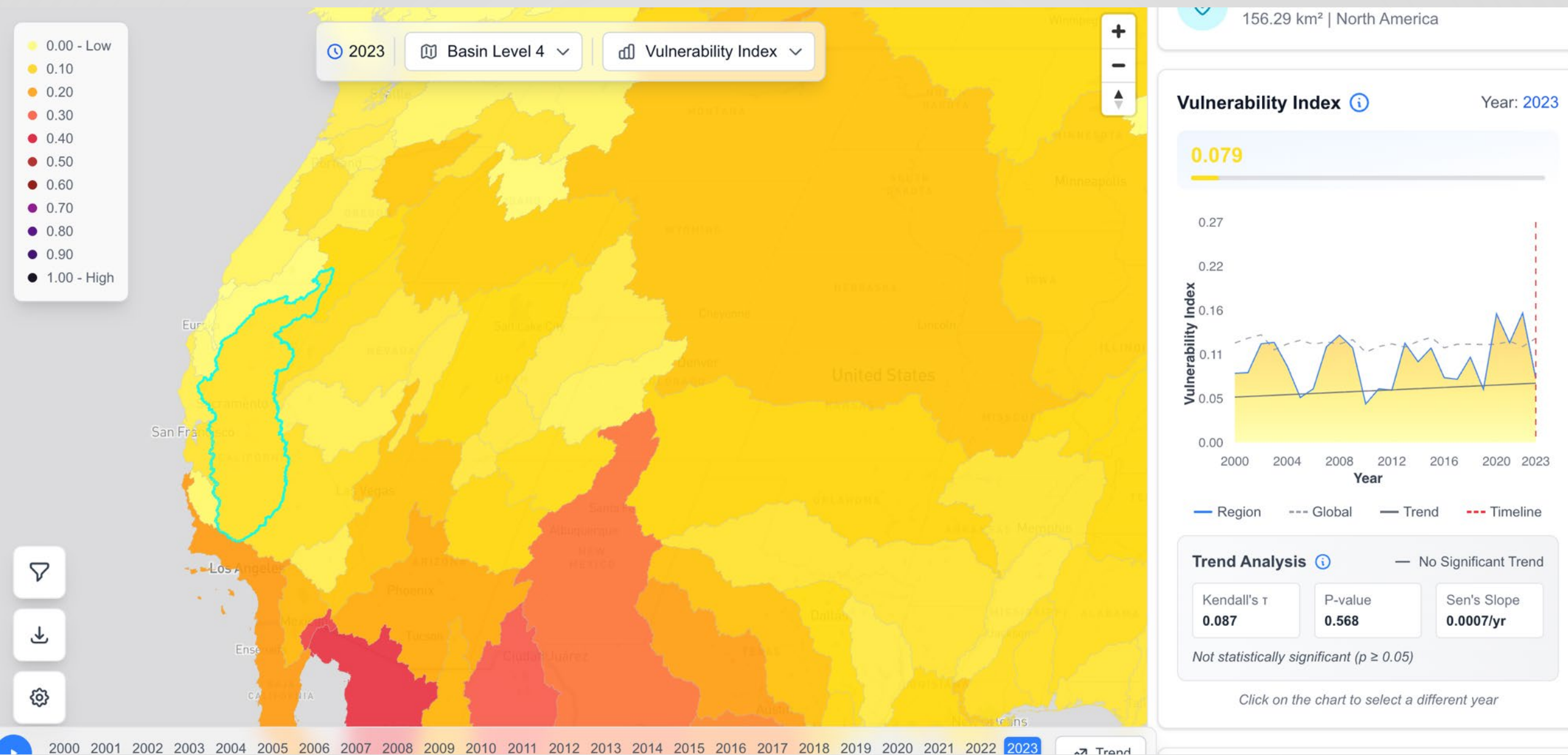
$$VCC = (WS + MC) \times HE$$

Coping capacity × Hazard x exposure =

VCC index

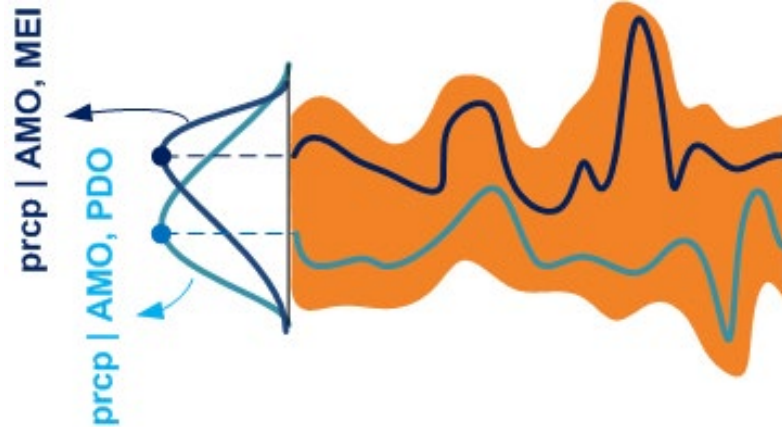


How do human decisions shape the impacts of compound and cascading hazards on communities and ecosystems?



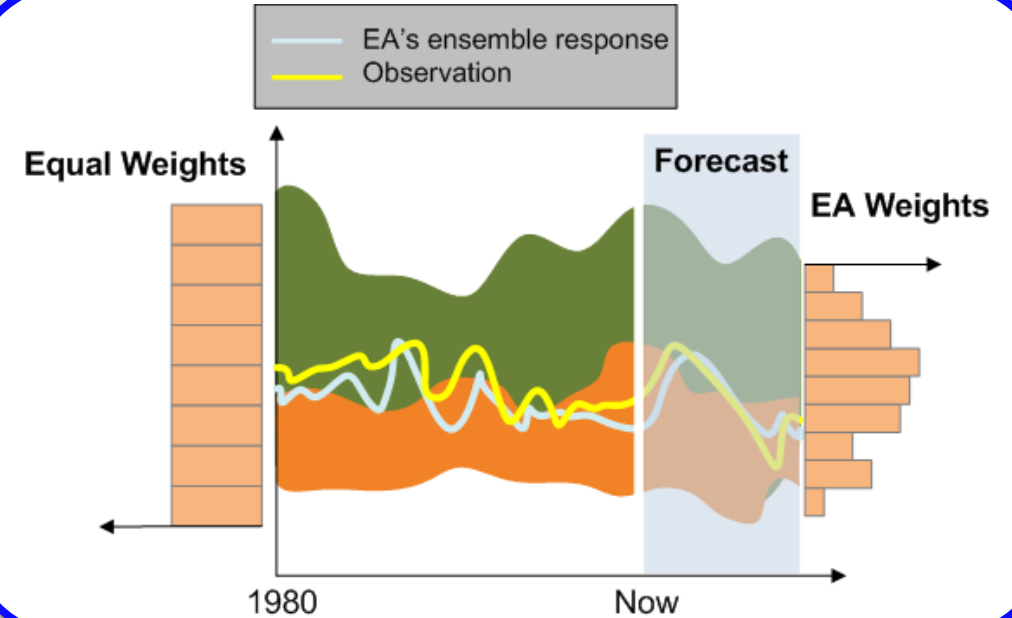
<https://water.eng.uci.edu/>

Statistical Prediction



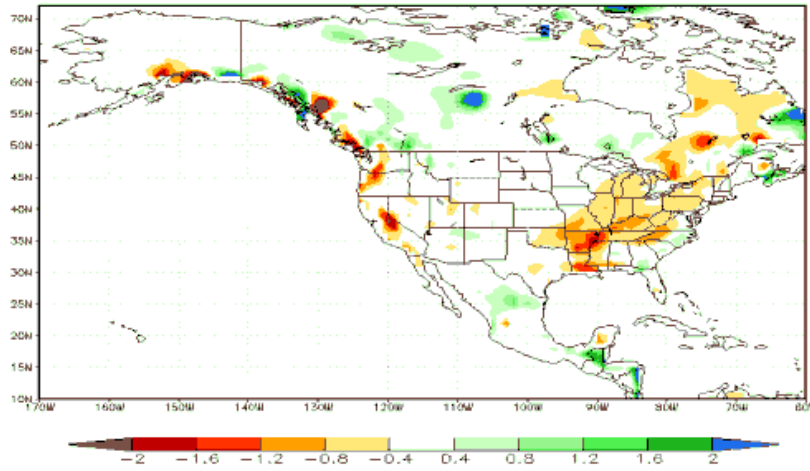
Hybrid Statistical-Dynamical Drought Prediction Framework

Hybrid
Physics-
based AI
Drought
Prediction
Using the
**Expert
Advice (EA)**
Algorithm

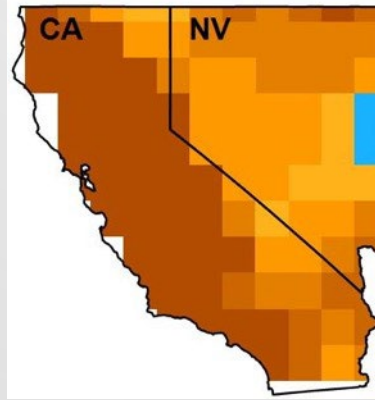


Dynamic Model Simulations

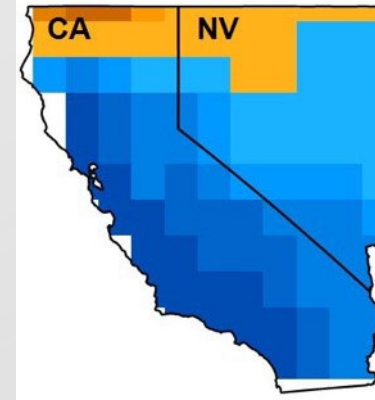
Observed Prate anom DJF 2014



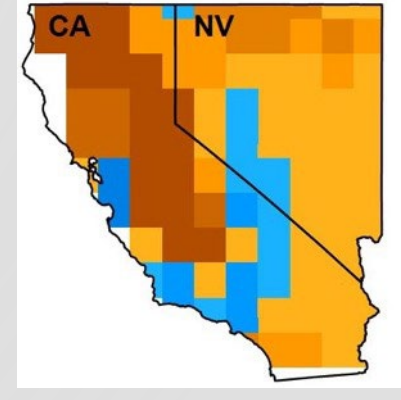
JFM (2006-07), Obs



JFM (2006-07), NMME



JFM (2006-07), Hybrid





NATIONAL
ACADEMIES

Sciences
Engineering
Medicine



Questions?

Contact Information:

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OPEN DISCUSSION – USER NEEDS

Purpose: Solicit feedback on a proposed approach for assessing user needs across the many critical DI&M audiences.

Approach for DI&M User Needs Assessment

Identify Gaps and Opportunities for Improvements

Develop an approach to:

- Gather actionable user specific input on potential indicators and metrics that would lead to directly improved decisions and reduction of drought related impacts
- Identify unique and also overlapping needs, across multiple user types, to inform gaps/opportunity
- Inclusion into the DI&M White Paper for 2026 (and continuing into 2027)



Template: DI&M User Needs Assessment

Key Questions

User Type:	Example Users:
Decisions: [What drought decision would they likely make? Whether they use DI&M today or not?]	Currently Used DI&M: [What indicators are most used for this group today?]
	Missing DI&M: [What indicators do they believe are most missing today?]
Impacts: [What are the consequences of missing metrics? In financial, societal, or other impacts?]	Resolution: [Need spatial - field, city, county, region, watershed, state - resolution?] [Need temporal – real-time, hourly, daily, weekly, monthly, yearly?] [Future forecasting – is forward looking needed?] [Use of AI] – is there a particular use of AI that could be applicable?]
	Four Categories: [Across four buckets: risks, thresholds, actions, and impact. Which requires the most new effort? Where are the gaps/opportunities greatest?]

Template Example: Environment

Needs Assessment for DI&M “User Requirements”

User Type: Environment	Example Users: NGOs such as TNC, EDF, American Rivers, etc.	
Decisions: 1)Functional flow (stream flow req'ts) 2)Groundwater dependent ecosystems 3)Surface right curtailments (from SWB)	Currently Used DI&M:	Streamflow gage information, species data US Drought Monitor D-Scale (but not streamflow specific)
	Missing DI&M:	Real-time gaging across many more stream reaches (SB 19). Missing biological flow-ecology relationships (for CEFF). Species data, related to pre and post drought resilience. Habitat data
Impacts: <u>Environmental</u> : Species impacts <u>Human</u> : Jobs affected by curtailments, human health impact of preserved functional flows <u>Financial</u> : Loss revenues from curtailments	Resolution:	<u>Spatial</u> : More dense coverage of all key stream reaches <u>Temporal</u> : Ideally near-real time (15 minutes) or hourly/daily <u>Forecasting</u> : Ability to do streamflow predictions in all reaches 5-15 days out. Aspiration would be to also forecast environment impacts of drought <u>Use of AI</u> : Possible spatial interpolation of missing data
	Four Categories:	High interest in “thresholds” that trigger actions. High interest in “impacts” (ecological impacts of drought)



Developing Drought Early Warning Systems for California

DRIP Drought Indicators Workshop

June 5, 2026

Alvar Escriva-Bou, PhD

Assistant Professor

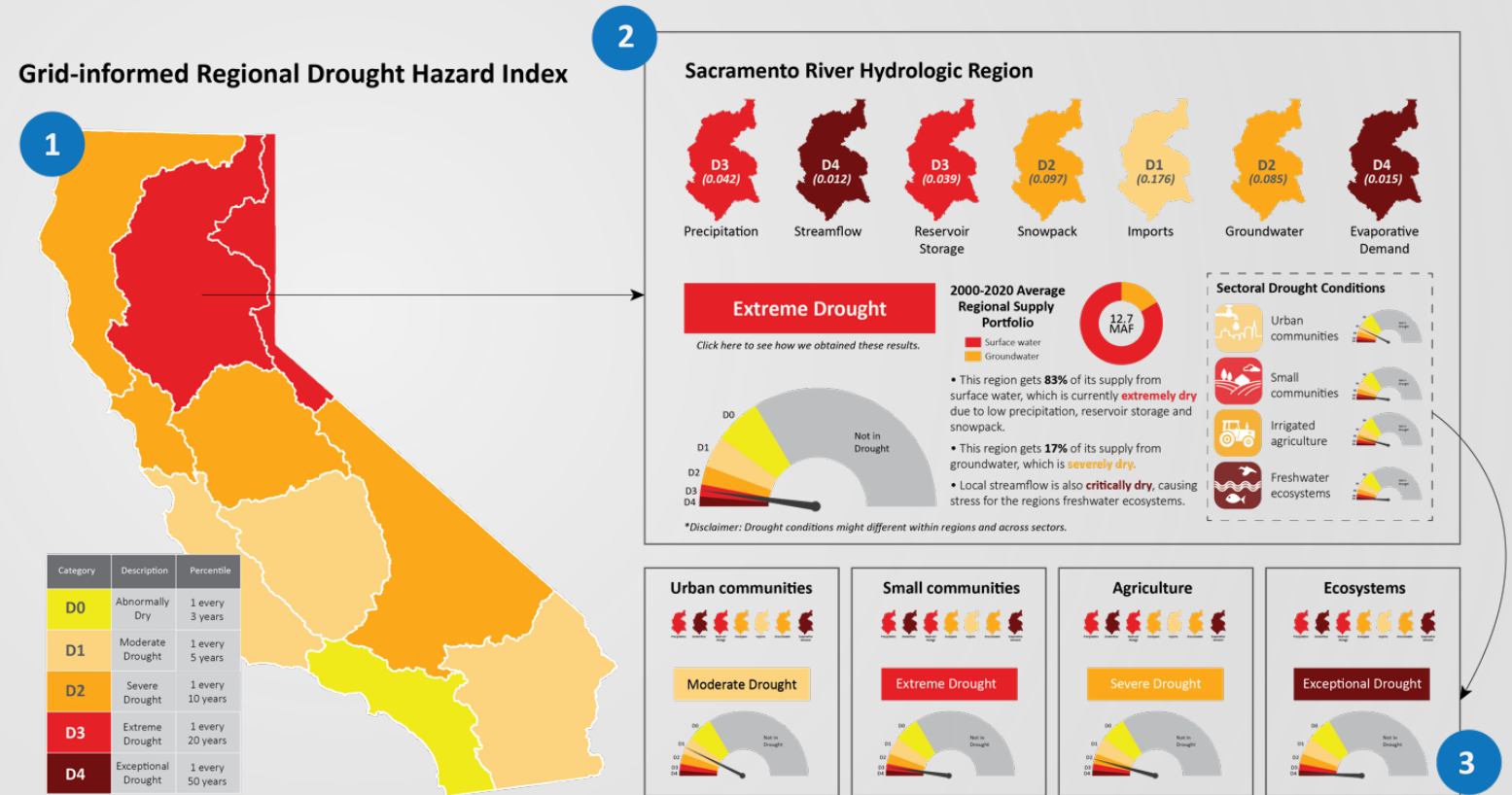
University of California, Davis



Supported by funding from National Oceanic Atmospheric Administration's (NOAA) National Integrated Drought Information System (NIDIS)

Our goal is to develop a Drought Early Warning Dashboard for California

- A public web-based dashboard updated monthly
- Estimation of statewide drought indicators and impacts for:
 - Cities
 - Small communities
 - Agriculture
 - Ecosystem

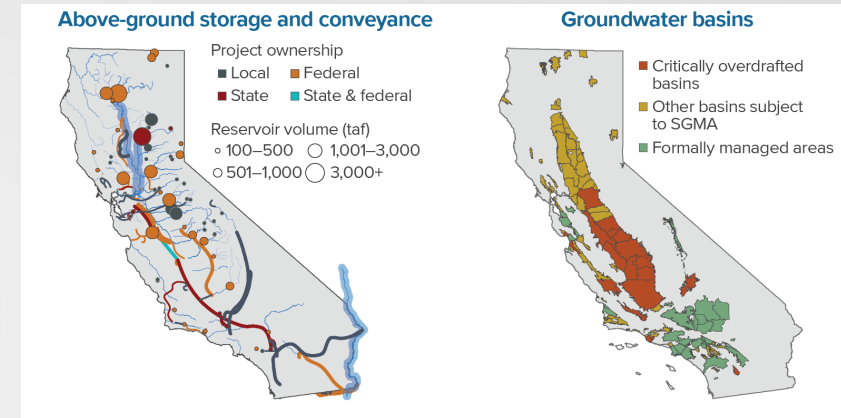


Web mock-up developed to help understand the goal of our project

It is key to better define drought conditions and impacts in California's highly managed system

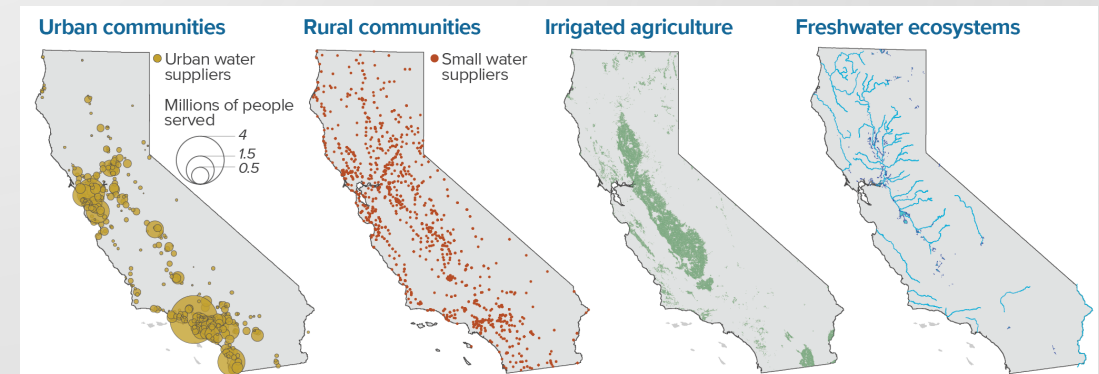
1 A more nuanced view of drought conditions (drought hazard)

- Incorporate water infrastructure and management
- Integrate users' supply portfolios



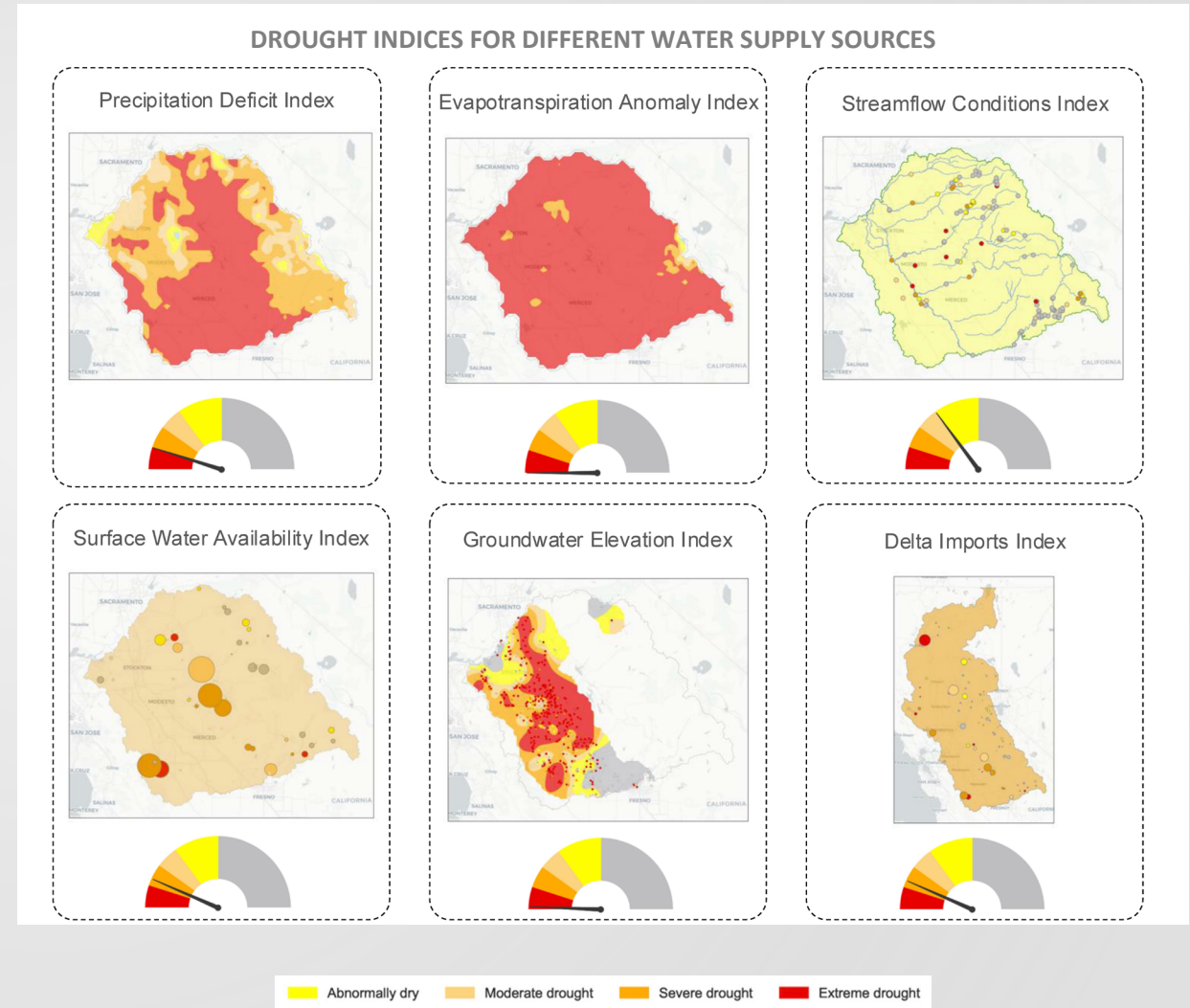
2 A better understanding of the link between drought conditions and impacts

- Understand users' exposure and vulnerability to drought



We have already developed methodologies and data that we'll use

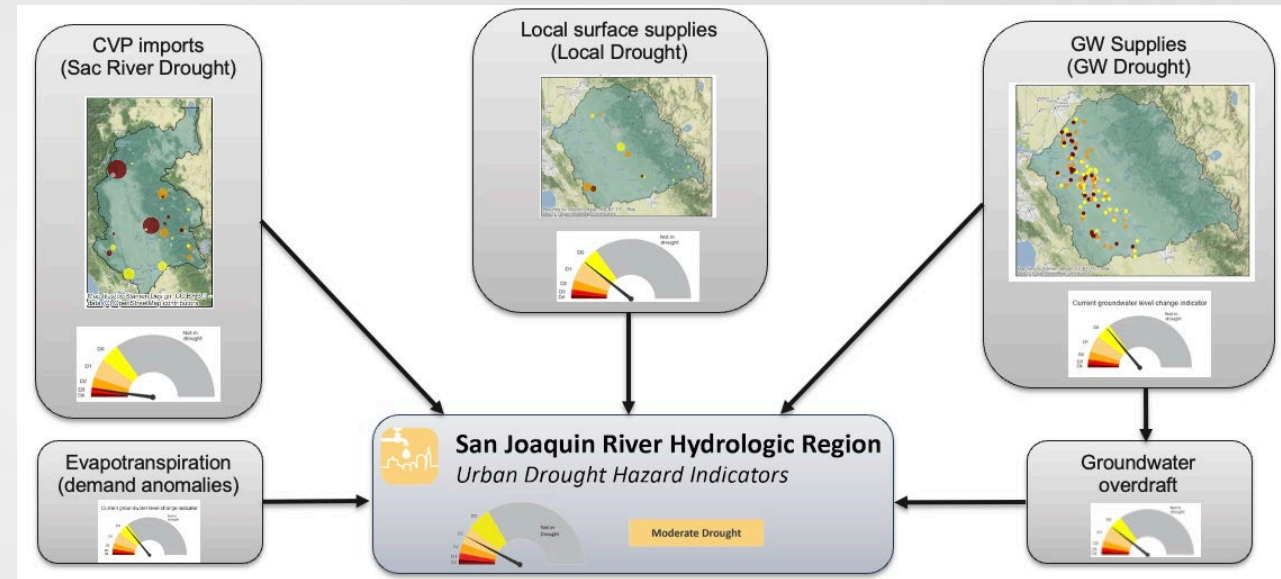
- With the goal of understanding reduction in water availability, we developed:
 - User-oriented drought hazard indicators for supply sources
 - Indicators for users with complex portfolios



We have already developed methodologies and data that we'll use

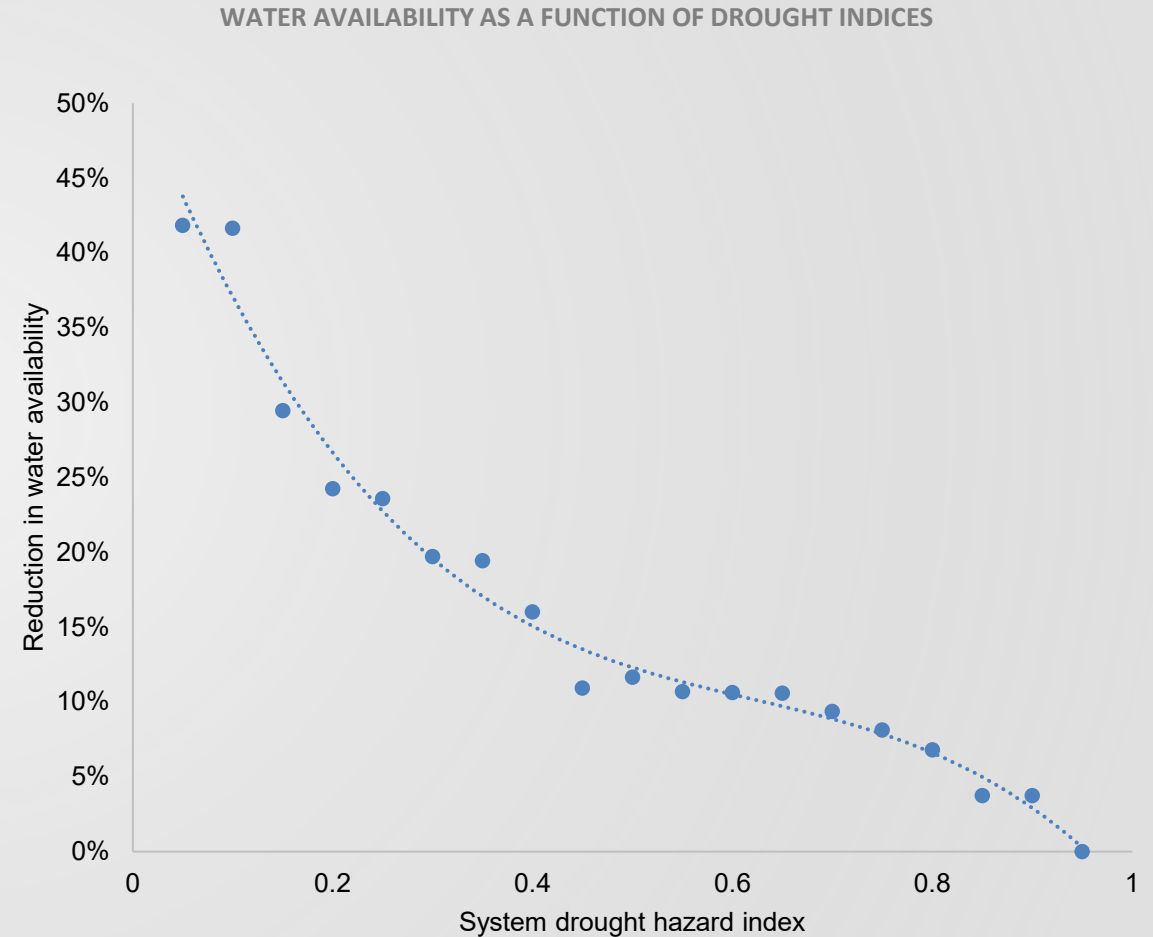
- With the goal of understanding reduction in water availability, we developed:
 - User-oriented drought hazard indicators for supply sources
 - Indicators for users with complex portfolios

DROUGHT INDICES FOR USERS WITH COMPLEX WATER PORTFOLIOS



We have already developed methodologies and data that we'll use

- With the goal of understanding reduction in water availability, we developed:
 - User-oriented drought hazard indicators for supply sources
 - Indicators for users with complex portfolios



We are developing the dashboard with a new project funded by NIDIS



Drought Hazard Indicators

Develop comprehensive statewide hazard indicators to track resource and moisture levels.



Drought Impact Estimation

Analyze and estimate environmental, agricultural, and economic drought impacts.



Web-Based Dashboard

Construct an interactive, robust visual interface for public and executive-level analytics.



Stakeholder Co-Production

Incorporate continuous end-user feedback and requirements directly into the design process.



National Scalability Assessment

Evaluate systemic models and data standard rules for scaling platforms beyond California.



KICKOFF DATE
June 15, 2026

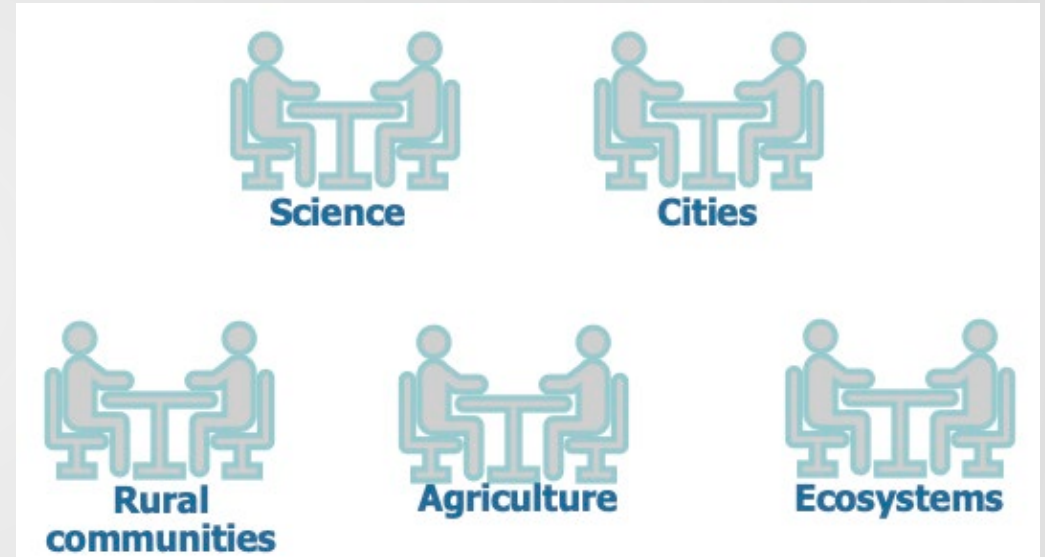


FUNDING PARTNER
NOAA – NIDIS

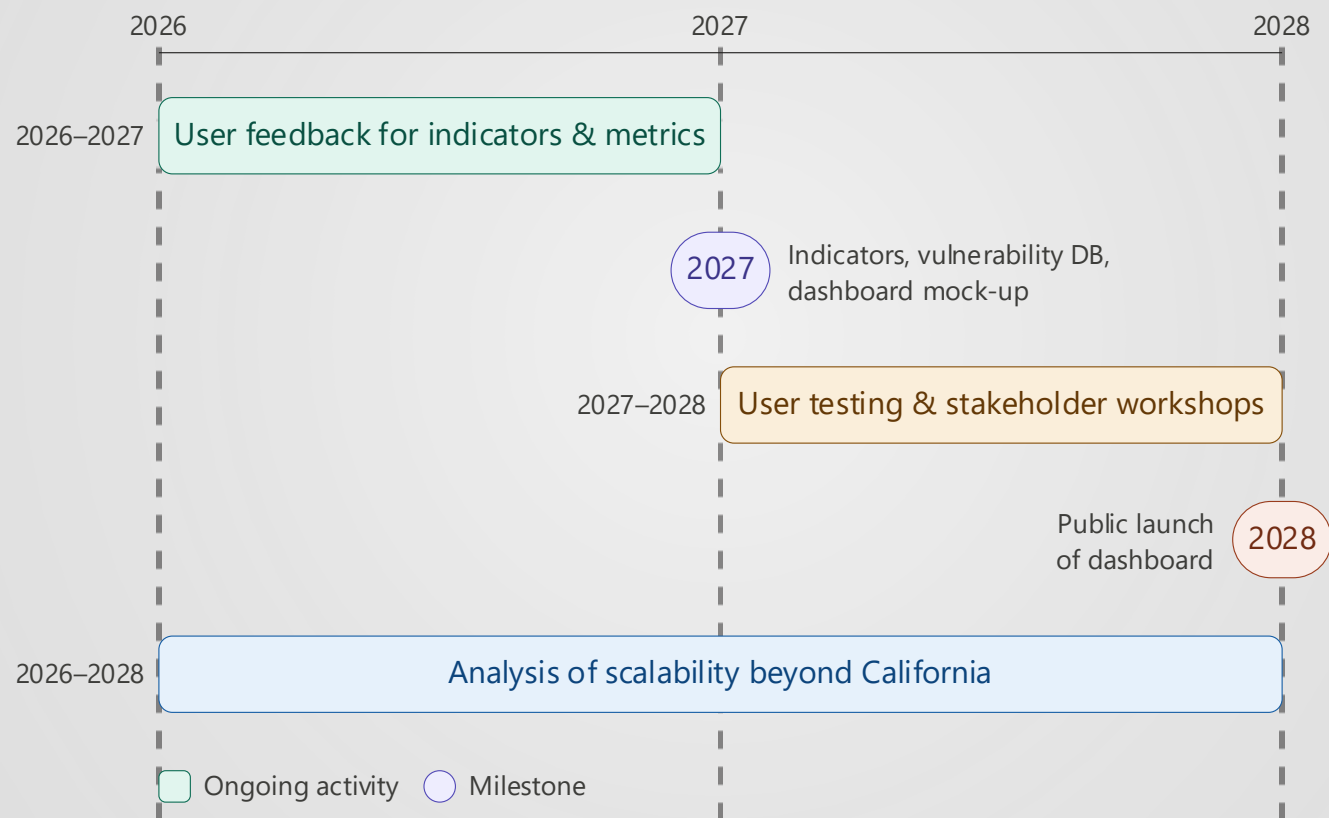
The project will be informed by relevant stakeholders

- We will convene five sectoral advisory groups to ground-truth assumptions and research questions and co-produce products
- Users will shape the product by:
 - Identifying key decisions users need to make
 - Designing sector-specific views and visualizations
 - Testing mock-ups with agencies and stakeholders
 - Refining usability, indicators, and impact communication

ADVISORY GROUPS WILL INFORM RESEARCH GOALS AND OUTCOMES



Expected outcomes and timeline



Thank you!

Don't hesitate to send me an email if you have any questions, comments or suggestions

Alvar Escriva-Bou



aescriva@ucdavis.edu



Assessing DI&M Audience Needs



Counties

Assess drought indicator information needs of CA counties as they relate to **County Drought Resilience Plans for domestic well users and state small water systems.**

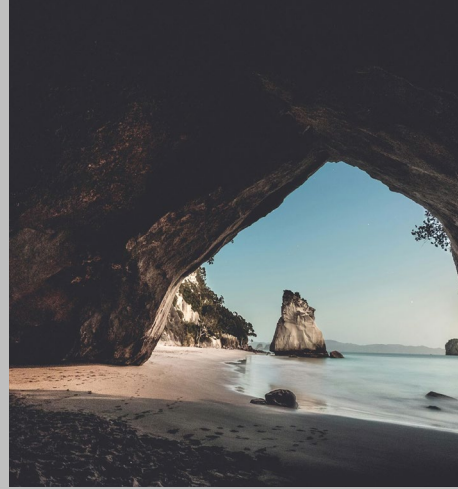
Draft memo by **Sep. 2026**



Media

Asses drought-related information needs of the media organizations to identify **which data and communications formats would best support accurate and timely reporting** on drought.

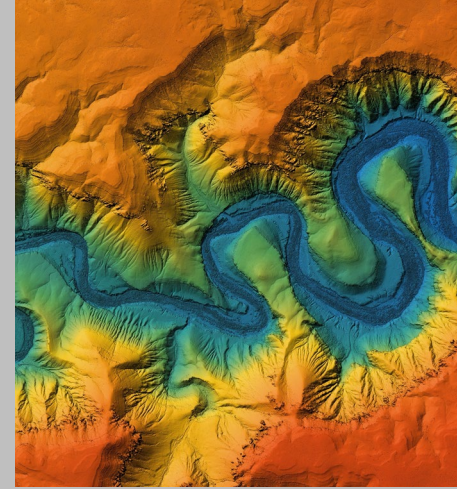
Interview summaries by **Mar. 2027**



Large Urban Suppliers

Document **existing drought metrics and forecasting processes** of large urban water suppliers to evaluate if there is an approach to using **regional metrics and frameworks more broadly at the state level.**

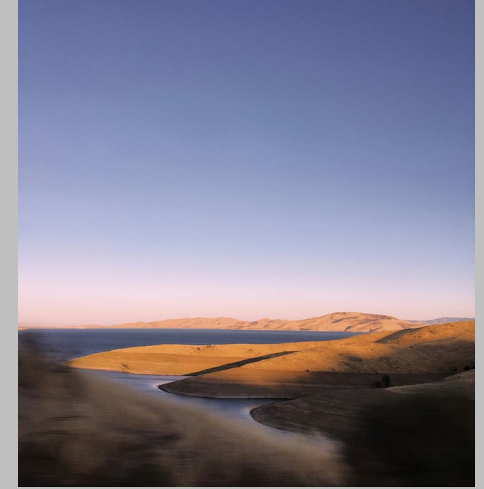
Interview summaries by **Mar. 2027**



State

Identify information needs and decision-making processes of CA state agencies as they relate to **emergency proclamations and drought response.**

Interview summaries by **May 2027**



Environmental Managers

Evaluate information needs of decision makers managing for environmental outcomes and ecosystem health to identify **which data and communication formats best support management of flows during dry periods.**

Interview summaries by **May 2027**

Approach, Deliverables, and Feedback



Approach

- Interviews
- Small group discussions
- Workshops



Deliverables

- Interview/discussion summaries
- Synthesizing webinar
- Memos on each user group



Feedback

- DRAFT county user group memo by **9/30/26**
- DRAFT memo on all user groups by **7/22/27**
- FINAL memo and synthesizing webinar by **8/31/27**



WORKING SESSION – CURRENT INDICATORS AND GAPS/ OPPORTUNITIES

Purpose: Discuss current inventory of indicators and metrics, sorted by the four categories of 1) risk, 2) thresholds, 3) actions and 4) impacts

Working Session Instructions [40 minutes]

Introduction (15 min): Recap the four categories of indicators and metrics

- Examples: Integrated examples of how drought indicators and metrics used in CA
- Current Inventory: Broader list of indicators, whether used in California or not

Questions for Discussion:

- 1. Breakouts** (15 min): Across the four categories, where do you think we should put our effort?
 - a. Can we name specific gaps or opportunities (either high-level or specific metrics)?
 - b. Which of these opportunities should be featured in the White Paper?
- 2. Group Discussion** (10 min): Hear readout from each breakout group
 - a. Discuss whether there is an obvious Top 10 opportunities to prioritize for further effort

KEY DROUGHT QUESTIONS (INDICATOR RELATED)

- | | | | |
|--|-----------------|---|------|
| 1. Are we in a <u>drought</u> ? How severe? What type? What sector? Where? When? | → Hazard | } | Risk |
| 2. Am I (or my <u>assets</u>) at risk? | → Exposure | | |
| 3. Level of <u>susceptibility</u> , given the broader situation (physical, institutional, economic)? | → Vulnerability | | |
| 4. At what <u>point</u> will action be taken? By whom? | → Thresholds | | |
| 5. What are the possible <u>actions</u> /response? | → Actions | | |
| 6. How <u>effective/efficient</u> was the response? | → Effectiveness | | |
| 7. What was (or will be) the <u>impact</u> (hydrologic, economic, societal, environmental)? | → Impacts | | |
| 8. What is the resulting drought <u>resilience</u> ? | → Resilience | | |

DI&M: SAMPLE INDICATORS (FOUR CATEGORIES)

1

Risk

Hazard Indicators

- US Drought Monitor, including DSCI
- Palmer Drought Severity Index (PDSI)
- Standardized Precipitation Index (SPI)
- Normalized Difference Vegetation Index (NDVI)
- Standardized Soil Moisture Index (SSI)

+many, many others...

2

Thresholds

SWP allocations

- Snow water equivalent (SWE) and reservoir levels
- Availability modeling that inform SW curtailments

County, NGO, Individuals

- GW levels and dry well reporting

Delta

- Saltwater intrusion

Water Agencies

- Water shortage contingency stages
- GSP minimum thresholds

3

Actions

State Agency

- # of Executive Orders and drought proclamations
- \$B in emergency drought response
- \$/well to restore access

Surface water

- # of curtailments
- % water deliveries (SWP, CWP, etc.)

Water systems

- % water conservation
- # of PWS consolidation orders

4

Impacts

Community

- # of dewatered wells
- # of people without sustainable access
- # of DACs affected

Agriculture

- % decrease in yields
- # of acres repurposed
- # of jobs lost
- \$ of lost ag revenue

Environment

- % decrease in fish species
- % change in subsidence
- Impact on forests, fires

Four Categories are Related (1 of 5)

Integrated Example: Urban Water Supplier (sample audience)

Risk	Thresholds	Actions	Impacts
1. Drought levels. US Drought Monitor D-Levels indicate severe drought in an area 2. Hazard. Low storage levels in critical reservoirs 3. Exposure. # of people (millions) of urban and suburban residents across Southern California 4. Vulnerability. Absolute AF water needs by segments (urban, ag, industrial) and heavy % reliance on imported water via State Water Project	1. DWR State Water Project. DWR sets the % allocation of water 2. Urban suppliers. Allocations mean the urban water agencies have to activate a more severe stage in their Water Shortage Contingency Plan	1. Conservation. % of urban water agencies passing emergency actions, such as local ordinances limiting outdoor watering and higher tier pricing on water bills. Recommending conservation	1. Behavior. % reduction in average per capita daily water use (GPCD) 2. Economic (suppliers). Lower \$ water revenue, given conservation measures. \$ increase in costs to acquire alternative sources of water. Worsening financial stability of local water agencies 3. Societal. Rise in \$ costs for monthly water bills. Number of dewatered wells (given increased use of groundwater).

Four Categories are Related (2 of 5)

Integrated Example: Agriculture / Irrigation Districts

Risk	Thresholds	Actions	Impacts
1. Drought levels. US Drought Monitor D-Levels indicate severe drought in an area 2. Hazard. Low storage levels in critical reservoirs 3. Exposure. # of high value permanent nut crop trees (almonds, pistachios) 4. Vulnerability. Required irrigation levels given permanent crops require irrigation (unlike annual crops)	1. US Bureau of Reclamation. Sets the % allocation of water for south of Delta agriculture contractors 2. SWB. Potential for surface water curtailments given low flow conditions in the river	1. Transfers. % of irrigation districts who must find alternative sources of irrigation water 2. Land repurposing. # of acres that require land repurposing (MLRP) given lack of available irrigation water	1. Land use. % reduction in irrigated acreage, acres left fallow, acres of nut trees that were bulldozed out of production 2. Financial. % increase in water costs (higher \$/AF) given need for transfer water. Financial implications for irrigation districts and farmers

Four Categories are Related (3 of 5)

Integrated Example: Groundwater / Counties / DW owners

Risk	Thresholds	Actions	Impacts
1. Drought levels. US Drought Monitor D-Levels indicate severe drought in an area (signal for the Counties) 2. GW Levels. % decline per GSA gw monitoring networks 3. Hazard. % or absolute decline in groundwater levels. # of dry well reports 4. Exposure. # of rural communities that are not part of a larger water district 5. Vulnerability. # of systems with reliance on a single well source, often next to agricultural wells 6. Water quality. % decline in GAMA water quality levels	1. GSP thresholds. Groundwater levels drop below the Minimum Thresholds (MT) defined by the local Groundwater Sustainability Agency (GSA) and cited in their Groundwater Sustainability Plans	1. Moratorium. GSA initiates moratorium on new well permits and enforces AF/acre limits for irrigation ag pumping 2. SWB SAFER. SAFER releases funding to deploy short-term response	1. Dewatering. Number of dry domestic wells, reported to the State. # of households that lost access to water 2. Financial. \$ amount spent by the State to provide emergency response to vulnerable communities

Four Categories are Related (4 of 5)

Integrated Example: Surface Water & Ecosystems

Risk

1. **Drought levels.** US Drought Monitor D-Levels indicate severe drought in an area
2. **Hazard.** Unfavorable snowpack metrics and SWE in upstream Klamath mountain location. Anticipated low flow in river
3. **Exposure.** Coho and Chinook salmon spawning routes with Scott River watershed and metrics show populations at risk
4. **Vulnerability.** Surface water demands > anticipated supply, given local ranching needs to irrigate

Thresholds

1. **Stream gages.** Low expected flows at the USGS Fort Jones gage is expected to drop < 50 CFS in mid-summer, which is below the recommended CEFF and SWB threshold
2. **Water availability.** SWB estimates low water availability given current conditions and diversion data from CalWATRS

Actions

1. **Curtailment.** SWB triggers an emergence curtailment order, asking junior rights holders to stop diversions

Impacts

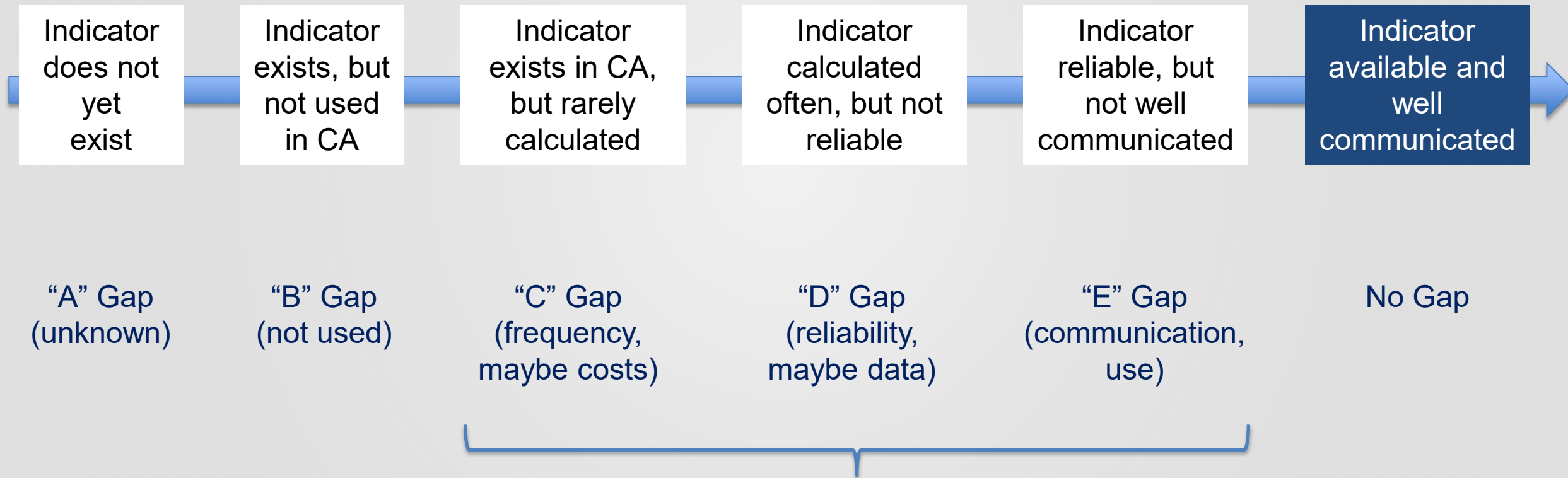
1. **Ecological.** Salmon population impacts (x% decline) avoided, given the curtailment order
2. **Societal.** Number of citizens who had drinking water preserved
3. **Economic.** Total \$ financial losses incurred by ranchers/farmers given curtailment. Job losses also estimated

Four Categories are Related (5 of 5)

Integrated Example: Subsidence and Water Infrastructure

Risk	Thresholds	Actions	Impacts
1. Drought levels. US Drought Monitor D-Levels indicate severe drought in an area 2. Hazard. Very limited surface water allocations to agriculture water districts 3. Exposure. Vulnerable water conveyance systems (CA aqueduct, Friant-Kern Canal, Delta-Mendota Canal) 4. Vulnerability. Land subsidence driven by overpumping of underlying aquifers	1. Subsidence rate. DWR estimated rate of change based on vertical land displacement measured via InSAR specified 2. GSA subsidence thresholds. GSP specified subsidence local minimum thresholds as set by the GSA	1. Regulatory enforcement. SWB steps in to place GSAs on probationary status under SGMA. GSAs forced to mandate well pumping reductions 2. Engineering. State agencies are forced to authorize infrastructure restoration projects	1. Operational. % loss of volumetric carrying capacity in water infrastructure 2. Financial. Absolute \$ capital expenditure required to physically repair, raise or re-engineer sinking public infrastructure

Gaps in DI&M: Gaps (indicators) exist along a spectrum



20th Century DI&M

A Review of Twentieth-Century Drought Indices Used in the United States

BY RICHARD R. HEIM JR.

Drought is a recurring phenomena that has plagued civilization throughout history. It affects natural habitats, ecosystems, and many economic and social sectors, from the foundation of civilization—agriculture—to transportation, urban water supply, and the modern complex industries. The wide variety of sectors affected by drought, its diverse geographical and temporal distribution, and the demand placed on water supply by human-use systems make it difficult to develop a single definition of drought.

The American Meteorological Society (1997) groups drought definitions and types into four categories: meteorological or climatological, agricultural, hydrological, and socioeconomic. A prolonged (e.g., of several months or years duration) *meteorological drought*—the atmospheric conditions resulting in the absence or reduction of precipitation—can develop quickly and end abruptly (in some cases, the transition can occur almost literally overnight). Short-term (i.e., a few weeks duration) dryness in the surface layers (root zone), which occurs at a critical time during the growing season, can result in an *agricultural drought* that severely reduces crop yields, even though deeper soil levels may be saturated. Hot temperatures, low relative humidity, and desiccating winds often add to the impact of the lack of rainfall (Condra 1944). The onset of an agricultural drought may lag that of a meteorological drought, depending on the prior moisture status of the surface soil layers. Precipitation deficits over a prolonged period that affect surface or subsurface water supply, thus

Knowing the history of drought index development helps take the confusion out of the complex issues of drought monitoring, drought impacts, and drought definitions.

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CORRESPONDING AUTHOR: Richard R. Heim Jr., Climate Monitoring Branch, Scientific Services Division, National Climatic Data Center, 151 Patton Avenue, Asheville, NC 28801-5001
E-mail: Richard.Heim@noaa.gov

In final form 12 February 2002

reducing streamflow, groundwater, reservoir, and lake levels, will result in a *hydrological drought*, which will persist long after a meteorological drought has ended. *Socioeconomic drought* associates the supply and demand of some economic good with elements of meteorological, agricultural, and hydrological

AMERICAN METEOROLOGICAL SOCIETY

AUGUST 2002 **BAMS** | 1149

August 2002

TABLE 1. Major drought indices discussed in this paper.

Index	Year introduced	Variables analyzed; application
Munger's Index	1916	Length of period without 24-h precipitation of 1.27 mm; daily measure of comparative forest fire risk
Kincer's Index	1919	30 or more consecutive days with less than 6.35 mm of precipitation in 24 h; seasonal distribution maps
Marcovitch's Index	1930	Temperature and precipitation; climatic requirements of the bean beetle
Blumenstock's Index	1942	Length of drought in days, where drought terminated by occurrence of 2.54 mm of precipitation in 48 h; short-term drought
Antecedent Precipitation Index	1954	Precipitation; a reverse drought index used for flood forecasting
Moisture Adequacy Index	1957	Precipitation and soil moisture; agricultural drought
Palmer's Index (PDSI and PHDI)	1965	Precipitation and temperature analyzed in a water balance model; comparison of meteorological and hydrological drought across space and time
Crop Moisture Index	1968	Precipitation and temperature analyzed in a water balance model; agricultural drought
Keetch–Byram Drought Index	1968	Precipitation and soil moisture analyzed in a water budget model; used by fire control managers
Surface Water Supply Index	1981	Snowpack, reservoir storage, streamflow, and precipitation; computed primarily for western river basins; statistical properties not well analyzed or understood
Standardized Precipitation Index	1993	Precipitation; allows measurement of droughts and wet spells in terms of precipitation deficit, percent of “normal,” probability of nonexceedance, and SPI at multiple simultaneous timescales with potentially different behavior at all of them
Vegetation Condition Index	1995	Satellite AVHRR radiance (visible and near-IR); measures “health” of vegetation
Drought Monitor	1999	Integrates several drought indices and ancillary indicators into a weekly operational drought-monitoring map product; multipurpose

2000 – 2025 CA Drought Indicators (7 Science Papers)

Summary of select science papers describing California drought indicators

Rethinking the Line in the Sand: How Science Redefined California's Drought Tracking

Before 2015, drought monitoring suffered from a major operational disconnect. While scientists created complex indicators, a striking survey revealed that 16 out of 18 Western states with official drought plans often did not use their own metrics. Water managers described them as "arbitrary guesses," "borrowed from other states," or "never tested."

However, as California's climate shifts and its massive water delivery infrastructure faces unprecedented strain, atmospheric scientists and hydrologists have fundamentally rewritten the rules of water tracking.

Recounting the period 2000 to 2015, four scientific papers (*McEvoy et al., 2012; Diffenbaugh et al., 2015; Steinemann et al., 2015; He et al., 2017*) describe a significant evolution. Together, they document how California moved away from crude, one-size-fits-all rainfall tallies and toward a highly sophisticated, multi-layered tracking system built specifically for the state's unique plumbing network.

Pre-read (sent out earlier this week)

Developing and Evaluating Drought Indicators for Decision-Making

ANNE STEINEMANN* AND SAM F. IACOBELLIS

Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California

DANIEL R. CAYAN

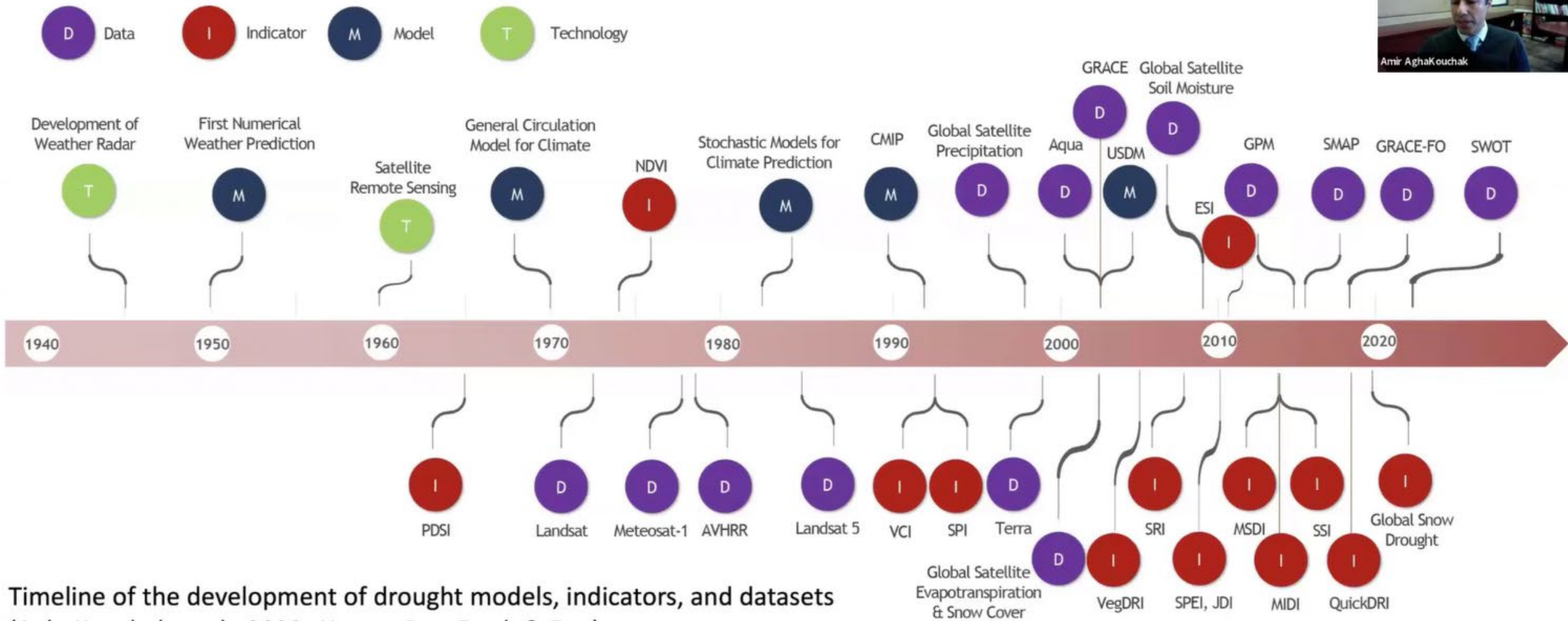
*Scripps Institution of Oceanography, University of California, San Diego,
and U.S. Geological Survey, La Jolla, California*

(Manuscript received 12 December 2014, in final form 28 March 2015)

Indicators and indicator systems can present a number of limitations for decision-making. For instance, indicators are often based on metrics that are subjective, statistically inconsistent across different temporal and spatial scales, noncomparable with other indicators, and disconnected from relative risk or historic conditions.

In addition, indicators in plans are typically selected in an ad hoc and arbitrary way, without understanding or testing their performance. Decision-makers often lament the lack of guidance for developing and evaluating indicators. For example, a recent survey of 19 drought managers from western states found that 16 of the 18 states with drought plans did not use their indicators, citing them as "not at all useful," "ignored," "a guess," "borrowed from another state," and "never tested" (Steinemann 2014).

1 RISK: TIMELINE OF RISK INDICATORS



Timeline of the development of drought models, indicators, and datasets
(AghaKouchak et al., 2023, *Nature Rev. Earth & Env.*)

1

Risks: 100+ possible drought risk indicators



nature reviews earth & environment

<https://doi.org/10.1038/s43017-023-00457-2>

Perspective

Check for updates

Toward impact-based monitoring of drought and its cascading hazards

Drought indicator	Drought Type	Category	Use or Limitation
Palmer Drought Severity Index (PDSI ¹)	Meteorological	S	PDSI information from different climate regions often cannot be compared as it is a non-standardized index.
Normalized Difference Vegetation Index (NDVI ²)	Ecological, Agricultural	C	It is a proxy that provides information on vegetation stress based on vegetation color. NDVI values from different environments cannot be easily compared.
Standardized Precipitation Index (SPI ³)	Meteorological	S	The most widely used standardized index that allows comparing droughts in different regions. Provides probabilistic drought severity information.
Vegetation Condition Index (VCI ⁴)	Ecological, Agricultural	C	It is a proxy that provides information on vegetation stress based on vegetation color. VCI values from different environments cannot be easily compared.
Percent of Normal Precipitation (PNP ⁵)	Meteorological	S	A simple index that shows deviation of precipitation from normal. Cannot be used to generate consistent probabilistic drought severity information in regions with very different climates.
Climatic Water Balance (CWB ⁶)	Meteorological, Hydrological	C	A water balance approach with multiple components. Cannot be used to generate consistent probabilistic drought severity information in regions with very different climates.
Vegetation Drought Response Index (VegDRI ⁷)	Ecological, Agricultural	C	A composite model-based indicator with operational applications. Cannot be used to generate consistent probabilistic drought severity information in regions with very different climates.
Standardized Runoff Index (SRI ⁸)	Hydrological	S	The most widely used standardized index that allows comparing hydrologic drought based on runoff data. Provides probabilistic drought severity information. In places where runoff is heavily regulated, SRI may not be very informative.
Standardized Precipitation-Evapotranspiration Index (SPEI ⁹)	Meteorological	C	Widely used indicator that goes beyond precipitation for meteorological drought. Method of evapotranspiration estimation significantly affect SPEI estimation.
Joint Drought Index (JDI ¹⁰)	Multiple	C	Integrates precipitation and streamflow using a multivariate approach. In places where runoff is heavily regulated, SRI may not be very informative.
Evaporative Stress Index (ESI ¹¹)	Agricultural, Meteorological	C	Widely used for describing flash drought and also stress on ecosystem and agriculture.
Multivariate Standardized Drought Index (MSDI ¹²)	Agricultural, Meteorological	C	Integrates precipitation and soil moisture for composite drought monitoring. Requires long-term records for reliable multivariate drought assessment.
Standardized Soil Moisture Index (SSI ¹²)	Agricultural	S	A standardized index that allows comparing droughts in different regions. Provides probabilistic drought severity information. Lack of reliable soil moisture information is a major limitation.
Microwave Integrated Drought Index (MIDI ¹³)	Multiple	C	Designed for integrating remotely sensed observations. It does not provide spatially consistent probabilistic drought severity information.

Rapid Change Index (RCI ¹⁴)	Ecological, Agricultural	C	Estimates accumulated magnitude of moisture stress changes and used as an indicator of flash drought.
Standardized Relative Humidity Index (SRHI ¹⁵)	Meteorological	S	A standardized index that allows comparing droughts in different regions. Provides probabilistic drought severity information. High SRHI values do not indicate lack of drought as high humidity does not necessarily translate to precipitation. SRHI may show the onset of meteorological drought before precipitation signal.
Multivariate Standardized Reliability and Resilience Index (MSRRI ¹⁶)	Anthropogenic, Socioeconomic	C	Combines climate information (top-down) with local water use and storage (bottom-up). It requires long-term records of water demand and storage that may not be available.
Evaporative Demand Drought Index (EDDI ¹⁷)	Meteorological, Ecological	C	It measures anomalies in the atmospheric evaporative demand across different scales. It can be used as an indicator of flash drought.
Quick Drought Response Index (QuickDRI ¹⁸)	Ecological, Agricultural	C	A composite model-based indicator with operational applications. Cannot be used to generate consistent probabilistic drought severity information in regions with very different climates.
Standardized Snow Water Equivalent Index (SWEI ¹⁹)	Hydrological	S	A standardized index that allows comparing droughts in different regions. Provides probabilistic drought severity information. Relies on SWE at a certain time (i.e., it does not track snow evolution during the entire snow season).

Supplementary table 1. A non-exhaustive selection of drought indices, their characteristics and limitations. Drought indicator category is represented with an S (a single drought indicator) or a C (a composite, multivariate or multi-variable indicator).

HANDBOOK OF DROUGHT INDICATORS & INDICES



Table 1. Indicators and indices listed in this handbook

Meteorology	Page	Ease of use	Input parameters	Additional information
Aridity Anomaly Index (AAI)	11	Green	P, T, PET, ET	Operationally available for India
Deciles	11	Green	P	Easy to calculate; examples from Australia are useful
Keetch-Byram Drought Index (KBDI)	12	Green	P, T	Calculations are based upon the climate of the area of interest
Percent of Normal Precipitation	12	Green	P	Simple calculations
Standardized Precipitation Index (SPI)	13	Green	P	Highlighted by the World Meteorological Organization as a starting point for meteorological drought monitoring
Weighted Anomaly Standardized Precipitation (WASP)	15	Green	P, T	Uses gridded data for monitoring drought in tropical regions
Aridity Index (AI)	15	Yellow	P, T	Can also be used in climate classifications
China Z Index (CZI)	16	Yellow	P	Intended to improve upon SPI data
Crop Moisture Index (CMI)	16	Yellow	P, T	Weekly values are required
Drought Area Index (DAI)	17	Yellow	P	Gives an indication of monsoon season performance
Drought Reconnaissance Index (DRI)	17	Yellow	P, T	Monthly temperature and precipitation are required
Effective Drought Index (EDI)	18	Yellow	P	Program available through direct contact with originator
Hydro-thermal Coefficient of Selyaninov (HTC)	19	Yellow	P, T	Easy calculations and several examples in the Russian Federation
NOAA Drought Index (NDI)	19	Yellow	P	Best used in agricultural applications
Palmer Drought Severity Index (PDSI)	20	Yellow	P, T, AWC	Not green due to complexity of calculations and the need for serially complete data
Palmer Z Index	20	Yellow	P, T, AWC	One of the many outputs of PDSI calculations
Rainfall Anomaly Index (RAI)	21	Yellow	P	Serially complete data required
Self-Calibrated Palmer Drought Severity Index (sc-PDSI)	22	Yellow	P, T, AWC	Not green due to complexity of calculations and serially complete data required
Standardized Anomaly Index (SAI)	22	Yellow	P	Point data used to describe regional conditions
Standardized Precipitation Evapotranspiration Index (SPEI)	23	Yellow	P, T	Serially complete data required; output similar to SPI but with a temperature component
Agricultural Reference Index for Drought (ARID)	23	Red	P, T, Mod	Produced in south-eastern United States of America and not tested widely outside the region
Crop-specific Drought Index (CSDI)	24	Red	P, T, Td, W, Rad, AWC, Mod, CD	Quality data of many variables needed, making it challenging to use
Reclamation Drought Index (RDI)	25	Red	P, T, S, RD, SF	Similar to the Surface Water Supply Index, but contains a temperature component

Soil moisture	Page	Ease of use	Input parameters	Additional information
Soil Moisture Anomaly (SMA)	25	Yellow	P, T, AWC	Intended to improve upon the water balance of PDSI
Evapotranspiration Deficit Index (ETDI)	26	Red	Mod	Complex calculations with multiple inputs required
Soil Moisture Deficit Index (SMDI)	26	Red	Mod	Weekly calculations at different soil depths; complicated to calculate
Soil Water Storage (SWS)	27	Red	AWC, RD, ST, SWD	Owing to variations in both soil and crop types, interpolation over large areas is challenging

Hydrology	Page	Ease of use	Input parameters	Additional information
Palmer Hydrological Drought Severity Index (PHDI)	27	Yellow	P, T, AWC	Serially complete data required
Standardized Reservoir Supply Index (SRSI)	28	Yellow	RD	Similar calculations to SPI using reservoir data
Standardized Streamflow Index (SSFI)	29	Yellow	SF	Uses the SPI program along with streamflow data
Standardized Water-level Index (SWI)	29	Yellow	GW	Similar calculations to SPI, but using groundwater or well-level data instead of precipitation
Streamflow Drought Index (SDI)	30	Yellow	SF	Similar calculations to SPI, but using streamflow data instead of precipitation
Surface Water Supply Index (SWSI)	30	Yellow	P, RD, SF, S	Many methodologies and derivative products are available, but comparisons between basins are subject to the method chosen
Aggregate Dryness Index (ADI)	31	Red	P, ET, SF, RD, AWC, S	No code, but mathematics explained in the literature
Standardized Snowmelt and Rain Index (SMRI)	32	Red	P, T, SF, Mod	Can be used with or without snowpack information

Remote sensing	Page	Ease of use	Input parameters	Additional information
Enhanced Vegetation Index (EVI)	32	Green	Sat	Does not separate drought stress from other stress
Evaporative Stress Index (ESI)	33	Green	Sat, PET	Does not have a long history as an operational product
Normalized Difference Vegetation Index (NDVI)	33	Green	Sat	Calculated for most locations
Temperature Condition Index (TCI)	34	Green	Sat	Usually found along with NDVI calculations
Vegetation Condition Index (VCI)	34	Green	Sat	Usually found along with NDVI calculations
Vegetation Drought Response Index (VegDRI)	35	Green	Sat, P, T, AWC, LC, ER	Takes into account many variables to separate drought stress from other vegetation stress
Vegetation Health Index (VHI)	35	Green	Sat	One of the first attempts to monitor drought using remotely sensed data

Water Requirement Satisfaction Index (WRSI and Geo-spatial WRSI)	36	Green	Sat, Mod, CC	Operational for many locations
Normalized Difference Water Index (NDWI) and Land Surface Water Index (LSWI)	37	Green	Sat	Produced operationally using Moderate Resolution Imaging Spectroradiometer data
Soil Adjusted Vegetation Index (SAVI)	37	Red	Sat	Not produced operationally

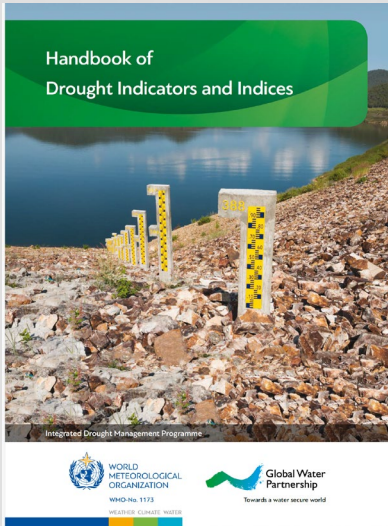
Composite or modelled	Page	Ease of use	Input parameters	Additional information
Combined Drought Indicator (CDI)	38	Green	Mod, P, Sat	Uses both surface and remotely sensed data
Global Integrated Drought Monitoring and Prediction System (GIDMaPS)	38	Green	Multiple, Mod	An operational product with global output for three drought indices: Standardized Soil Moisture Index, SPI and Multivariate Standardized Drought Index
Global Land Data Assimilation System (GLDAS)	39	Green	Multiple, Mod, Sat	Useful in data-poor regions due to global extent
Multivariate Standardized Drought Index (MSDI)	40	Green	Multiple, Mod	Available but interpretation is needed
United States Drought Monitor (USDM)	41	Green	Multiple	Available but interpretation is needed

Note: Indicators and indices are sorted by 'ease of use' and then alphabetically within each 'ease of use' category.

Key to variables:

AWC = available water content,
CC = crop coefficient,
CD = crop data,
ER = ecoregion,
ET = evapotranspiration,
GW = groundwater,
LC = land cover,
Mod = modelled,
Multiple = multiple indicators used,
P = precipitation,

PET = potential evapotranspiration,
Rad = solar radiation,
RD = reservoir,
S = snowpack,
Sat = satellite,
SF = streamflow,
ST = soil type,
SWD = soil water deficit,
T = temperature,
Td = dewpoint temperature,
W = wind data.



2 Thresholds: List of some of the critical CA thresholds

Category	Threshold	Who Manages
Surface Water	State Water Project allocations, via Bulletin 120 data and Exceedance Model	DWR
	Central Valley Project (CVP) allocations, via priority tier system	US Bureau of Reclamation (USBR)
	Sacramento (40-30-30) and San Joaquin (60-20-20) Hydrologic Indices	DWR
Bay-Delta & Water Quality	Decision 1641 Electrical Conductivity Salinity Limits	SWB, along with USBR and DWR
	X2 Estuarine Habitat Protection Outflow Target	USFW, CDFW and National Marine FS
	Harmful Algal Bloom (HAB) Public Health Advisory Tiers	CA Water Quality MC, Regional WB
Groundwater (SGMA)	GSP Minimum Thresholds	GSAs, with review by DWR and SWB
	SGMA Undesirable Results	GSAs, with review by DWR and SWB
	Maximum Subsidence Velocity Triggers (via InSAR)	DWR, with management by GSAs
Water Infrastructure	Hydroelectric Powerplant Dead Pool Elevation	DWR
	Shasta Lake Cold Water Pool Storage Reserves	USBR, along with NMFS
Urban Water UWMP	Water Shortage Contingency Plans, Stages 1-6	Urban Water Suppliers
	“Making Water a California Way of Life” Efficiency Budget	SWB
Ecosystems	CEFF given stream gage readings and 5 Functional Flows	SWB Div of Water Rights and CDFW

Actions: Previous Actions/Appropriations from 2012-2016

What Can We Learn From How the State Responded to the Last Major Drought?

Summary

For the second consecutive year, the state is experiencing extremely low rates of precipitation. As we prepare for what could be an extended period of dry conditions, it is helpful to review how the state responded to the last major drought. Such information can inform—and thereby potentially improve—the state's current and ongoing response to developing conditions. In this report, we summarize the major activities, spending, and policy actions undertaken by the state to respond to the severe drought that occurred from 2012 through 2016. We also describe current conditions, and highlight some key lessons the Legislature can learn from previous efforts to help guide its response to the emerging drought. (We will provide our analysis of the Governor's May Revision drought spending proposals in a future document.)

LAO

GABRIEL PETEK
LEGISLATIVE ANALYST
MAY 2021

LAO
(Legislative Analyst Office)
May 2021

Figure 1

State Drought Response Appropriations

2013-14 Through 2016-17 (In Millions)

Activity	Amount
Water Supply	
Support groundwater management and cleanup	\$843
Improve/increase water recycling, wastewater treatment, stormwater management, and desalination	609
Fund Integrated Regional Water Management projects	473
Improve drinking water infrastructure	311
Subtotal	(\$2,235)
Emergency Response	
Expand/enhance fire protection	\$384
Address emergency drinking water needs	115
Provide food and other assistance to drought-affected communities and farmworkers	99
Conduct statewide drought assistance, monitoring, and response	55
Remove and dispose of dead trees	41
Monitor/enforce water rights and conservation regulations	20
Various other activities	21
Subtotal	(\$734)
Water Conservation	
Increase urban water efficiency and conservation	\$126
Increase agricultural water efficiency and conservation	110
Fund innovative water efficiency technologies	30
Conduct conservation outreach and public messaging	23
Increase water efficiency at state facilities and wildlife refuges	28
Subtotal	(\$287)
Environmental Protection	
Emergency fish and stream activities	\$70
Eradicate water hyacinth	4
Study and model flows	3
Subtotal	(\$78)
Total	\$3,334

Many funded actions taken during the 2012-2016 drought.

Q: To what extent should indicators and metrics exist to track actions as they happen (not just 5 years after the drought ends)?

3 Actions: Possible action indicators and metrics for CA

- Curtailment orders (SWB)
- Data and telemetry req'ts

Water Rights Enforcement

Groundwater

- Pumping caps, extraction fees
- Drilling moratoriums (GSA)
- Basin probationary status (SWB)
- Emergency response

- Water Shortage Contingency Plans stages (Utilities)
- Outdoor irrigation bans
- Drought surcharges

Urban Municipal

Infrastructure Operations

- Drought salinity barriers (DWR)
- Reservoir ops (USBR/USACE)
- Fast track water market transfers
- Temporary urgency change petitions (related to Delta)

Ecosystem

- Cannabis cultivation forbearance
- Hatchery relocations (CDFW)
- Suspend env review for GW recharge
- Water hyacinth management
- Expand fire protection

4 Impact Metrics (from Drought Impact Reporter)



Water Supply & Quality

- Dry wells
- Voluntary/mandatory restrictions
- Changes in water rates
- New well permits
- Water allocations/ allotment

Agriculture

- Ag impacts
- Income loss
- Reduced crop yields
- Increased irrigation costs
- Cost of new water sources

Business & Industry

- Changes in demand for goods or services
- Reduction in employment
- Bankruptcy
- Other economic impacts

Energy

- Effects on power production including hydropower
- Change in electricity rates
- Change in power options

Fire

- Enacting burning restrictions
- Increased fire risk, including increase of fire fuels
- Occurrence of fire (acres, number of fires)

Plants & Wildlife

- Loss of biodiversity
- Loss of trees from rural and urban landscapes
- Reduction of habitat
- Increased stress on species
- Loss of wetlands

Relief, Response

- Disaster declarations
- Aid programs
- Govt relief and programs
- County-level declarations

Society/Public Health

- Health-related problems
- Increased concentration of contaminants
- Loss of human life
- Respiratory ailments

Tourism/Recreation

- Closure of rec areas
- Water access or navigation problems
- Bans on rec activities

Impact Metrics: Most critical for California?

Agriculture

1. Net Idled/Fallowed Cropland Acreage
2. Agricultural-Sector Job Losses
3. AG Revenue or Yield Losses
4. Water Transfer Costs
5. Groundwater Pumping Energy Surcharges
6. Orchard Removal (Bulldozed Acreage)
7. Increased Forage Costs

Community

1. Domestic Well Failures
2. Number of People/DACs Without Supply
3. Hauled/Bottled Water
4. Utility Revenue Decrease
5. Subsidence Conveyance Capacity Declines
6. Subsidence Repair Costs
7. Water Quality Increased Costs

Environment

1. Species Mortality Rates
2. Harmful Algal Blooms
3. Urban canopy loss
4. Impact on forests
5. Fire fighting costs

Public Health

1. Dust/particular matter
2. Illness incidence
3. Water Quality Impacts
4. Water Affordability
5. School Absenteeism

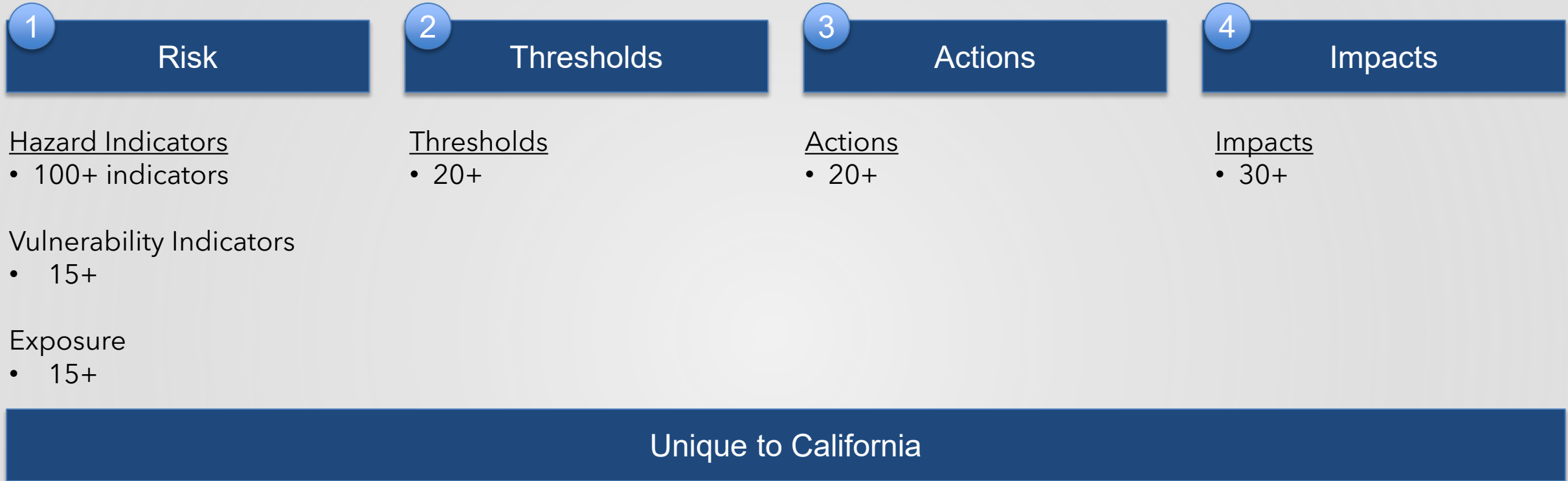
Energy

1. Hydropower Loss
2. Grid Replacement Costs
3. Carbon Impacts

Question: What is missing? What's critical to track?



DI&M: SUMMARY (200+ INDICATORS FOR CA)



Working assumptions:

- **Hazard Indicators.** We can use a subset of the ~100 global indicators that already exist, and choose those most relevant to CA. Then, we have CA specific hazard, exposure, and vulnerability indicators that are sub-region, sector level, and by supply mix
- **Thresholds, Actions, and Impacts.** Highly unique and custom to California

Key Question: Can we establish predictive relationships between Risk indicators and Thresholds, Actions, and Impacts?
For example, can we create leading indicators that proactively link drought risk levels into estimated domestic well failures?

DI&M: QUOTES (GAPS/OPPORTUNITIES)

“We need to start with practitioner needs, not indicators. How do we link this to decisions, such as supply and demand assessments and curtailments. We need a framework to think through metric types.” Robyn G and Alyssa S (CWDC)

*“We’re focused on anticipating water system failures. We would ideally have a drought hazard indicator akin to US Drought Monitor, but **locally relevant and CA specific**. That and more funding.”* Eric Z (SWRCB)

*“Some of the biggest gaps today are in **impacts** and links to **cascading hazards**, such as wildfire. We also need better predictions, such as snow and short-term, physics-based predictions.”* Amir A and Phu N (UC Irvine)

*“We need impact metrics mapped to **unique end users**. How do we ensure the most relevant indicators are clear for each audience? Sort of like a guidebook for most key inputs (or recipe for key ingredients).”* Ben M (LCI)

*“A key opportunity is for us to really define what is great **sector level engagement**. We know granular sector indicators are needed, but how do we create those so they are usable, useful and used?”* Amanda S and Andy N (NIDIS)

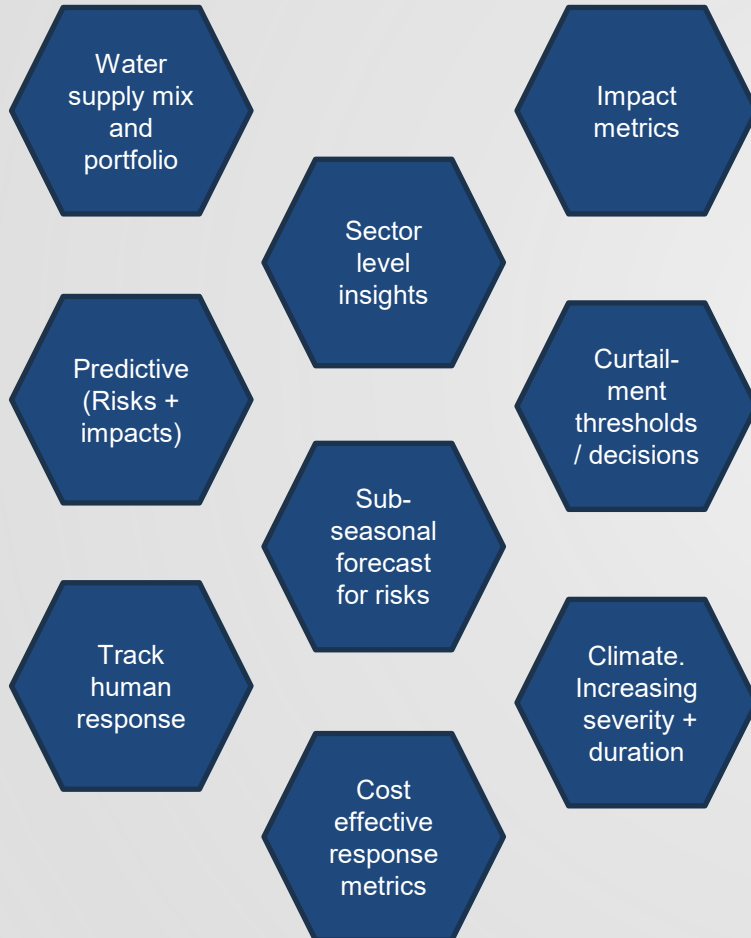
*“We need more **impact metrics**, especially on the agriculture side. Similar with cities and drinking water, including affordability. Financials and multi-benefit need a link as well.”* Erik P (UN ANR)

DI&M: POSSIBLE GAPS, KEY CONSIDERATIONS

Sample Gaps

FOR DISCUSSION

(Many possible combinations possible,
each aimed at different audiences)



15 min breakouts... then 10 minute group

What are your Top 10 Opportunities?

- 1. User needs.** Identify specific DI&M needs by specific audiences (10-15)?
- 2. Thresholds.** Work with DRIP Collaborative members to list key decisions and thresholds that are affecting each audience
- 3. Impacts.** Clarify exactly where top ~30 impact metrics can be found. Catalog how cataloged and calculated
- 4. TBD...**

Working Session – Discussion [25 minutes]

- Participants are invited to join a breakout discussion to reflect on the initial findings and address the key questions posed.
- Please identify one participant who can report back on 2-3 discussion items.

Questions for Discussion:

- 1. Breakouts** (15 min): Across the four categories, where should DRIP focus our efforts?
 - a. Can we name specific gaps or opportunities (either high-level or specific metrics)?
 - b. Which of these opportunities should be featured in the White Paper?
- 2. Group Discussion** (10 min): Hear readout from each breakout group
 - a. Discuss whether there is an obvious Top 10 opportunities to prioritize for further effort

WHITE PAPER OUTLINE

Purpose: Introduce the white paper outline

DI&M White Paper outline

- I. **Introduction**
 - A. Problem/Background
 - 1. How drought is often communicated today
 - 2. The need for clarification (why DI&M feels so complicated)
 - 3. Implications of status quo (lack of clarity)
 - B. Process and analysis goals
 - 1. Stated vision
 - 2. Understanding current efforts and landscape
- II. **Collaborative Approach/- participatory development to addressing the stated problem**
 - A. 4 Category framework
 - B. Current integrated examples of how DI&M works (or doesn't work)
 - C. Participation of the DRIP Collaborative, NIDIS, SMEs, others
- III. **Overarching Findings** (longest/most detailed section/bulk of paper)
 - A. Assessing user needs via deep dive with each DI&M audience ("user centric")
 - A. Focus on counties, media, etc.
 - B. Key learnings
 - 1. Current DI&M usage today
 - 2. What's missing, across the four category framework
 - 3. What is our current capability to solve these gaps/opportunities
 - C. Roadmap and resources needed
- IV. **Coordination - Hosting and communication**
 - A. State level - what exists and how State could more effectively use DI&M
 - B. Local Level - what exists and how Local could more effectively use DI&M
 - C. How coordination/communication can be improved
- V. **Appendix**
 - A. Analysis resources - current landscape and gaps
 - 1. Timeline of CA specific drought indicators (historical)
 - 2. What's being used today (current inventory)
 - 3. Potential for moving forward (future), highlighting possible yearly timeline

Next Steps

Drought Indicators and Metrics – start user needs work to inform audience perspectives

DRIP Collaborative meeting (July 17)

- Report on key learnings from Workshop #2 and gaps/opportunity work
- Summarize early insights from user needs work (counties, media)
- Discuss updated outline for proposed DI&M White Paper

Next DI&M workshop – likely in August

- Continuing discussion on gaps/opportunities, including data needs

THANK YOU FOR YOUR CONTRIBUTION TODAY!

THANK YOU!

Top Opportunities? (Based on what we've heard so far)

Top Opportunity	Why	Inspired by:
User needs, sector co-development	Critical to get down to specific audiences; What's working and what's not. Hear directly from the users of DI&M	NIDIS SoCal Pilot (public health) and CWDC work
Sub-sector, sub-regional, with supply mix portfolio	We lack locally actionable risk metrics	Alvar/UC Davis work
Impact metrics (better mapping and communication)	We don't really understand impacts until AFTER. Hard to be proactive and invest scarce resources, if we don't know the results	Erik P work and CDPH thoughts about human impacts
Adding in vulnerability/exposure into risk metrics	Hazard indicators alone don't tell whole story. New methods now possible to get at exposure and coping capacity	Amir, DWR Vulnerability Tool, CDPH, LCI Vulnerability communities work
Predictive indicators	AI/ML that can help fill data gaps, translate and predict. Hence we can act sooner	Eric Z SWB predictor work, Jeanine Jones S2S prediction
Thresholds/Actions	These categories of metrics are not well documented or understood	Alvar/UC Davis work, NIDIS SoCal pilot, many others

...plus overall improved communication! Maybe all explained (or linked) on CA Water Watch?