Linking Indicators of Drought Hazard to Multi-Sectoral Impacts: An Application to California

Final Workshop
May 8, 2023

Alvar Escriva-Bou, Jeff Mount, Ellen Hanak, Mike Dettinger, Ted Grantham, Josué Medellín-Azuara, Kurt Schwabe, Andrew Ayres, and Annabelle Rosser

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

Workshop Agenda

Welcome and workshop objectives	2:00 p.m.
Review of project goals and achievements	2:05 p.m.
Defining drought for California water users	2:15 p.m.
Linking drought conditions and impacts	3:00 p.m.
Discussion about implications and next steps	3:30 p.m.
Workshop ends	4:00 p.m.

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Workshop objectives

- Presentation of the results
- Gather feedback on the progress so far
- Discussion about next steps

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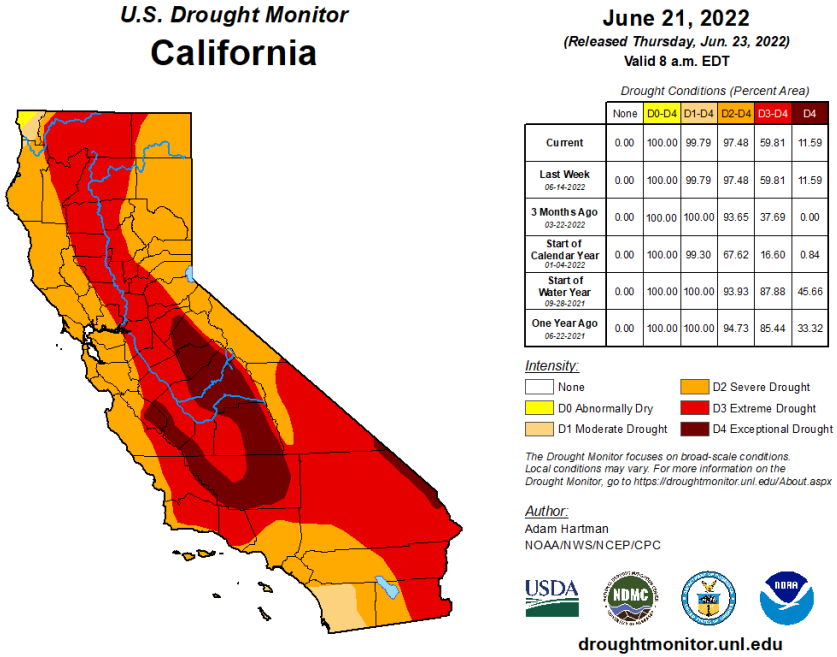
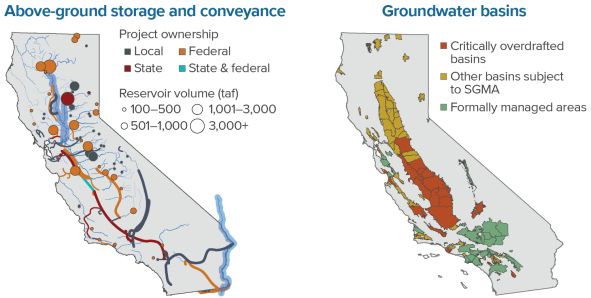
Current drought indicators only focus on local hydrometeorological conditions

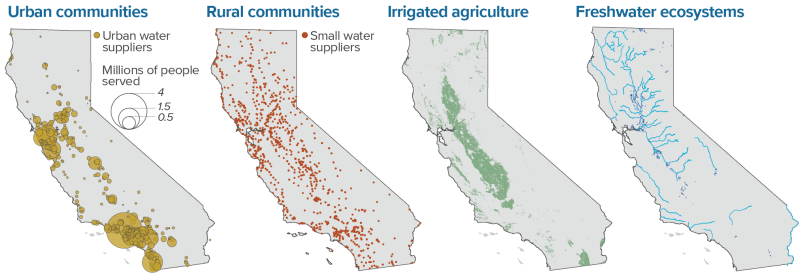


Our goal was to develop a more tailored characterization of drought conditions in California

1 Incorporating water infrastructure and management



2 Developing sector-specific drought hazard indicators



3 Linking drought indicators and impacts for different sectors

4 Co-developing decision support tools

Achievements: Engagement and Outreach

- Convened 12 sectoral advisory group workshops: Science, Agriculture, Cities, Small Communities, and Environment.
- Convened multiple targeted engagement meetings with relevant organizations
  - Department of Water Resources, State Water Resources Control Board, California Water Commission, California Urban Water Agencies, California Data Collaborative, etc.

Achievements: Outreach

- Held two public events (400+ attendees each)
  - Is California Ready for Drought (May 2021)
  - Farming in a State of Extremes (April 2022)
- Published seven blog posts
  - California's Latest Drought in 4 Charts (May 2021)
  - Anticipating and Addressing the Impacts of the Drought (May 2021)
  - How better data can help California avoid a drinking water crisis (June 2021)
  - The Current Drought: Time to Hope for the Best, Prepare for the Worst (Nov 2021)
  - Managing Water Stored for the Environment During Drought (Nov 2021)
  - Are California's Cities Conserving Enough Water? (Dec 2021)
  - How are California's Cities Managing the Drought (Oct 2022)
- Presented at various professional conferences:
  - California Collaborative Data Summit (August 2021), AGU Fall Meeting (December 2021), Annual Salmonid Restoration Conference (April 2022), E&J Gallo Water Summit (May 2022), AGU Fall Meeting (December 2022), EGU General Assembly (April 2023)

Achievements: Research Outcomes

- Policy briefs
  - Drought in California factsheet update (April 2021)
  - Drought and California's Agriculture (April 2022)
- Scientific articles (1 published + 3 in preparation)
  - Rebuilding Resilience: Drought and Declining Freshwater Species in California in January/February 2023 Water Resources IMPACT magazine
  - Indicators of Drought Hazard for California's Multi-sectoral and Heavily Managed Water Systems (in preparation)
  - Defining Drought Hazard for Complex Water Systems (in preparation)
  - Linking Drought Hazard and Drought Impacts (in preparation)
- Other related publications
  - Economic Impacts of the 2020–22 Drought on California Agriculture (Medellin-Azuara et al, November 2022)
  - Policy Brief: The Future of Agriculture in the San Joaquin Valley (Escriva-Bou et al, February 2023)

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  - Defining indicators for users with complex portfolios
  - Environmental drought indicators

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Drought can be simply—but carefully—defined as “insufficient water to meet needs” Kelly Redmond (2002)

But different users have different sources, management tools, and needs

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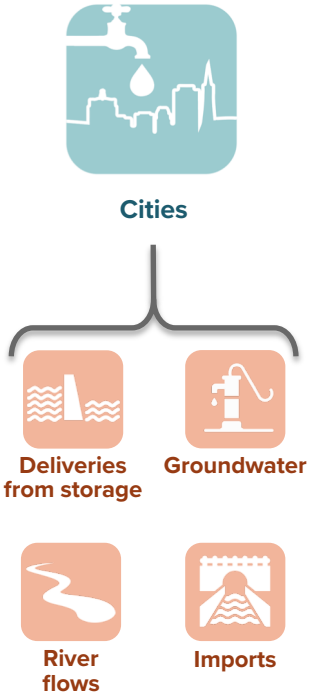

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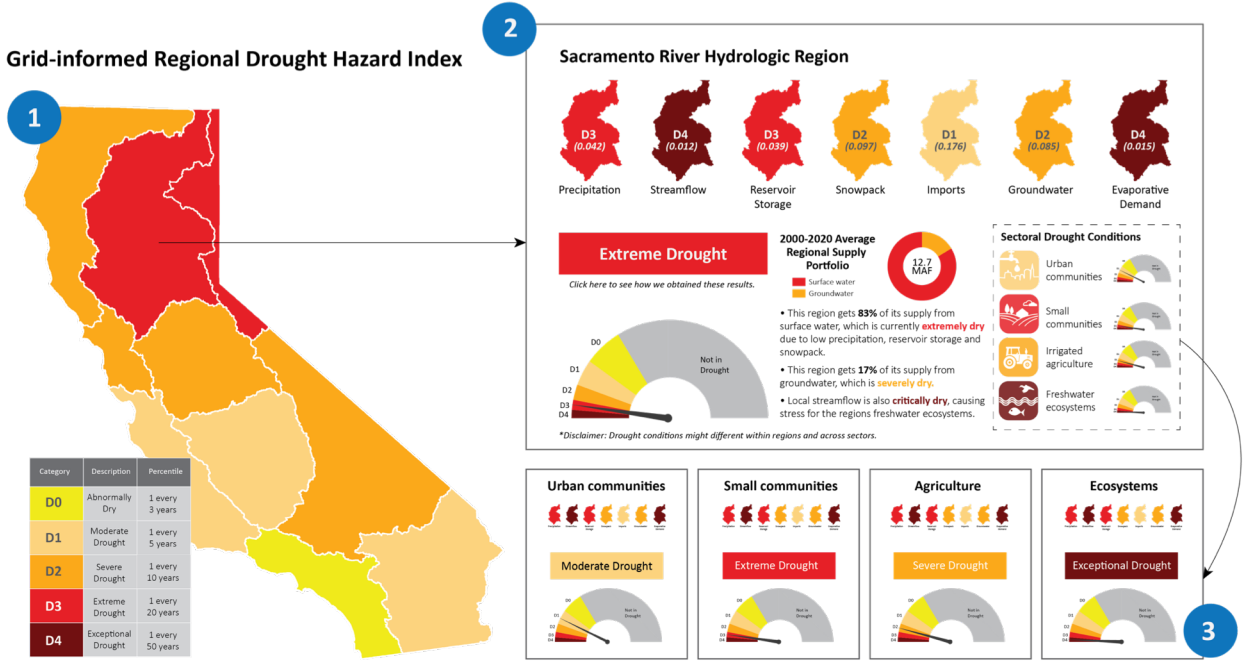
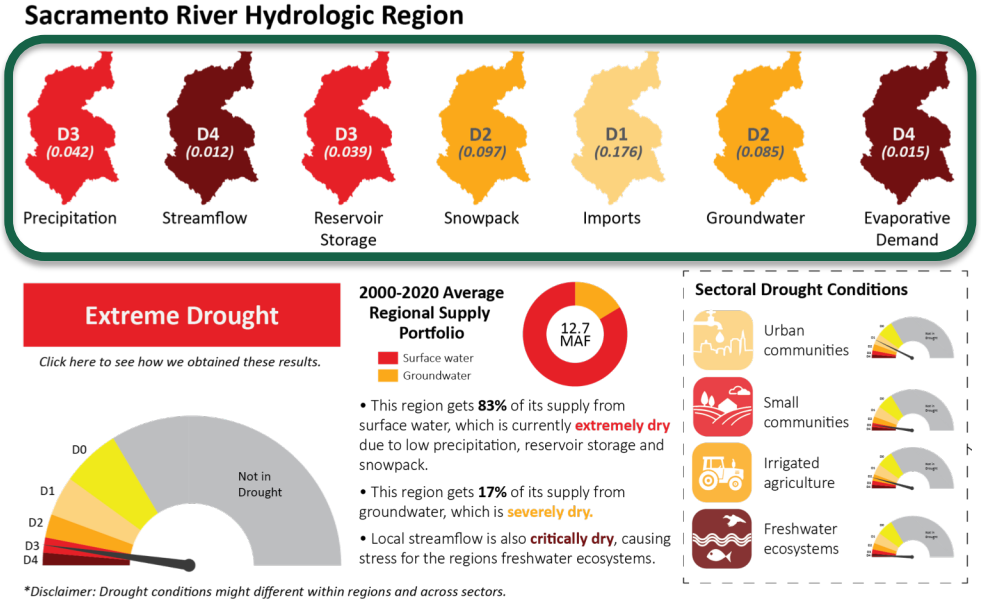
Drought indicators need to respond to this complexity, maintaining simplicity



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

Drought indicators need to respond to this complexity, maintaining simplicity

1. By defining indicators for different sources of water (or users' needs)



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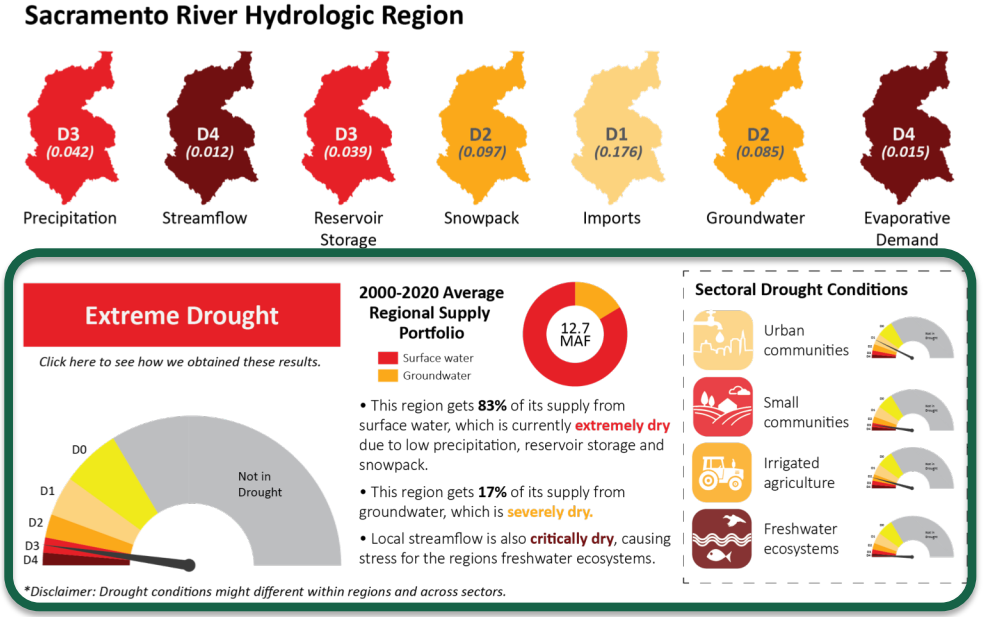
2. By defining indicators for users with complex supply portfolios



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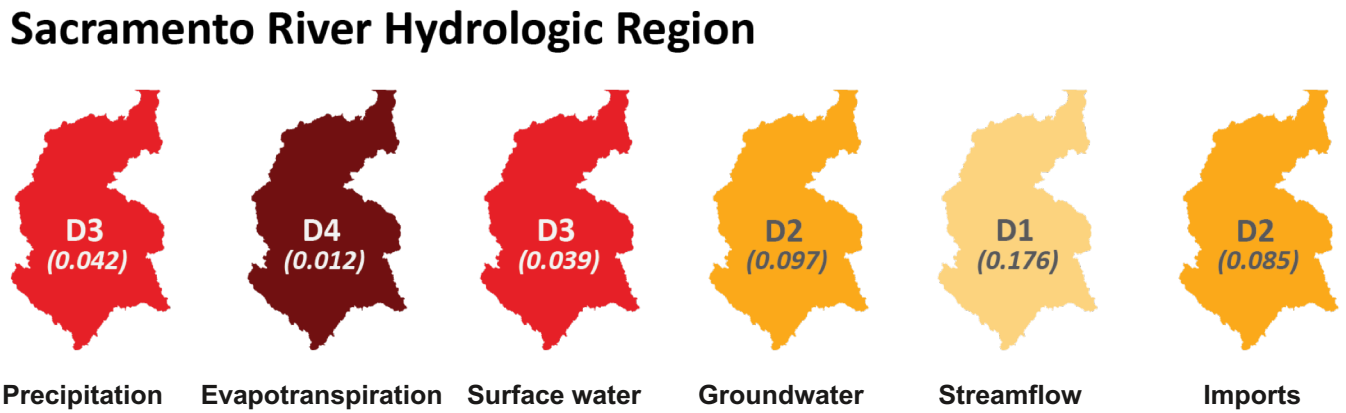
Defining drought indicators for different sources of water (or users' needs)



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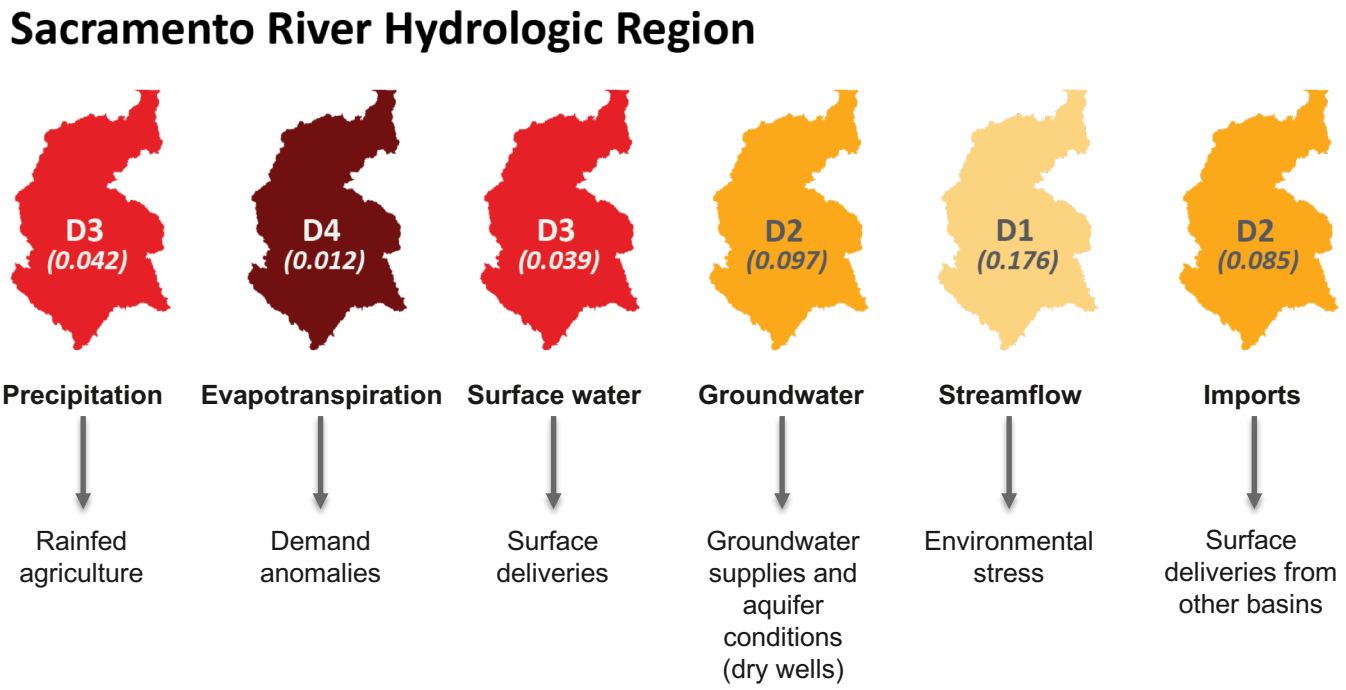

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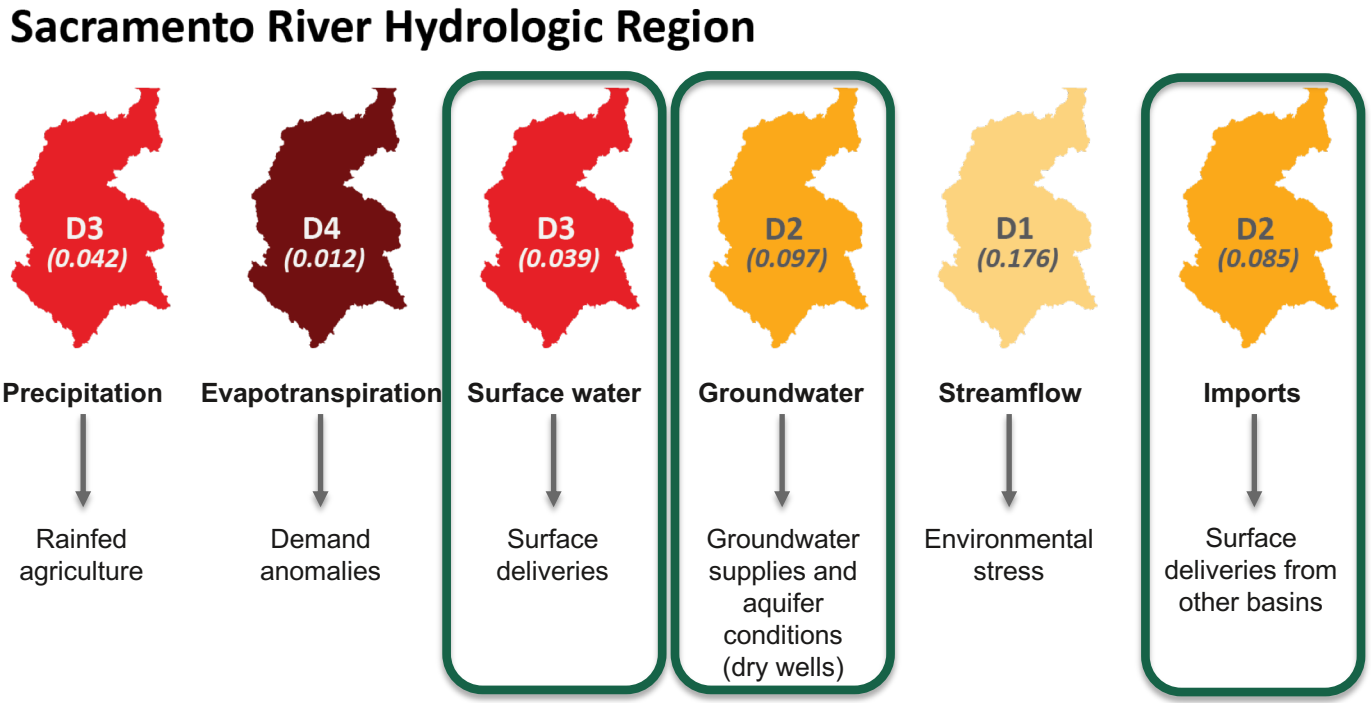
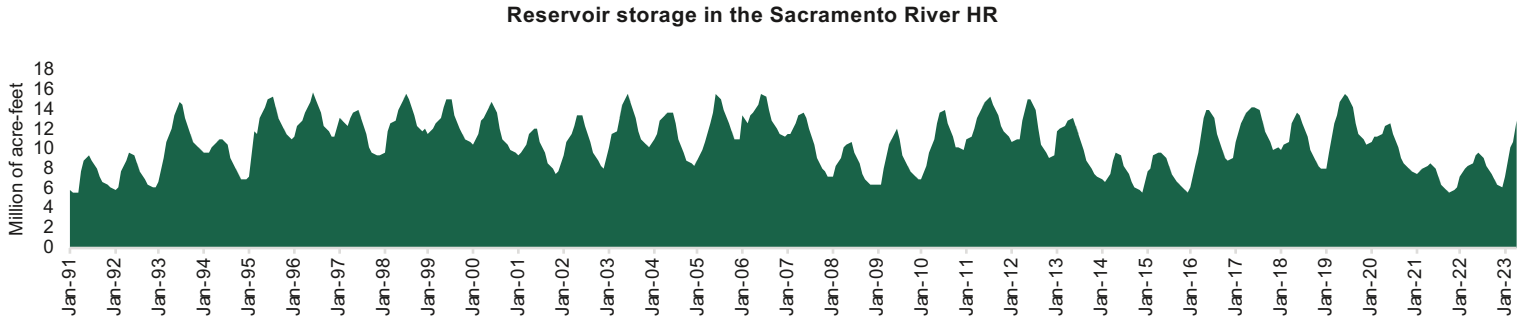


Our indicators are based on percentiles, which measure how often an event happened historically



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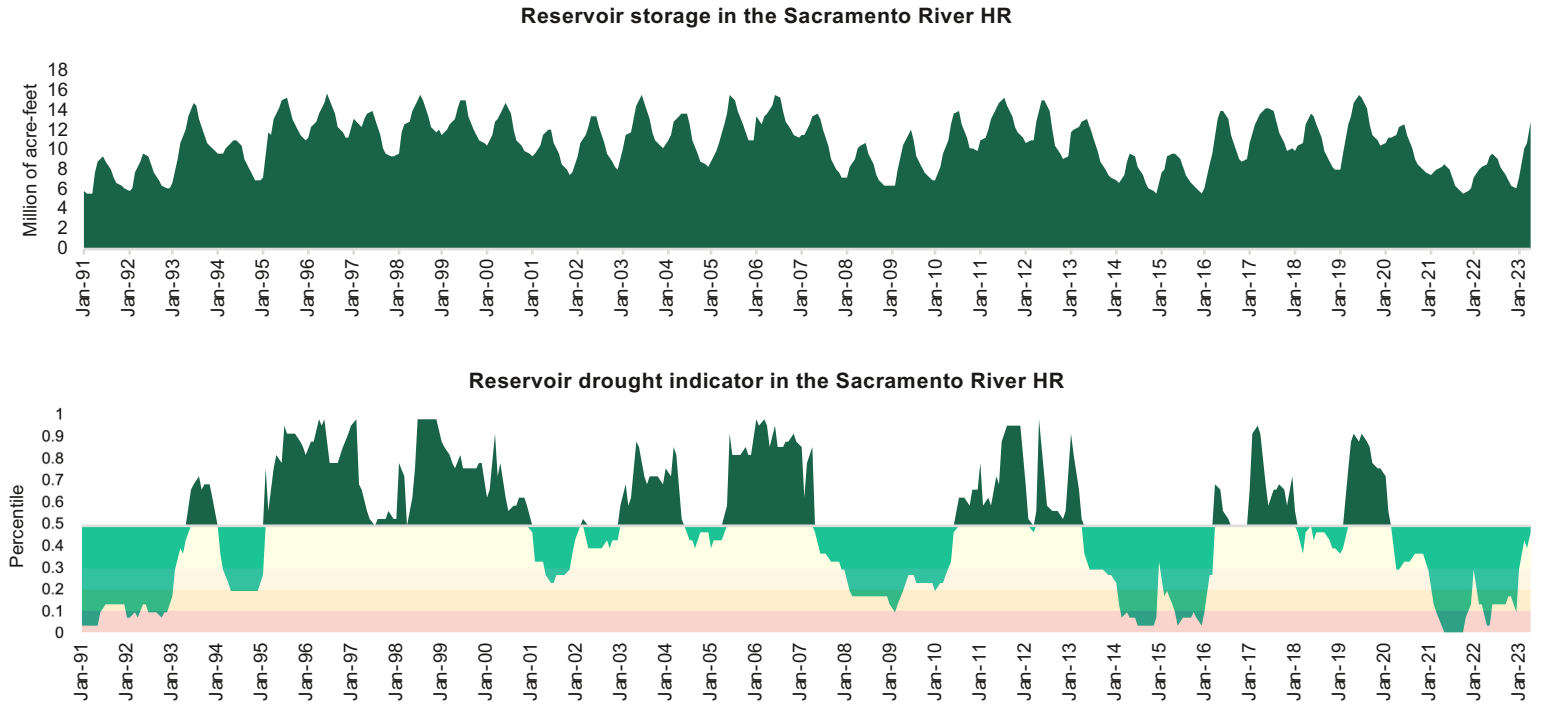

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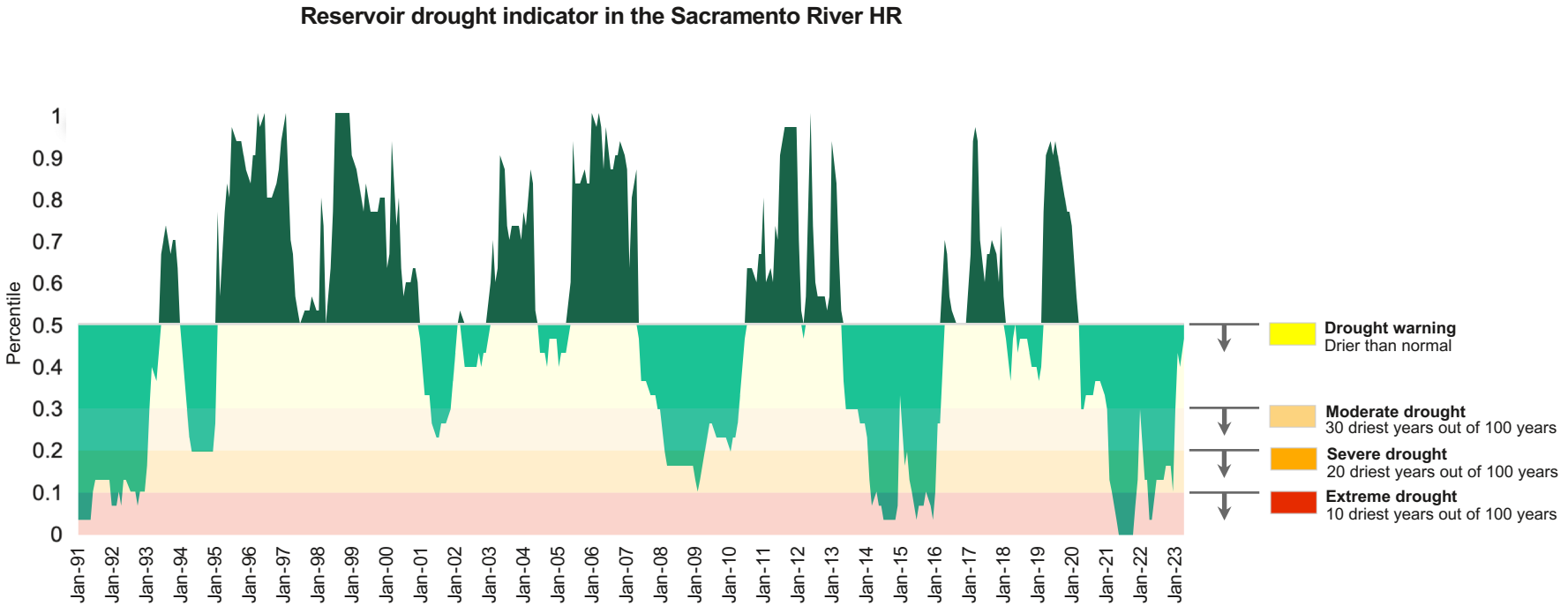

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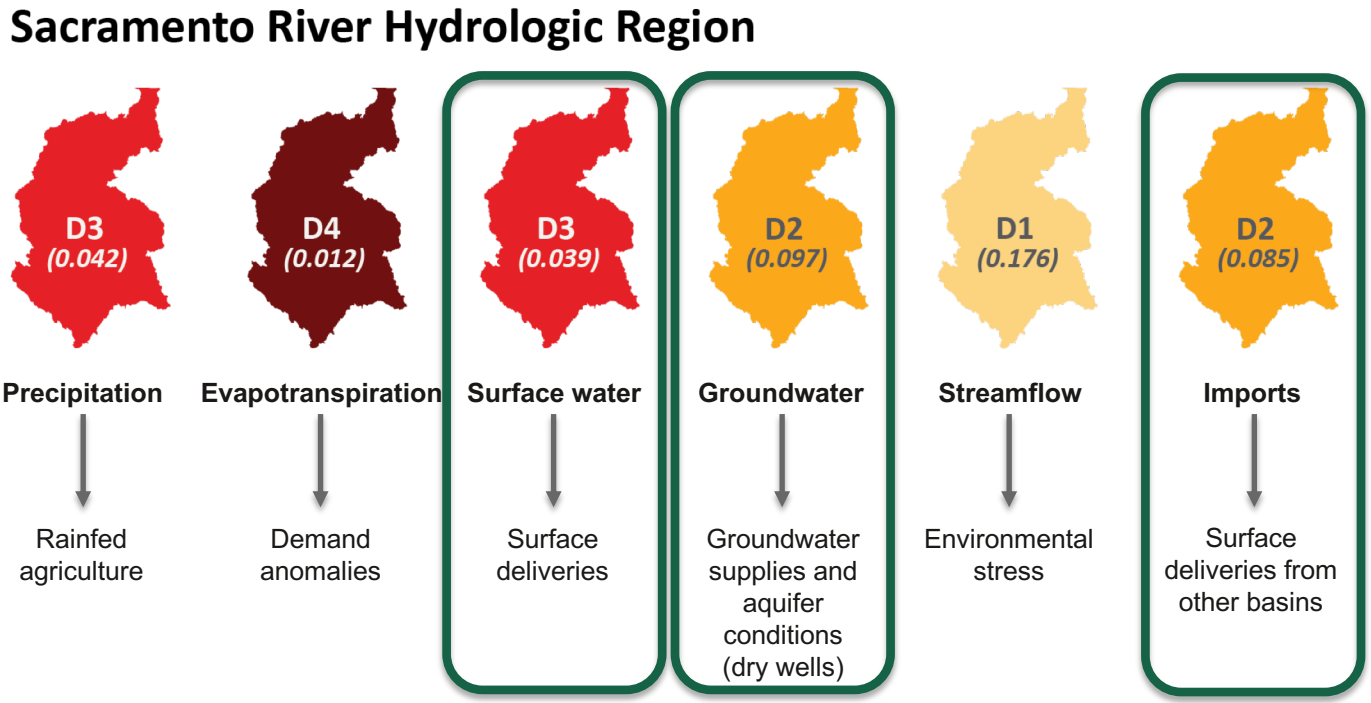
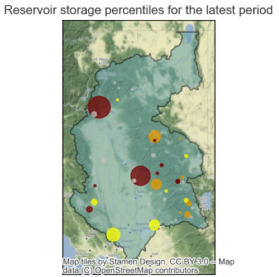
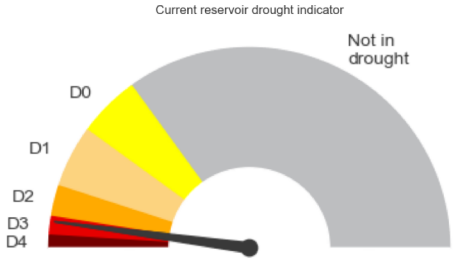
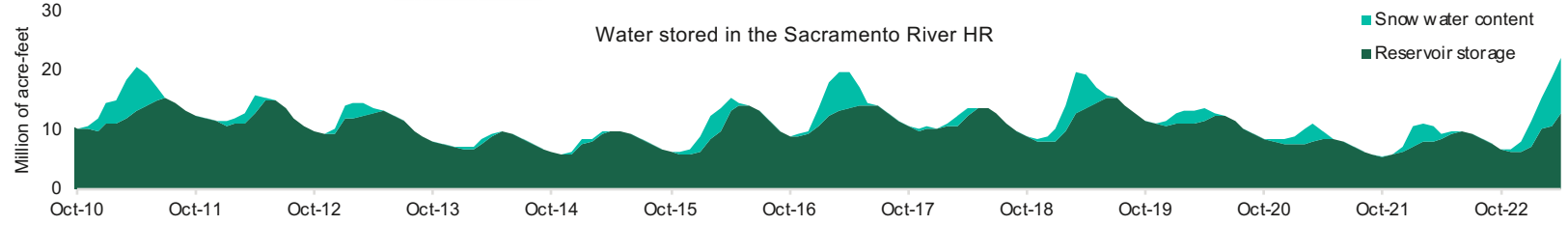
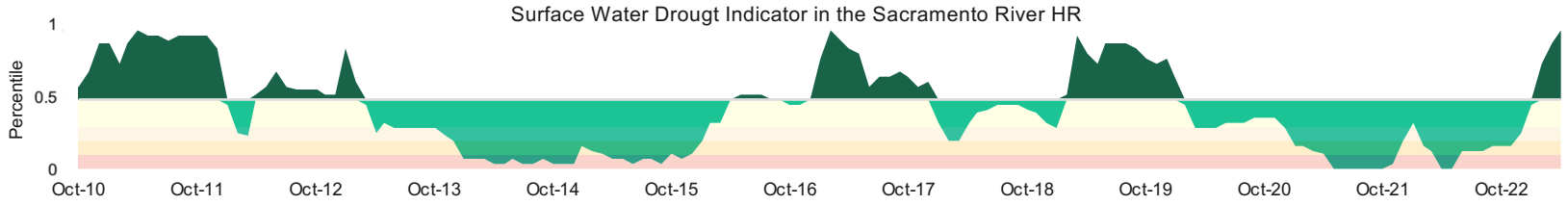


Drought indicator for surface supplies is based on reservoir storage and snowpack

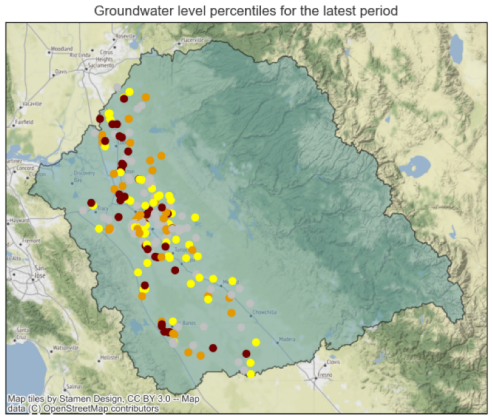


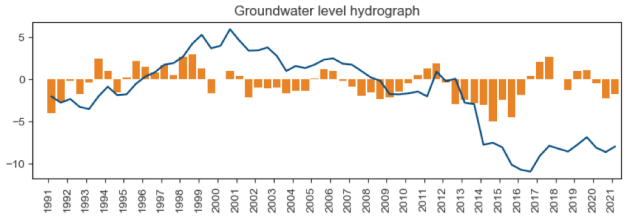


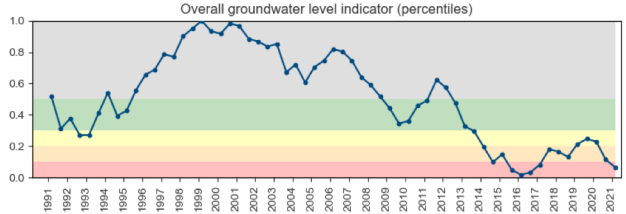


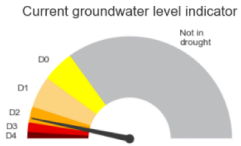


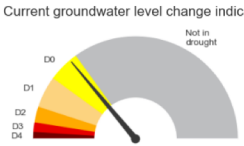
Drought indicator for groundwater is based on groundwater elevation (and its annual change)

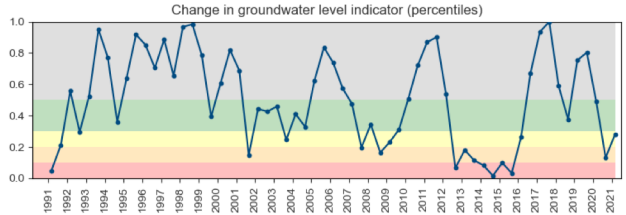








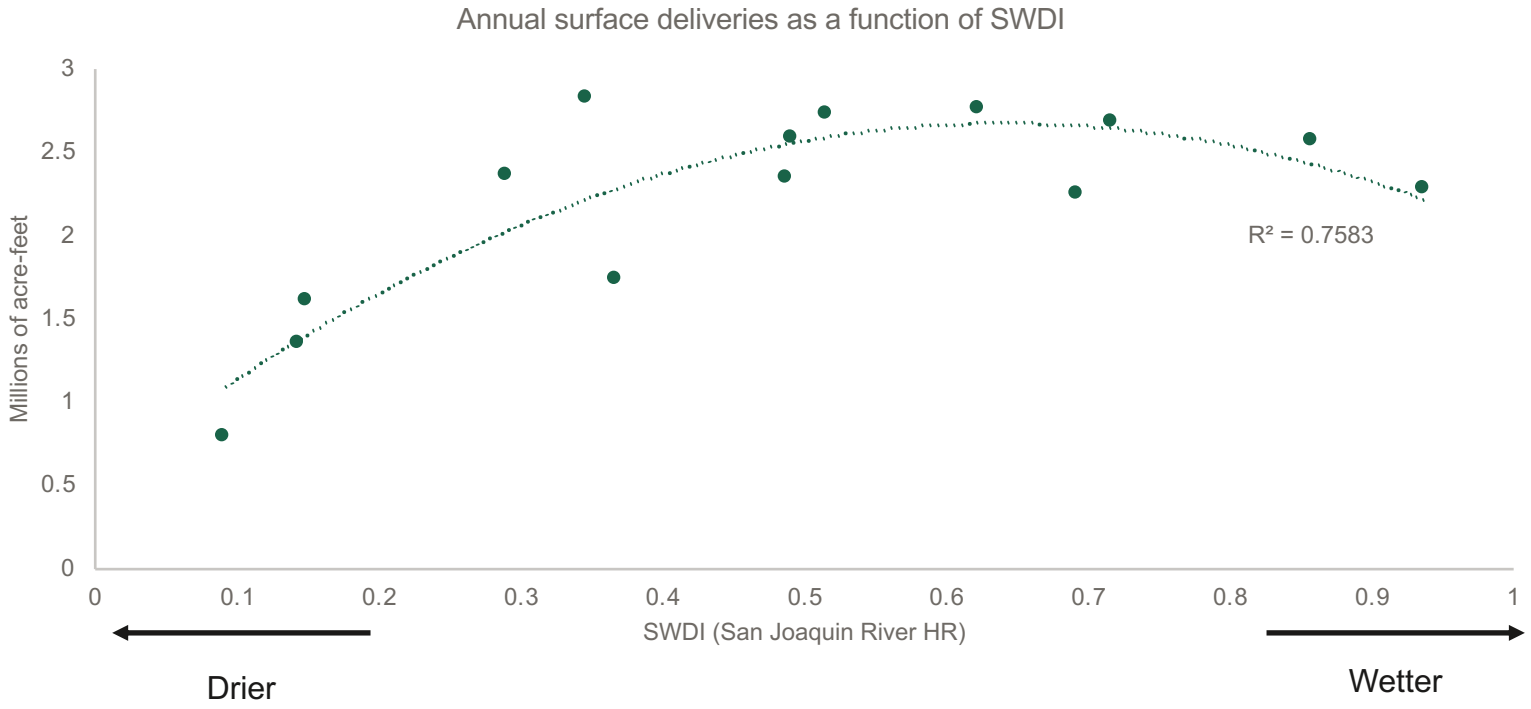




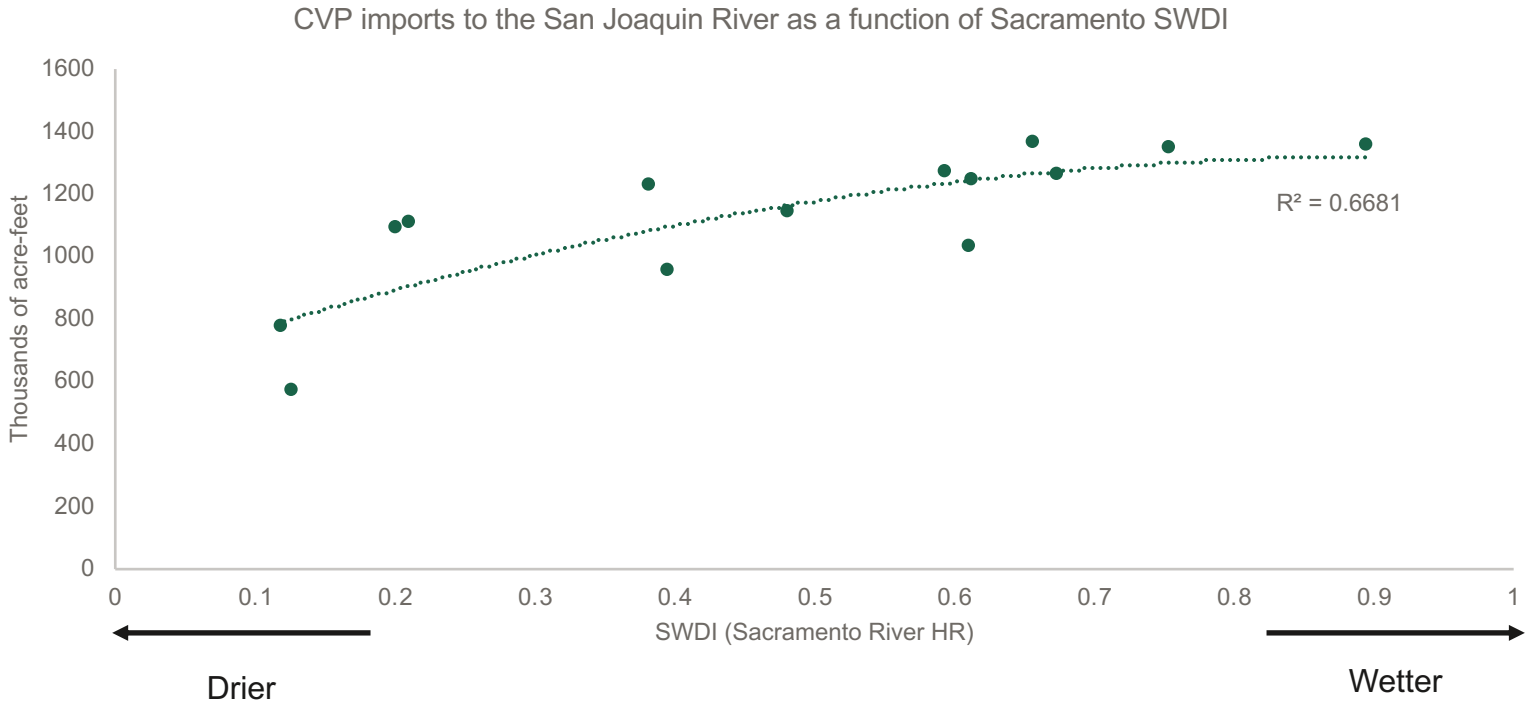
These droughts indicators are meant to respond to users' needs

- Surface water drought indicator
  - Local surface deliveries
  - Imports
- Groundwater indicator
  - Groundwater deliveries
  - Dry wells
- Evapotranspiration
  - Demand anomalies
- …

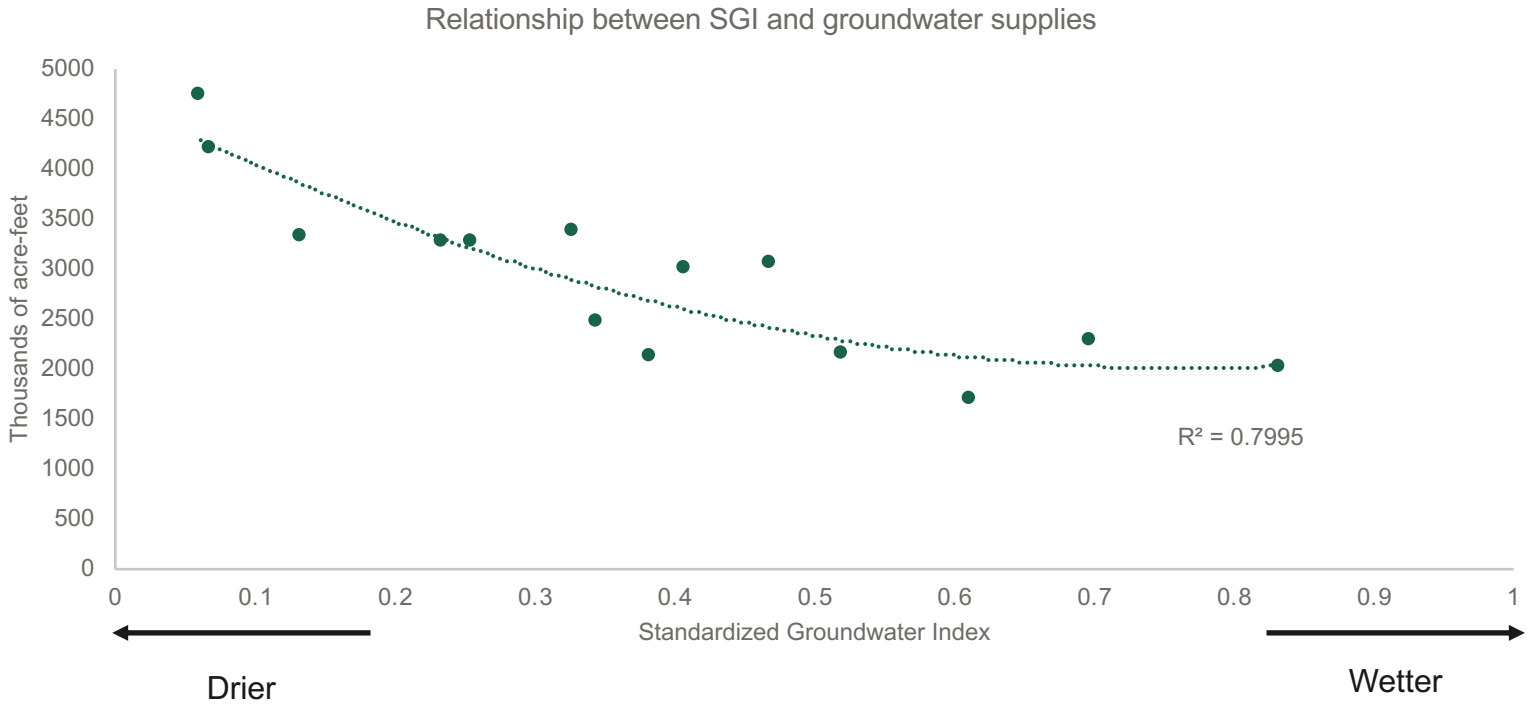
Surface deliveries are highly correlated with the Surface Water Drought Indicator (SWDI)



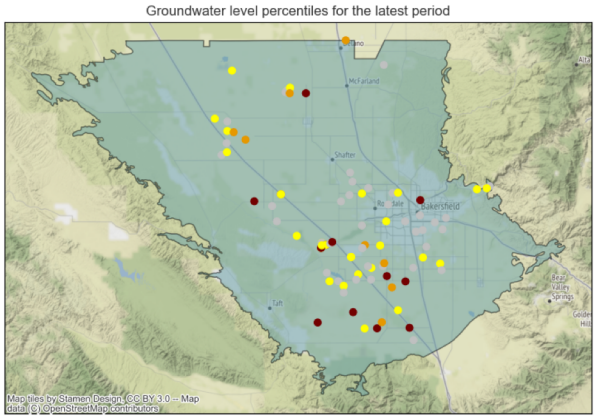
And to obtain imports to other regions, we can also use the SWDI of the exporting basin

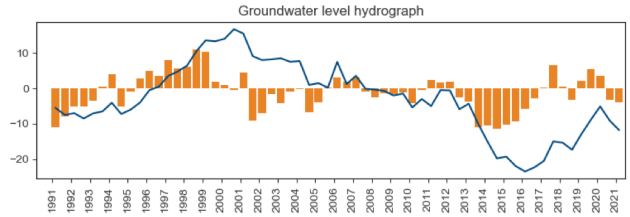


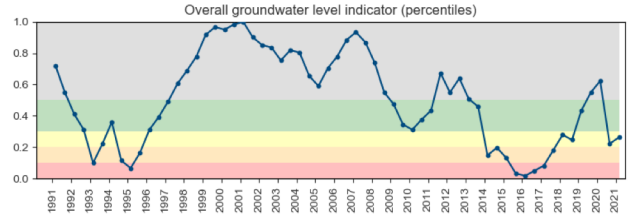
Groundwater supplies are also correlated with the groundwater indicator

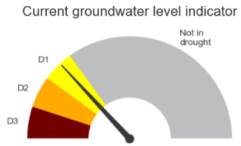


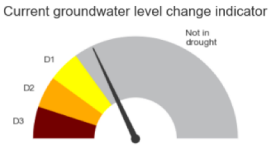
The groundwater drought indicator obtained for each region is also useful for small communities

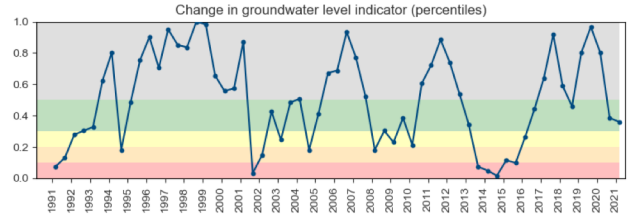












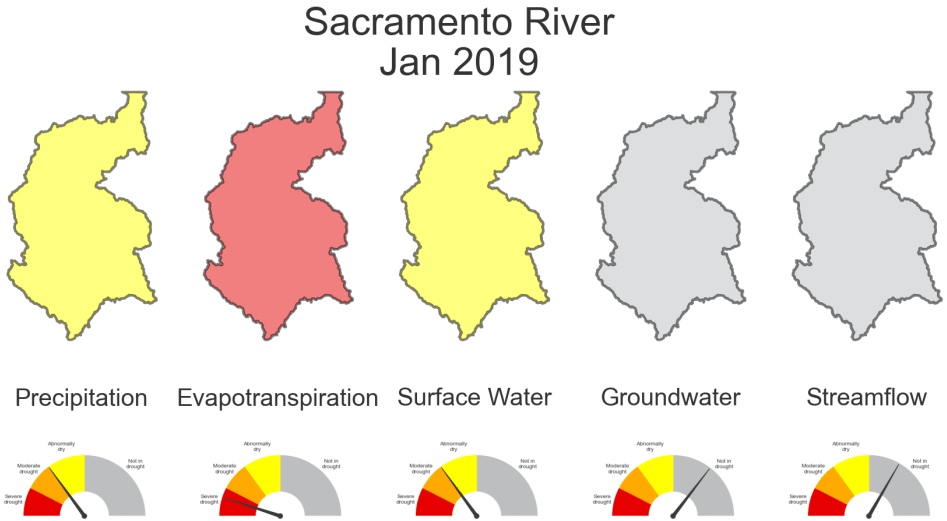
Dry wells obtained from changes in groundwater elevation

Wells impacted in the Central Valley by fall 2021

Wells impacted in the Central Valley by fall 2022 if drought persists

We have completed the drought indicators for different water sources (or users' needs)

Animation of drought hazard indicators from Jan 2019 to Apr 2023



Recap on drought indicators for different water sources (or users' needs)

- We defined a handful of drought indicators that can be helpful for different types of water users in California
- We compiled the data and calculated these indicators for all hydrologic regions
- These indicators are meant to respond to users' needs

Questions so far?

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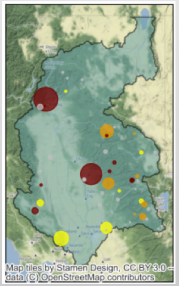
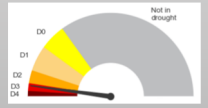
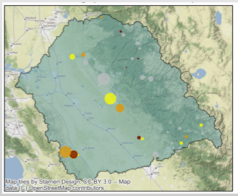
Now, let's focus on drought indicators for users with complex supply portfolios

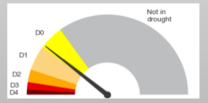
CVP imports
(Sac River Drought)



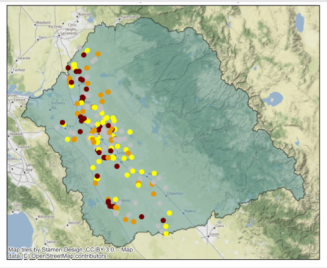


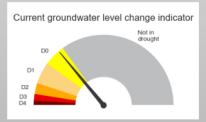
Local surface supplies
(Local Drought)





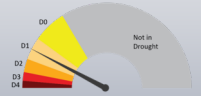
GW Supplies
(GW Drought)





San Joaquin River Hydrologic Region

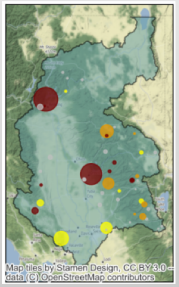
Urban Drought Hazard Indicators

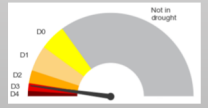


Moderate Drought

Now, let's focus on drought indicators for users with complex supply portfolios

CVP imports
(Sac River Drought)





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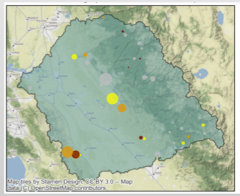
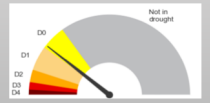
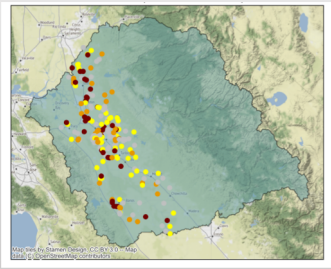
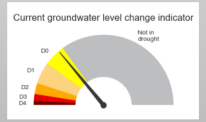
(Local Drought)



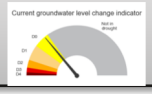


GW Supplies
(GW Drought)



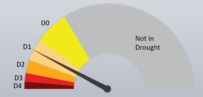


Evapotranspiration
(demand anomalies)



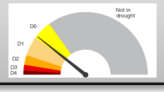
San Joaquin River Hydrologic Region

Urban Drought Hazard Indicators



Moderate Drought

Groundwater
overdraft



Drought can be defined as “insufficient water to meet needs”

$$Shortages = Expected\ demands\ - Expected\ supplies$$

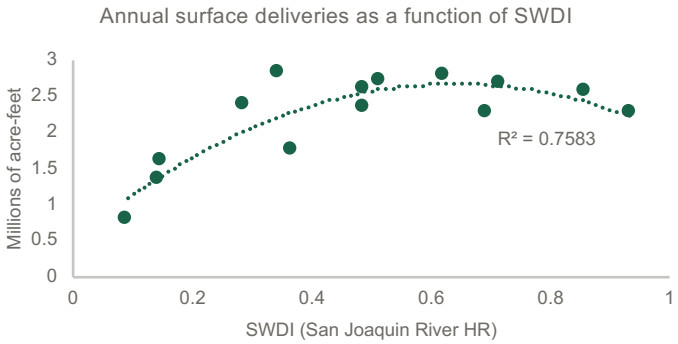
Drought can be defined as “insufficient water to meet needs”

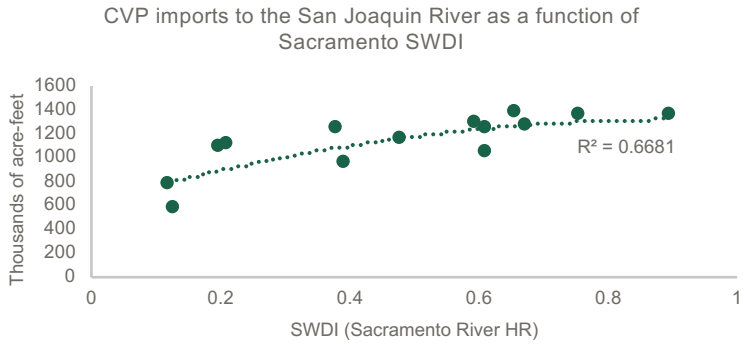
$$\boldsymbol{Shortages = Expected\ demands\ - Expected\ supplies}$$

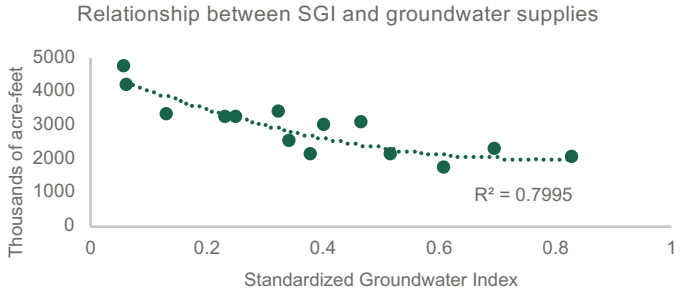
$$Expected\ demands = Average\ demands\ * Anomalies$$

$$Expected\ supplies = Surface\ supplies + Imports + GW\ supplies^{*} + \ \ldots$$

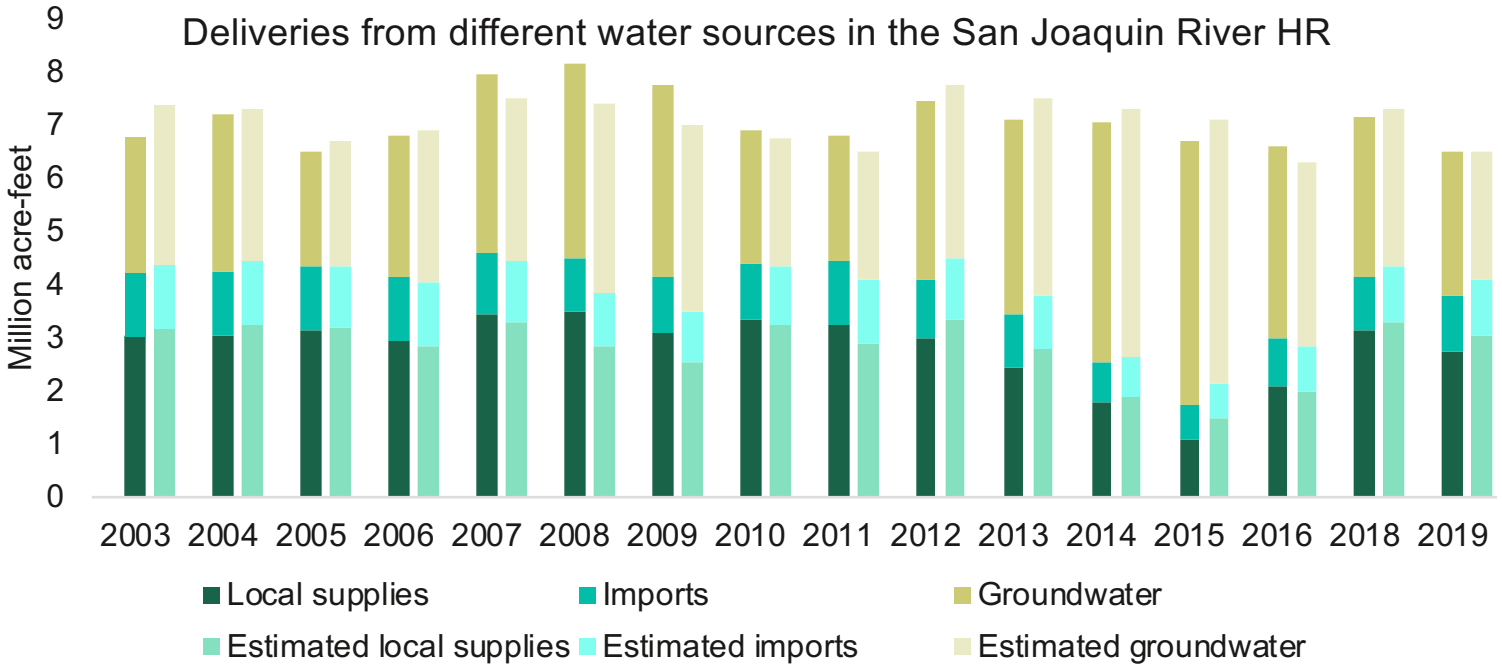
Using the previous relationships between drought indicators and deliveries…



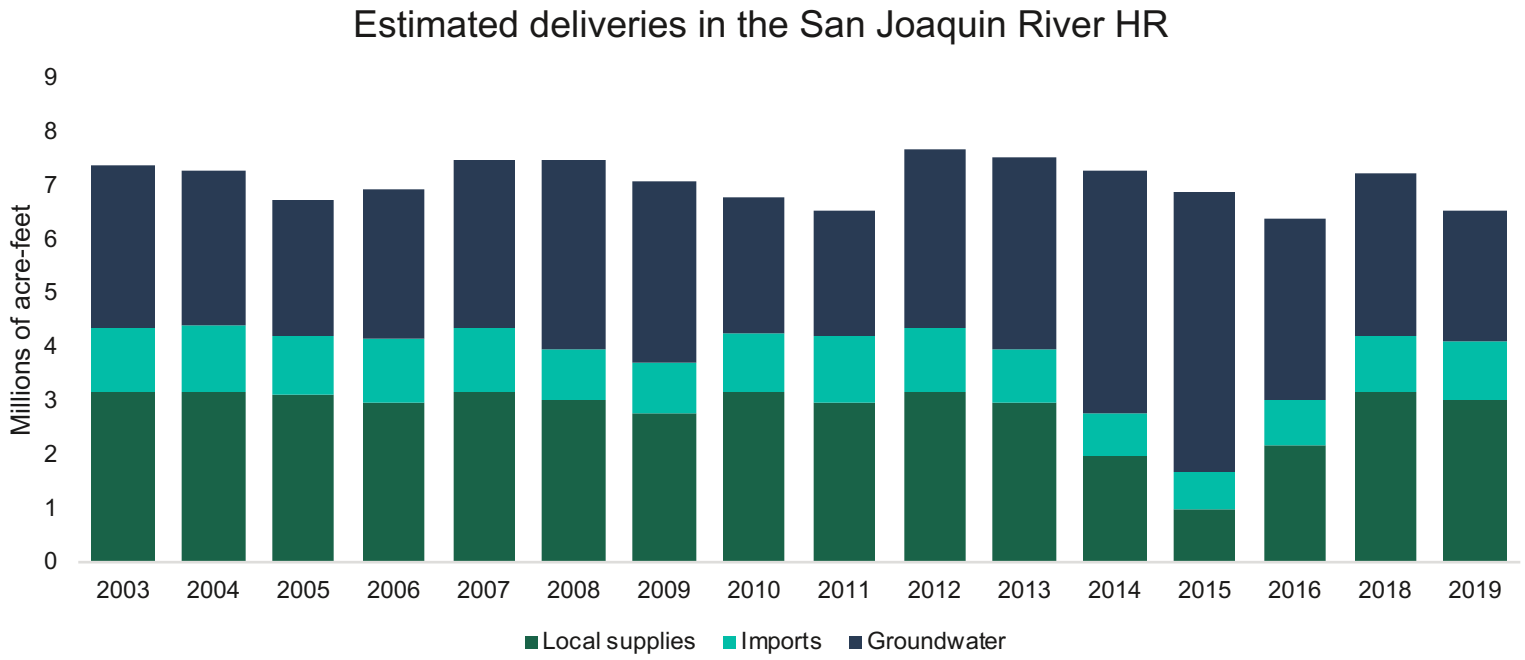




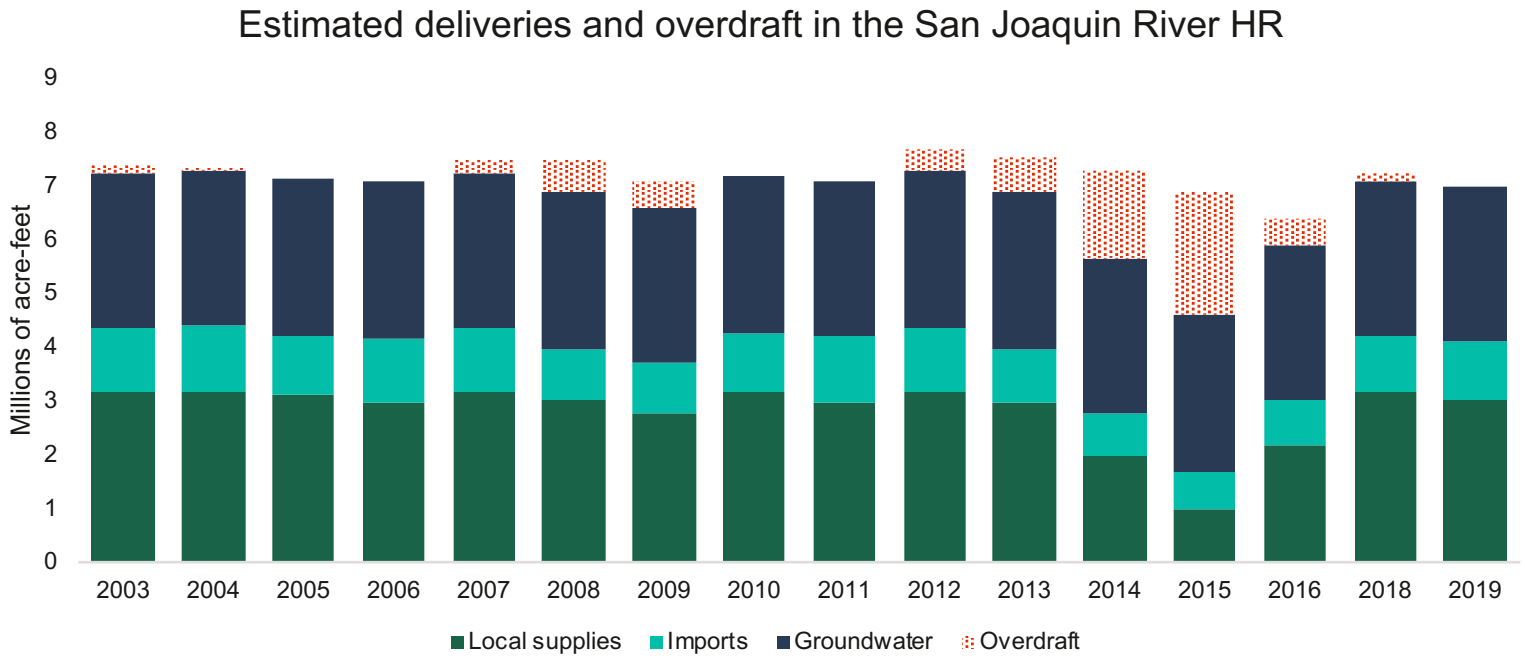
We can estimate total supplies, using actual data from DWR water balances



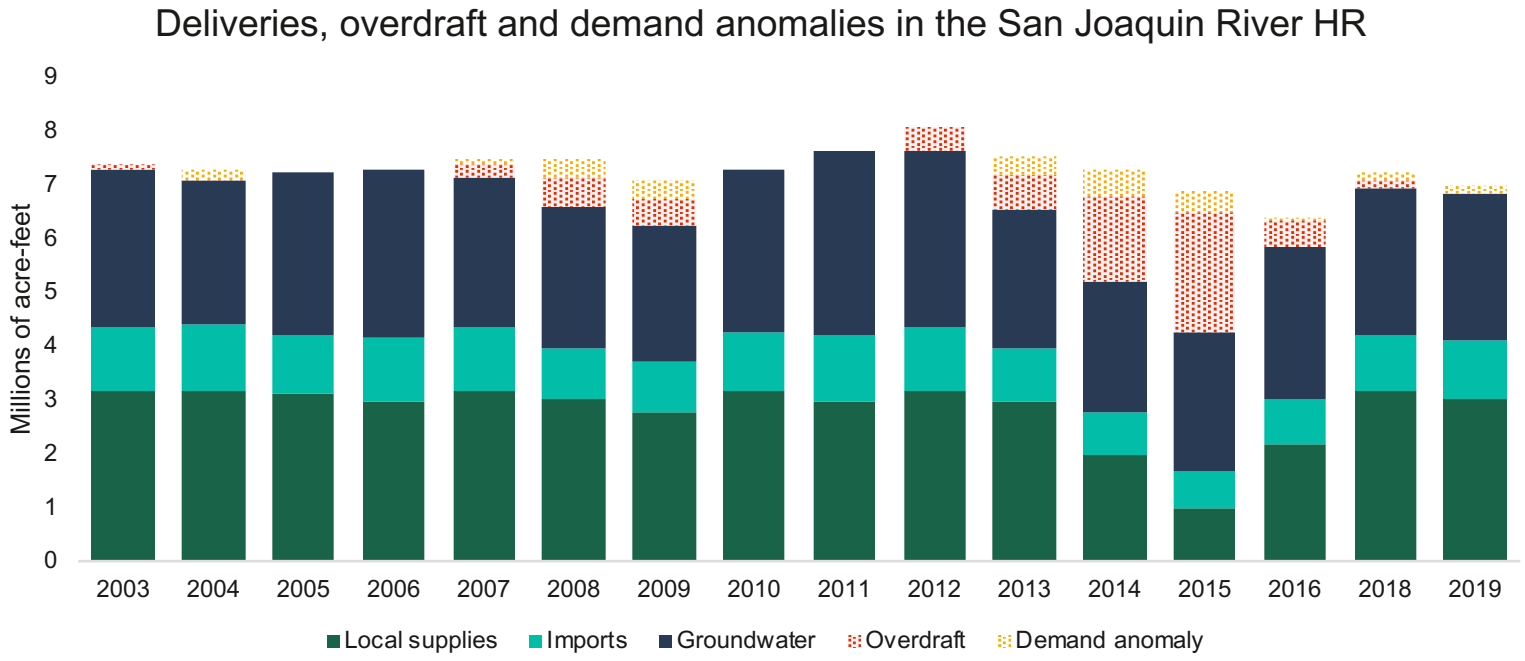
So using source-specific drought indicators we estimate deliveries



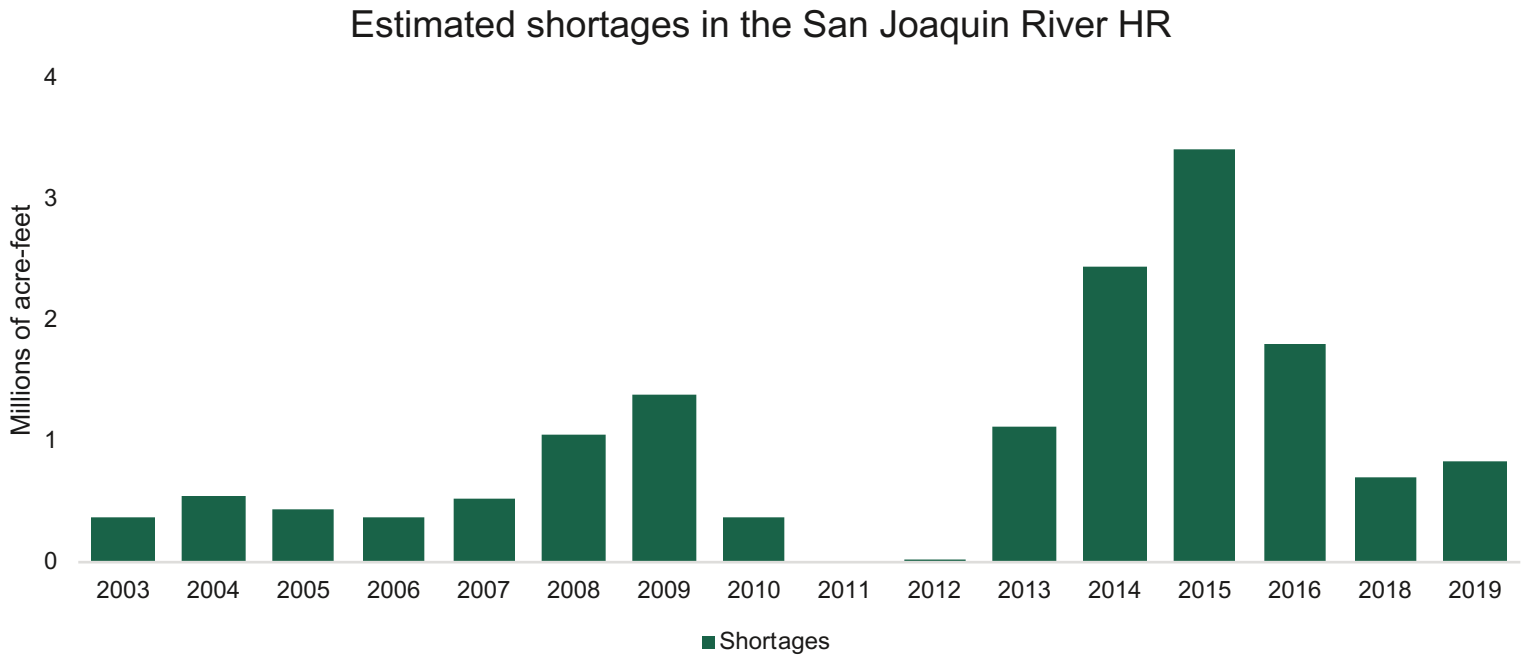
We correct to account for overdraft



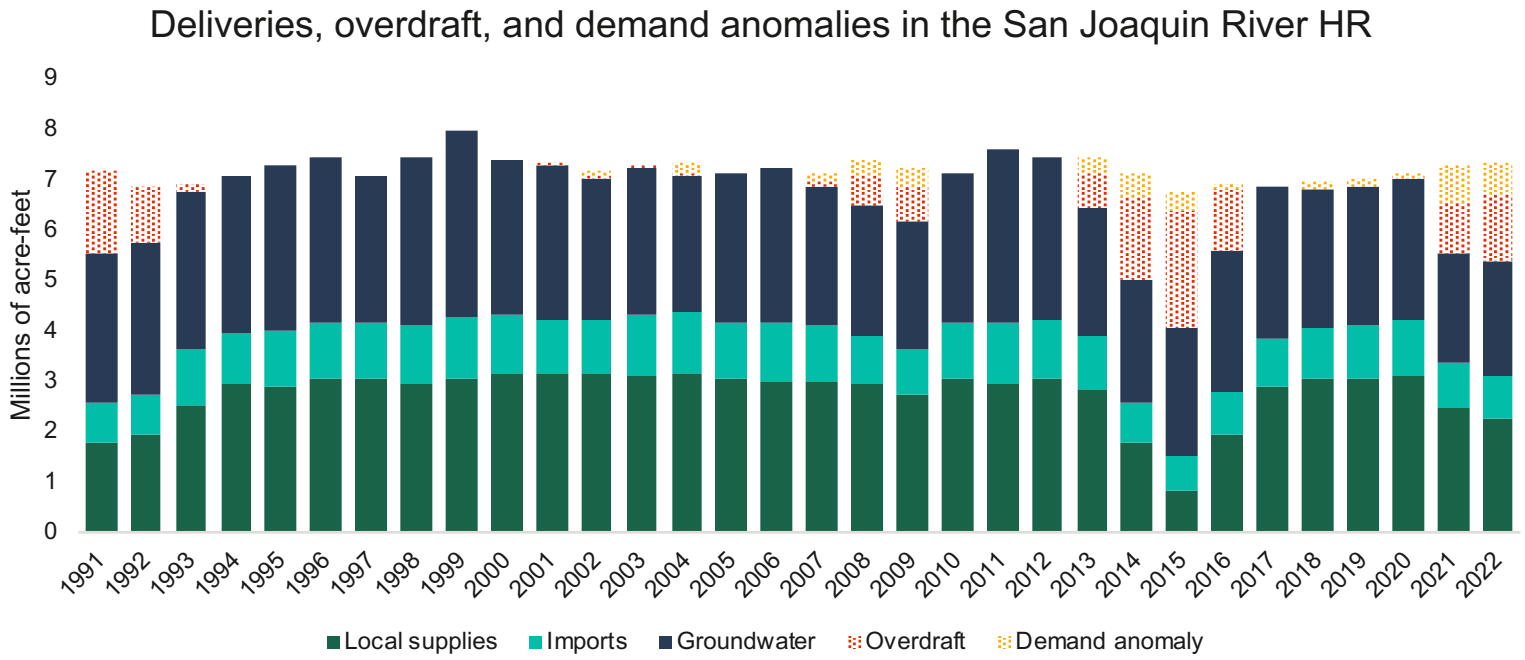
And also to take into consideration changes on crop demands given higher evaporative needs



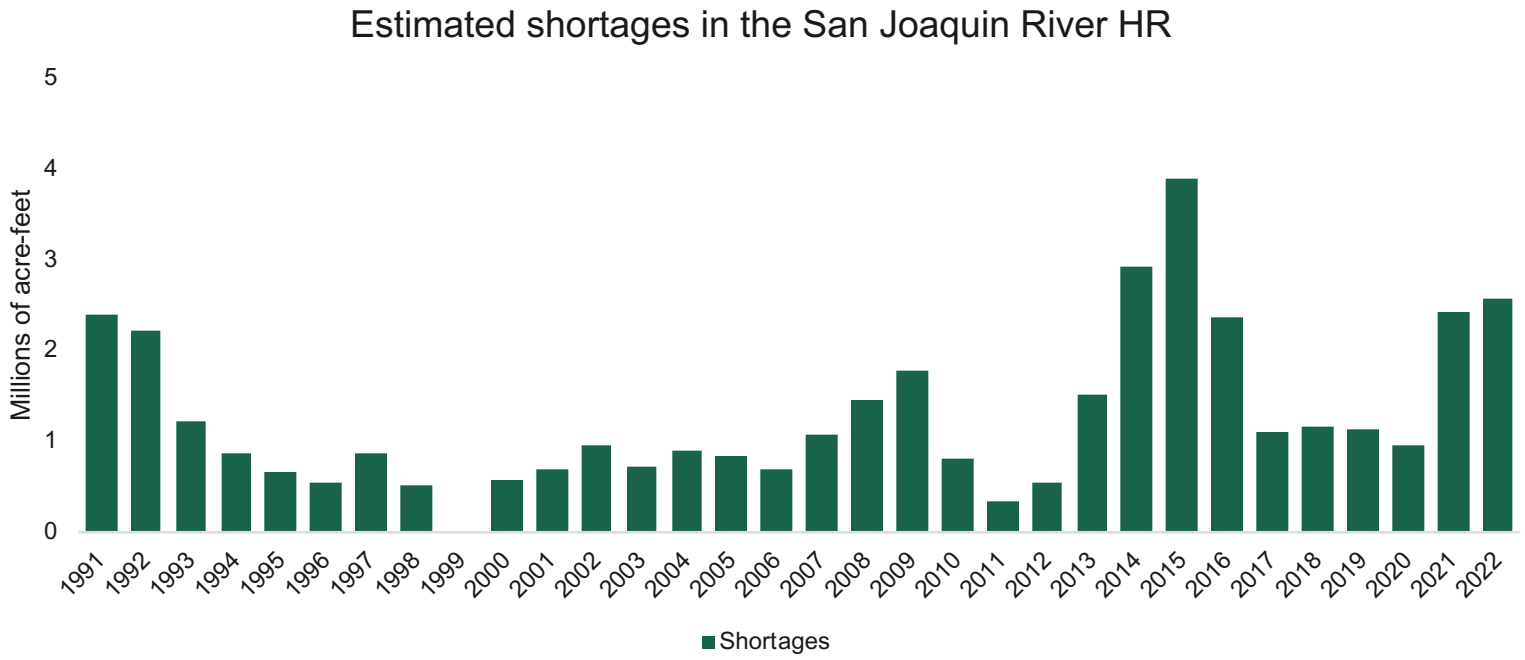
Shortages are obtained as a difference from maximum deliveries



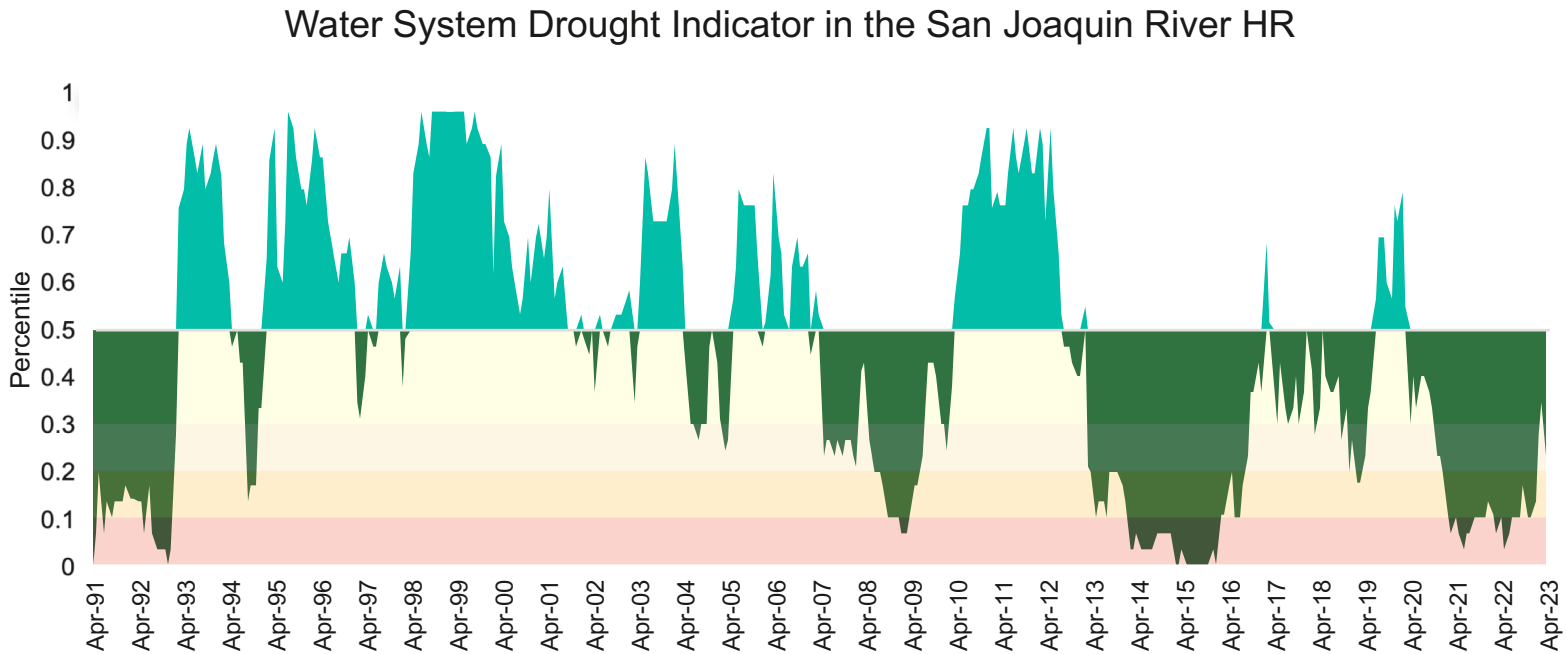
Once calibrated, and given that we have data on drought indicators, we can extrapolate results…



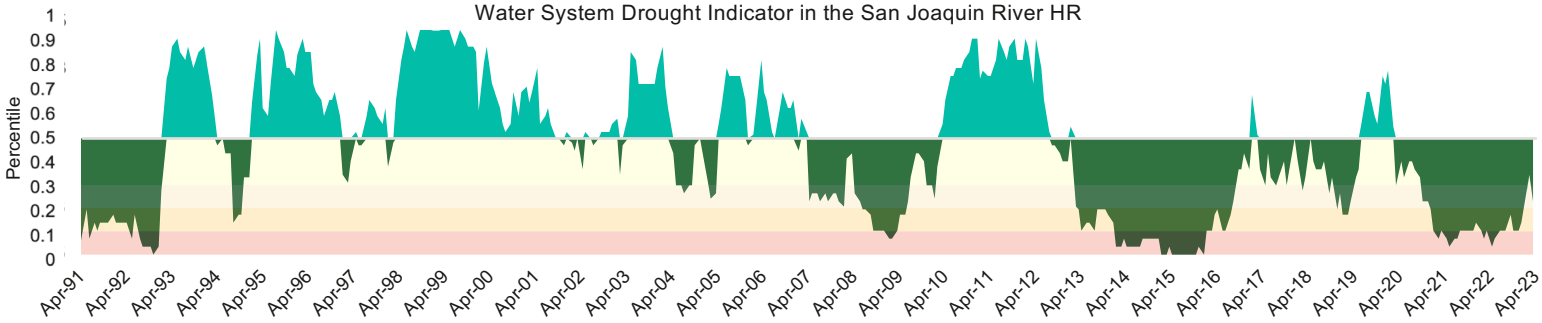
Obtaining also historical shortages to then…

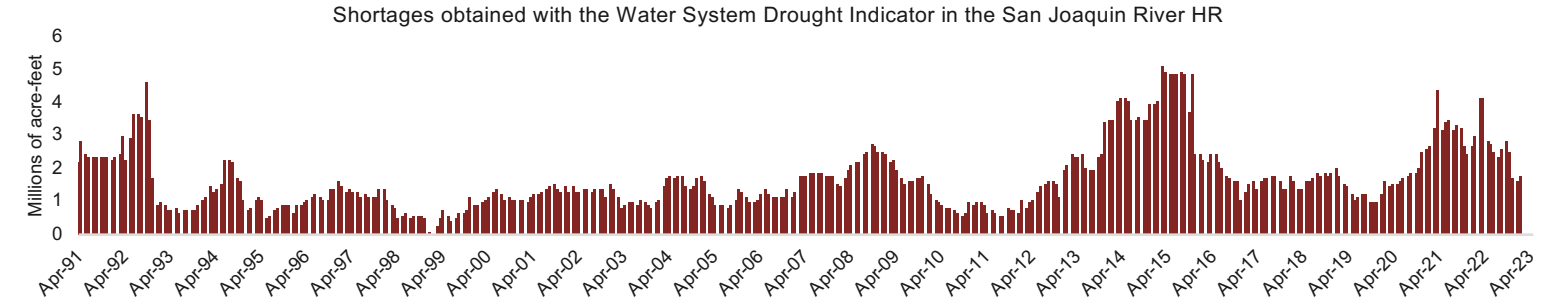


… obtain the system drought indicator for any time in the historical record

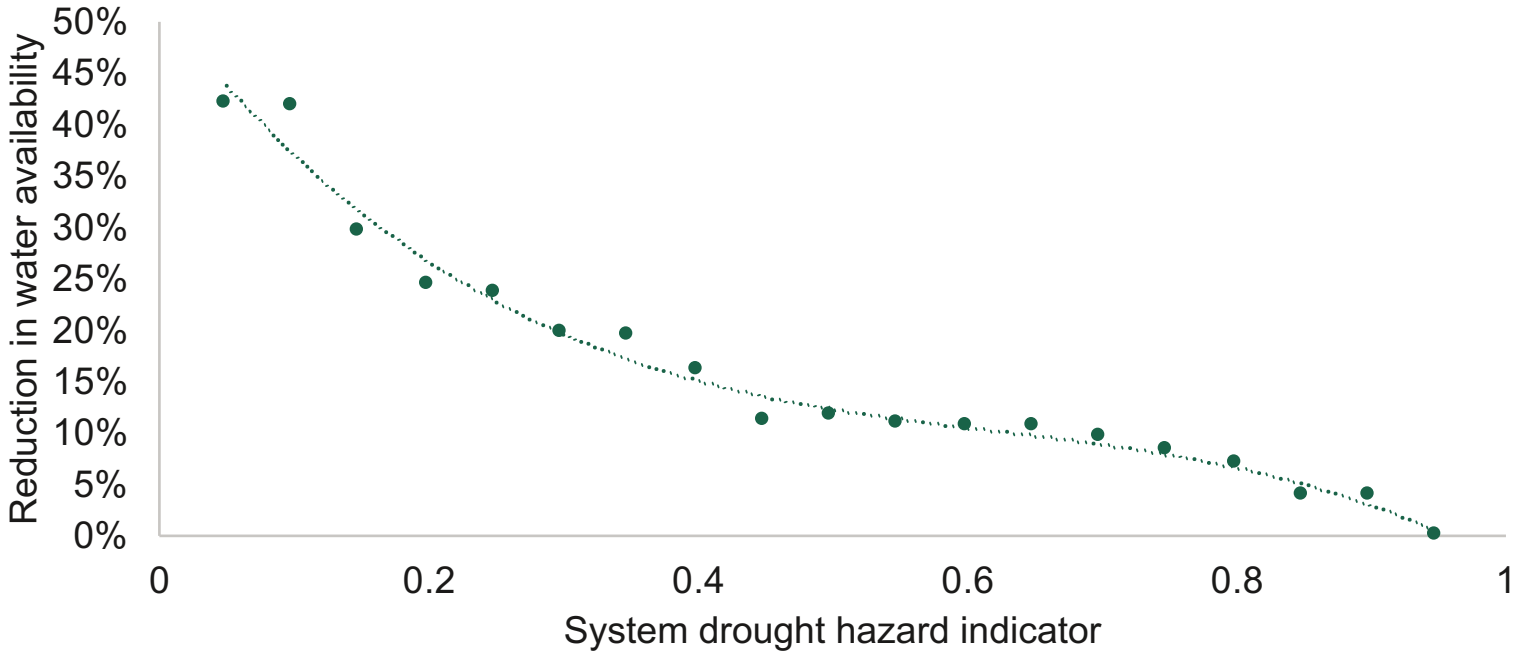


The system drought indicator is related directly with water shortages…





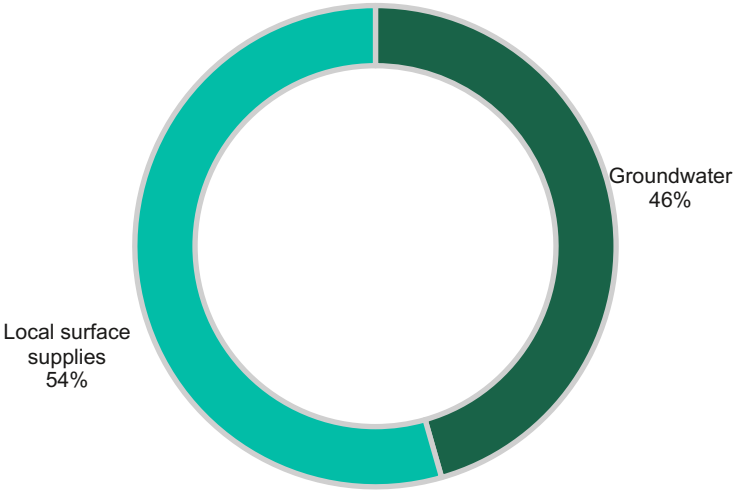
And can be translated to reduced water availability



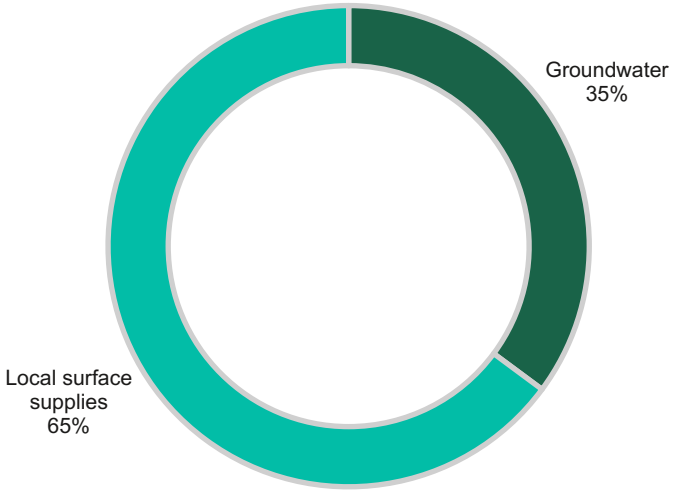
Many cities and irrigation districts in California have complex portfolios, so this framework is helpful

We assessed the system drought indicator for different sectors in the Sacramento River

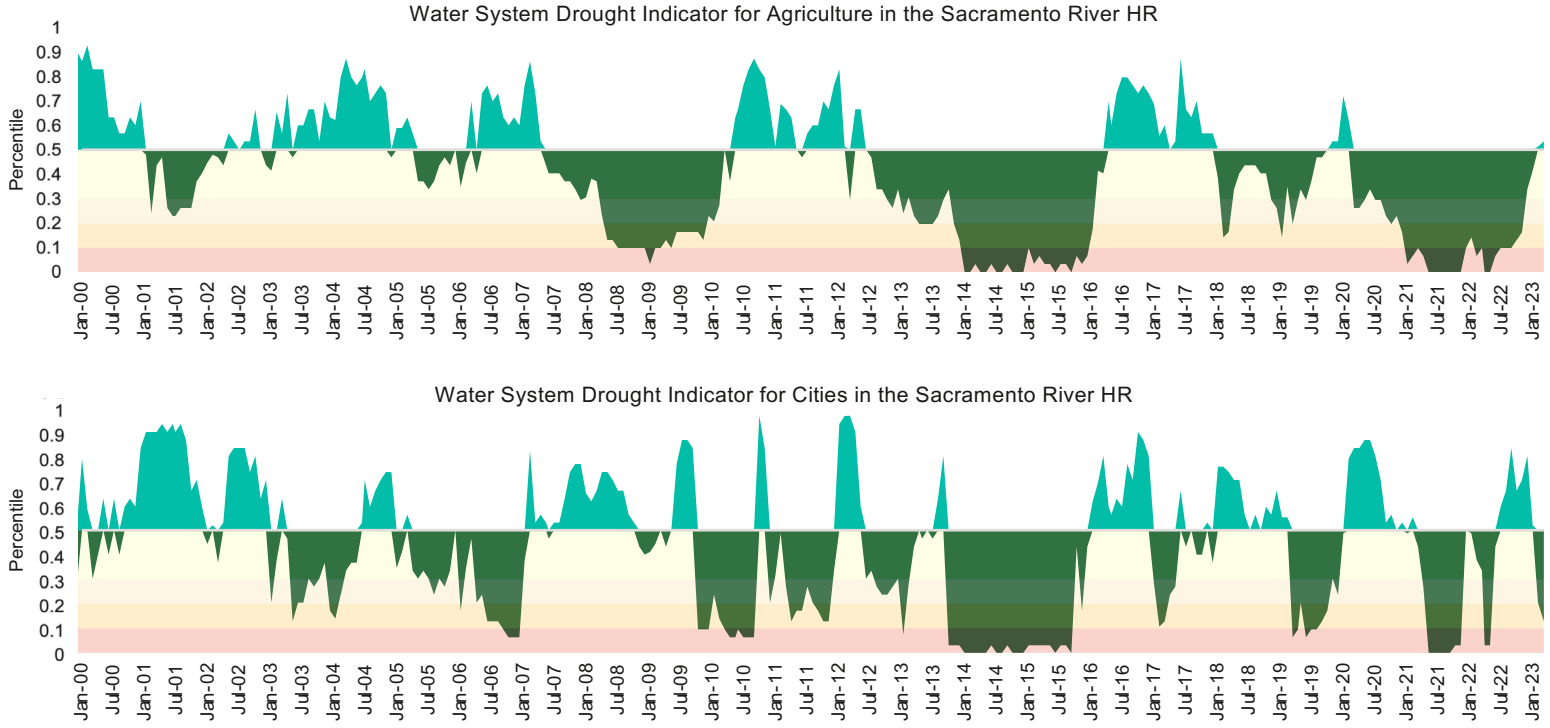
Urban supply portfolio



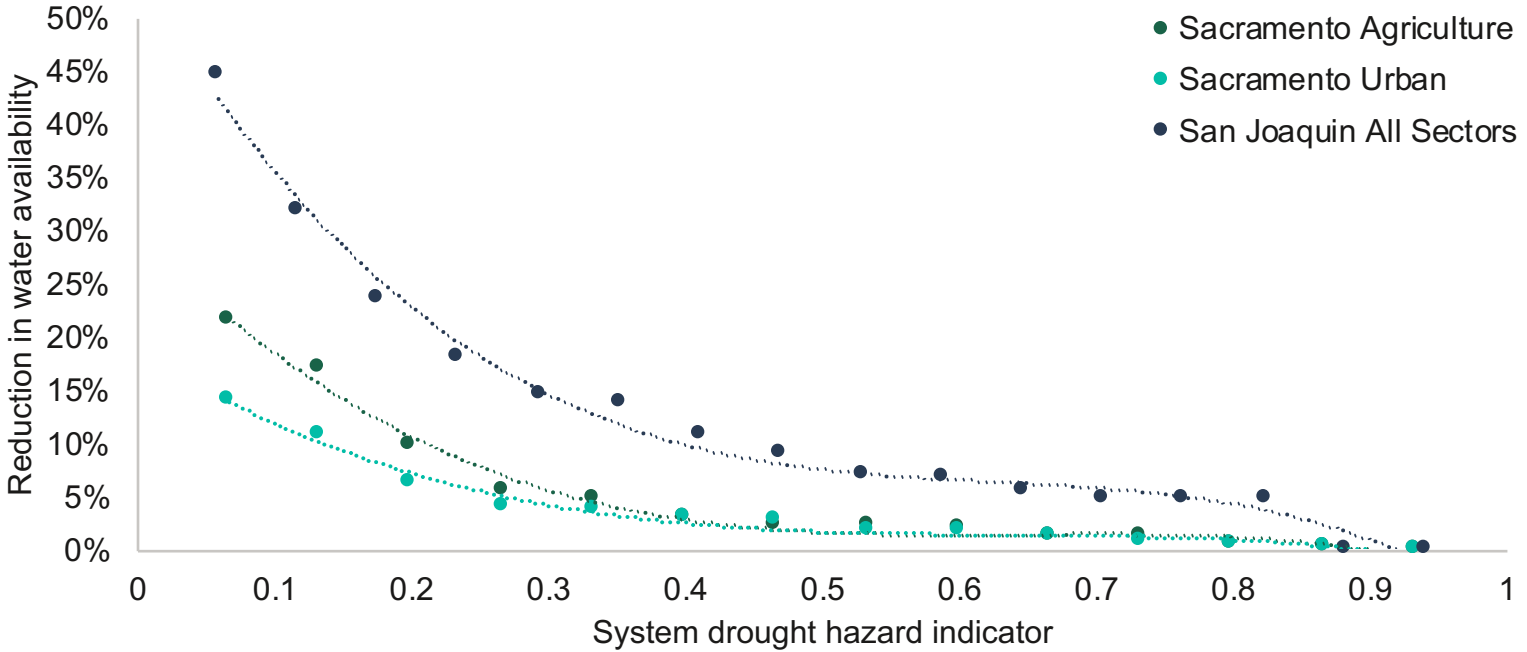
Agricultural supply portfolio



Sectors with different portfolios have different drought indicators



The relationship between the drought hazard indicator and the reduction in availability is key



Recap on drought indicators for complex portfolios

- We have developed a methodology to estimate drought conditions for users with complex portfolios
- The system drought indicator is related directly with shortages (or reduced water availability)
- We have shown that different sectors with different portfolios have different drought conditions

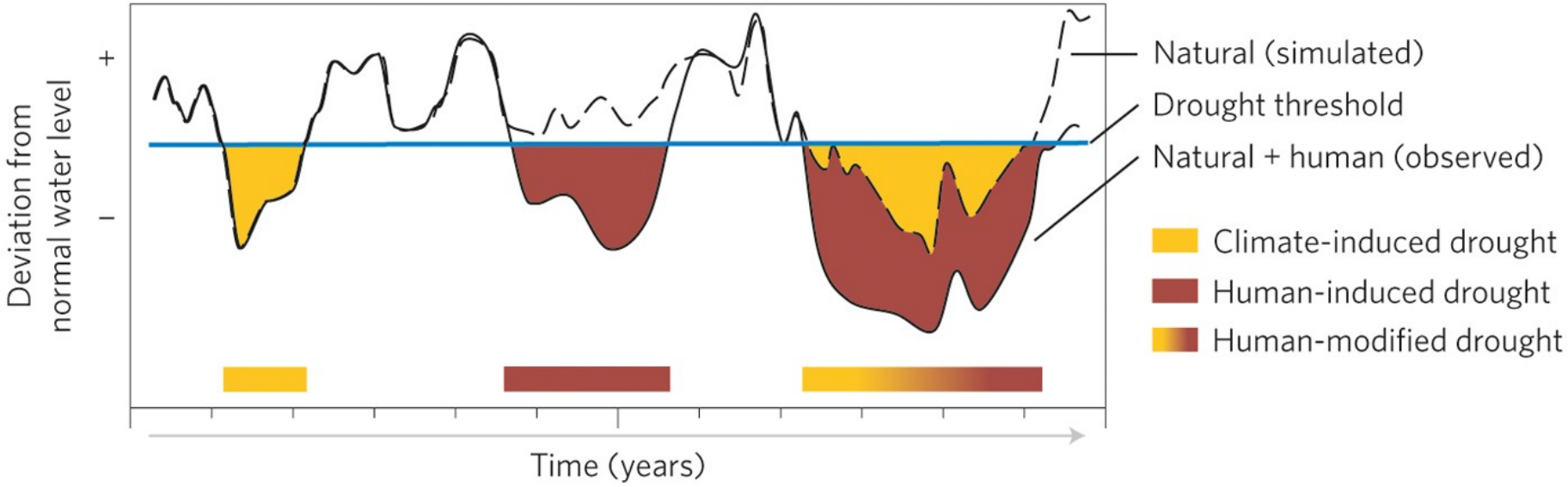
Questions so far?

Workshop Agenda

- Welcome and workshop objectives 2:00 p.m.
- Review of project goals and achievements 2:05 p.m.
- Defining drought for California water users 2:15 p.m.
  - Defining indicators for different water sources (or users' needs)
  - Defining indicators for users with complex portfolios
  - Environmental drought indicators

Ecosystem responses to drought

Ecological drought intensified by human activities



Source: Van Loon et al. 2016 *Nature Geoscience*

NIDIS drought categories

D0 - Abnormally Dry

- Soil is dry; irrigation delivery begins early
- Dryland crop germination is stunted
- Active fire season begins

100.0% of CA (D0–D4)

D1 - Moderate Drought

- Dryland pasture growth is stunted; producers give supplemental feed to cattle
- Landscaping and gardens need irrigation earlier; wildlife patterns begin to change
- Stock ponds and creeks are lower than usual

100.0% of CA (D1–D4)

D2 - Severe Drought

- Grazing land is inadequate
- Fire season is longer, with high burn intensity, dry fuels, and large fire spatial extent
- Trees are stressed; plants increase reproductive mechanisms; wildlife diseases increase

92.4% of CA (D2–D4)

D3 - Extreme Drought

- Livestock need expensive supplemental feed; cattle and horses are sold; little pasture remains; fruit trees bud early; producers begin irrigating in the winter
- Fire season lasts year-round; fires occur in typically wet parts of state; burn bans are implemented
- Water is inadequate for agriculture, wildlife, and urban needs; reservoirs are extremely low; hydropower is restricted

80.3% of CA (D3–D4)

D4 - Exceptional Drought

- Fields are left fallow; orchards are removed; vegetable yields are low; honey harvest is small
- Fire season is very costly; number of fires and area burned are extensive
- Fish rescue and relocation begins; pine beetle infestation occurs; forest mortality is high; wetlands dry up; survival of native plants and animals is low; fewer wildflowers bloom; wildlife death is widespread; algae blooms appear

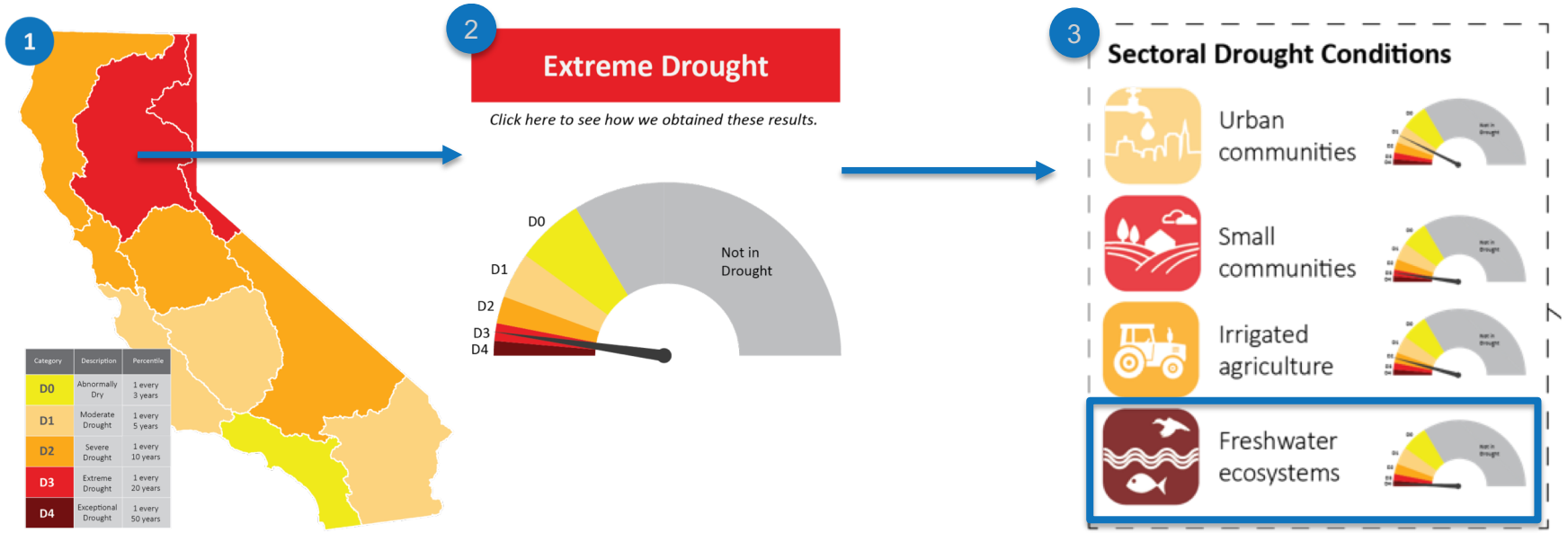
28.3% of CA (D4)

Source(s): NDMC, NOAA, USDA

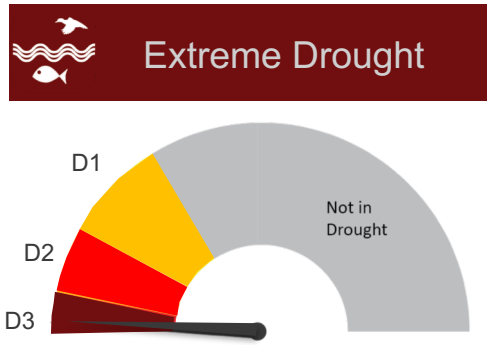
Extensions on NIDIS drought monitor

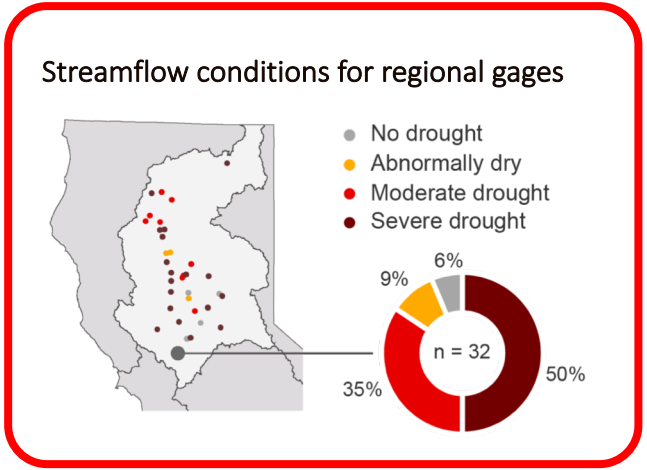
- Represent ecologically available water, accounting for both meteorological drought and management actions
- Account for antecedent drought conditions (lag effects)
- Use transparent, quantitative methods for indicator calculation

Vision for drought monitor 2.0



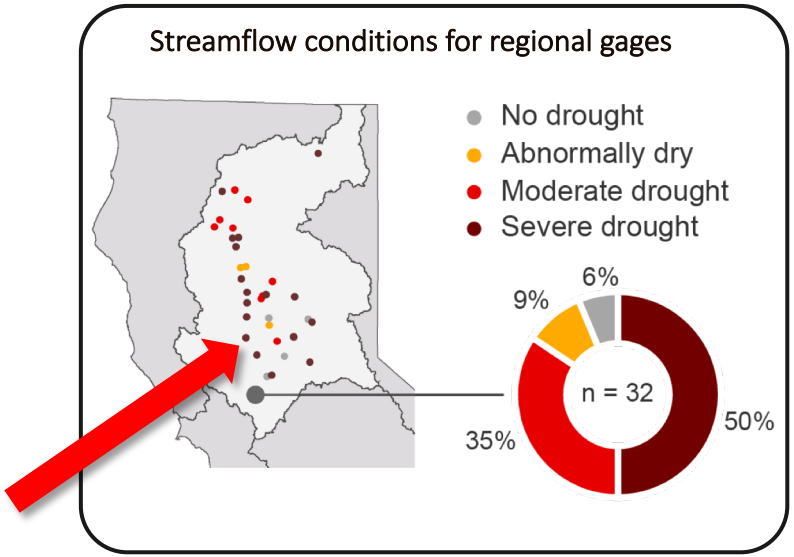
Ecosystem drought indicator dashboard





- Freshwater ecosystems are experiencing extreme drought stress as a consequences of extreme low precipitation, high evapotranspiration, and low snowpack, and warm temperatures.
- Stream flows in the region exhibit extreme drought conditions
- Native freshwater species are likely experiencing high physiological stress, reproductive failure, and high mortality from limited water availability and water quality degradation.

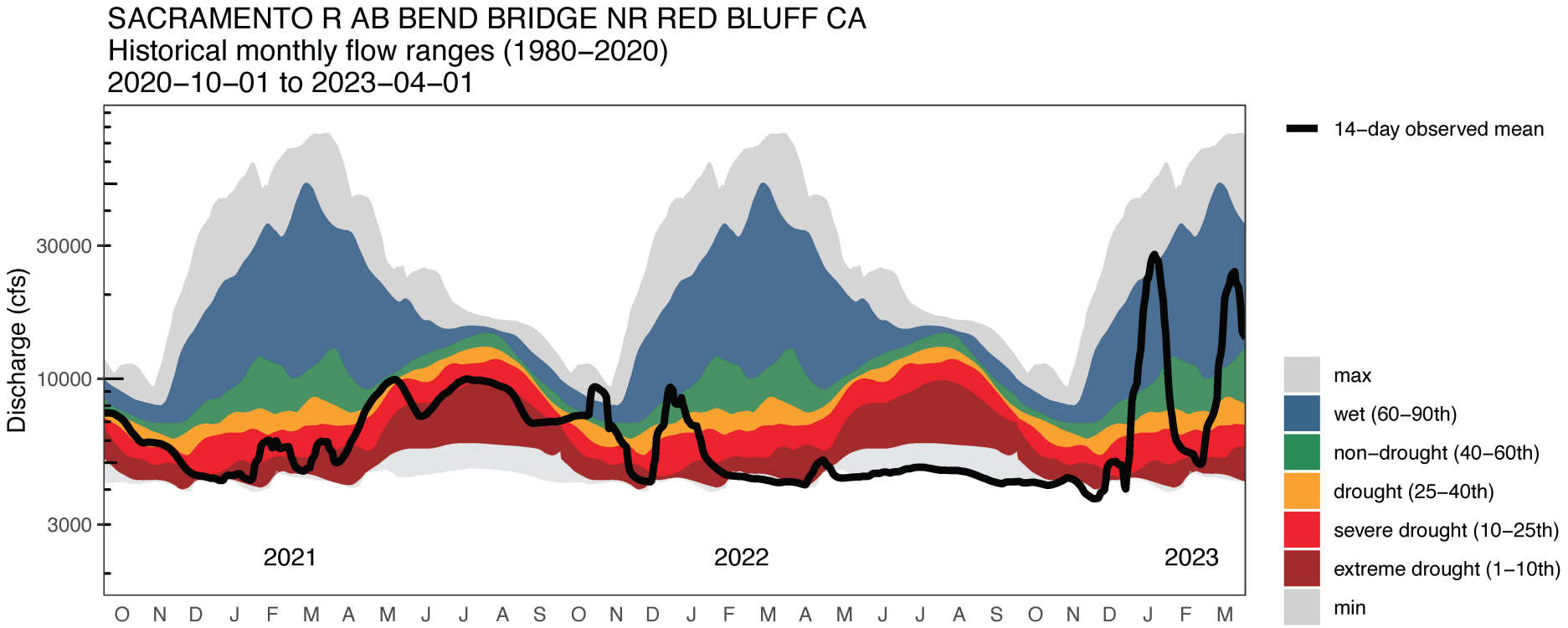
Regional streamflow drought indicator



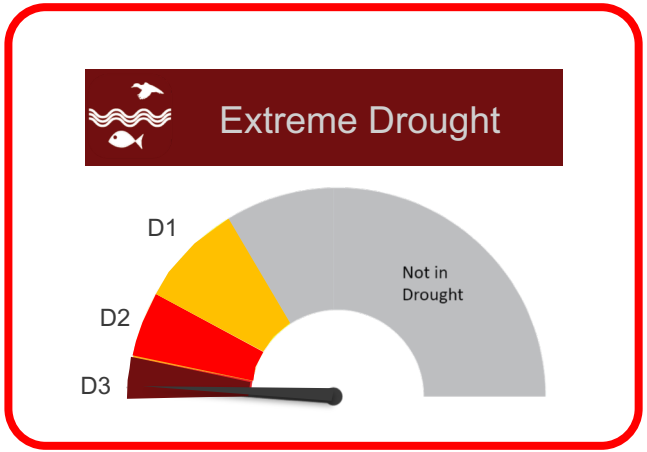
Streamflow indicator classification

Non-drought (D0)	<50% of gages with flows <40th percentile
Moderate drought (D1)	≥50% of gages with flows <40th percentile
Severe drought (D2)	≥50% of gages with flows <25th percentile
Extreme drought (D3)	≥50% of gages with flows <10th percentile

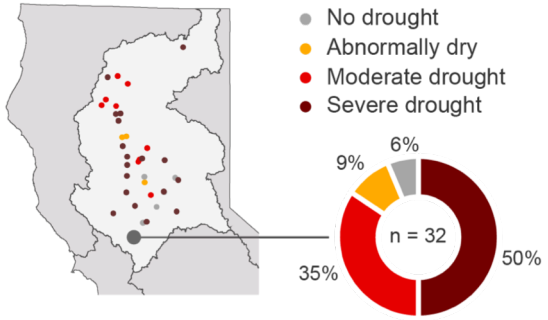
Station specific flow conditions



Ecosystem drought indicator dashboard



Streamflow conditions for regional gages



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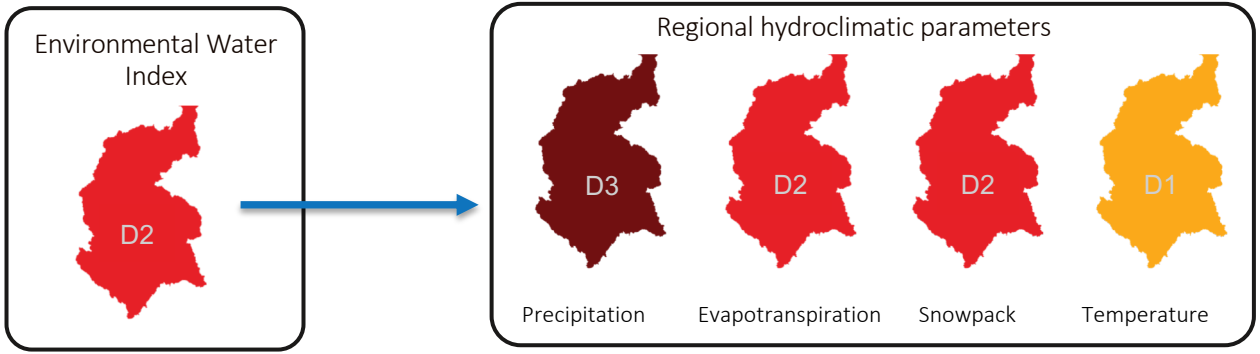
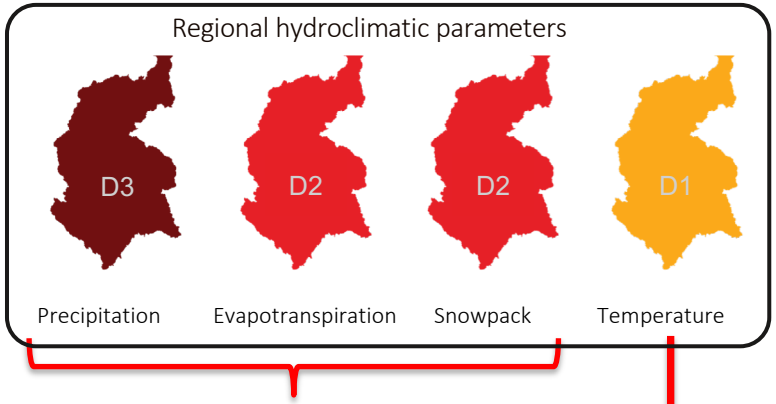
Environmental water indicator



Environmental water indicator components



Runoff = Precip – ET – ΔSnowpack

Max monthly temp

Regional environmental water indicator

$$\text{E-water}_i = \beta_{1,i} \times \text{runoff}_i + \beta_{2,i} \times \text{runoff}_{i-3} + \beta_{3,i} \times \text{runoff}_{i-11} + \beta_{4,i} \times \text{temp}_i$$

Runoff for current month

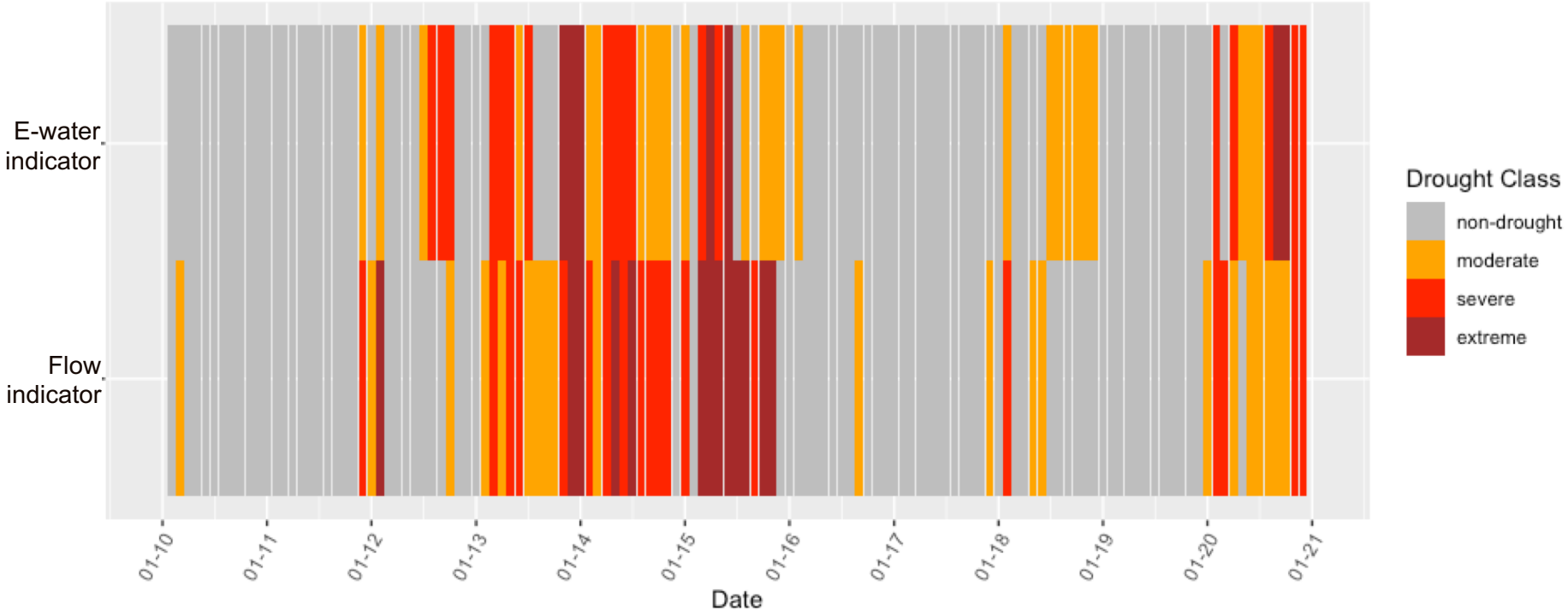
Mean runoff for current and previous 3 months

Mean runoff for current and previous 11 months

Mean max monthly temperature for current month

where i = month, x = antecedent period,
$\beta_{x,i}$ = monthly parameter weight (0 - 1)

Regional environmental water drought indicator vs. streamflow drought indicator (2010 – 2021)



New ecological drought indicators

- Provide a transparent and flexible tool to assess ecological drought risk in California
- Indicators reflect ecologically available water and account for influence of management operations and antecedent conditions
- Further analysis needed to link indicators to specific ecological drought impacts

Questions so far?

Workshop Agenda

Welcome and workshop objectives	2:00 p.m.
Review of project goals and achievements	2:05 p.m.
Defining drought for California water users	2:15 p.m.
Linking drought conditions and impacts	3:00 p.m.
Discussion about implications and next steps	3:30 p.m.
Workshop ends	4:00 p.m.

The second major goal of the project was to show how to link drought indicators and impacts

"Drought impacts are a not only a function of natural event, but also a function of how humans manage and adapt to these events"

Dry conditions in the area of Lake Mendocino in Mendocino County.
Source: DWR

The second major goal of the project was to show how to link drought indicators and impacts

"Drought impacts are a not only a function of natural event, but also a function of how humans manage and adapt to these events"

- We used a qualitative approach to develop a methodology to link drought hazard and impacts
- Focused on specific examples or case studies

Dry conditions in the area of Lake Mendocino in Mendocino County.
Source: DWR

Drought impacts can be characterized by a combination of hazard, exposure and vulnerability

Drought impacts can be characterized by a combination of hazard, exposure and vulnerability

The possible occurrence of natural or human-induced physical events

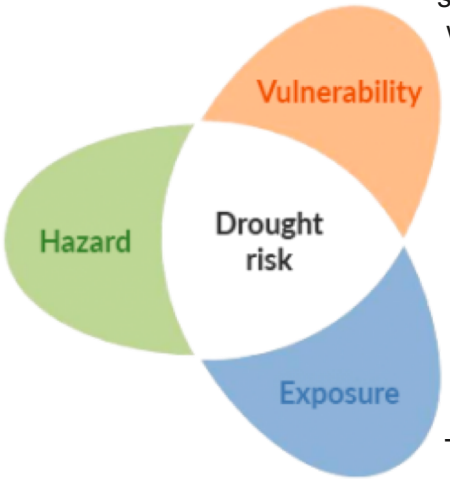
Drought impacts can be characterized by a combination of hazard, exposure and vulnerability

The possible occurrence of natural or human-induced physical events

The total population, its livelihoods and assets in an area in which drought hazard events may occur

Drought impacts can be characterized by a combination of hazard, exposure and vulnerability

The propensity of exposed elements to suffer adverse effects when impacted by a drought event



The possible occurrence of natural or human-induced physical events

The total population, its livelihoods and assets in an area in which drought hazard events may occur

Drought impacts can be characterized by a combination of hazard, exposure and vulnerability

Actions to reduce vulnerability

- Water prioritization
- Water trading
- Conservation campaigns
- Emergency policies
- Safety nets

Actions to reduce hazard

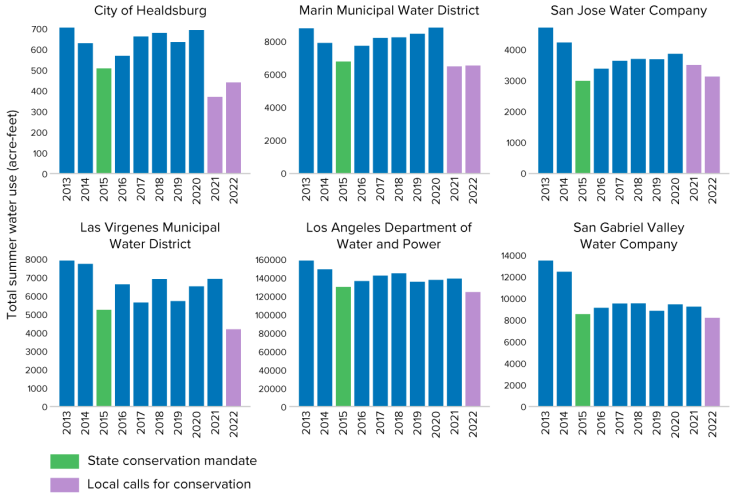
- Infrastructure
- Water rights
- Regulations

Actions to reduce exposure

- Land planning
- Crop planning

Drought hazard is related to built infrastructure and regulations

During 2021 and 2022, agencies with vulnerable supply portfolios were more impacted, so they enacted conservation

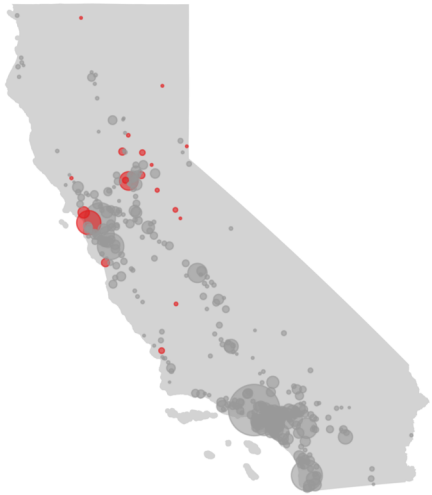


SOURCE: SWRCB Urban Water Supplier Monthly Reports, October 2022.
NOTES: These bar charts illustrate the total water use of each urban agency during summer months, June through August, from 2013 to 2022.
FROM: PPIC Blog, October 2022.

- Water users with more diversified portfolios have lower risks
- New infrastructure (i.e. new connection to surface water) can help reducing risk
- Regulations (i.e. environmental regs, water seniority, SGMA, etc.) also affect drought hazard

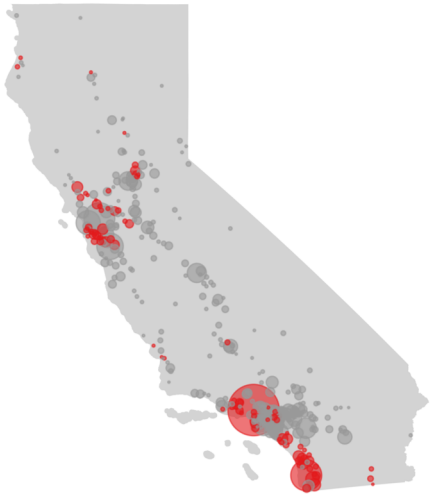
Local supply portfolios are key in assessing drought hazard

Surface water dependent



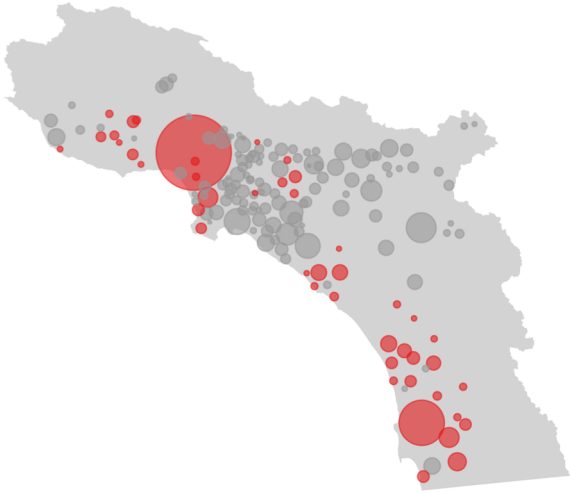
Groundwater dependent

Purchase or import dependent

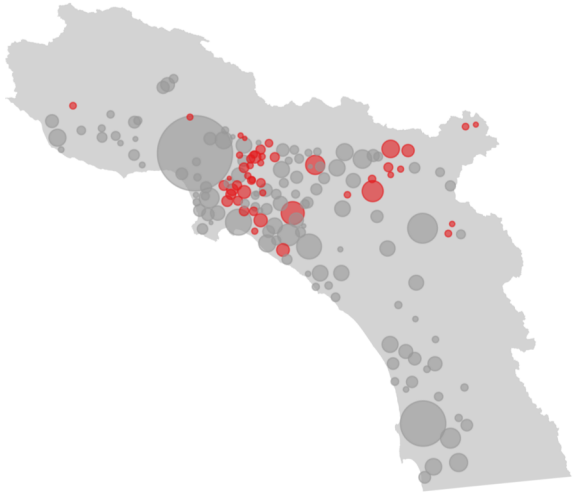


Local supply portfolios are key in assessing drought hazard

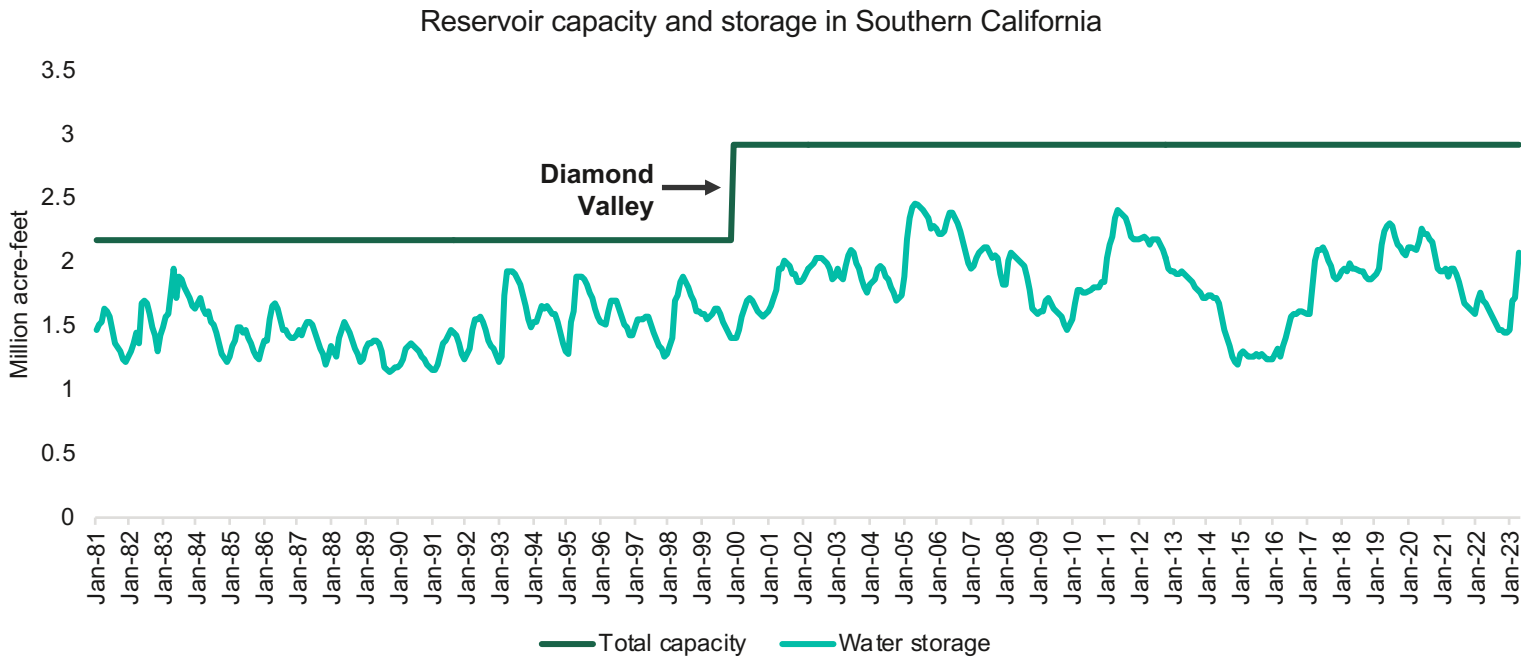
Purchase or import dependent



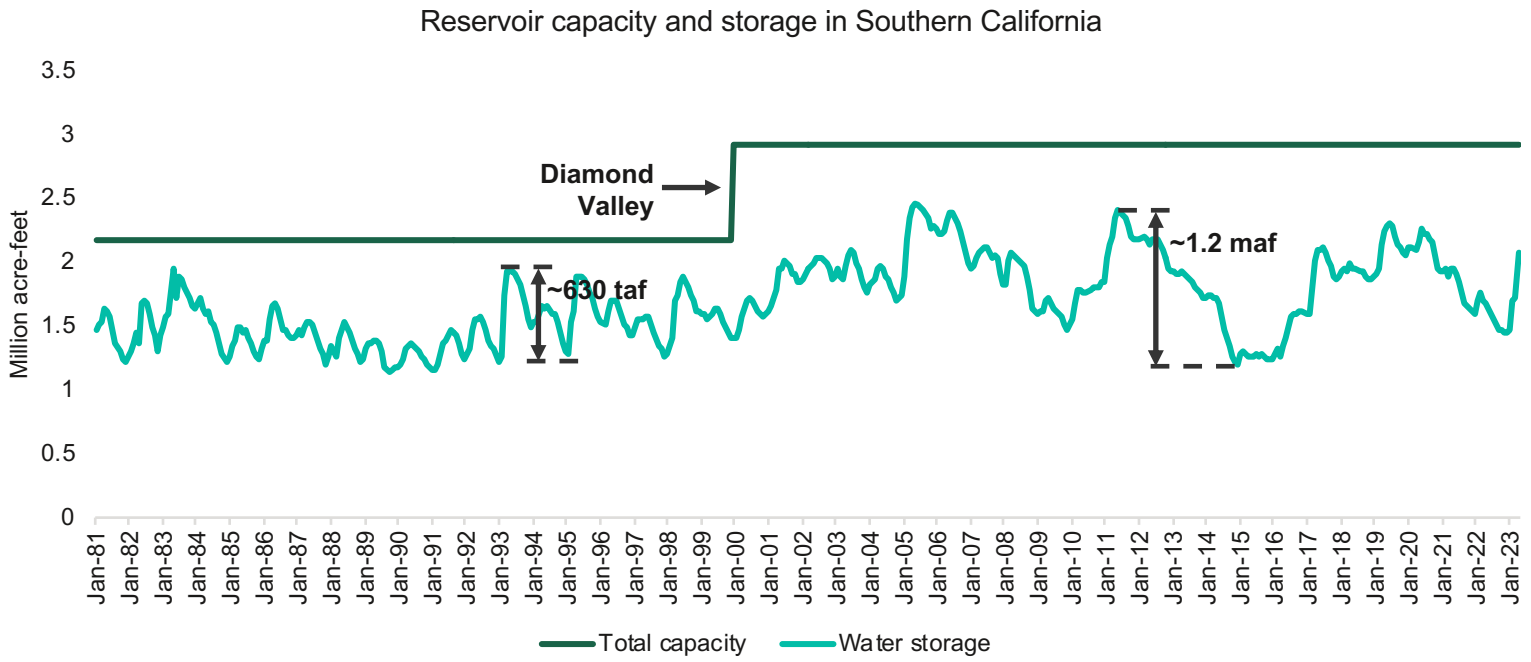
Groundwater dependent



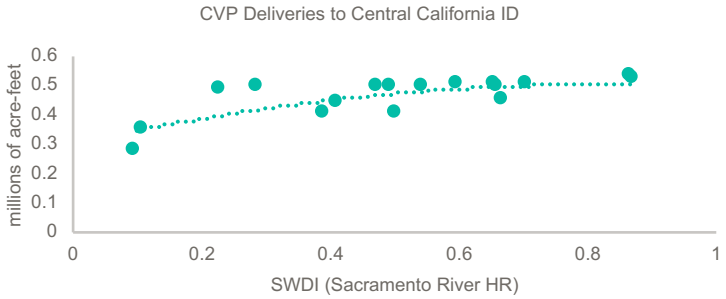
Infrastructure helps managing drought hazard

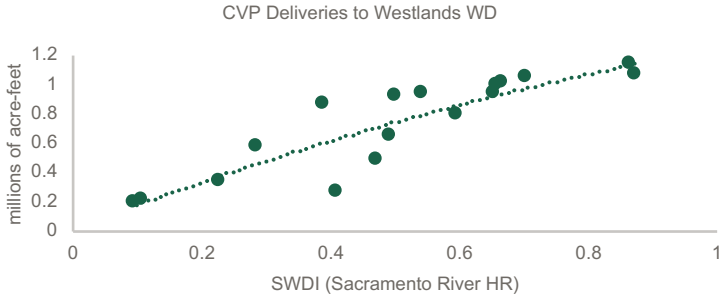


Infrastructure helps managing drought hazard

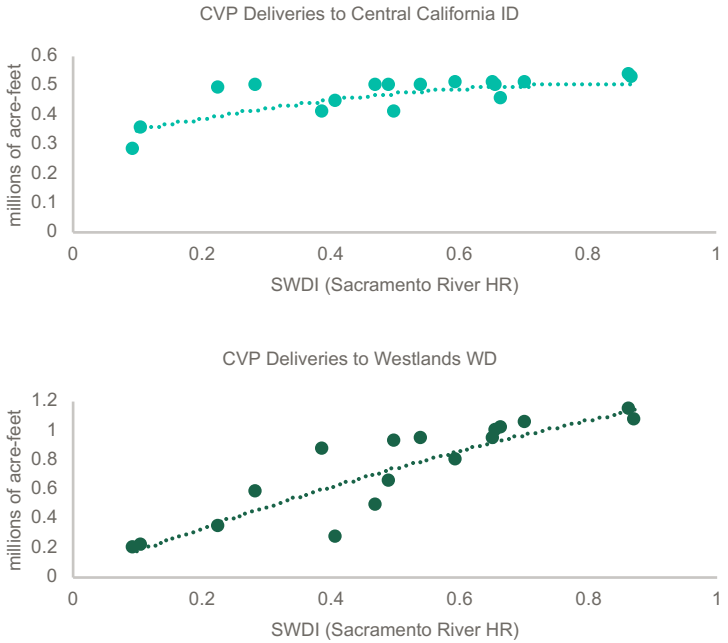


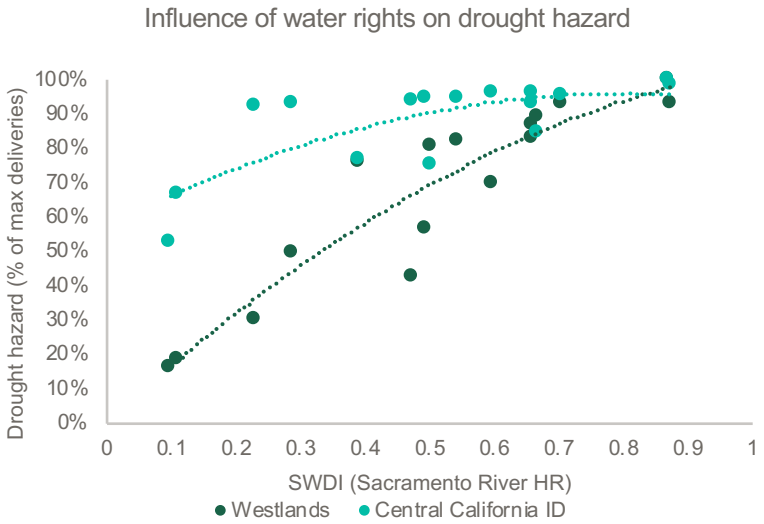
Regulations have a big impact in users' drought hazard





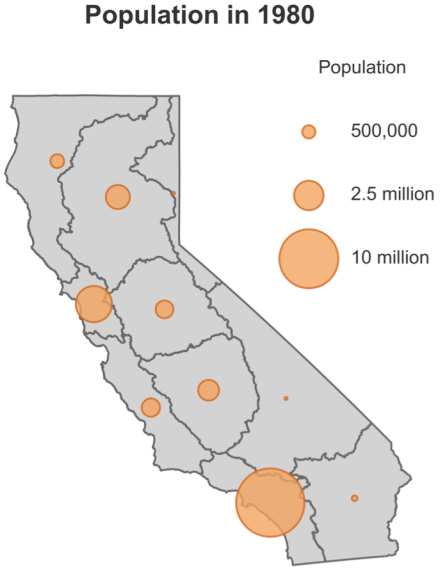
Regulations have a big impact in users' drought hazard





Only when there are exposed assets, there can be drought impacts

- Population is a good indicator of exposure for cities
  - California has increased its exposure significantly in recent decades
  - Population is plateauing, but some regions will still grow, increasing risk



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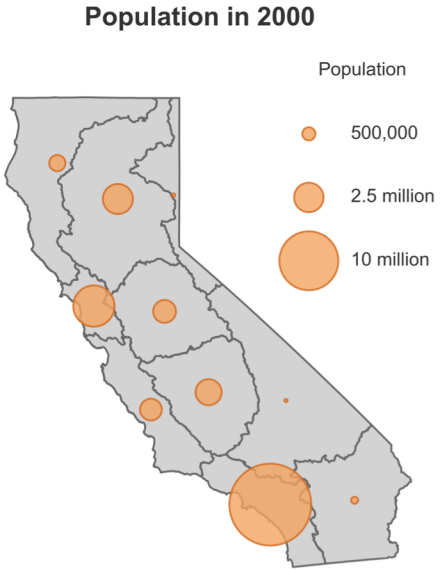

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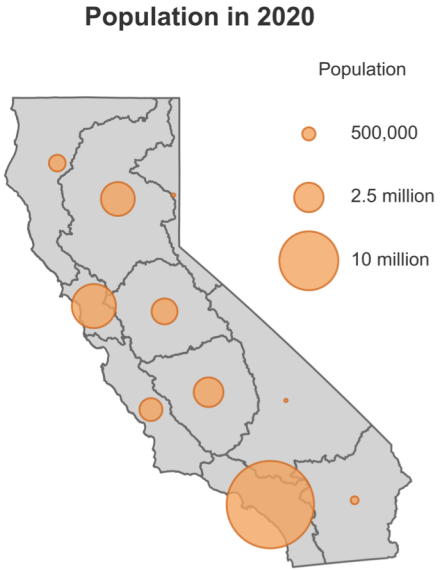

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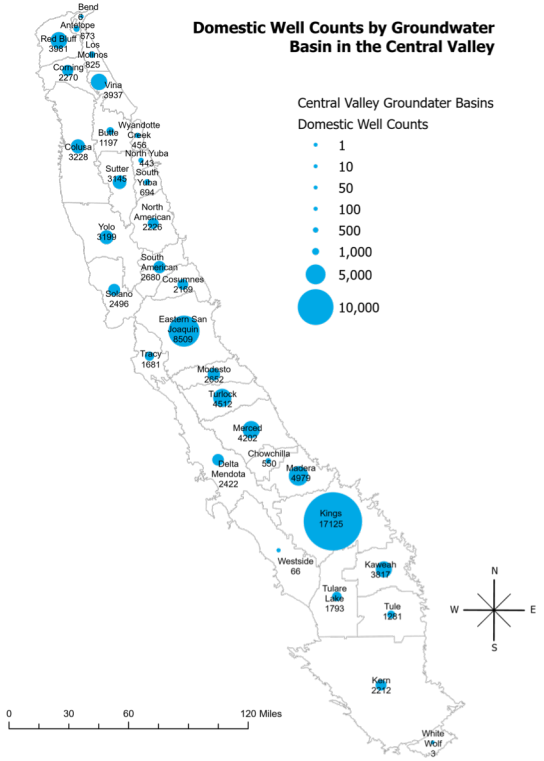

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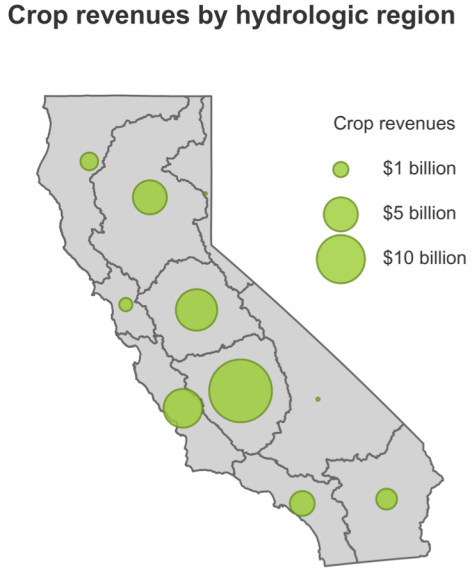
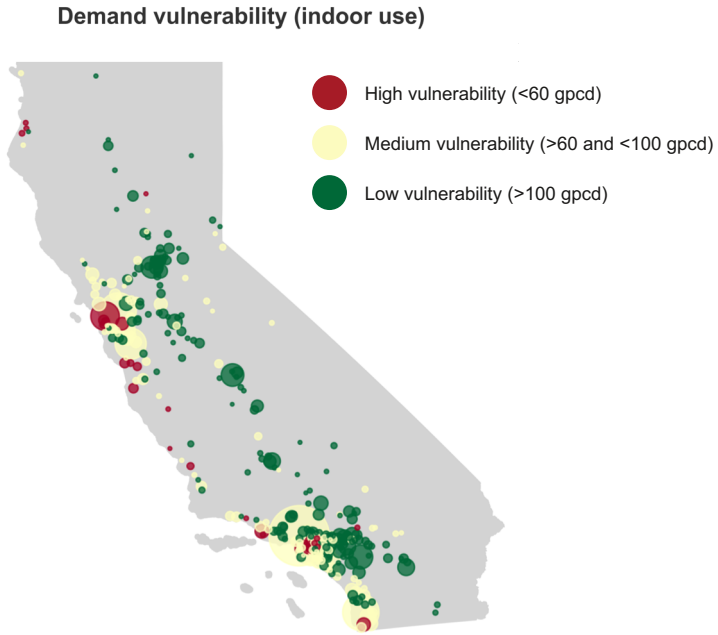
- And there are also important differences in agriculture exposure across regions



Assessing how vulnerable are different sectors to water shortages is key to understand impacts

- Demand hardening, or access to water trading can determine vulnerability of urban agencies



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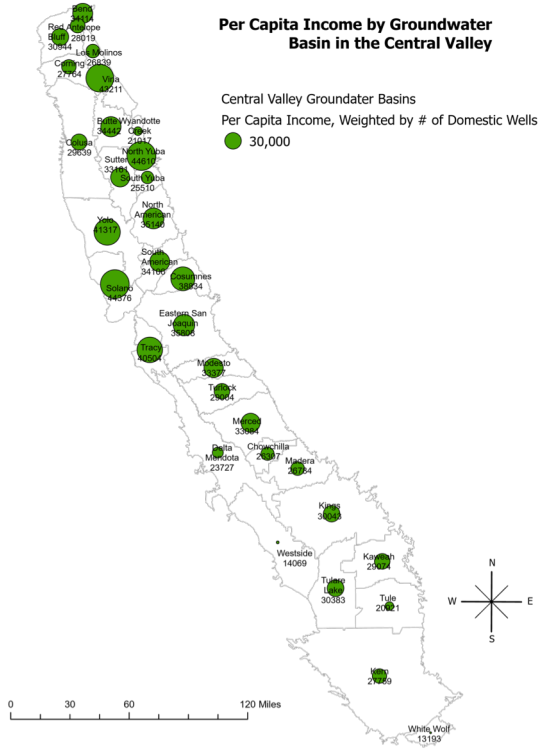
- Small communities are highly vulnerable socio-economically, being less able to respond to shortages (i.e. fixing wells)



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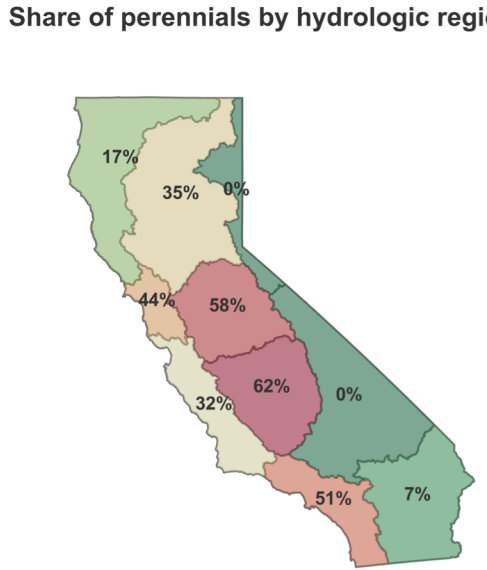

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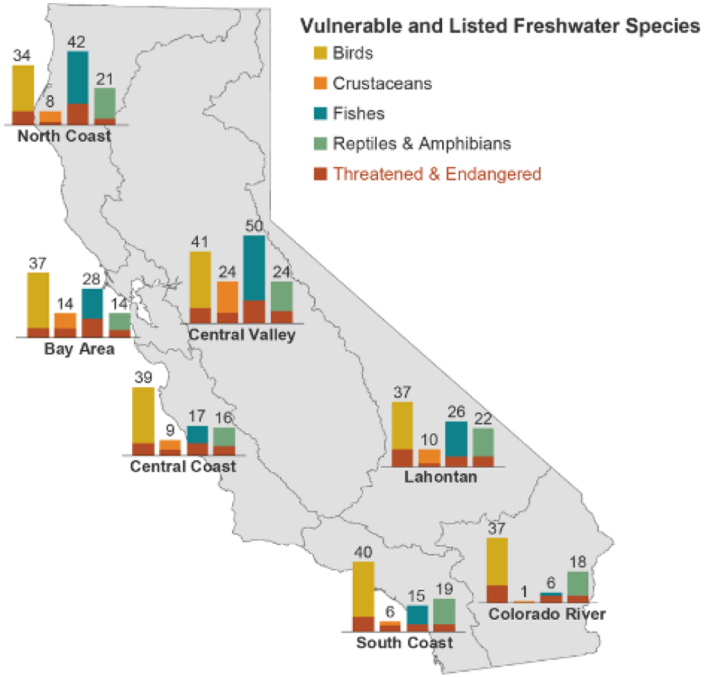
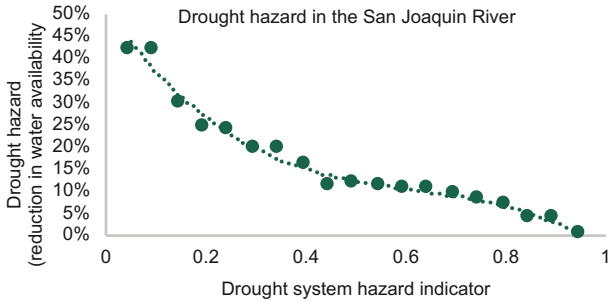
- Endangered species can serve as an indicator of environmental vulnerability



Drought impacts can be assessed as a combination of hazard, exposure and vulnerability



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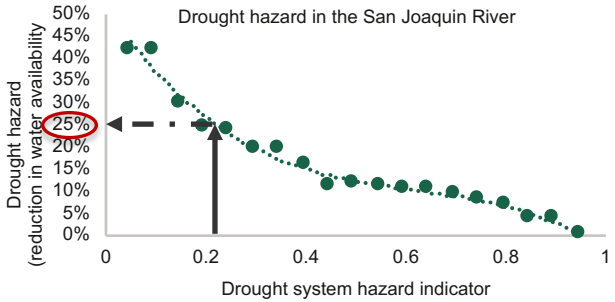

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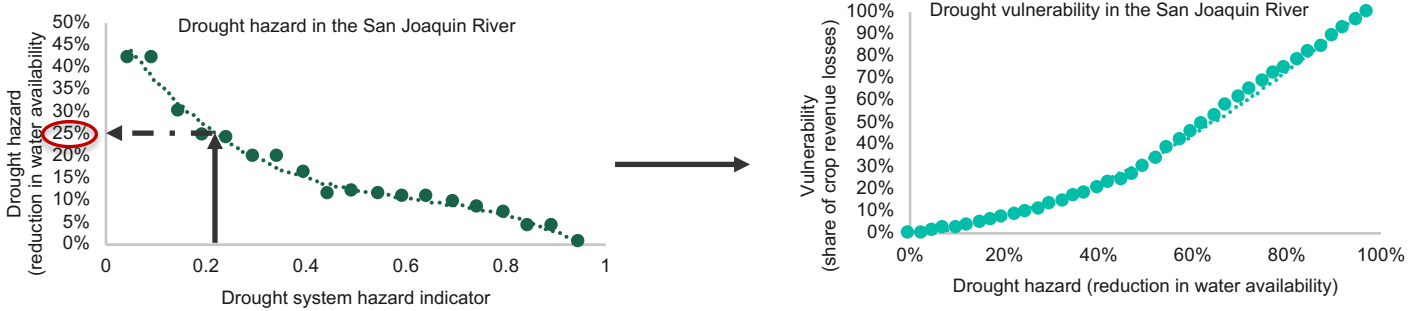

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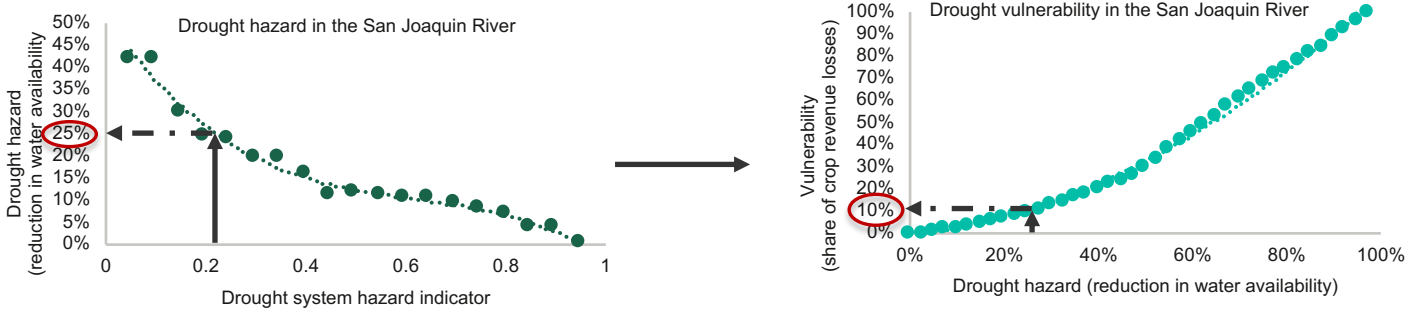

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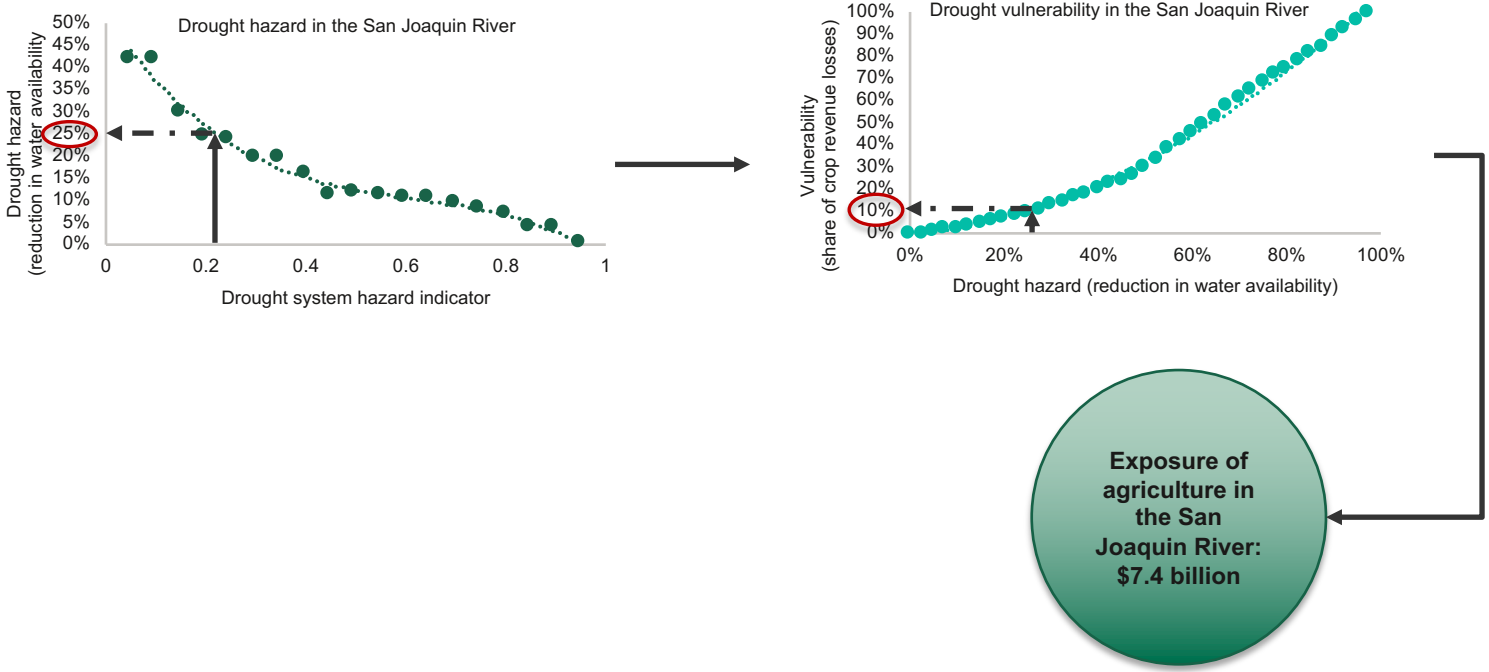

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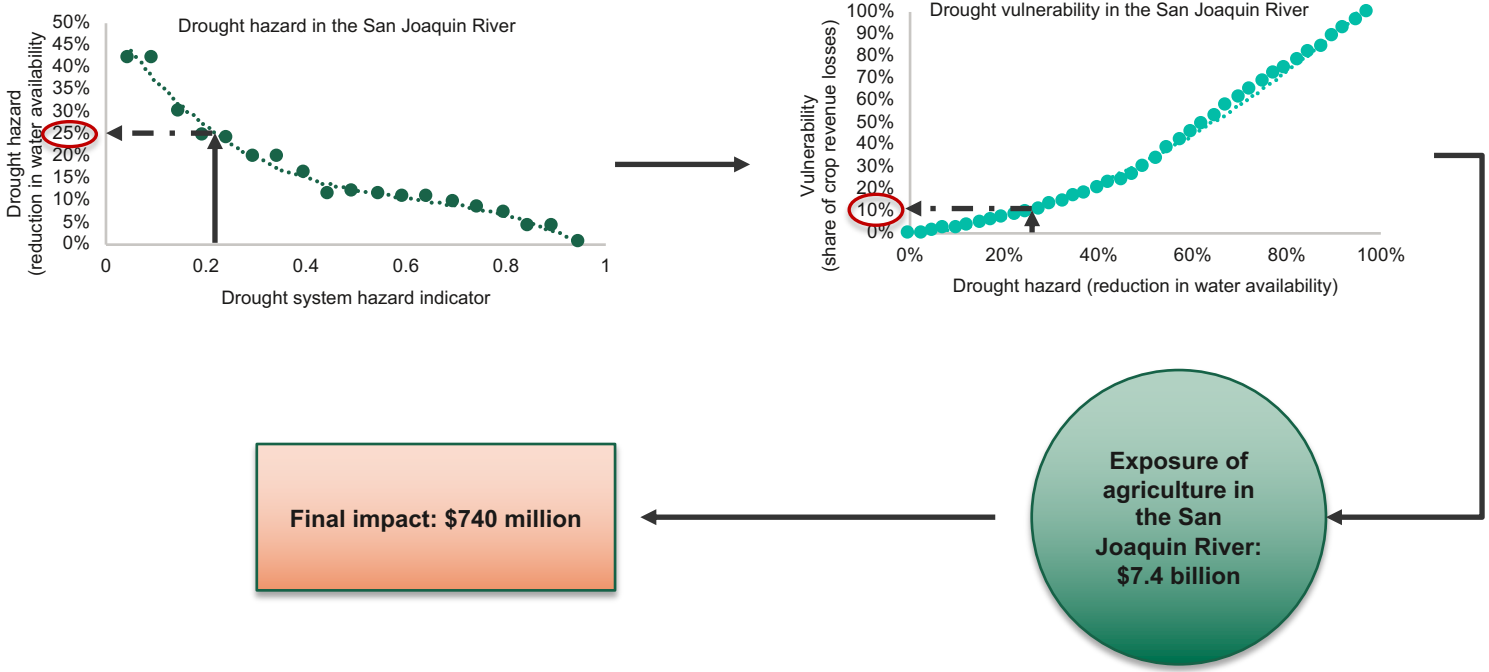
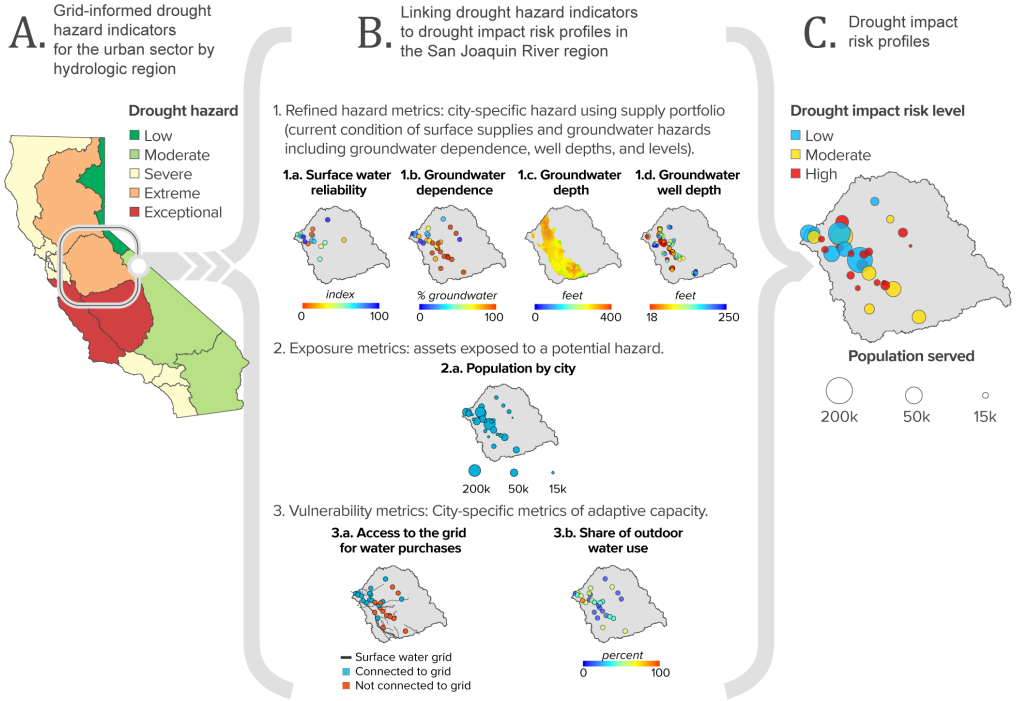


Qualitative approaches can be used also to develop drought impact risk profiles



Recap on linking drought hazard and impacts

- To estimate drought impacts is key to understand the hydroclimatic conditions, but also users' exposure and vulnerability
- There are interdependences and tradeoffs between hazard, exposure and vulnerability that need to be identified
- Impacts can be minimized by reducing any of the components of drought hazard

Questions so far?

Workshop Agenda

Welcome and workshop objectives	2:00 p.m.
Review of project goals and achievements	2:05 p.m.
Defining drought for California water users	2:15 p.m.
Linking drought conditions and impacts	3:00 p.m.
Discussion about implications and next steps	3:30 p.m.
Workshop ends	4:00 p.m.

Next steps

- Deliverables
  - Public repository with code and data (and summary methods)
  - Academic papers
  - Engagement process document
- Phase 2
  - California Drought Dashboard: A web-based platform to identify multi-sectoral drought hazard indicators and expected impacts in California

Open discussion

- Any suggestions to improve our analyses?
- Are we missing anything?
- Could be this useful in California? How?
- What would you like to see in future developments?

Thank you!

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

Alvar Escriva-Bou

escriva@ucla.edu

@AlvarEscriva