Vulnerability to Water Shortage Under Current and Future Water Supply-Demand Conditions Across U.S. River Basins

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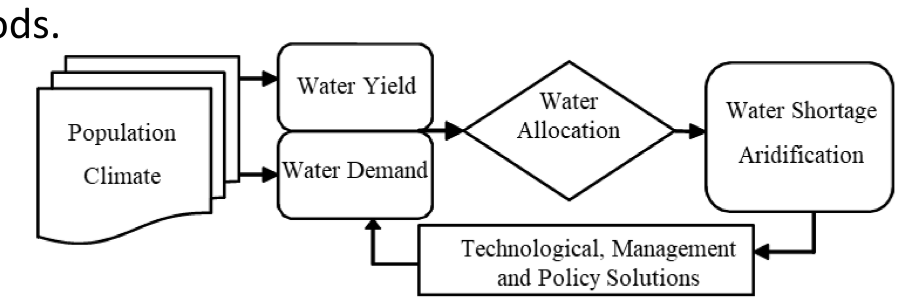
Introduction

- Future changes in **climate** and **population** may cause a decrease in freshwater availability and an increase in water demand leading to more frequent **water shortage** conditions.
- The enhanced characterizations of changes in water shortage conditions from **interannual to decadal** events are requisite to the appropriate management and planning of future water resources, and improved implementation of regional adaptation and mitigation strategies.

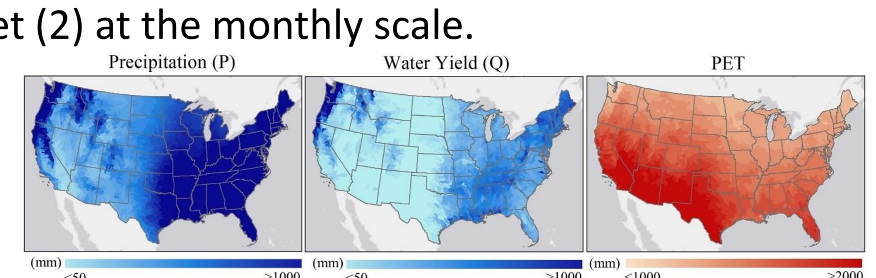
Objectives

- This study proposes an approach to improve the vulnerability assessments of U.S. river basins to the shortage at the interannual to decadal timescales by characterizing shifts in intensity, duration, and frequency (IDF) of water shortage events from current (1986-2015) to future (2070-2099) periods.



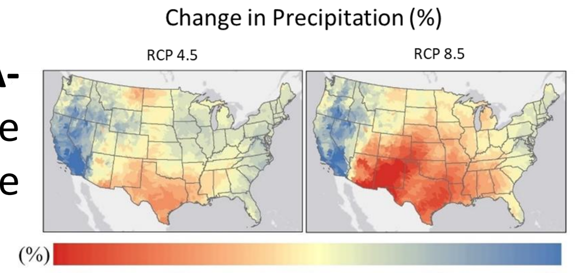
(1) Climate Projection

- The **current** precipitation and temperature of U.S. river basins (1986-2015) were obtained from the Daymet dataset (1) and then biased corrected using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate dataset (2) at the monthly scale.



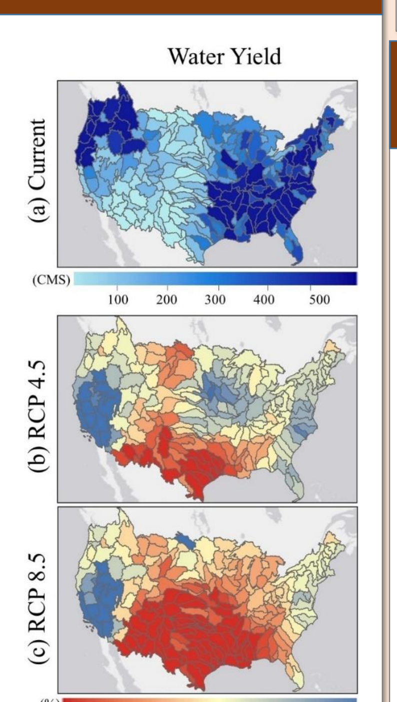
- The **future** precipitation, temperature, and wind speed of U.S. river basins were obtained from the downscaled Multivariate Adaptive Constructed Analogs (MACA) datasets (3).
- We selected the **IPSL-CM5A-MR** model that represents the **worst-case** scenario for the future climate conditions (4).

Change in Precipitation (%)



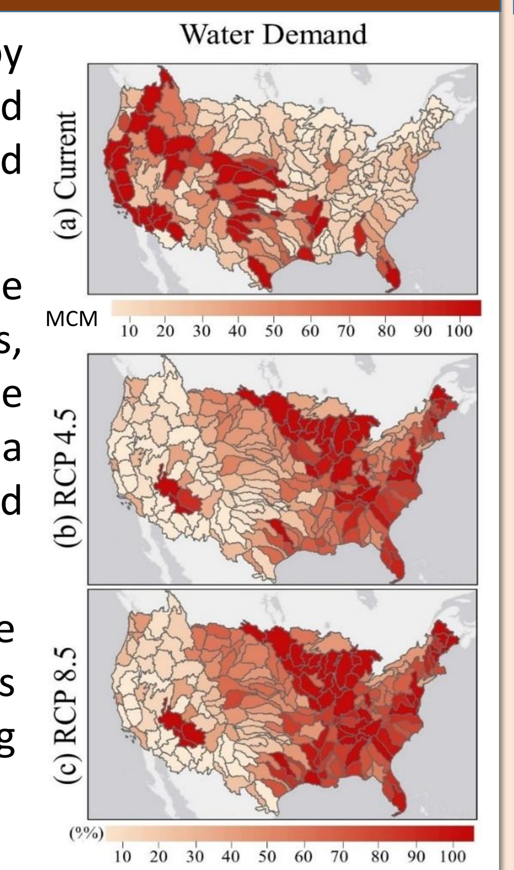
(2) Hydrological Projection

- The Variable Infiltration Capacity (VIC) hydrologic model was implemented in this study to evaluate the hydrologic response of the climate change emission scenarios.
- The model is set up, calibrated and evaluated by Oubeidillah et al. (2014) using matching the simulated monthly total streamflow with the observed monthly runoff from the USGS WaterWatch runoff dataset (5) for each HUC8 subbasin.



(3) Water Demand Projection

- The monthly water demand of each HUC4 river basin was estimated by summing projections for six water use sectors including domestic and public, agricultural irrigation, thermoelectric, industrial, commercial, and mining, livestock, and aquaculture.
- The current water use data were obtained from the USGS water use circulars and for thermoelectric power water use from (Diehl & Harris, 2014). The future water withdrawal for each sector was estimated as the product of a water use driver such as population and irrigated area; and a water withdrawal rate such as domestic withdrawals per capita and irrigation withdrawal per unit area.
- The A1B scenario from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment set of global socioeconomic scenarios was chosen to project future changes in population and income levels using the AIM global emissions model.



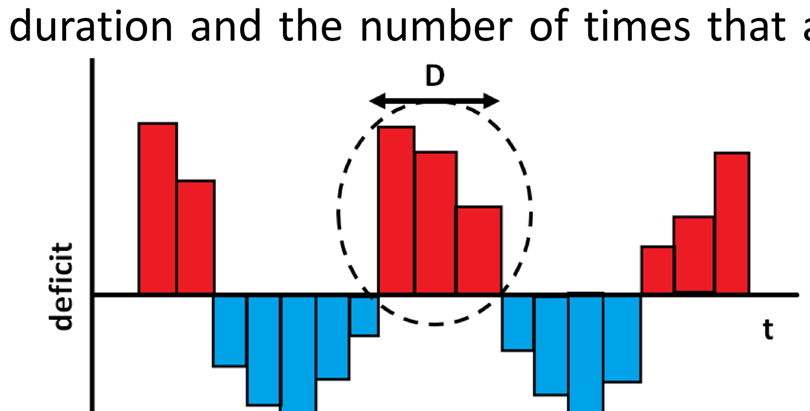
(4) Water Supply Projection

- The Water Evaluation and Planning (WEAP) model was applied in this study to estimate the water supply allocated to each HUC4 river basin.
- The WEAP model used in this study was set up by Brown et al., (2019) (6) at HUC04 watersheds spatial scale. The WEAP model runs at the monthly time step for the period of 1985 to 2099 to calculate the past and future water supply of each HUC4 river basin.
- The water supply of a basin was defined as the amount of water available to meet demands for a given month and obtained from the sum of water yield, net trans-basin diversions, reservoir storage from the prior month, and inflow from upstream minus the sum of required instream flow release, reservoir evaporation, and any required release to satisfy downstream demands.

(5) Water Shortage Projections

- The probabilistic approach developed by Heidari et al., (2020) (7) was used in this study to assess shifts in intensity, duration, and frequency (IDF) of water shortage events across the CONUS at the monthly and annual scales.
- The duration (D), intensity (I), and frequency (F) of a water shortage event were respectively defined as the number of consecutive months/years where water demand exceeds water supply, the cumulative water deficit divided by its duration and the number of times that a specific event occurs.
- The water shortage events were modeled using the mixture Gamma-GPD distribution.

$$F(x|r,a,\xi,\beta,u,\phi_u) = \begin{cases} (1-\phi_u)\dfrac{G(x|r,a)}{G(u|r,a)} & x < u \\ (1-\phi_u) + \phi_u\, g(x|\,\xi,\beta,u) & x \geq u \end{cases}$$



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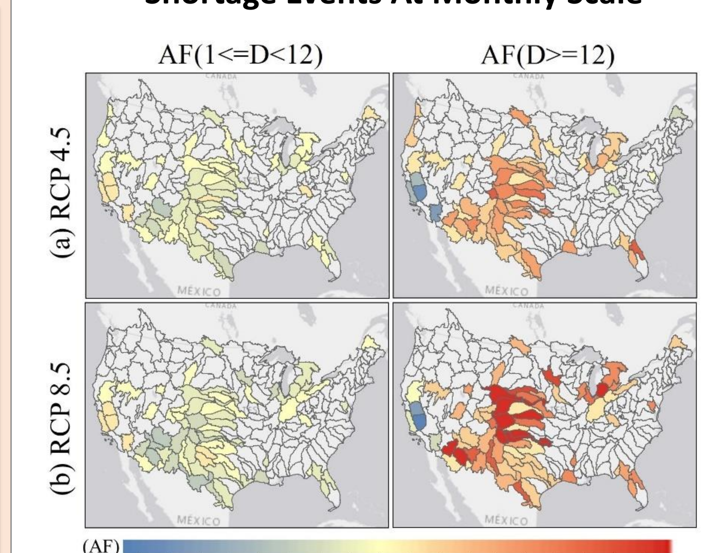
Results and Conclusion

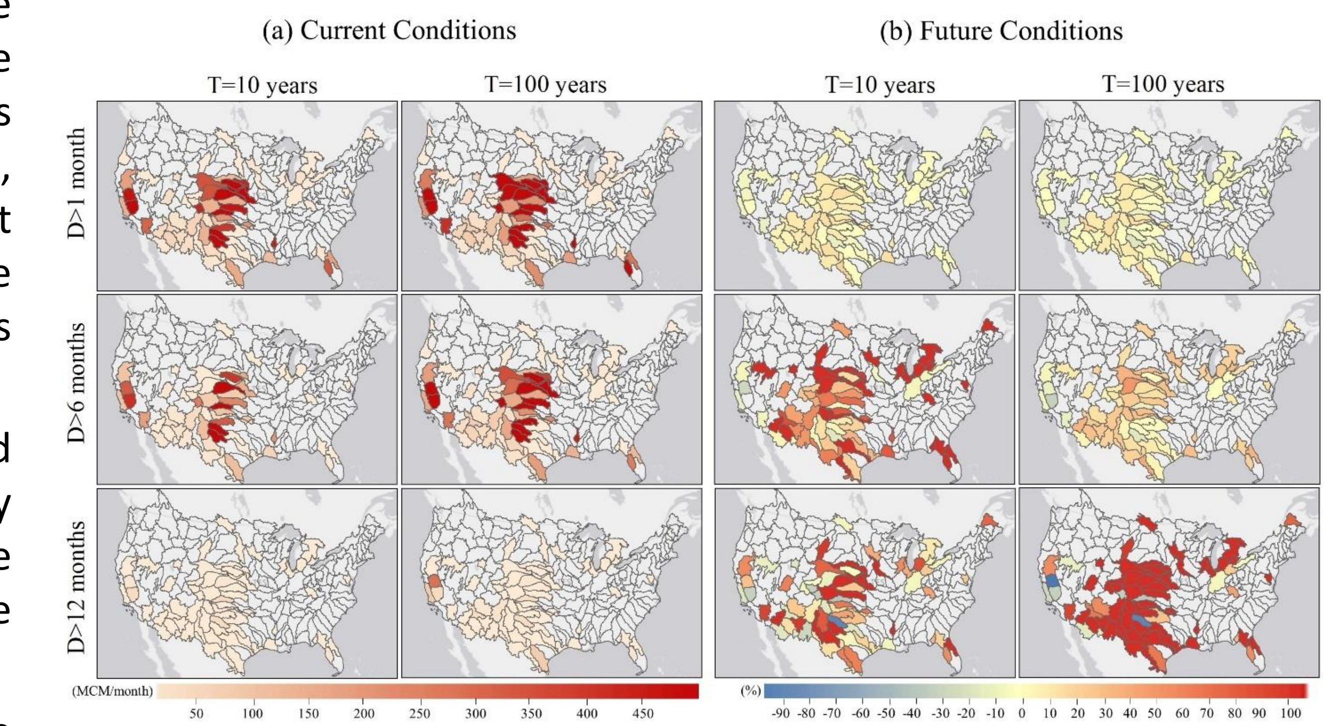
- The findings under the worst-case scenario at the conterminous scale indicates that the river basins located in the Southwest, Southern, and the middle Great Plain regions may experience more intense water shortage conditions at the end of the century.
- Conversely, the river basins located in the West Coast region are likely to experience a decrease in the intensity of water shortage conditions.
- The Southwest, Southern, and the middle Great Plain river basin are likely to experience less frequent interannual (D<12 months), annual (D>1 year), and multi-year (D>3 years) events in the future.
- However, the frequency of over-year (D>12 months) events at the sub-annual scale and decadal (D>10 years) events at the annual scale were projected to increase in the future in these regions.

The Frequency Amplification Factor of Water Shortage Events At Monthly Scale

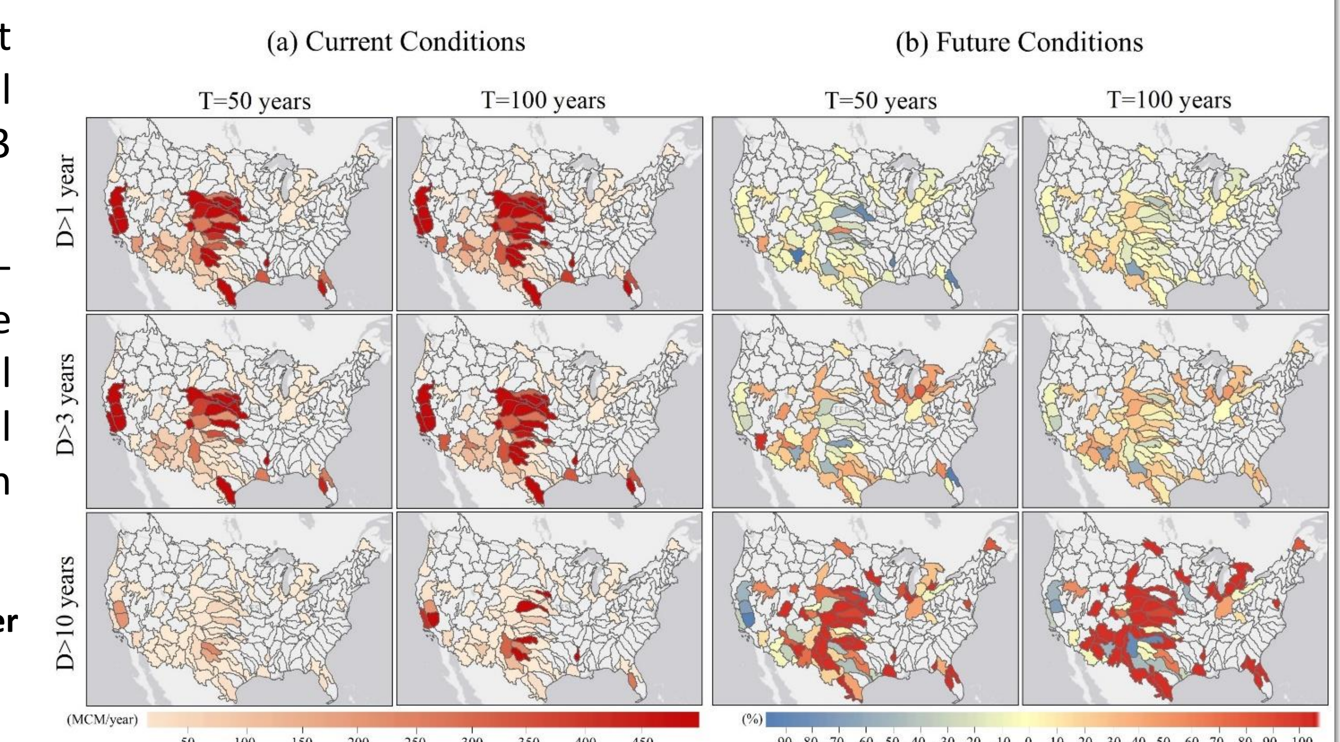


- Although the frequency of over-year (D>12 months), and decadal (D>10 years) events were estimated to decrease in the West Coast regions under the on average the driest climate change scenario for the CONUS, the interannual (D<12 months) events at the monthly scale and annual (D>1 year) and multi-year (D>3 years) events at the annual scale were projected to increase in the future in the West Coast regions.
- The intensity of water shortage events with longer duration and higher return periods is likely to be more affected in the future in response to climate changes and population growth.

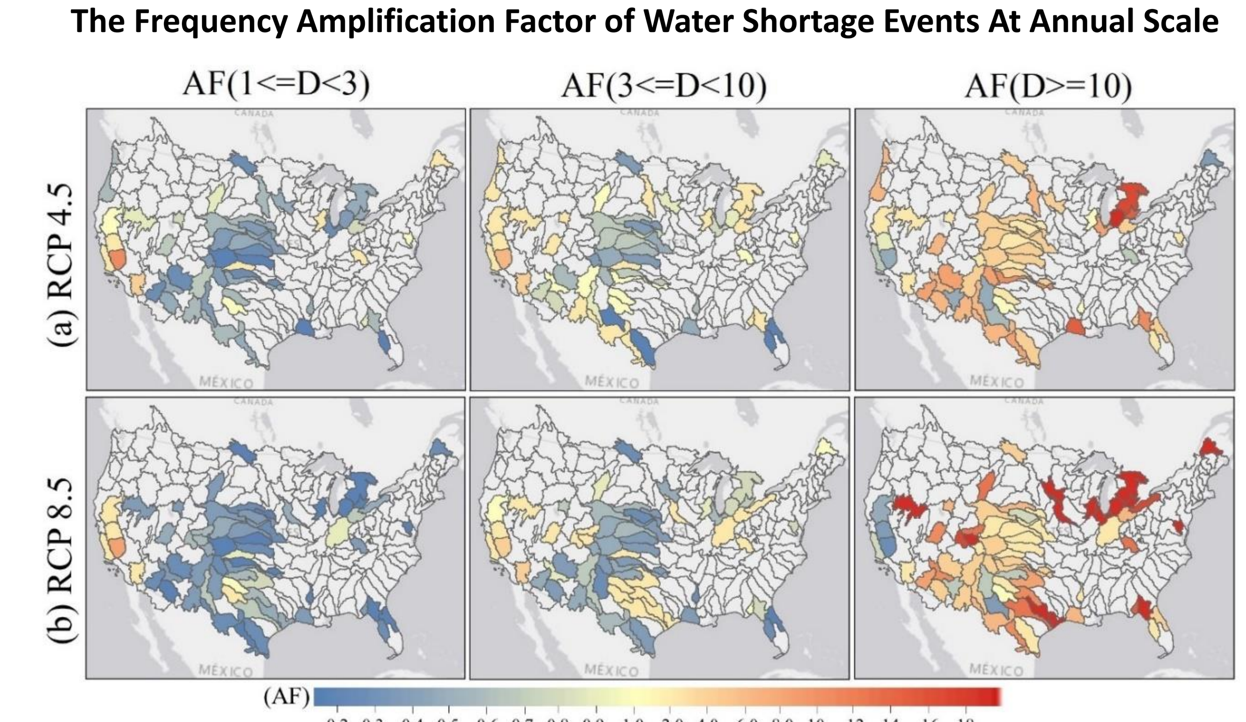
Intensity of Current and Future Water Shortage Events At monthly Scale



Intensity of Current and Future Water Shortage Events At Annual Scale



The Frequency Amplification Factor of Water Shortage Events At Annual Scale



Basins that are more vulnerable to changes in demand (demand-based), supply (supply-based), or both