Conjunctive use of surface and groundwater to mitigate water shortage during drought in the Contiguous United States

Ximing Cai, Tushar Apurv

Ven Te Chow Hydrosystems Laboratory

Department of Civil and Environmental Engineering

University of Illinois at Urbana-Champaign

Contact: xmcai@illinois.edu

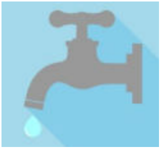
Drought propagation mechanism: the role of natural and human factors

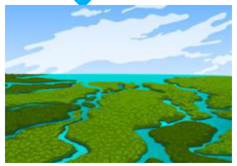
Drought propagation

Meteorological drought: precipitation deficit

Soil moisture/agricultural drought: soil moisture deficit

Hydrologic drought: streamflow/ groundwater deficit





Water supply drought: lack of sufficient water to meet water supply requirements

Apurv el al. 2017 *Water Resources Research*

Influencing factors

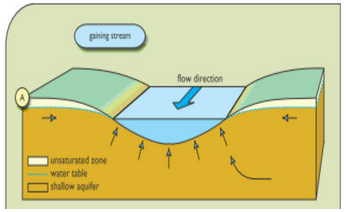
Land atmospheric interactions, teleconnections with sea surface temperatures, global warming

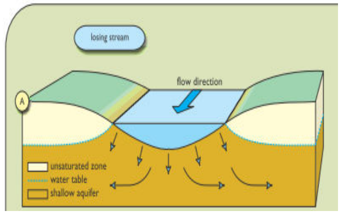
Climate characteristics such as aridity, seasonality and rainfall timing

Climate characteristics, watershed characteristics such as soil, vegetation and groundwater characteristics

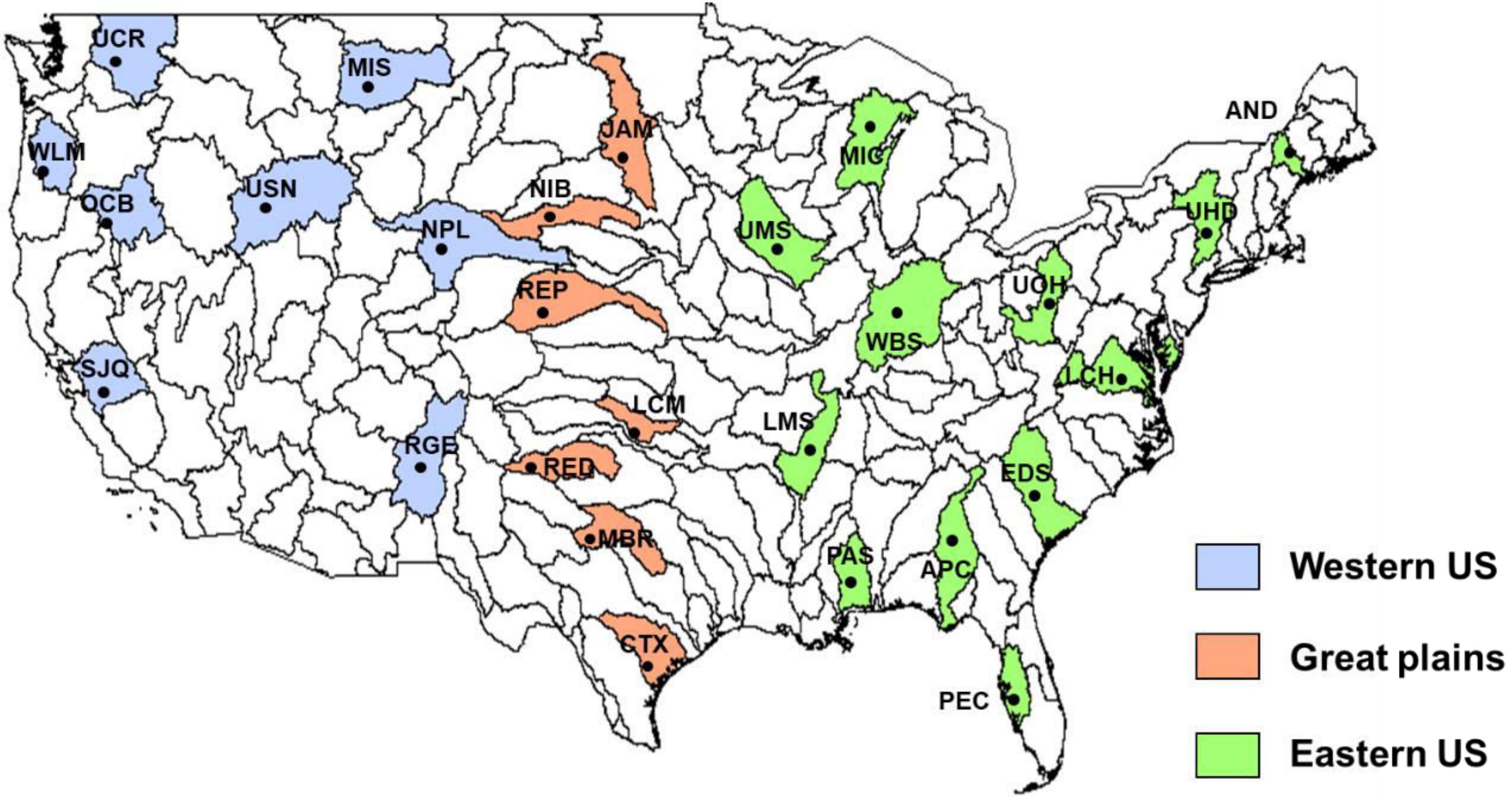
Water supply system infrastructure, water demand, reservoir operation and groundwater pumping

Potential of conjunctive use of surface and groundwater to mitigate water shortage during a drought event



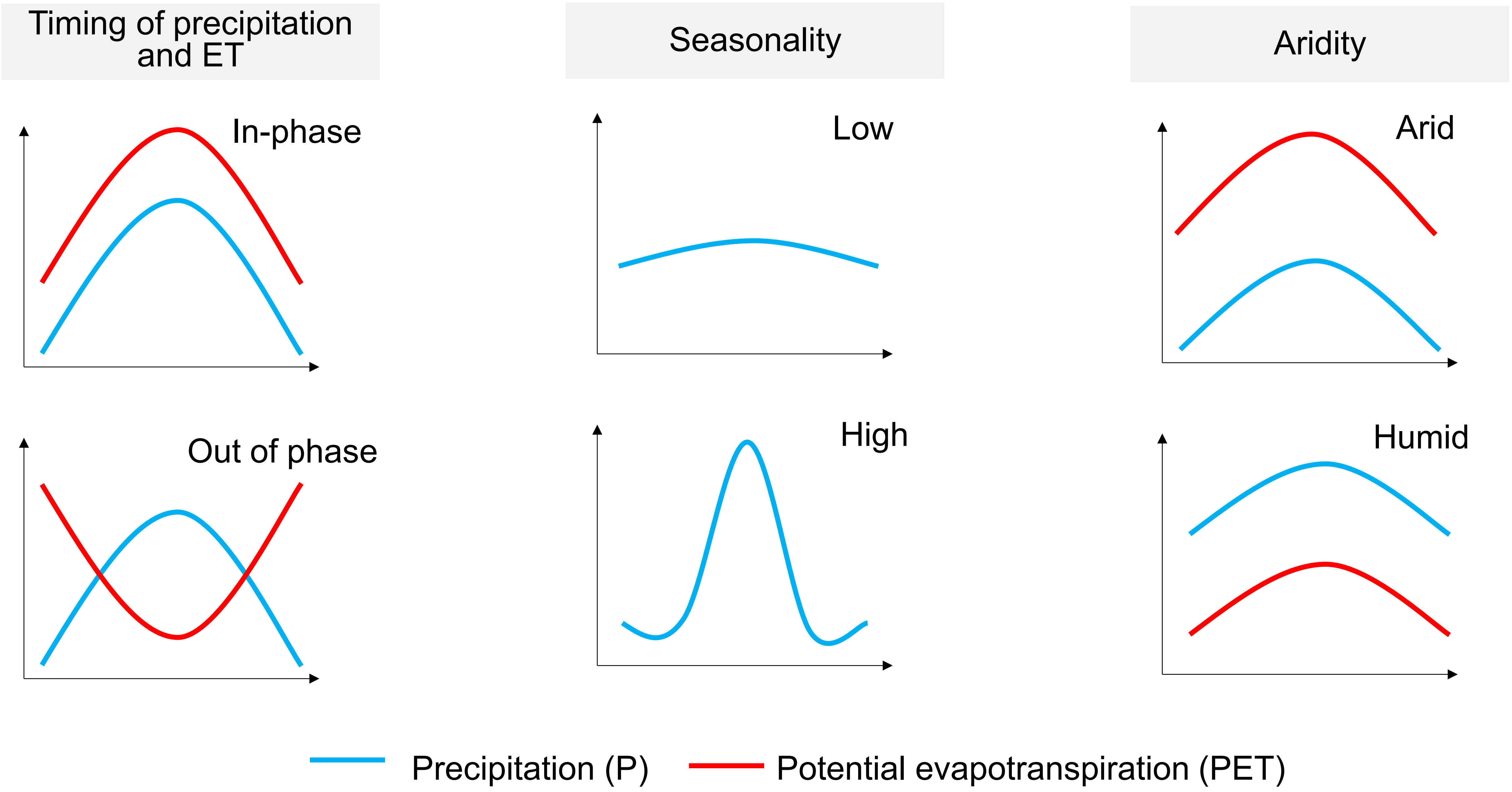


Study areas



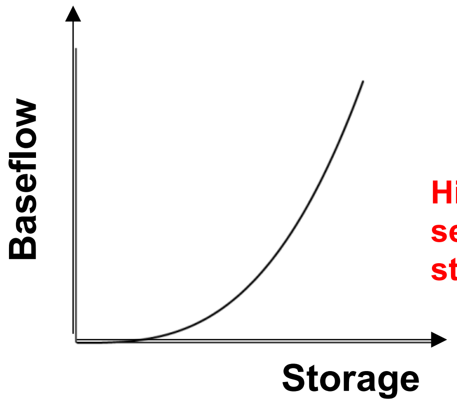
Selected study watersheds in the Contiguous United States (CONUS) with various climate and watershed properties

Regional climate characteristics – relation between P and PET



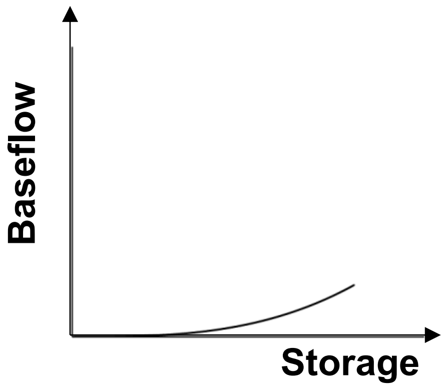
Factors affecting storage-discharge relationships

Western US



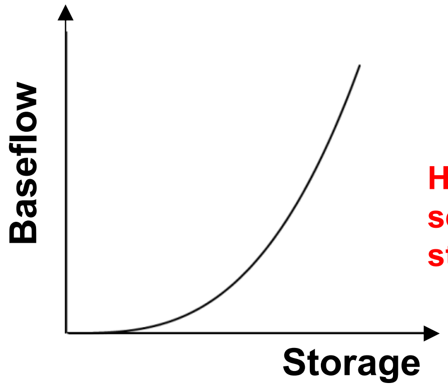
High discharge sensitivity to storage

Great Plains



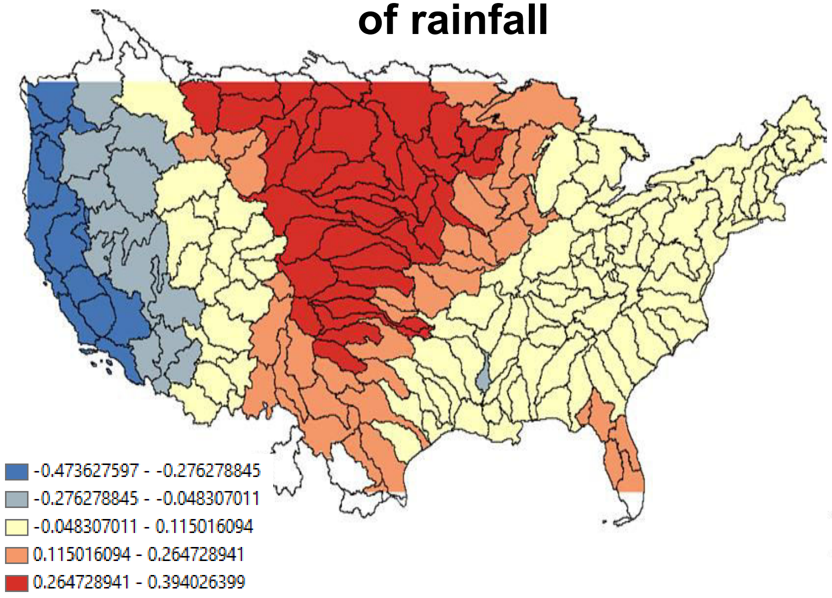
Low discharge sensitivity to storage

Eastern US

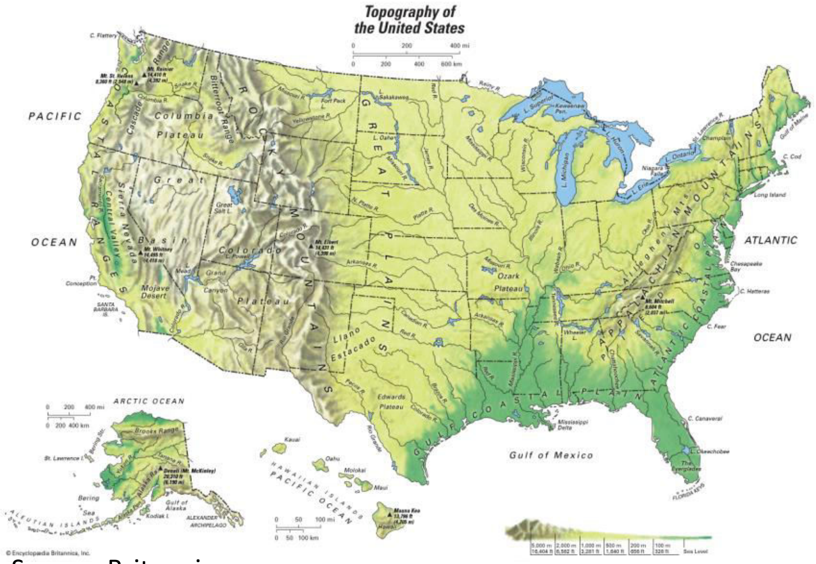


High discharge sensitivity to storage

Climate: aridity and timing of rainfall

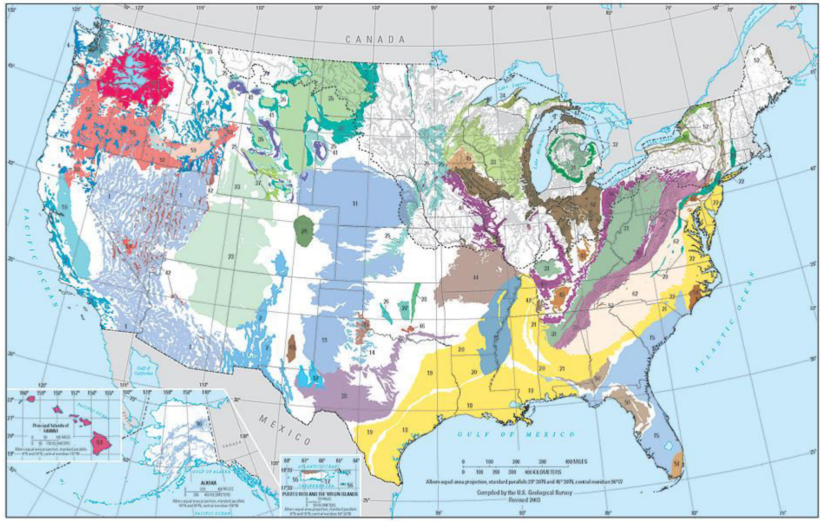


Topography



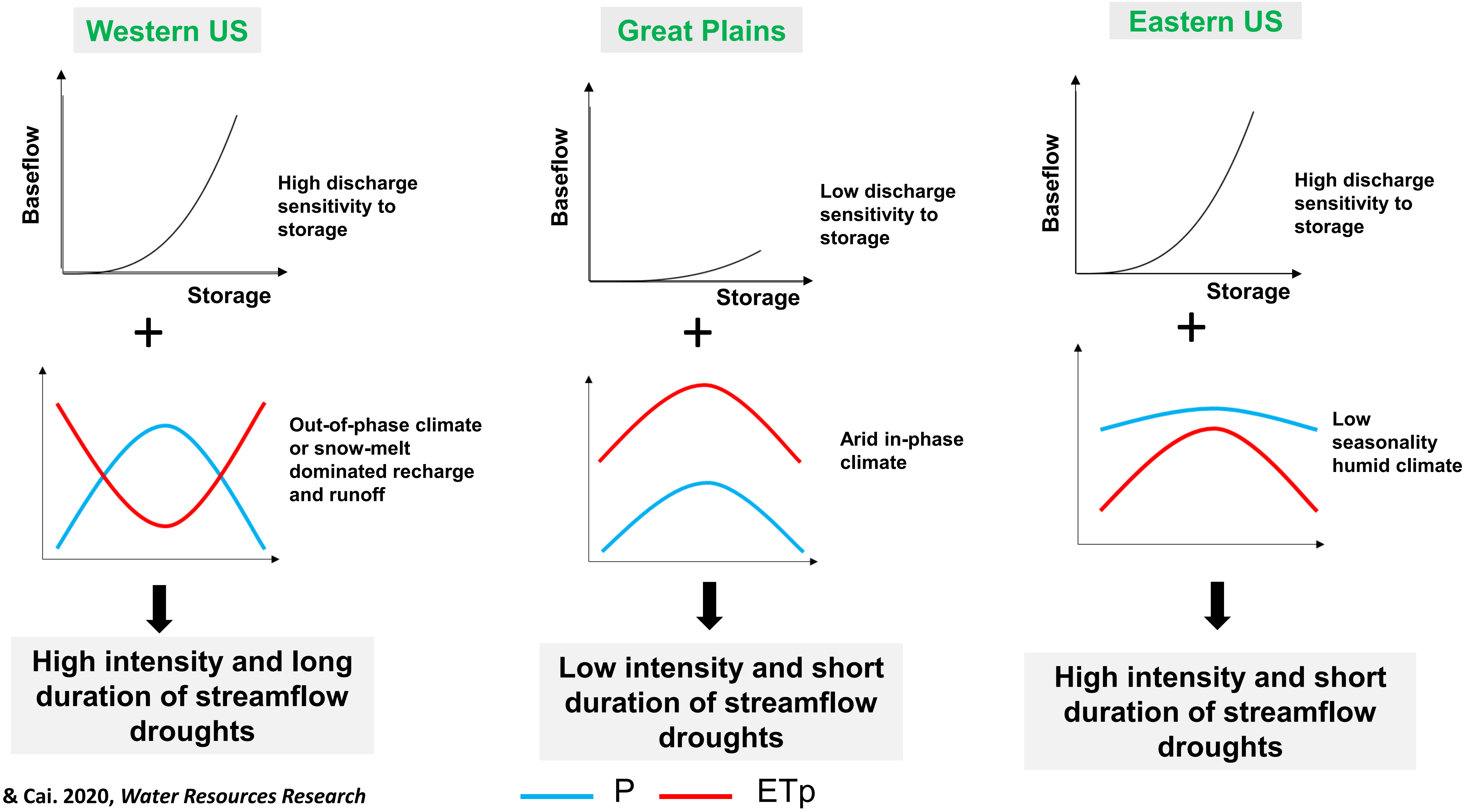
Source: Britannica

Geological properties



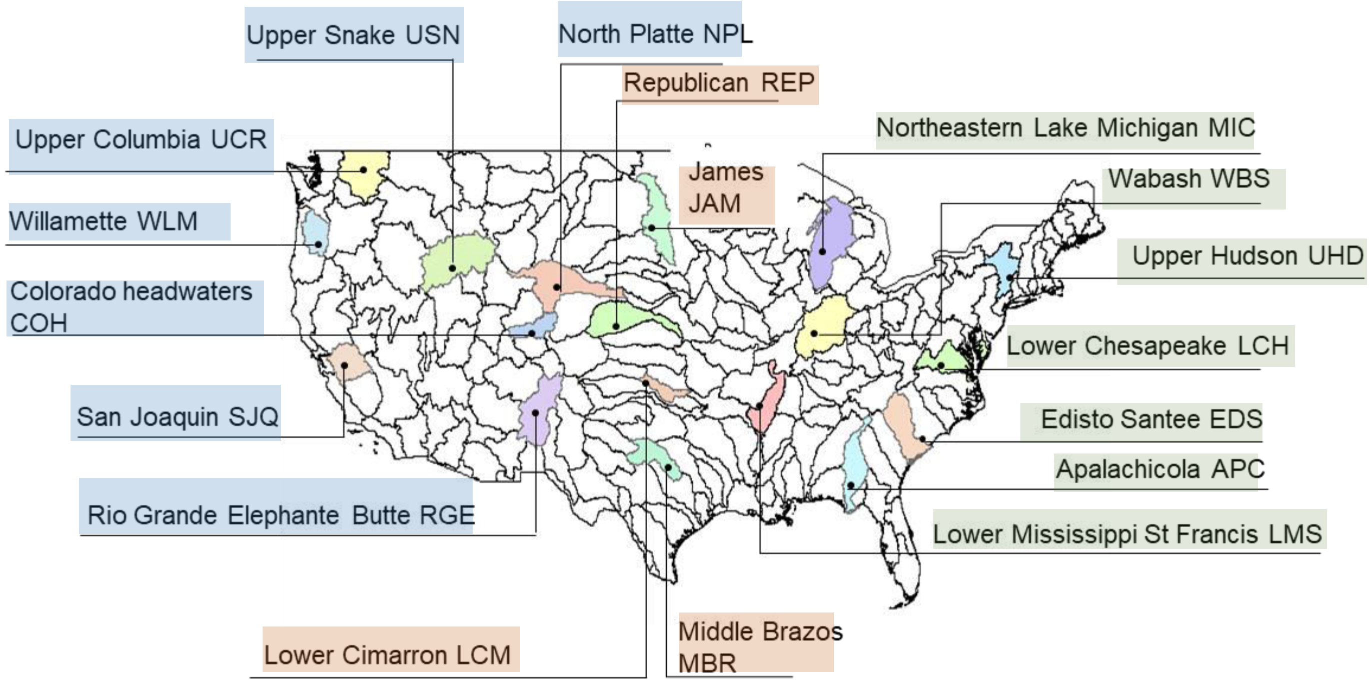
Source: USGS

Interaction of watershed and climate properties: impact on hydrologic drought



Apurv & Cai. 2020, *Water Resources Research*

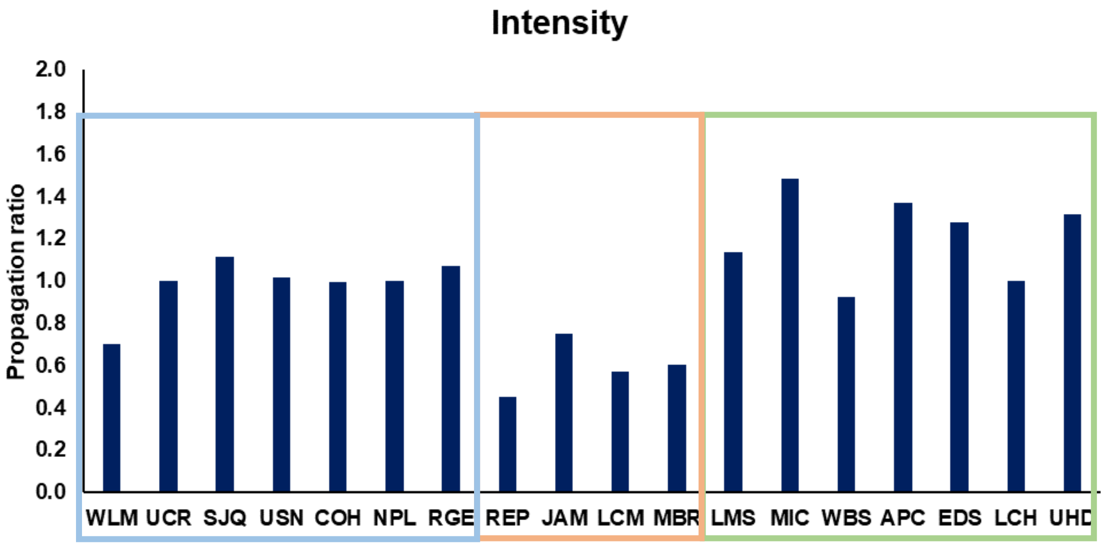
Hydrologic drought results

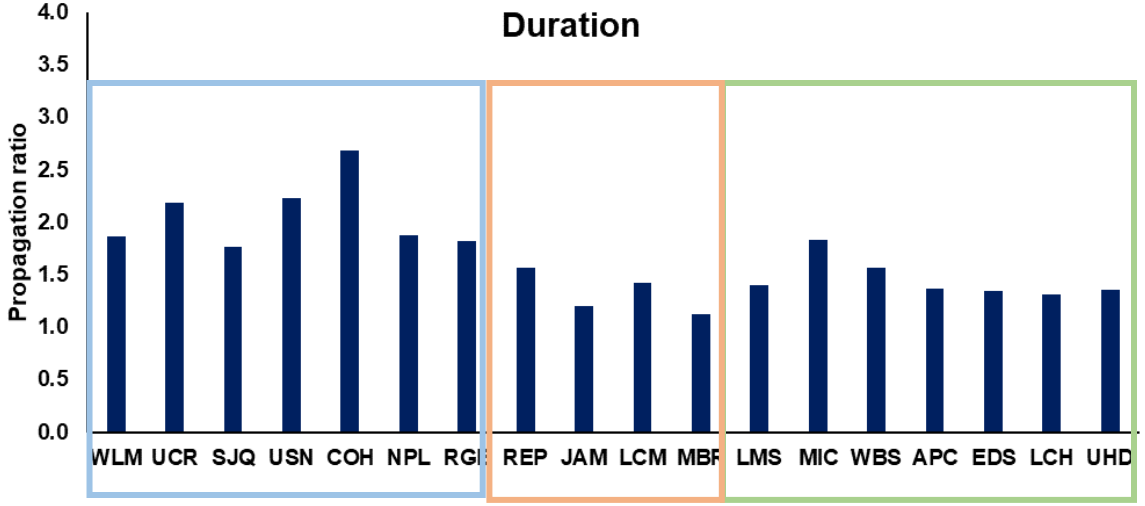


Eastern US High intensity and Low duration

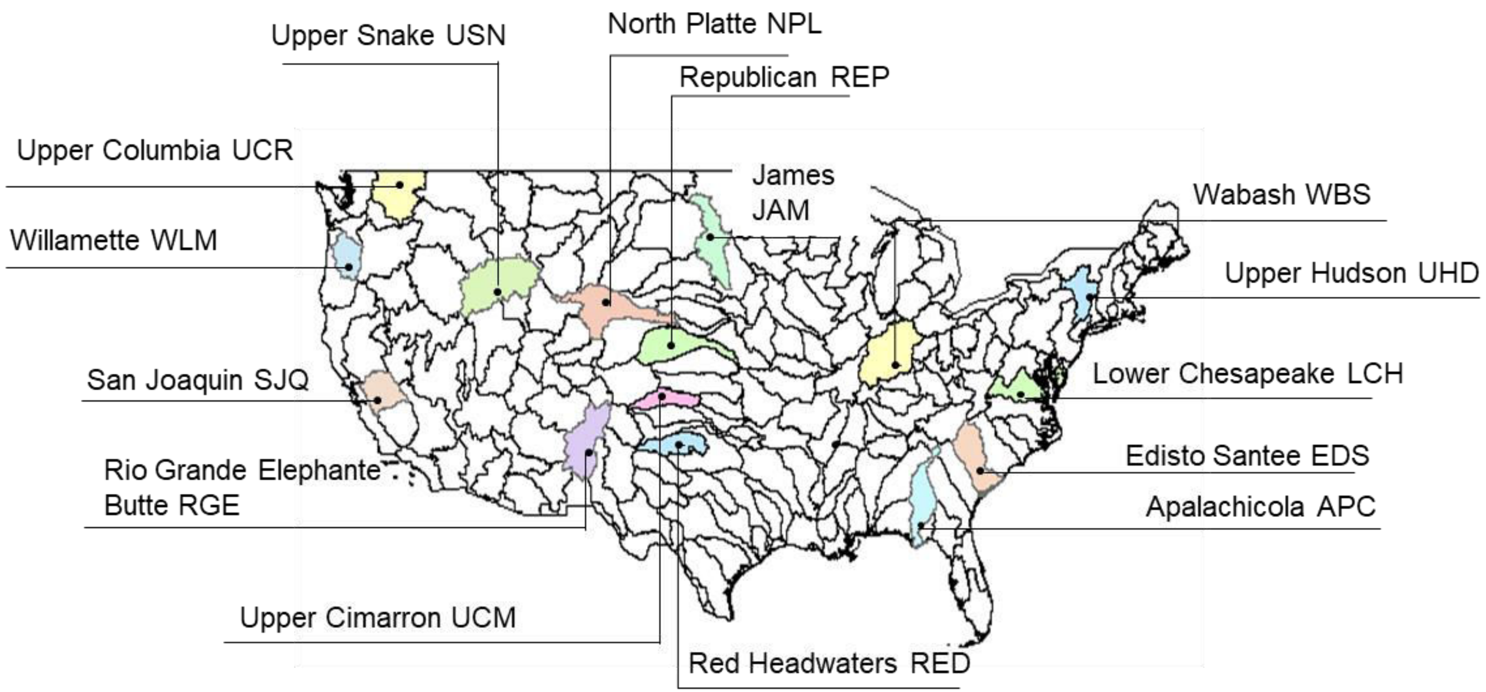
Great plains Short duration and low intensity

Western US High duration and high intensity

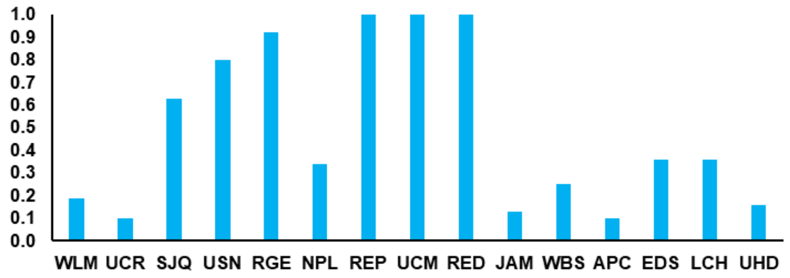




Water supply system characteristics

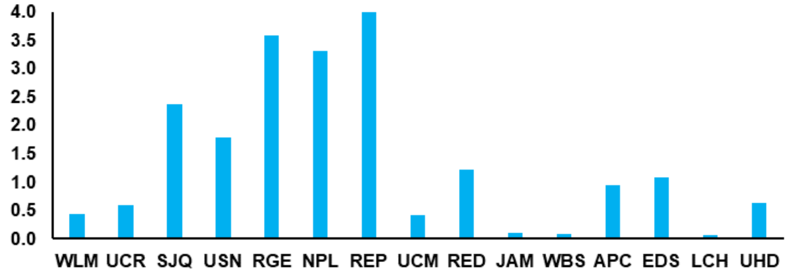


Water demand



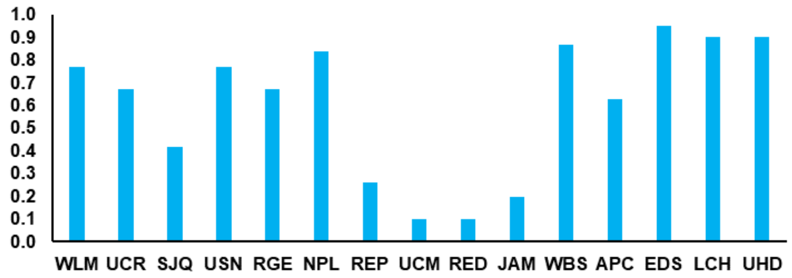
$$\alpha = \frac{\text{Water demand}}{\text{Mean annual streamflow}}$$

Storage capacity



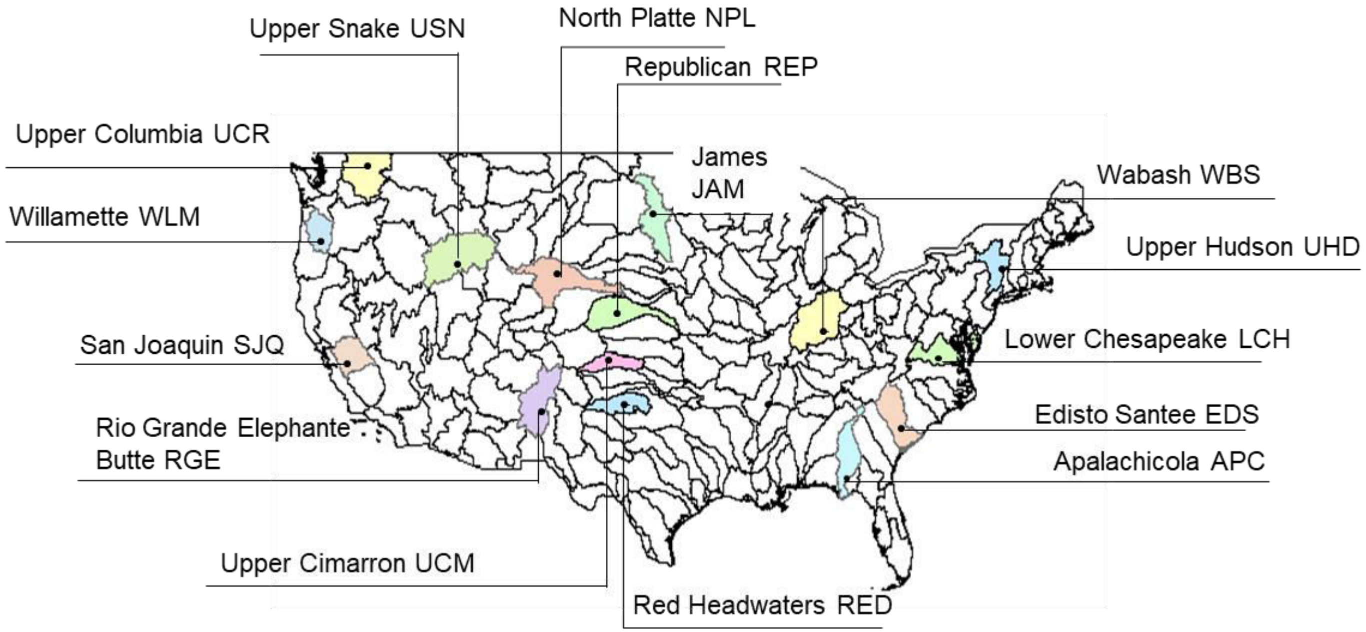
$$K_* = \frac{\text{Storage capacity}}{\text{Annual streamflow variability}}$$

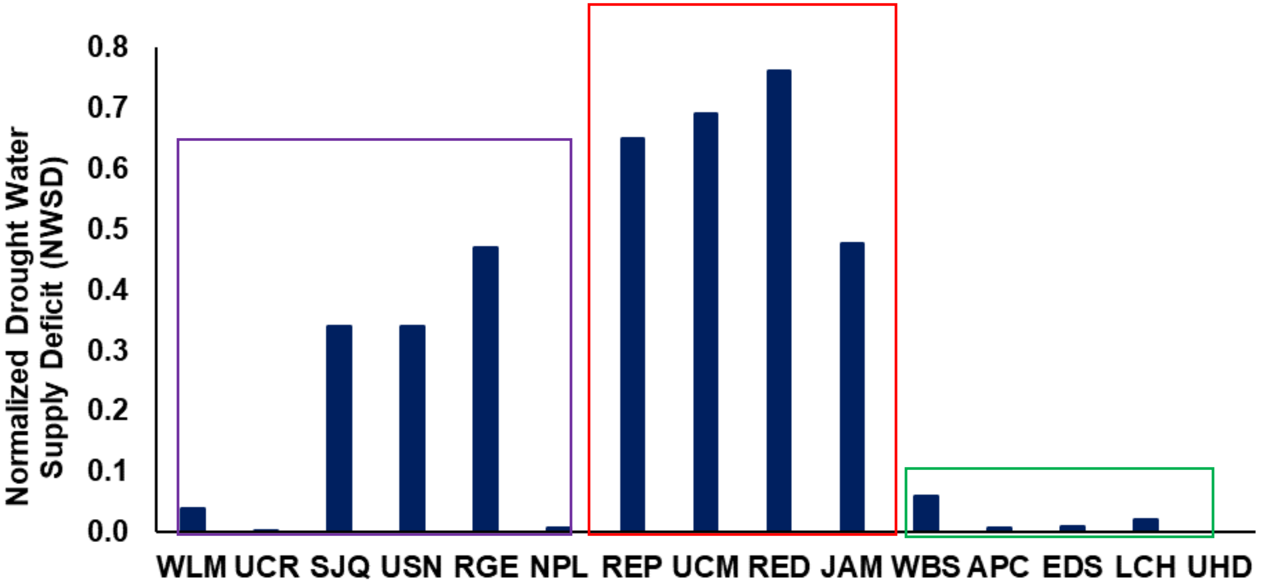
Surface water use fraction



$$swRatio = \frac{\text{Surface water demand}}{\text{Total water demand}}$$

Water supply deficits



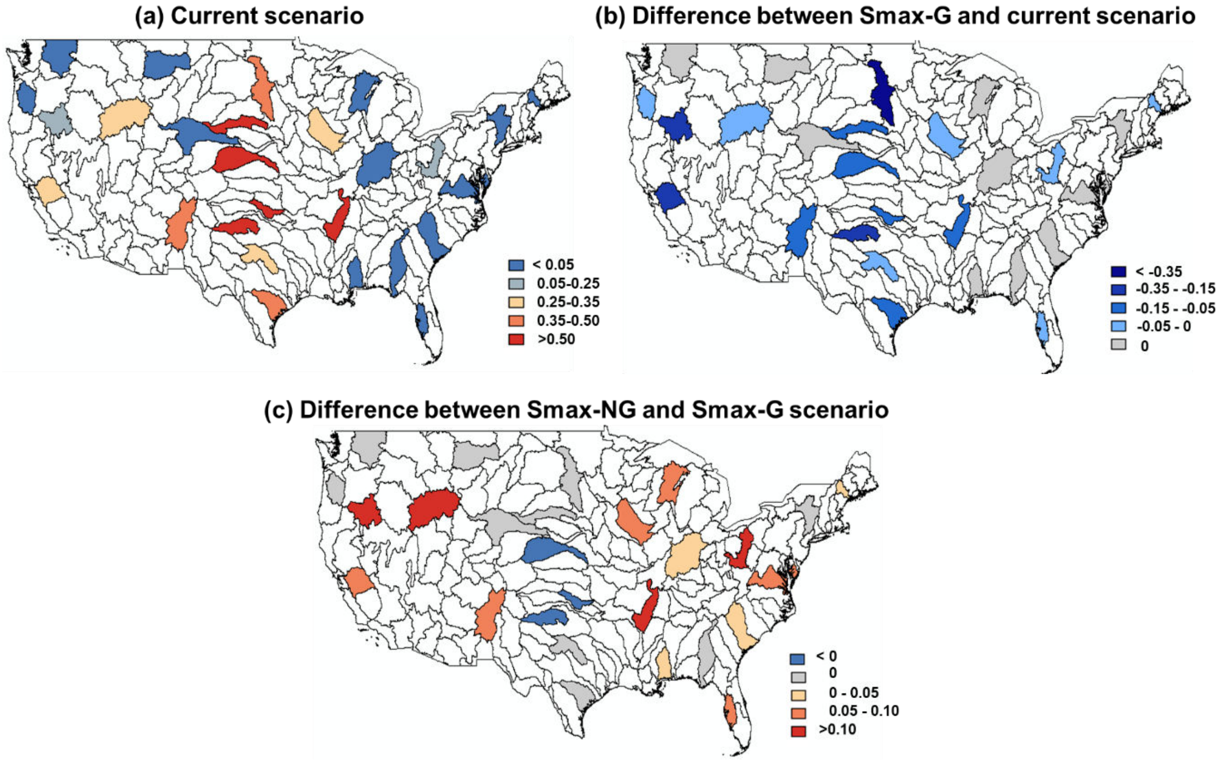


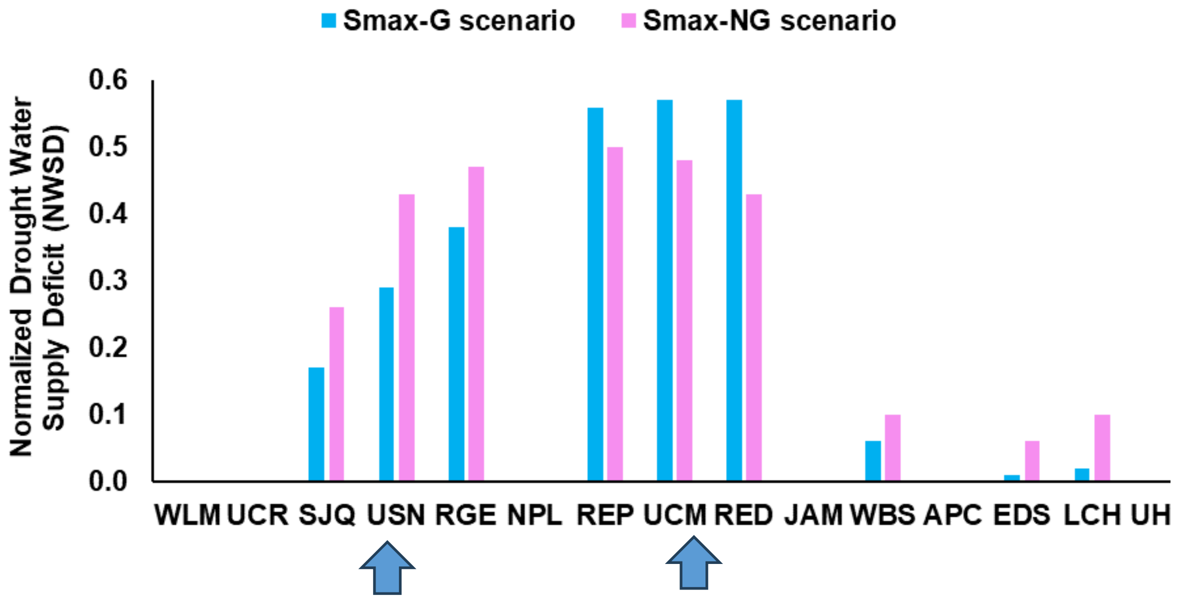
Modelling scenarios to explore the conjunctive use of surface and groundwater:

BAU	Current use of surface and groundwater
Smax-G scenario	Surface water is used for water supply, and groundwater is used only when surface water is not available
Smax-NG scenario	Only surface water is used, and groundwater pumping is not allowed

Effect of surface and groundwater use

Water supply deficits





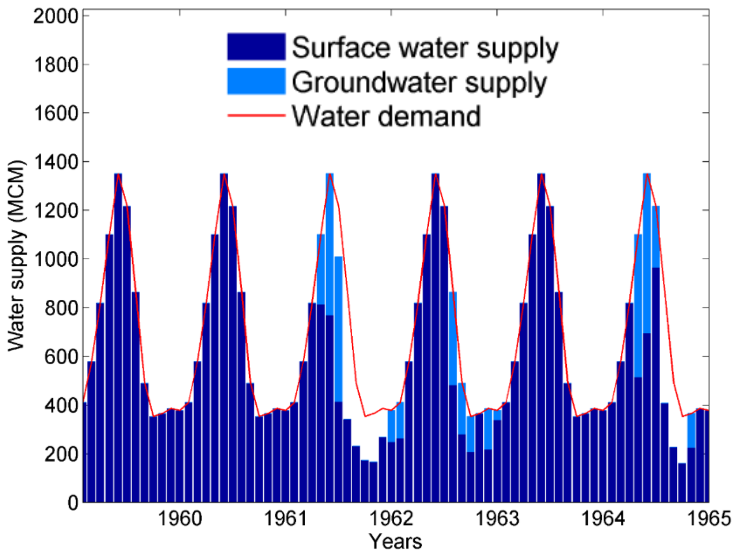
Groundwater recharge through winter precipitation can supplement surface water supply during droughts.

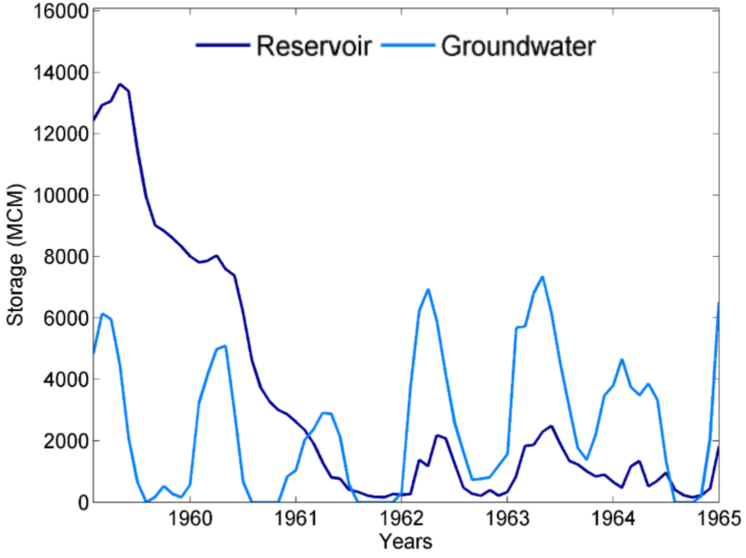
The alluvial aquifers in this region provide a stable baseflow

Example from Western US: San Joaquin

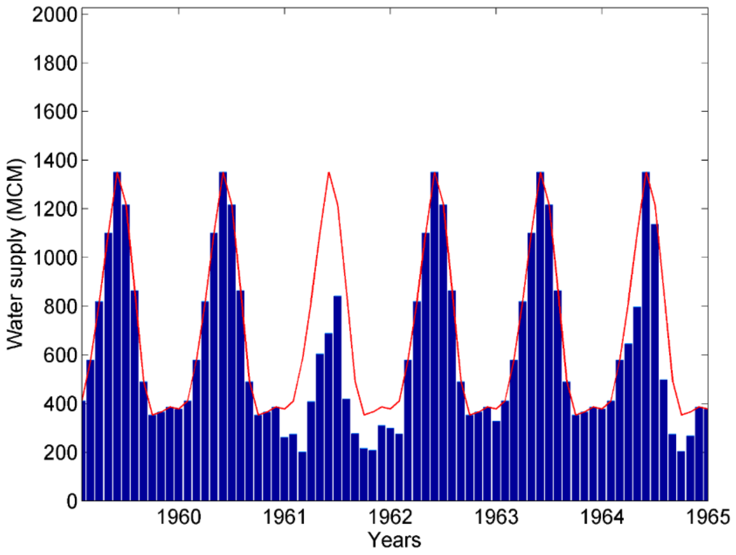
Water Supply | **Storage**

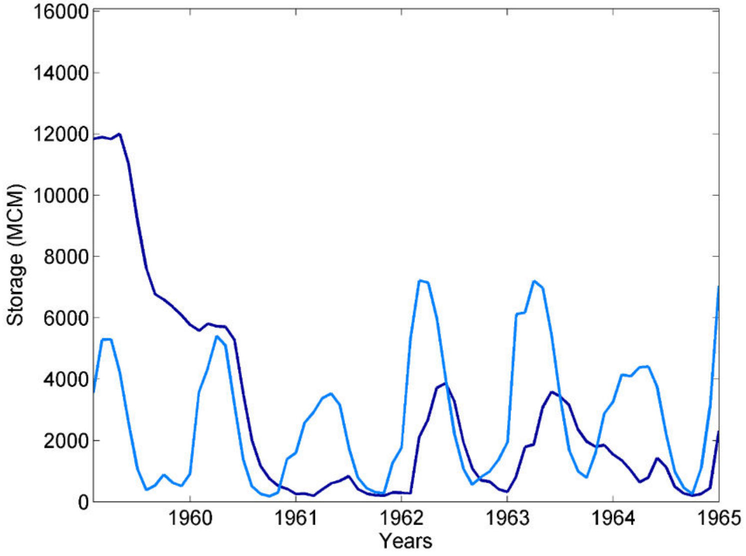
With groundwater pumping





Without groundwater pumping



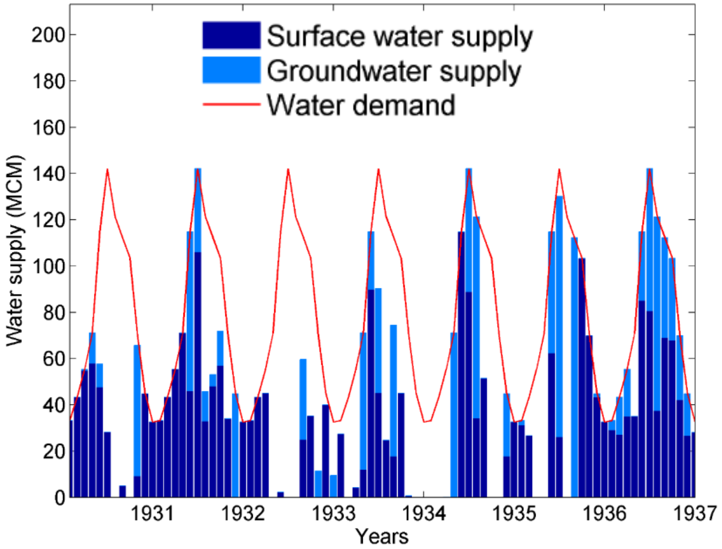


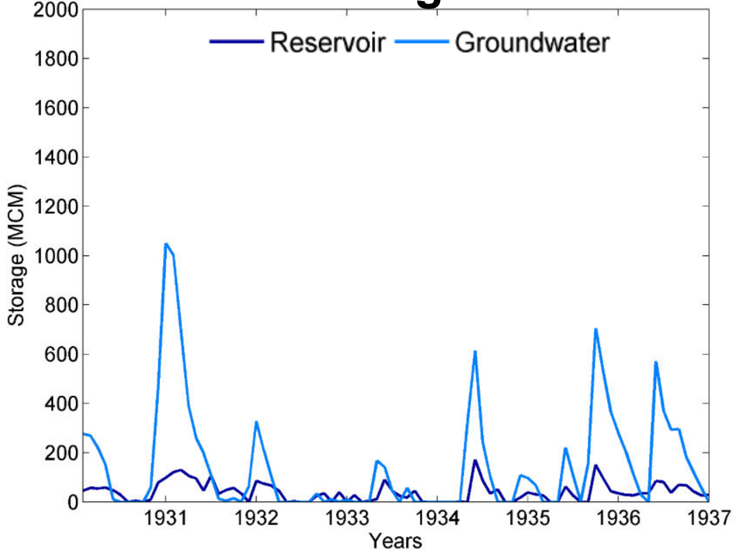
Water supply deficits are lower when both surface and groundwater are used

Example from Great Plains: Red Headwaters

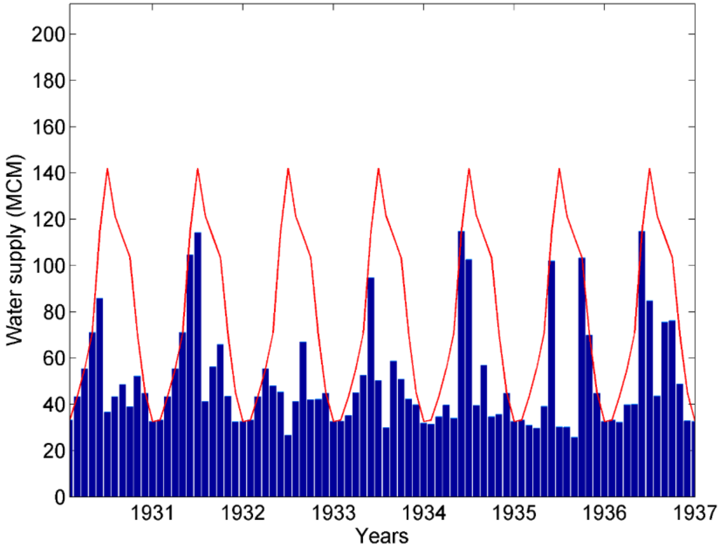
Water Supply | Storage

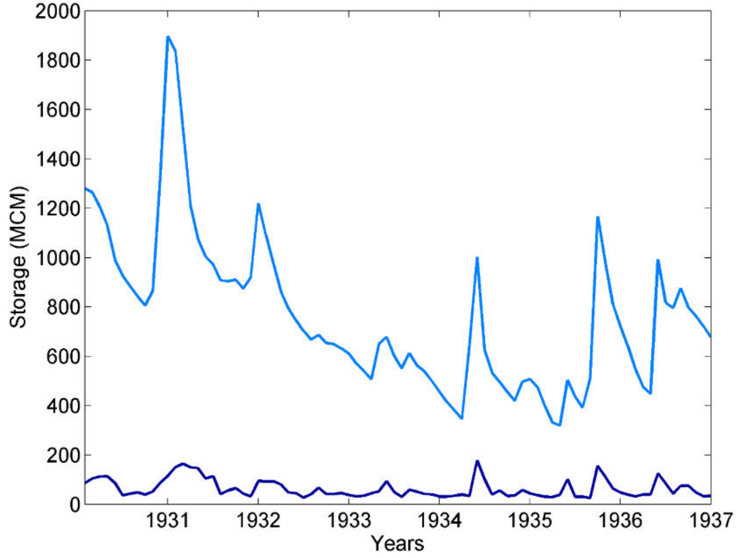
With groundwater pumping





Without groundwater pumping





Water supply deficits are lower when only surface water is used

Implications

- In WUS watersheds: the groundwater use in these watersheds is not confined to the drought periods and is also being used to meet water demands in normal or wet years, leading to depletion of groundwater storage for drought
    - Effective conjunctive surface and groundwater use also requires an institutional structure- Groundwater Management Act was passed in 2014 in Californian, which emphasizes on recognizing the connection between surface and groundwater resources (Owen et al. , 2019).

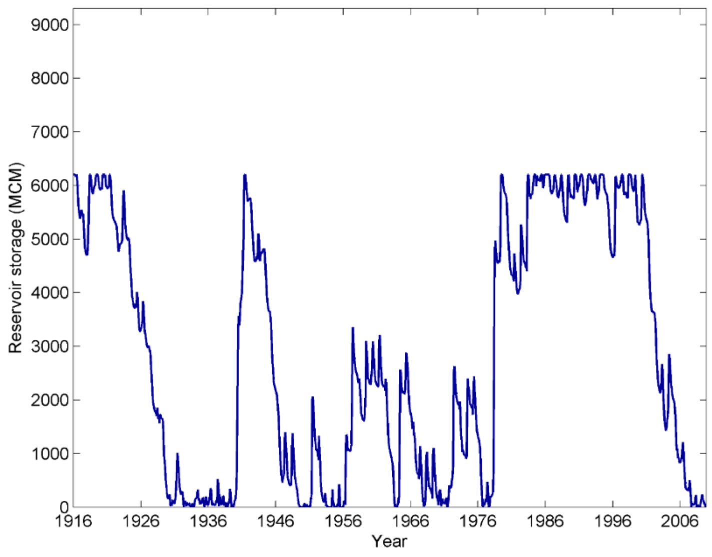
- In CUS, especially the Great Plains, the first need is to bring down the unstainable water use amount; the second is to make groundwater as a reserved resource for baseflow during drought events

- In EUS watersheds, several metropolitan cities lack access to groundwater; there is a need for expansion of storage capacity.

Conclusions

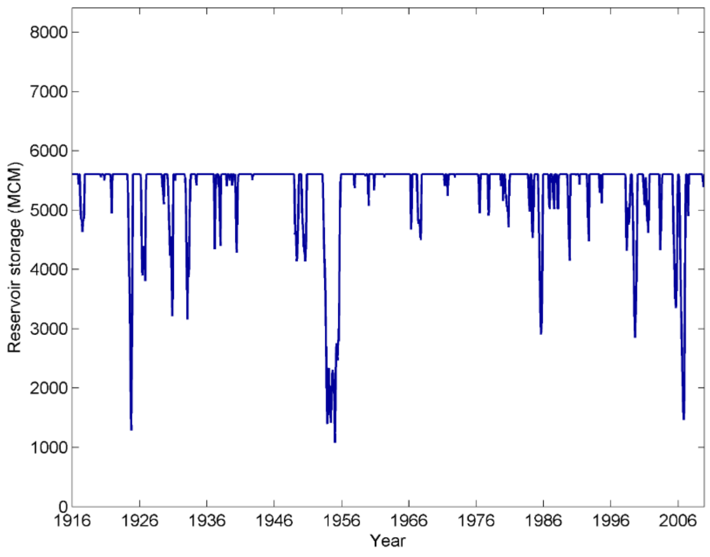
- A regional approach within the geo-context
- Drought propagation mechanisms based on natural and human factors
- The role of groundwater for drought preparedness

Contrasting water supply systems in southwest and southeast US



Rio Grande

$(K_* = 3.59)$



Apalachicola

$(K_* = 0.95)$

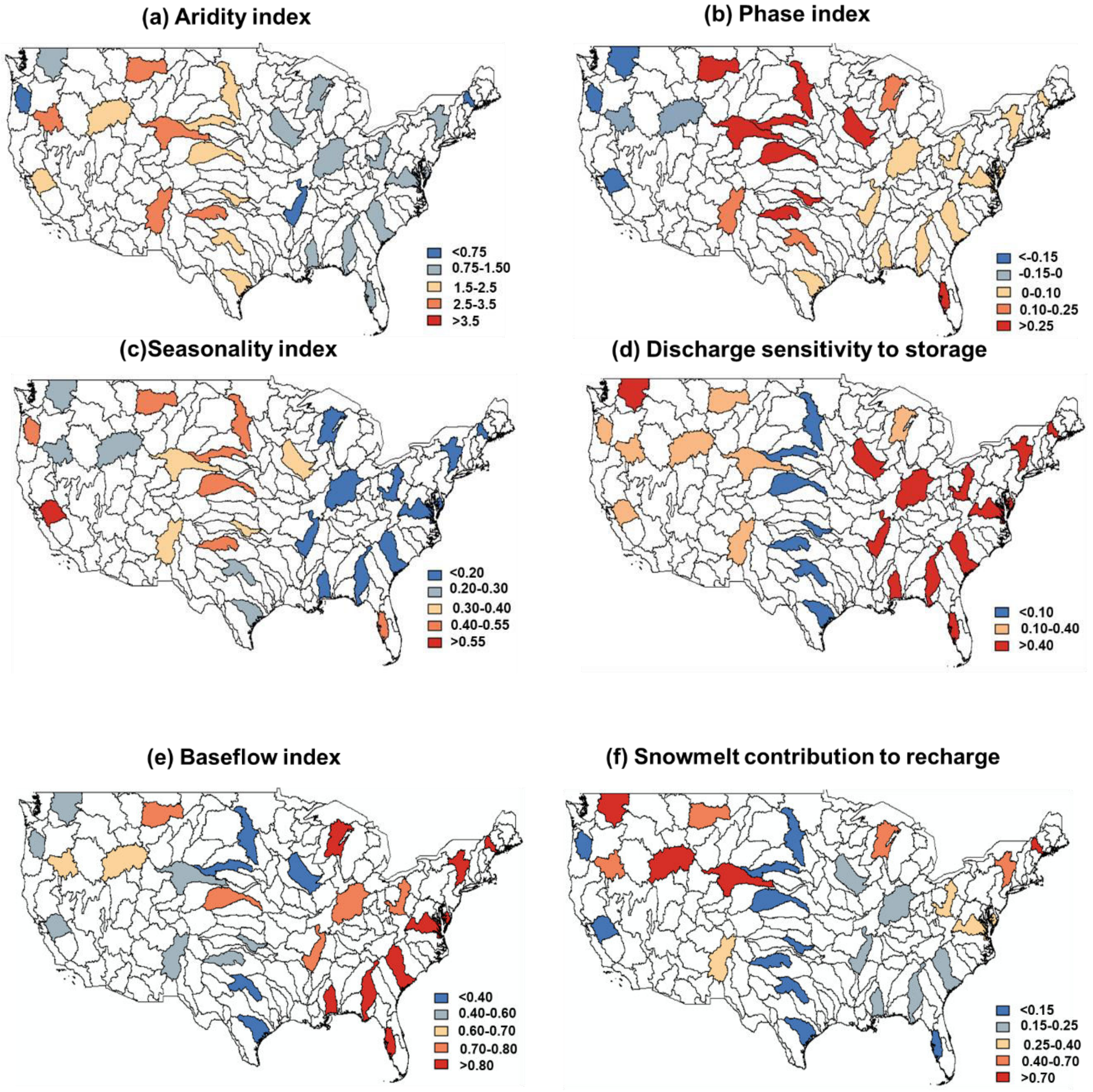
$$K_* = \frac{\text{Storage capacity}}{\text{Annual streamflow variability}}$$

Vulnerability of water supply droughts in southeast US

- Increased drought frequency since 1980s
- Increasing municipal and thermoelectric power water demands; the region has the fastest population growth rate in the US
- Several metropolitan cities in the region lack access to groundwater
- Capacity expansion may be required to mitigate water supply droughts in the future

Apurv & Cai. 2020, *Earth Future*

Factors affecting storage-discharge relationships



Climate and watershed properties of the selected watersheds

While the watersheds in the WUS have a winter dominated precipitation regime, those in the CUS receive most precipitation in summer (Fig b).

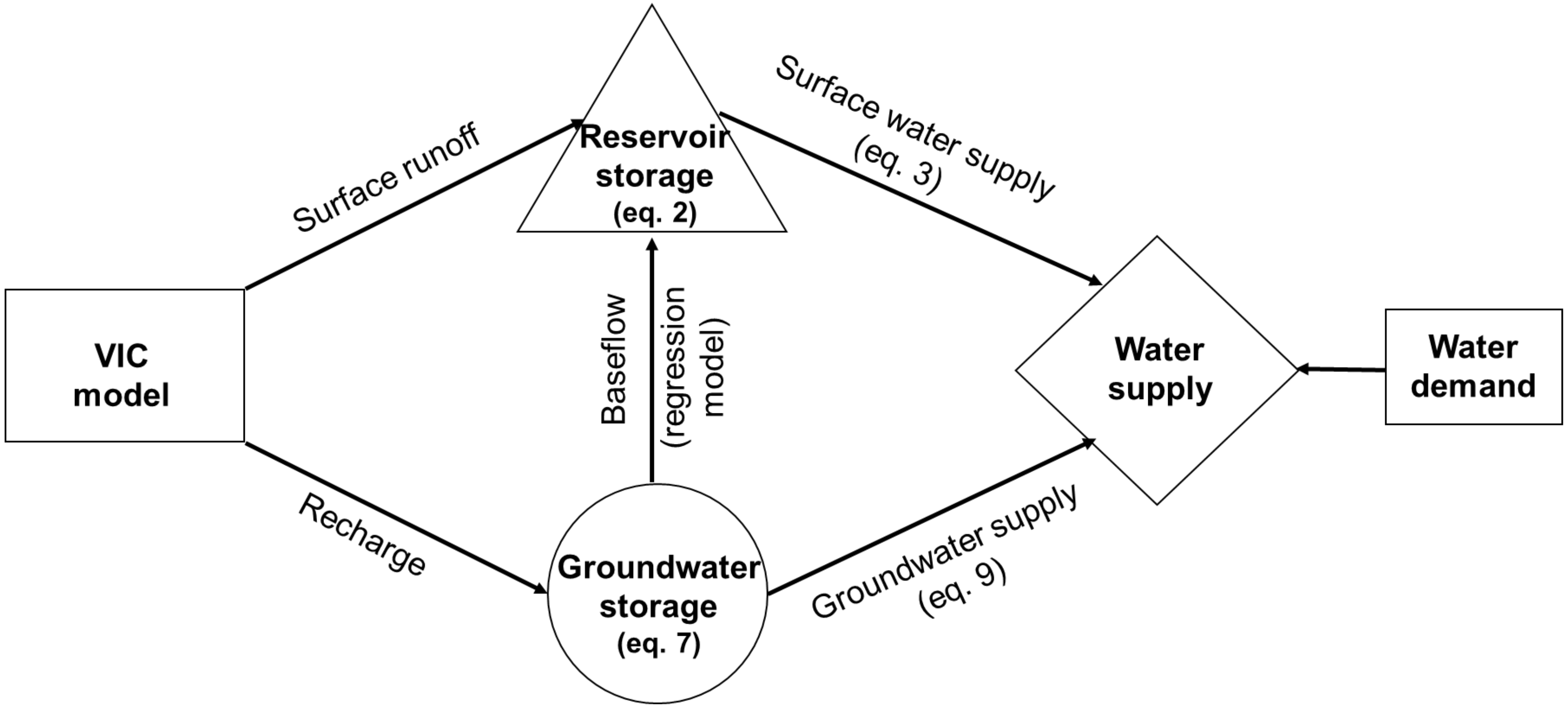
The seasonality of precipitation is high in the CUS watersheds and low in the EUS (Fig c).

The EUS watersheds have the strongest sensitivity of discharge with respect to deep-layer storage, followed by the WUS, and CUS (the Great Plains) very low sensitivity in the deep-layer storage (Fig d).

Baseline index is highest in the EUS and lowest in the Great Plains watersheds (Fig e).

Snowmelt plays an important role in the recharge generation in the watersheds of the Rocky Mountain region, Great Lakes region and in the northeast US (Fig f).

Water supply deficit assessment – an integrated hydrologic-infrastructure model



Schematic diagram of the water supply system model. VIC model is used for estimating surface runoff and recharge, which are used as inflows for the reservoir and recharges to groundwater, respectively. The surface and groundwater storages are connected through baseflow, which is modelled as a function of groundwater storage using a regression model.