ARIZONA TRI-UNIVERSITY

RECHARGE AND WATER RELIABILITY PROJECT

WRRC Water Webinar:

A Guide to Key Findings

August 13, 2026

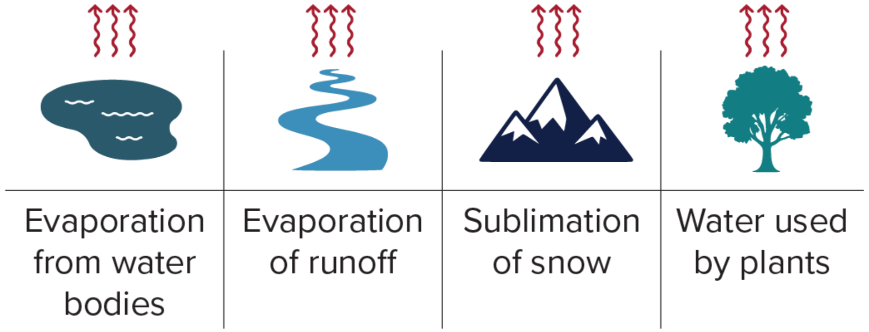
ASU Arizona State University

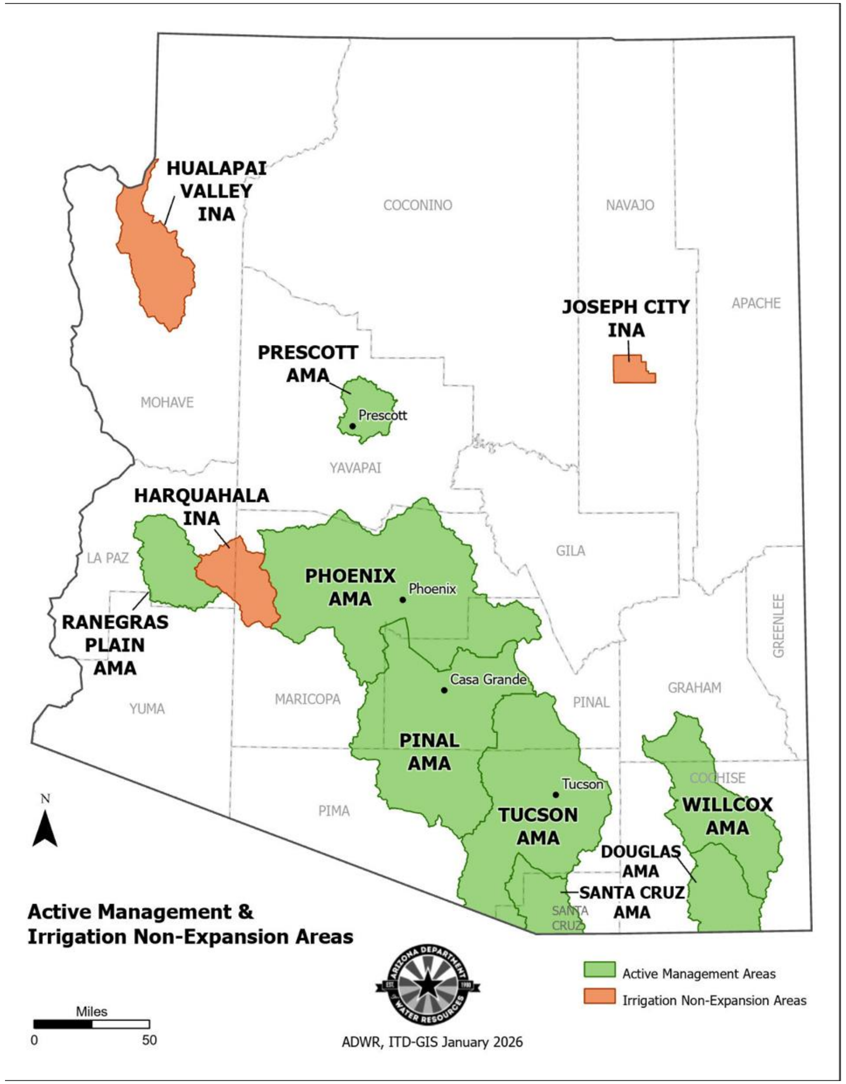
The University of Arizona

NAU Northern Arizona University

Guiding Question(s)

Where and *how* can we capture and recharge water that is currently lost to the atmosphere (evaporation, sublimation, or transpiration) or generated via enhanced runoff to enhance Arizona's groundwater supplies?





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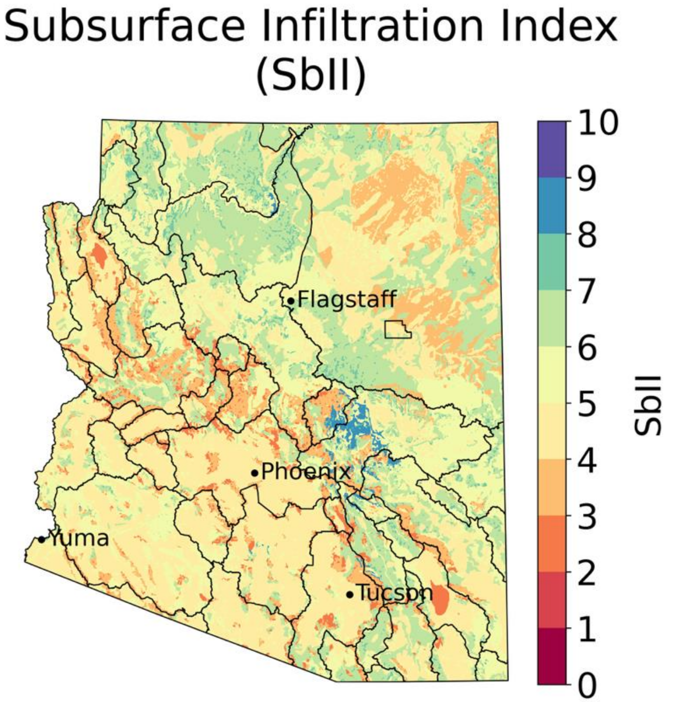
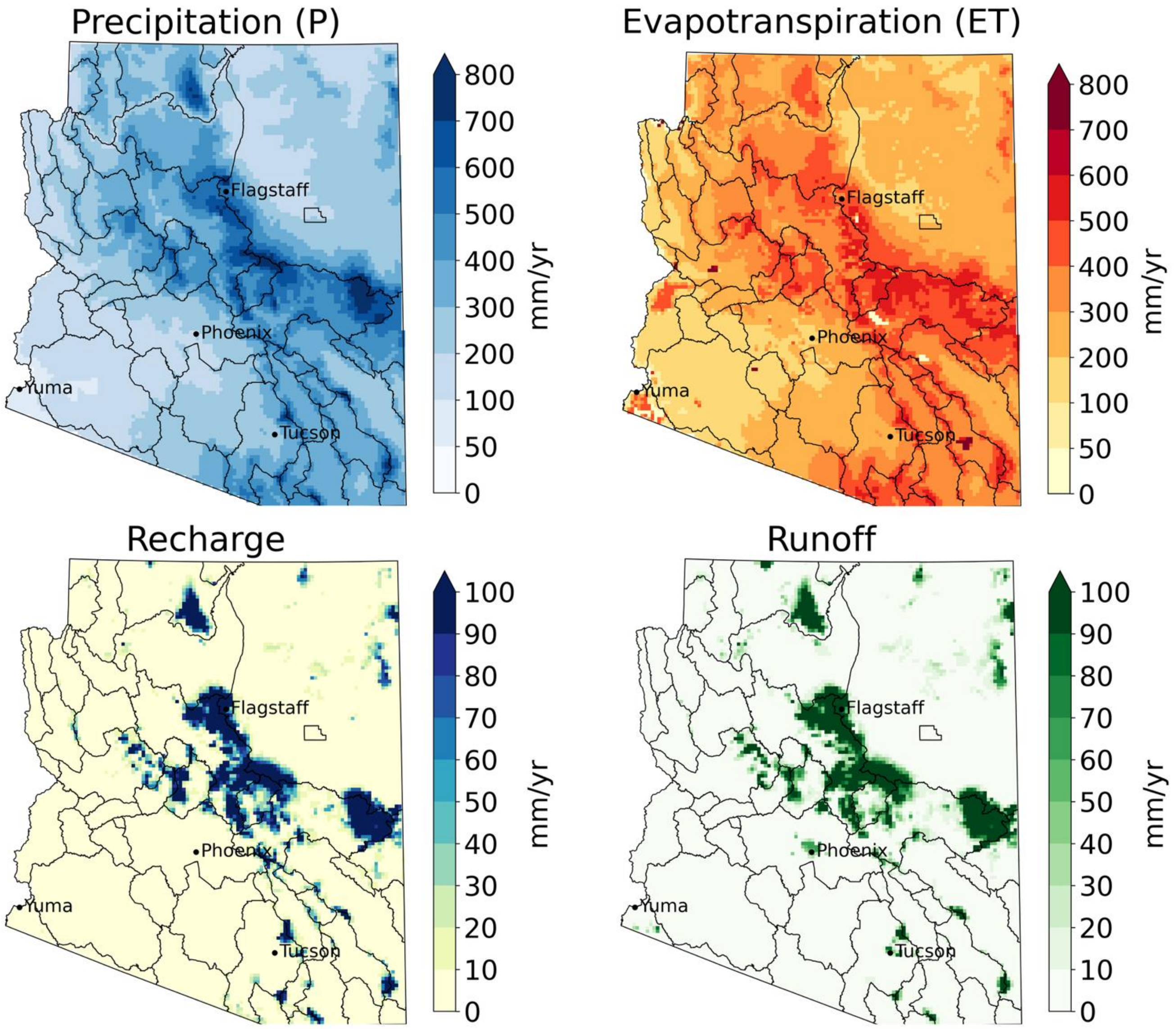
Where can we capture & recharge water?

Consider partitioning of the **natural hydrologic cycle** across the state and **underlying geology** suitable for recharge.





How can we capture & recharge water?

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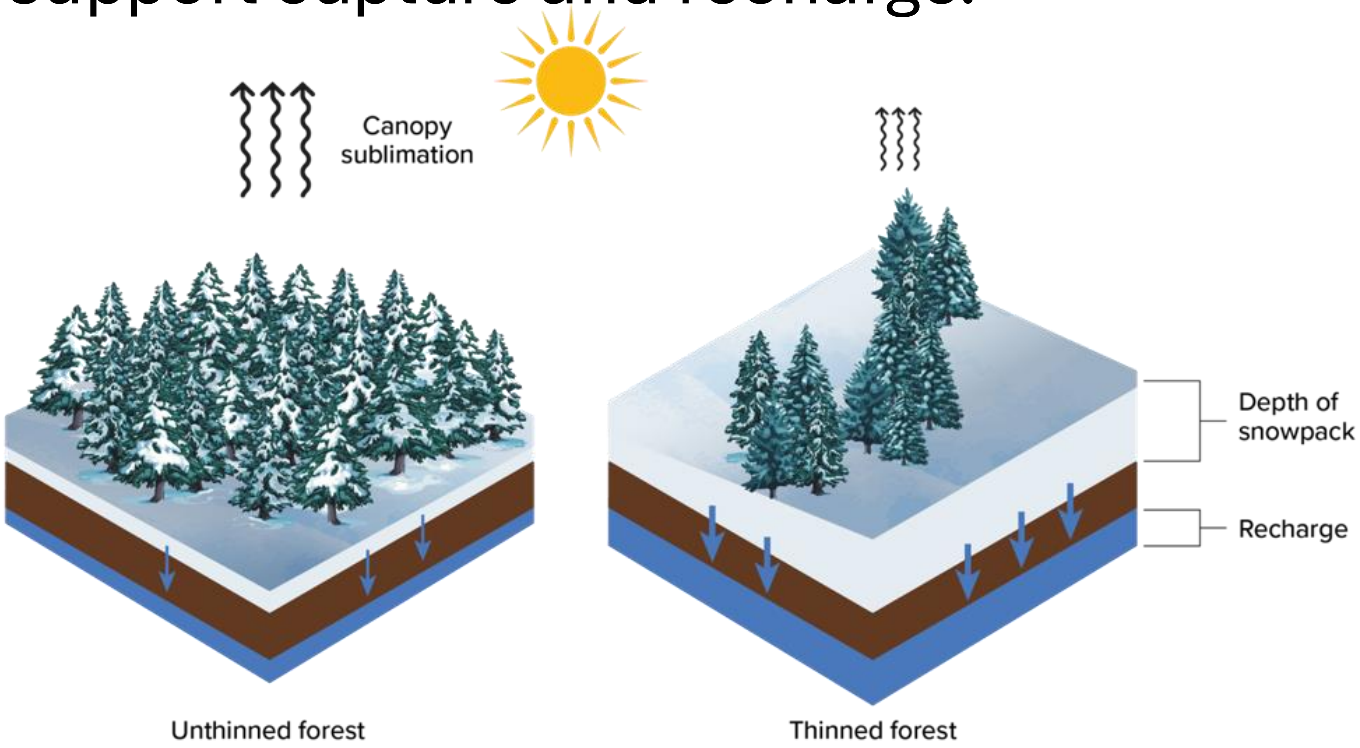
Consider how **land management strategies** can influence the natural hydrologic cycle to support capture and recharge.

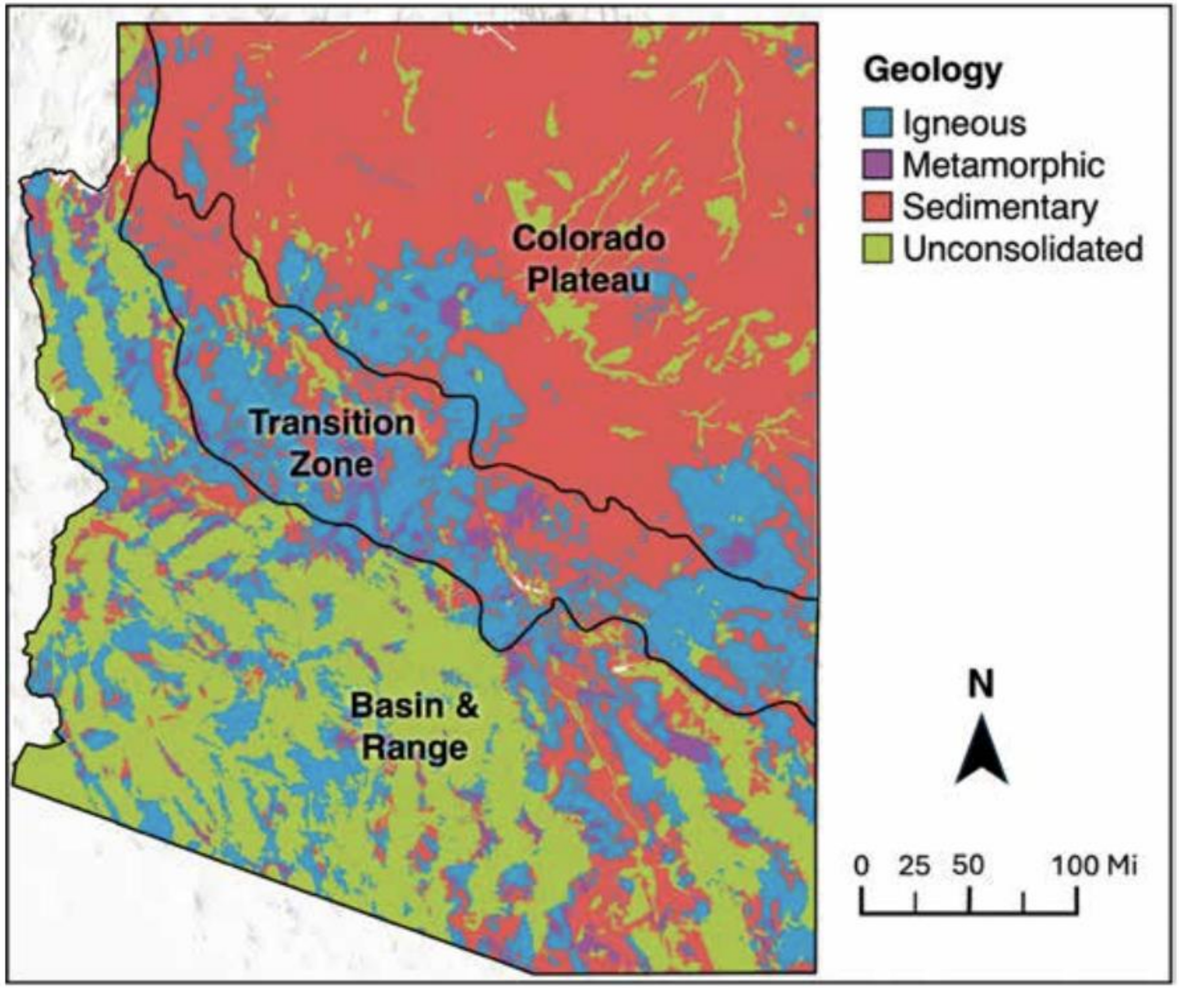


Forest thinning in intentional patterns can reduce sublimation and increase depth and persistence of snowpack. Longer lasting snowpack leads to slower melting, which increases the likelihood of groundwater recharge.

San Carlos Apache Tribe Restoration Crew installing erosion control structures as part of a spring restoration project on Mt. Graham

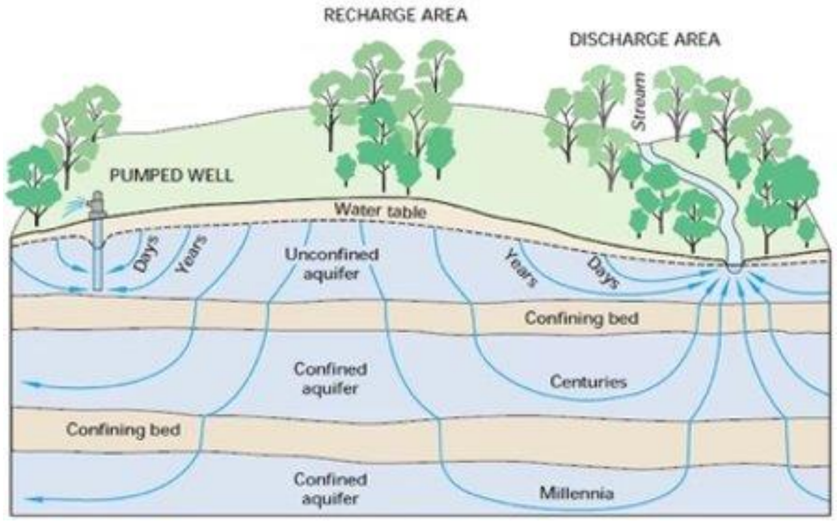
Arizona's Landscape Diversity

- Physiographic Provinces:
  - Basin & Range
  - Colorado Plateau
  - Transition Zone/Mogollon Rim
- Landscapes:
  - Forests
  - Grasslands
  - Urban
  - Rural



Fundamentals of Groundwater Recharge

- Groundwater recharge influenced by many factors:
  - Depth to groundwater
  - Subsurface properties (e.g. fractures, clay layers)
  - Frequency of water availability
  - Ponding time(s) of water
- Variation through time:
  - Amount of water recharged can vary over time
  - Recharge time(s) can also vary from days to millennia



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Key Findings

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Statewide Hydroclimate Assessment

Modeling framework:

Meteorological forcing:
- Historical (1980-2020)
- Future (through 2099)

→

Noah-MP (4 km, 1 h)
+
NWM (1 km, 1 h)

→

Water balance components:
P + ET + Recharge + Runoff

Key products:
- *Historical and future statewide water balance reconstruction*
- *Climate-change projections through 2100*
- *Profiles for all 51 ADWR groundwater basins*

Arizona’s Natural Water Balance

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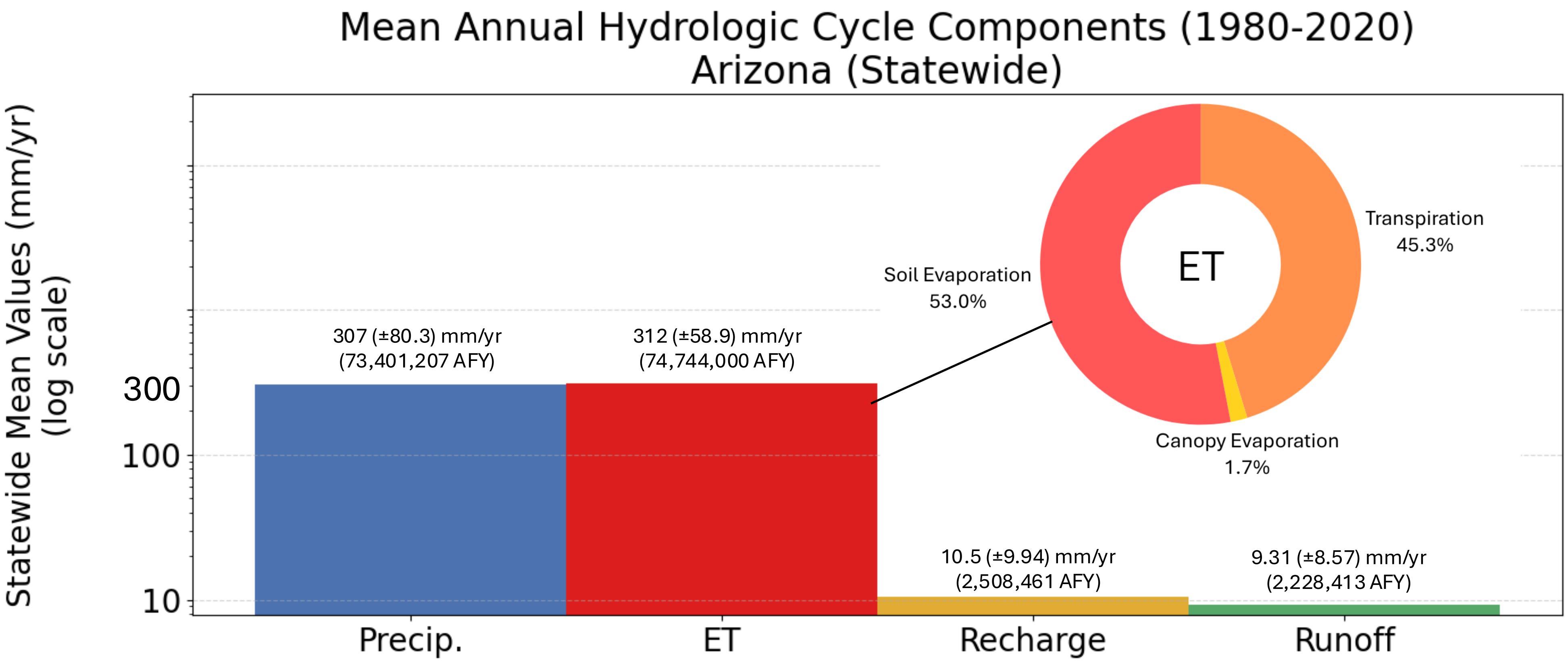

Most precipitation in Arizona returns to the atmosphere through evapotranspiration, while less than 3% becomes groundwater recharge

Where Does Recharge Occur in Arizona?

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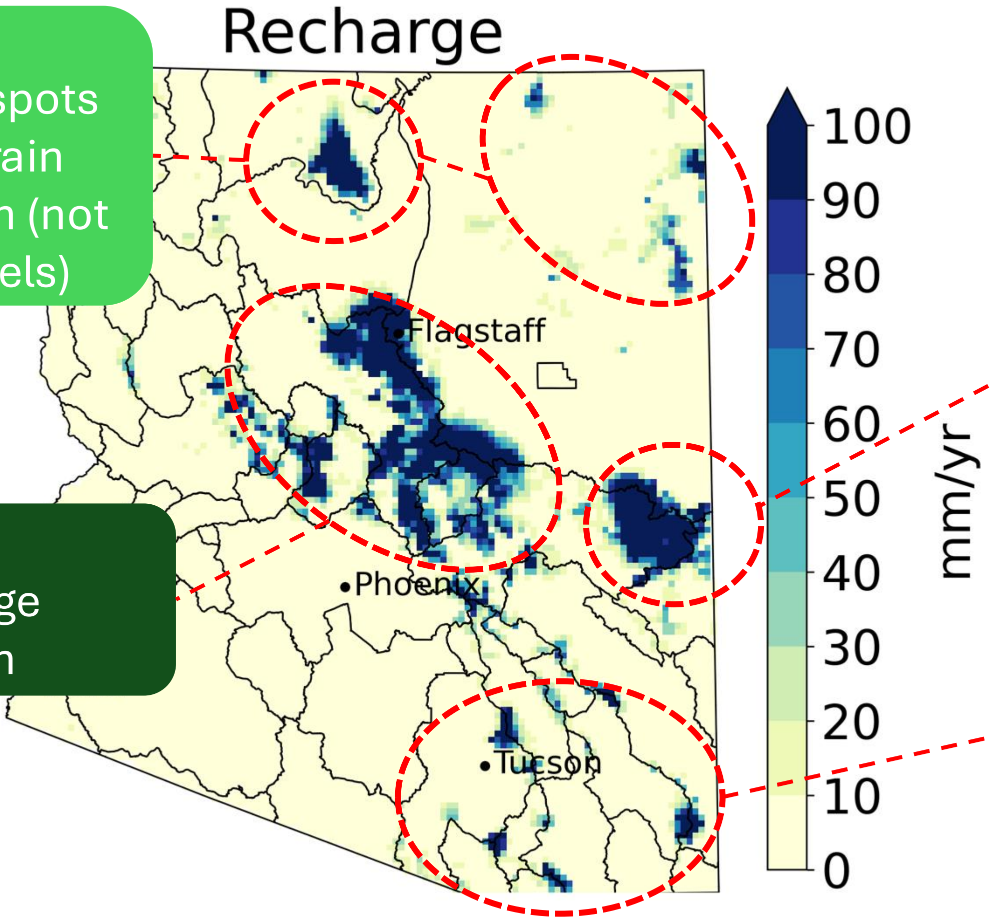
Colorado Plateau:
- Localized recharge hotspots
- Fractured and karst terrain may facilitate infiltration (not represented in the models)



Mogollon Rim:
- Highest statewide recharge
- Major water-source region

White Mountains:
- Important recharge and runoff generation

Sky Islands:
- Localized recharge hotspots

Recharge is not evenly distributed across Arizona:
- *Highest in mountainous source regions*
- *Lowest in southwestern desert basins*
- *Basin-scale variability ranges from <1% to >10% of precipitation*

When Does Recharge Occur in Arizona?

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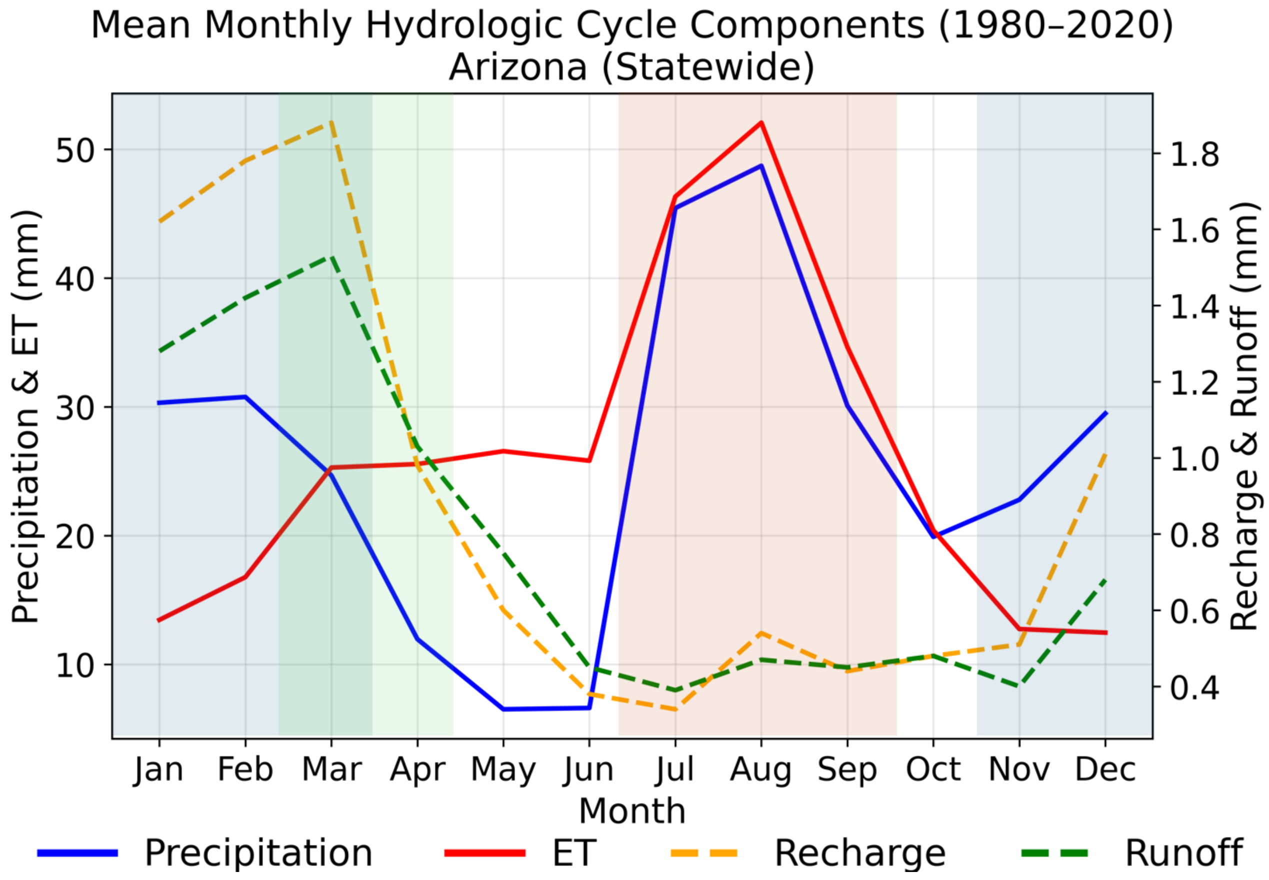


Winter frontal systems (Nov–Mar)
- Precipitation exceeds ET
- Water availability increases
- Recharge opportunities increase

Late winter–spring recharge peak (Feb–Apr)
- Peak recharge
- Peak runoff
- Influenced by winter precipitation and snowmelt in high-elevation watersheds

Summer monsoon (Jul–Sep)
- Large precipitation inputs
- ET also increases substantially
- Lower recharge efficiency than winter precipitation

Recharge is strongly seasonal:
- *Greatest during winter and spring*
- *Enhanced by winter precipitation and snowmelt*
- *Not all precipitation contributes equally to recharge*

Strengths and Limitations of Statewide Hydroclimate Modeling

Strengths:

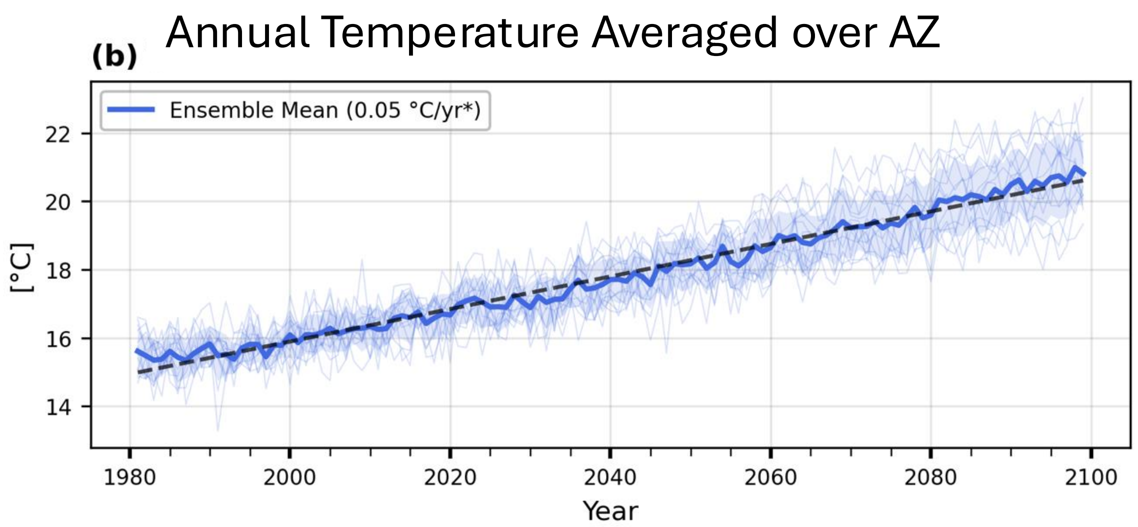
- Statewide and basin-scale water balance characterization
- Identification of recharge-producing regions
- Evaluation of spatial and seasonal variability
- Climate-change impact assessment
- Screening-level support for recharge opportunity assessment

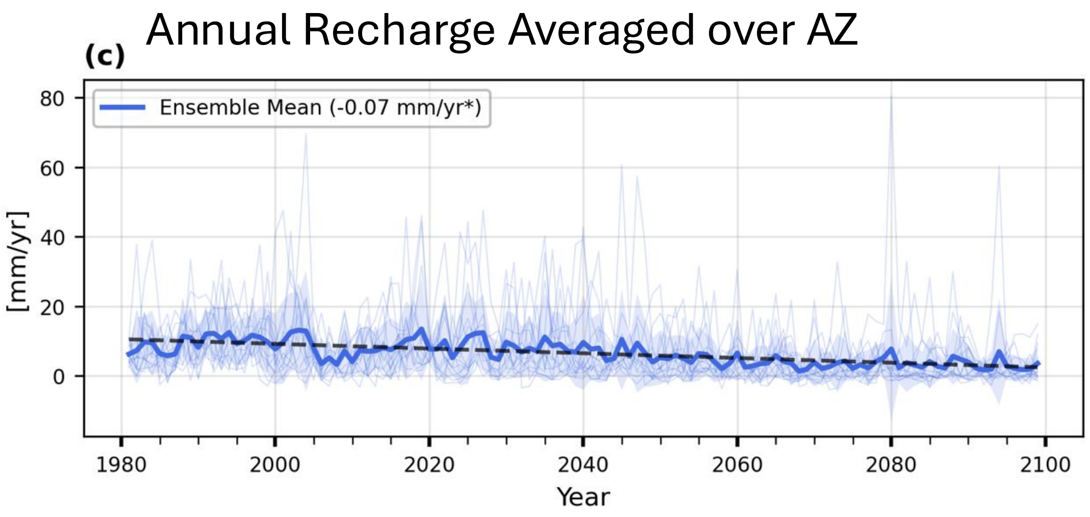
Limitations:

- Simplified groundwater processes
- No representation of karst and fractured-rock flow
- No groundwater pumping or managed recharge
- No irrigation, water deliveries, or reservoir operations in the natural water balance
- Not intended for at-site specific scales

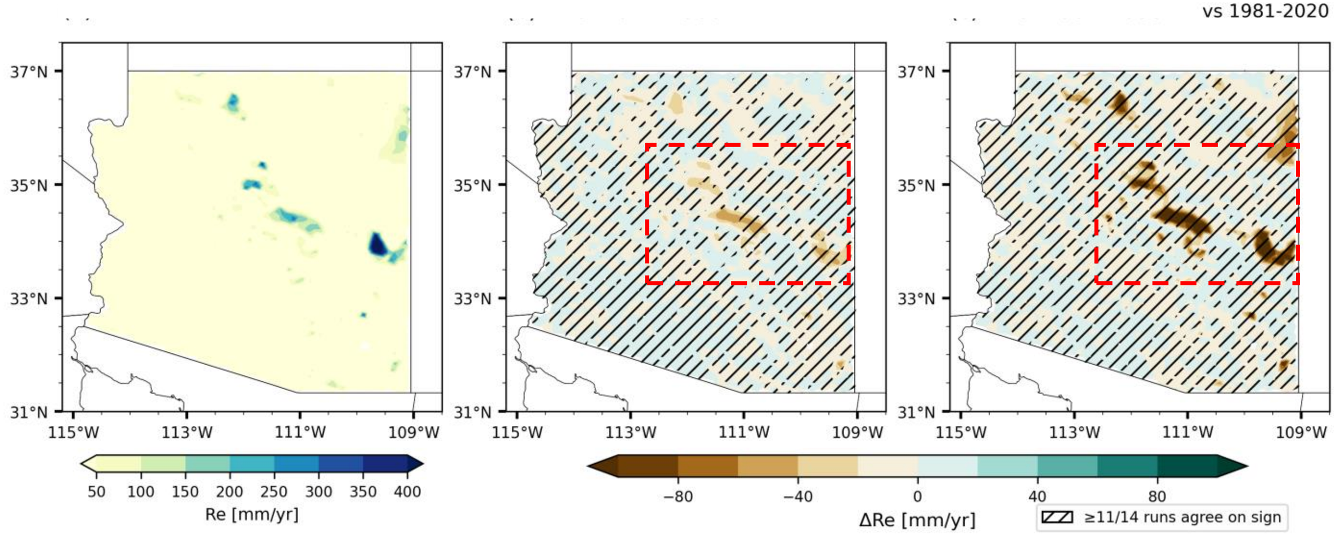
These models are powerful tools for understanding statewide patterns and supporting strategic planning, but local recharge assessments should also consider groundwater conditions, geology, and human water use

Future Climate Projection



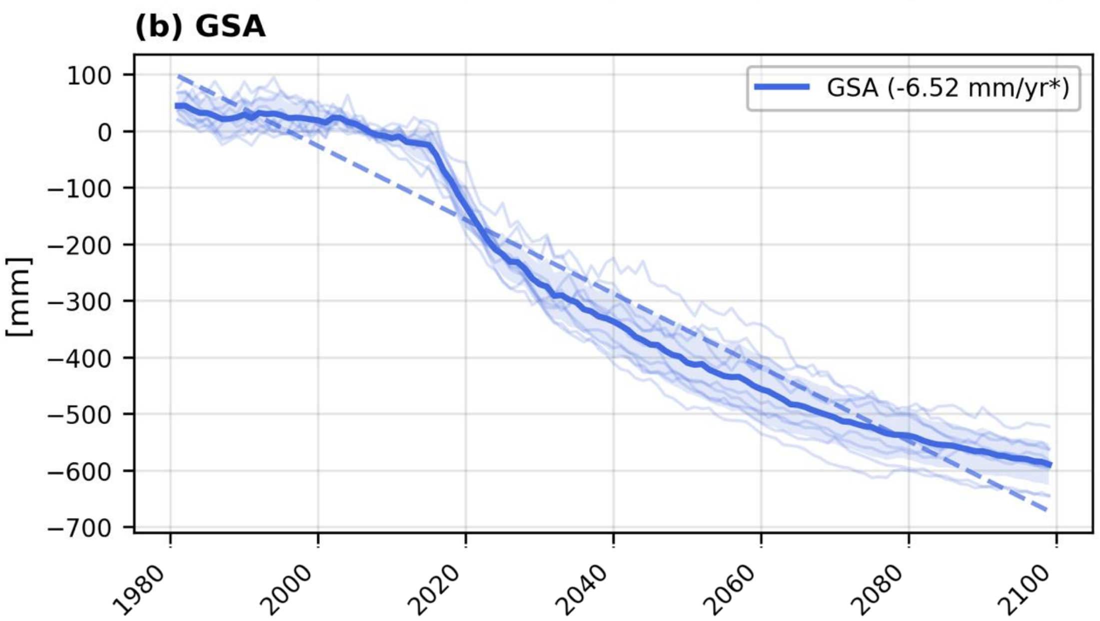


- Warming (~6℃ by 2099 relative to 1981)
- Recharge will decrease and be very close to zero (on average) by 2099
- The mountains have the largest decrease.

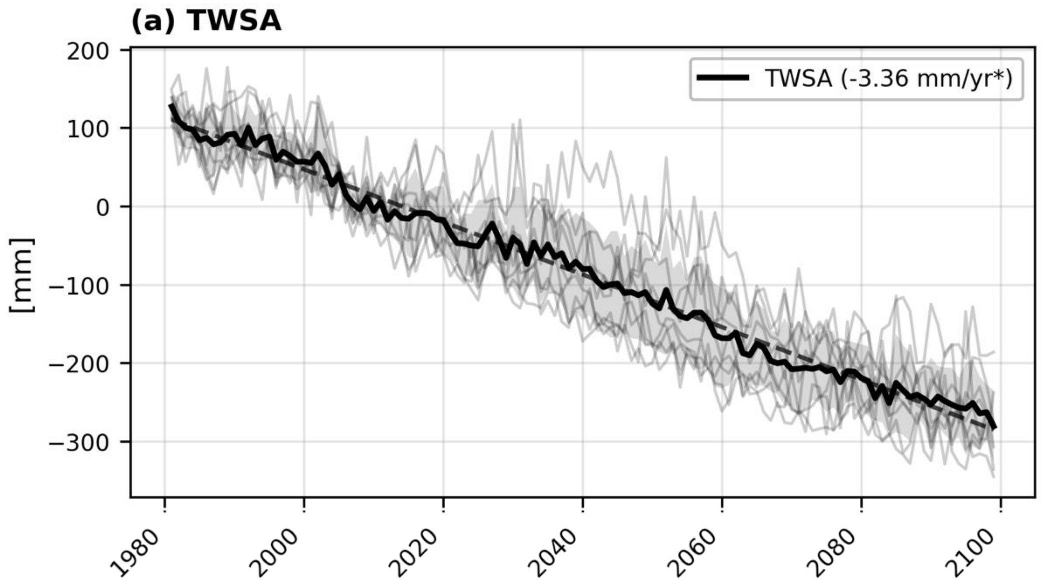


Future Climate Projection Impact to GW

Groundwater Storage Anomaly
(Considered as Change in GW Storage)
Averaged over AZ



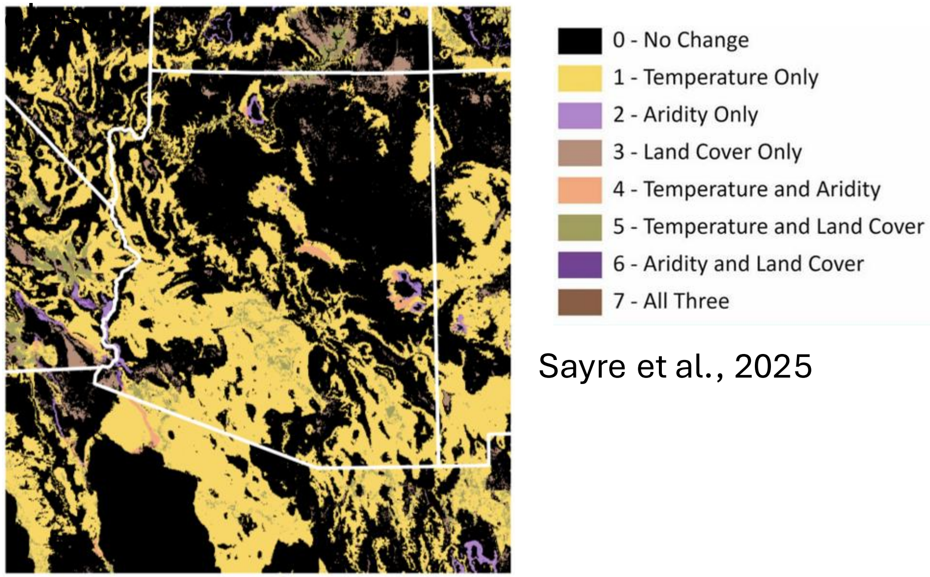
Total Water Storage Anomaly Averaged over AZ



Combined impact of climate and vegetation change

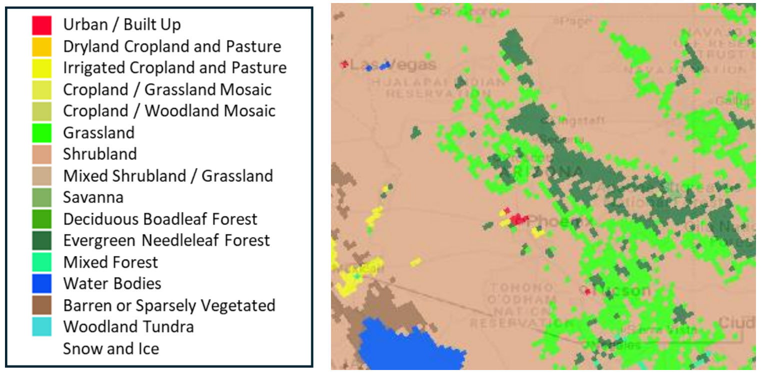
- Hypothetical extreme land cover change scenario:
  - Forests/grasslands no longer well suited to projected climate
  - Change pixels: forest/grassland + shifted climate class
- About 13% of land cover changed: Mogollon Rim and central/SE Arizona grasslands

Changes in climate (temperature or aridity)

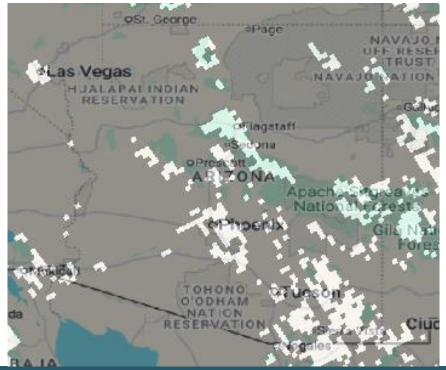


Sayre et al., 2025

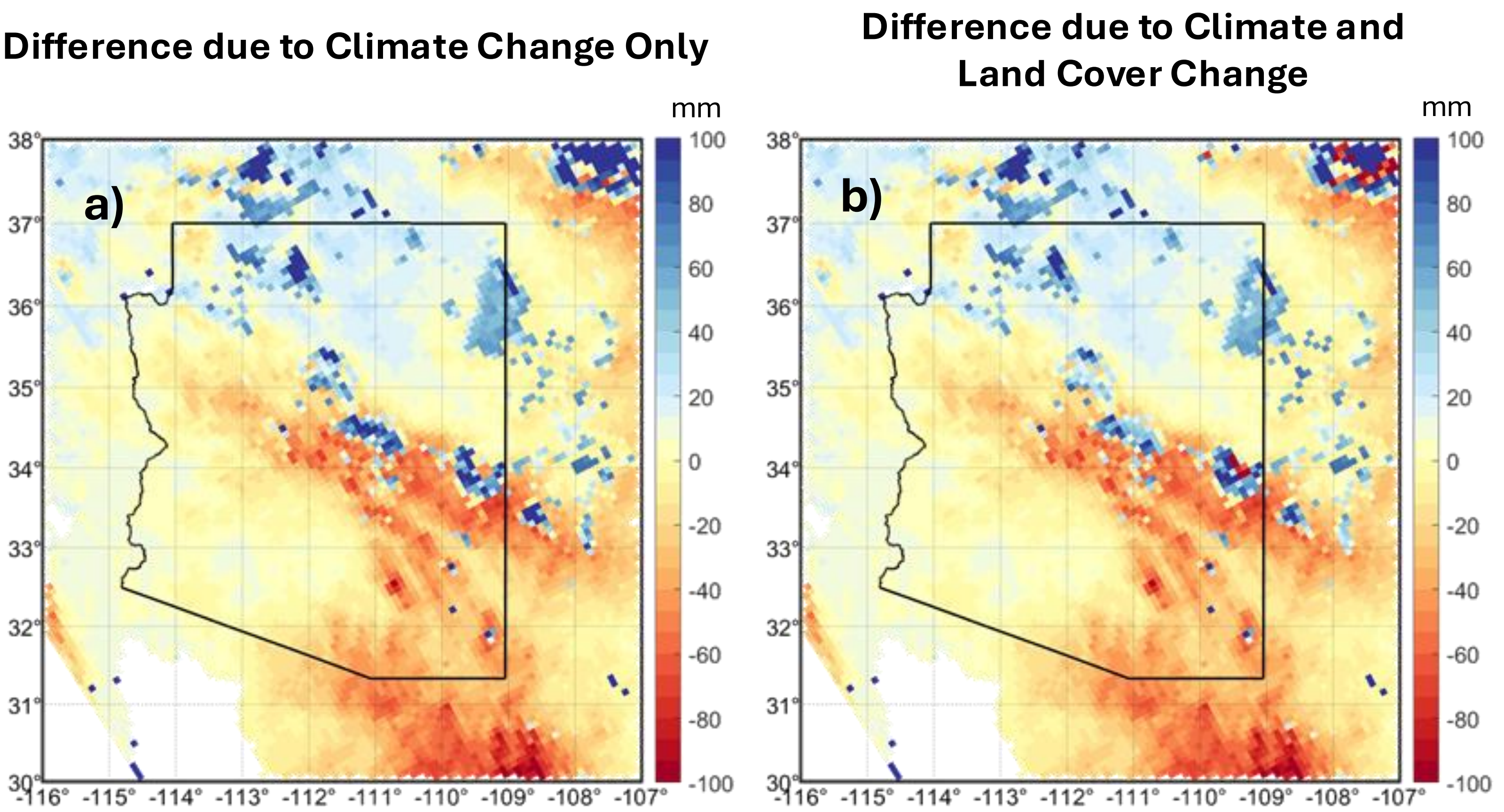
Current Land Cover



Pixels that Change



Combined impact of climate and vegetation change: ET



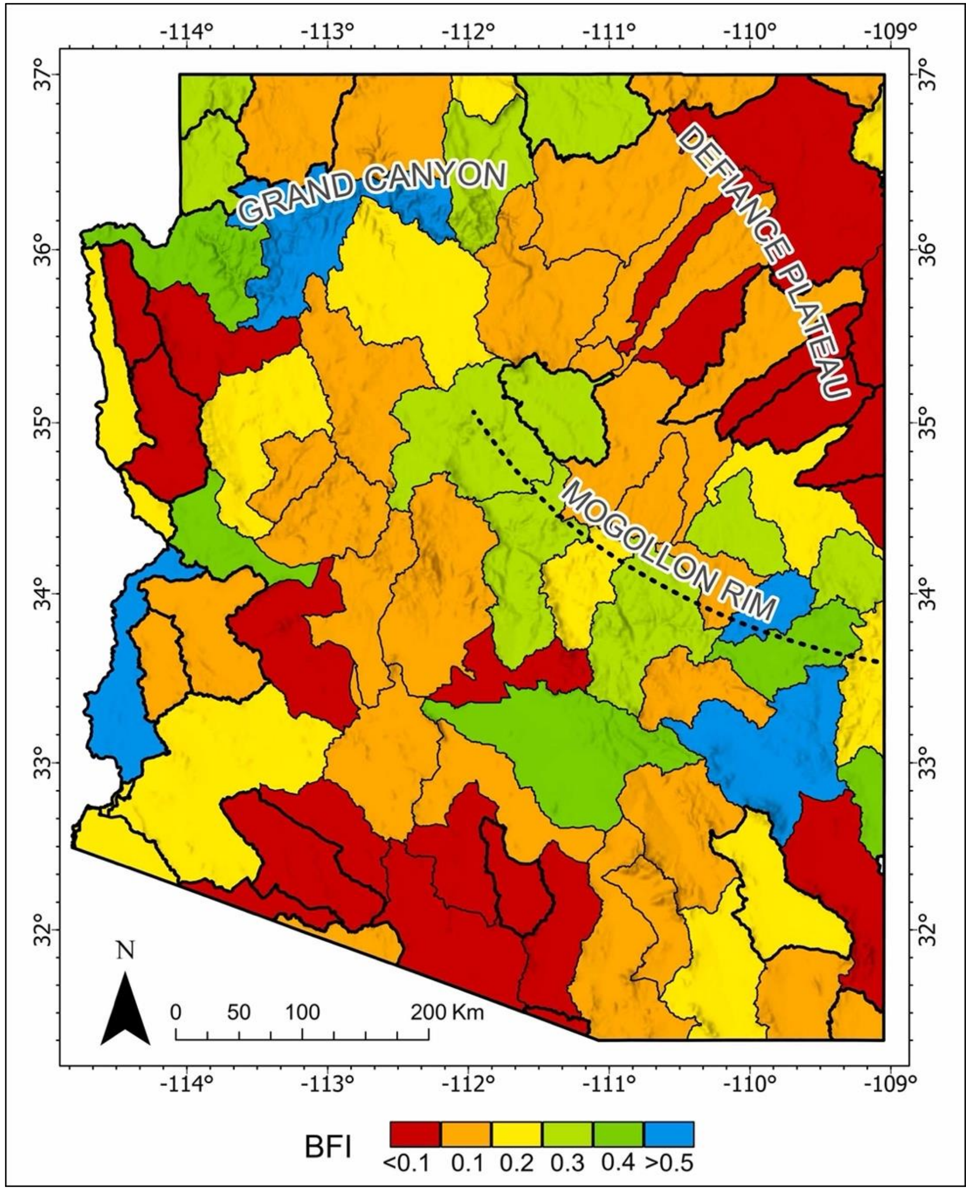
2060-2099 (Current Land) minus 1981-2020 (Current Land)

(2060-2099 (Modified Land) minus 1981-2020 (Current Land) Cover

- High elevations:
    - ET rises with atmospheric demand; recharge declines
- Low elevations:
    - ET follows precipitation changes
- Climate dominates, land-cover signal still visible.

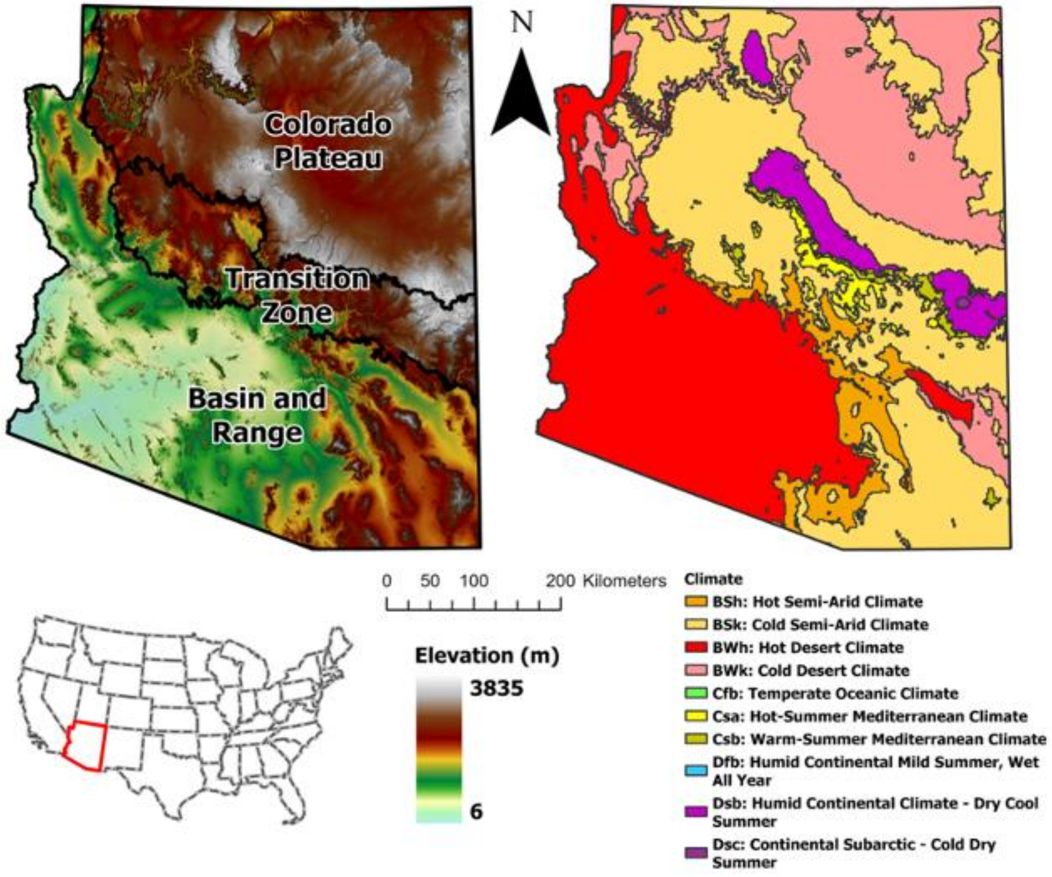
Base flow in Arizona

- **~32% of average annual streamflow statewide** (1990-2020)
- **Highest** on Colorado Plateau and Mogollon Rim, where geology stores and slowly releases water (karst and volcanic terrain)
- **Lowest** in Basin and Range watersheds dominated by episodic monsoon runoff

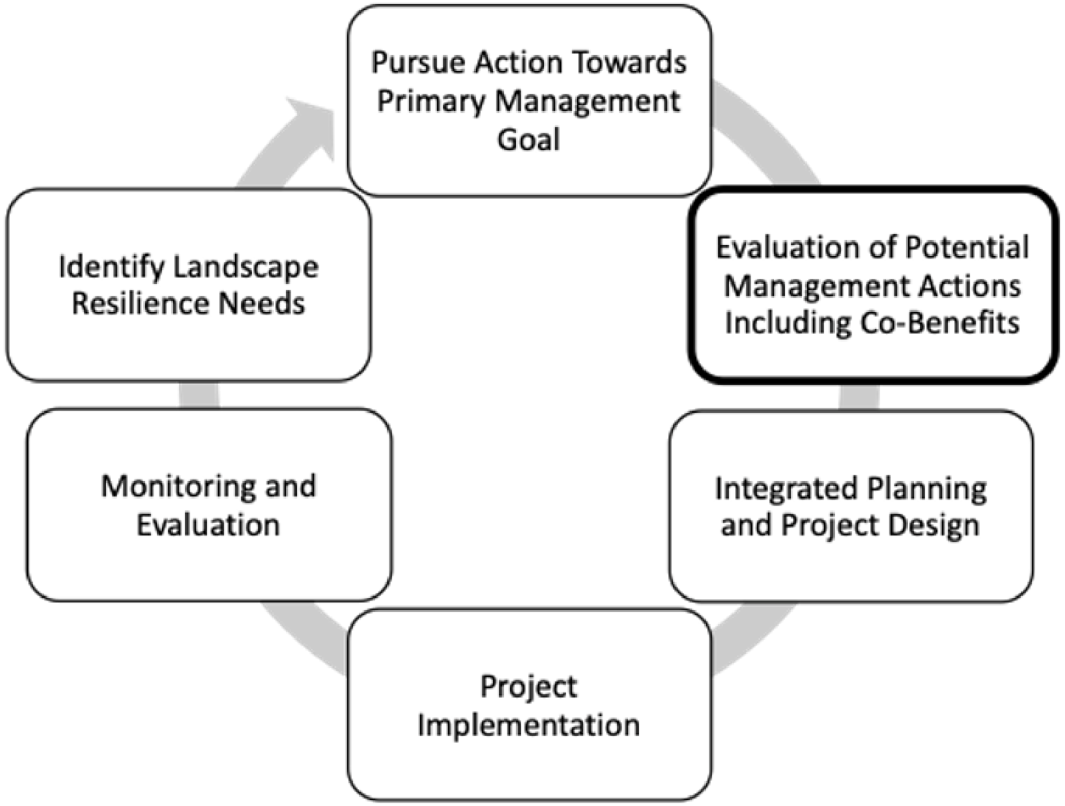


Beyond MAR: Opportunistic Recharge Enhancement ("all hands on deck")

- Integrate recharge considerations into primary land and water management goal(s)
- Increase water availability for human and environmental systems
- Cross-disciplinary, scalable framework
- Example applications: forest management, flood control, post-wildfire management, road building



General ORE Framework

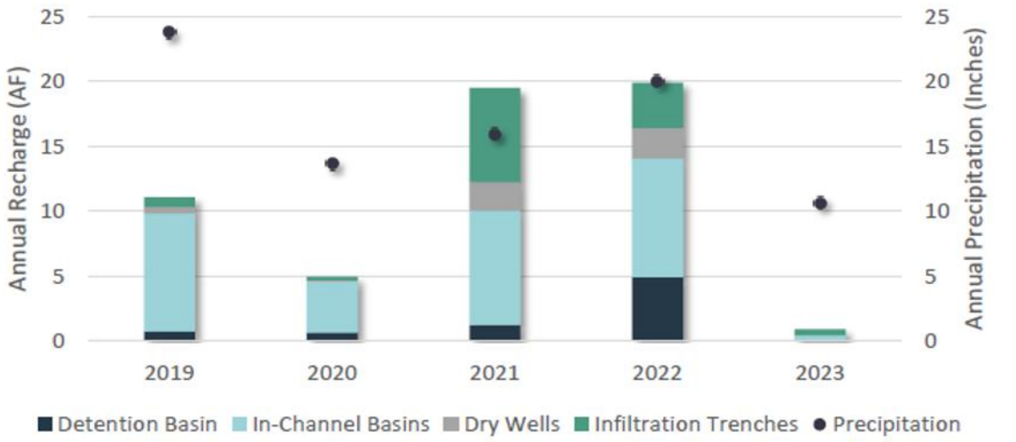


1. High Level Considerations
- Clarify recharge priority in overall project
- Identify priority features (e.g. high quality habitat, recreational areas)
- Consider existing infrastructure and evaluate existing data

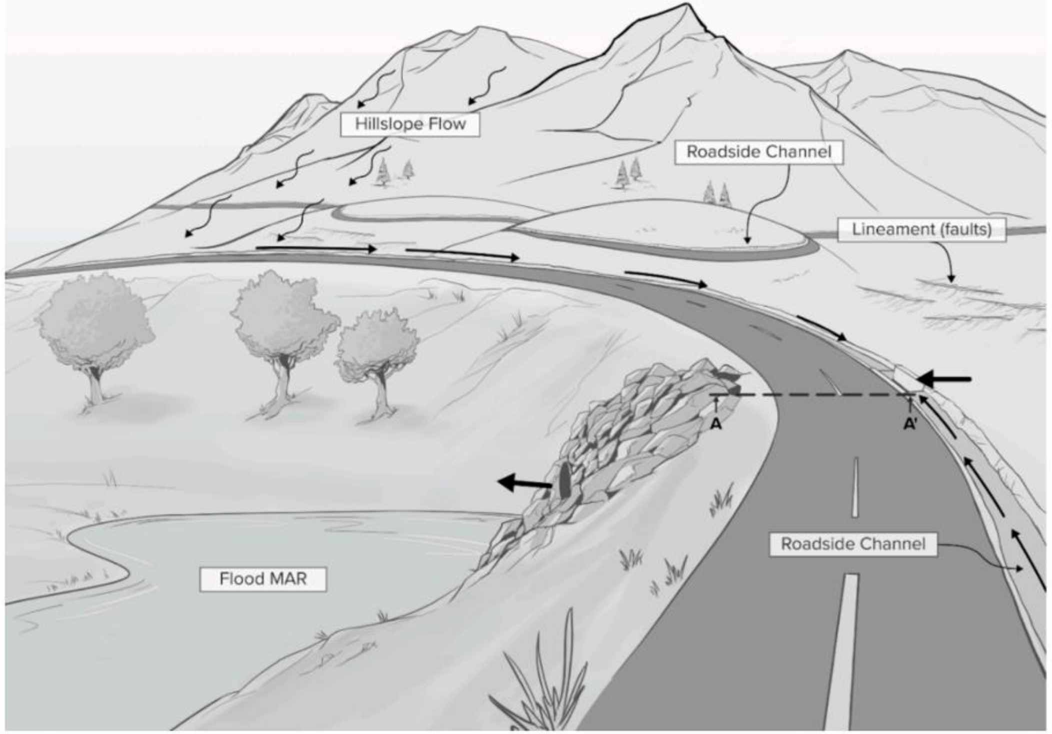
2. Identify Potential Sources of Water
- Redirection from evapotranspiration (e.g. increased snowpack/vadose zone water due to thinning)
- Slow down or pond surface water (e.g. floodwater, wastewater)

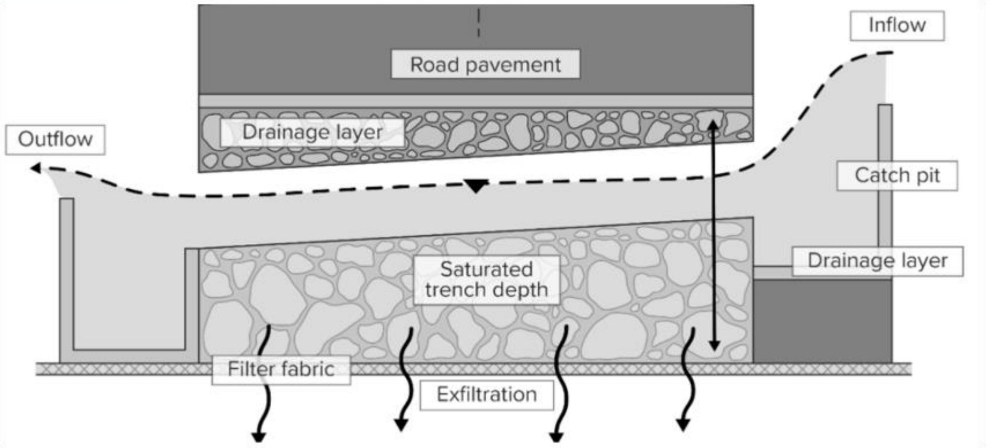
3. Identify Potential Sinks for Water
- Areas with high connectivity to groundwater and/or riparian zones (e.g. karsts, natural channels, existing recharge zones)
- Ecologically or socially important areas

4. Evaluation
- Potential volumes of water anticipated and time scales of interest (including role of seasonality and interannual variability)
- Costs associated with recharge enhancement techniques
- Comparison with existing priorities
- Maintenance needs and costs



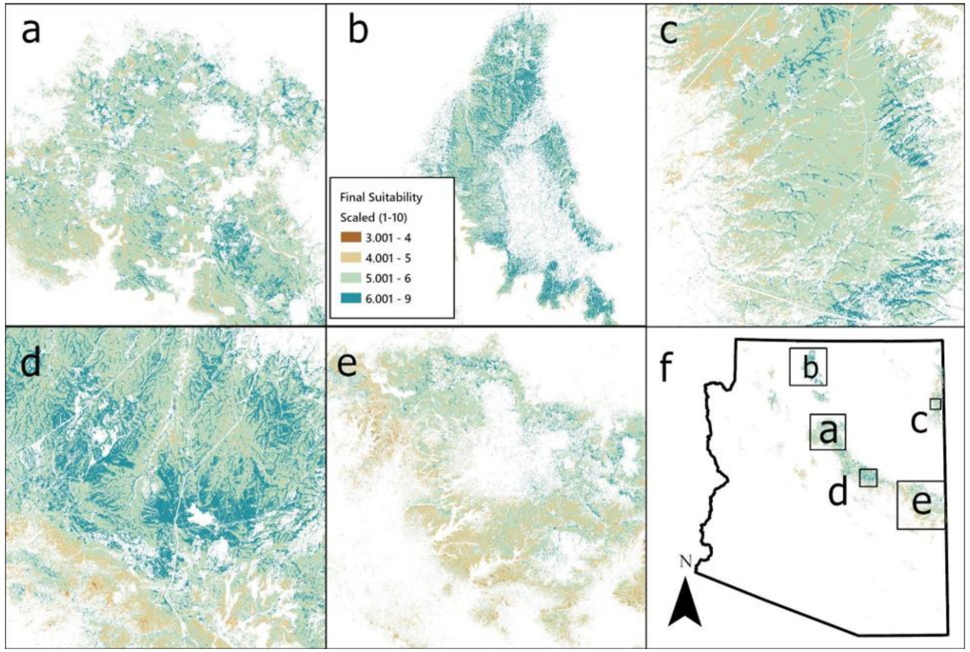
Hydrologic monitoring results from the Palominas Flood Control and Recharge Project 2019-2023, JE Fuller and Cochise County.



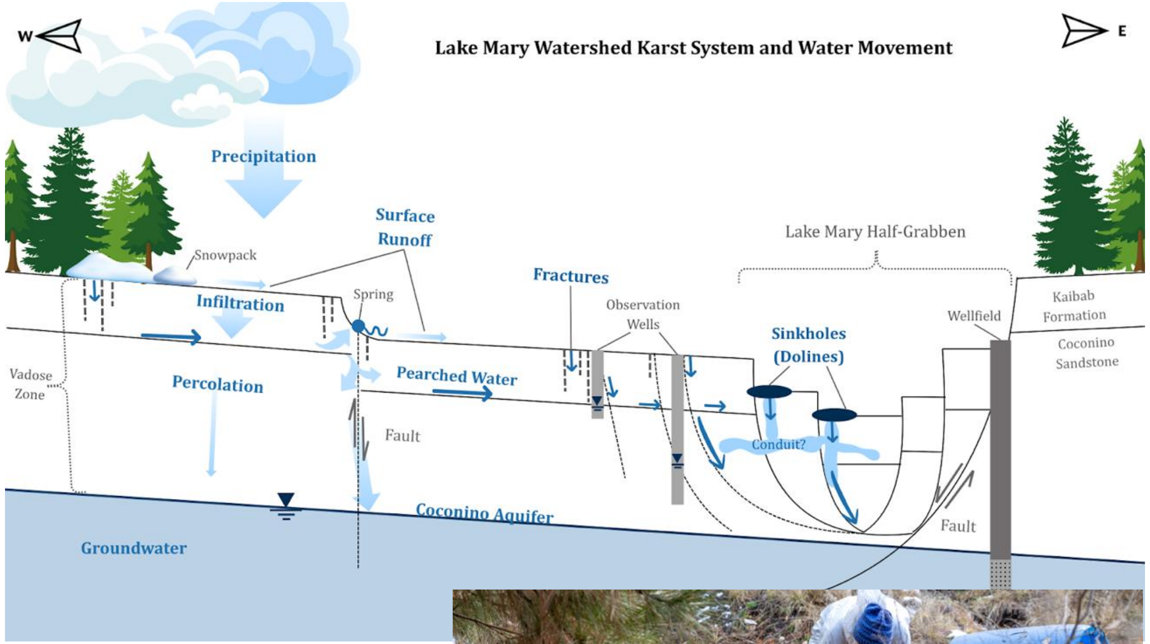


Meles et al., 2024

Forested and Karst Areas Present Opportunities



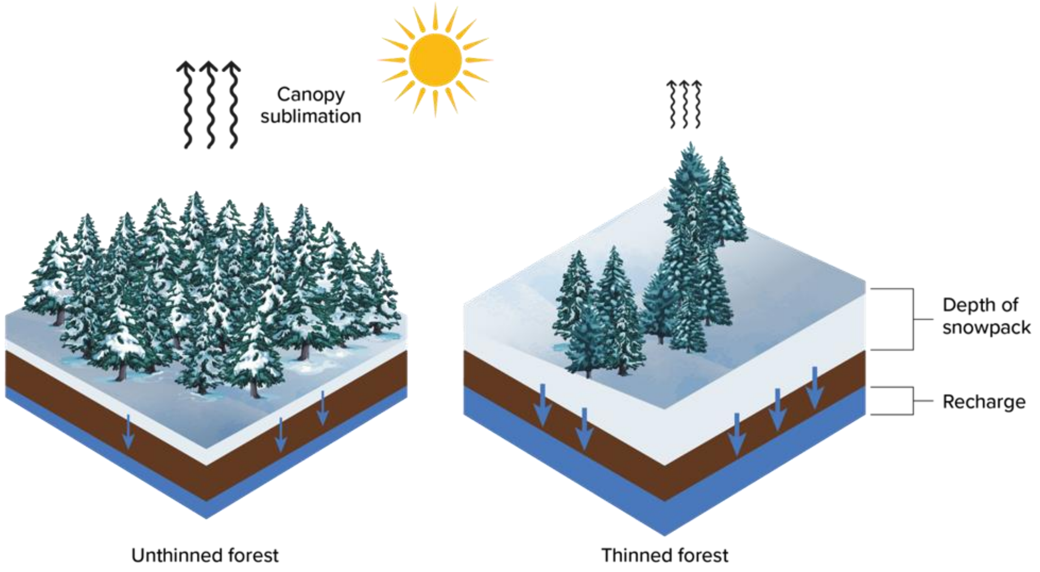
High suitability
 Snow dominated forests
 Underlain by carbonate rocks
Lima et al in review

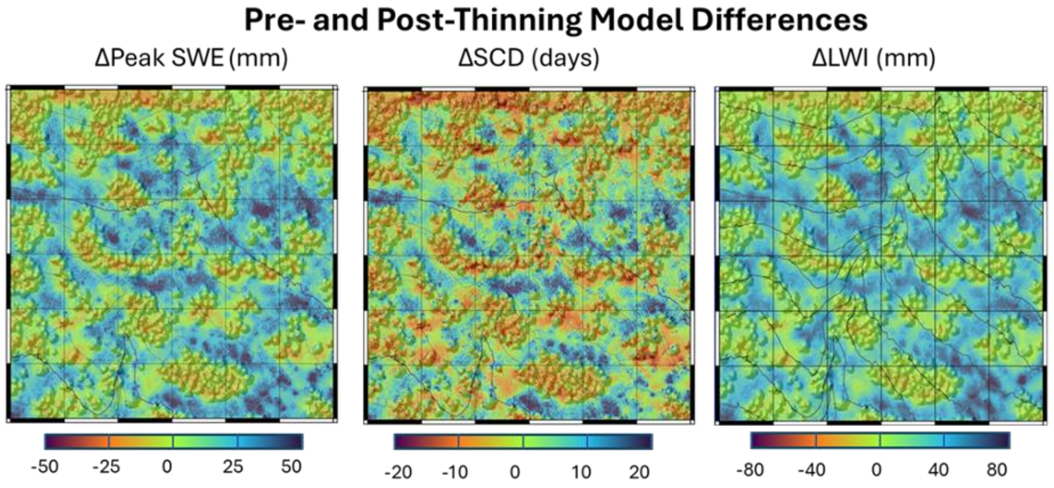


Rapid recharge
Focused recharge
Combs et al in prep

Forest thinning Impacts on Snow

- Thinning generally increases Peak SWE, SCD and LWI
- Larger canopy gaps (e.g. through larger spacing between groups of trees) were more effective at increasing LWI
- Maximizing shading (e.g. by orienting gaps E-W) was better at prolonging SCD

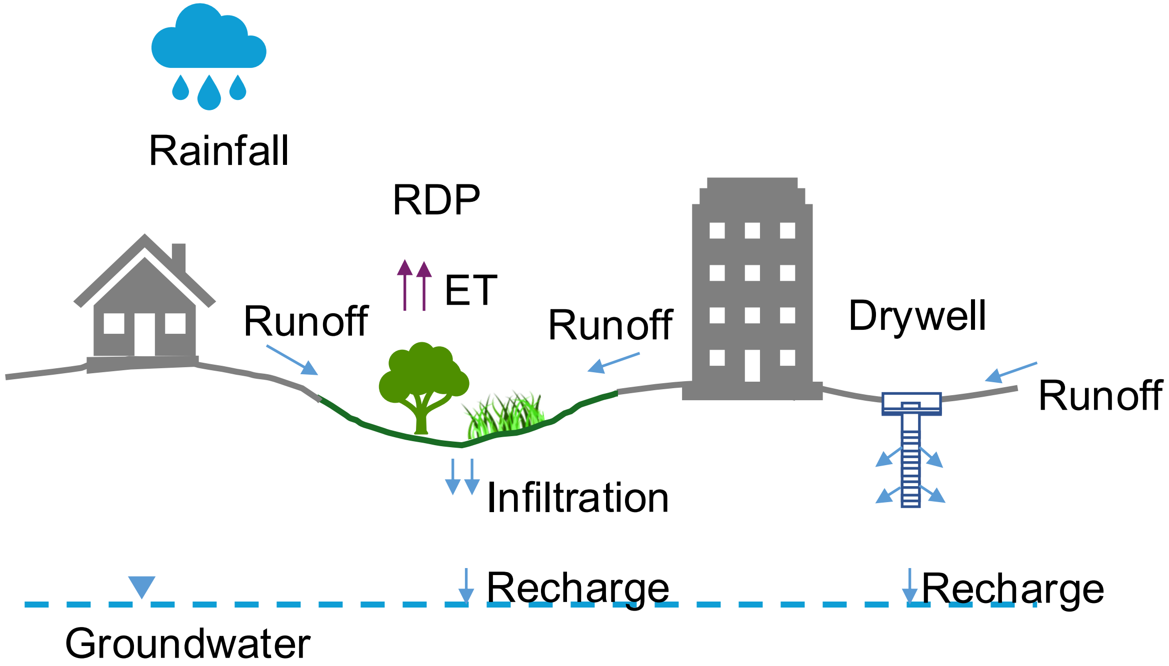




Broxton et al., 2025

Urban Strategies: Drywells + RDPs

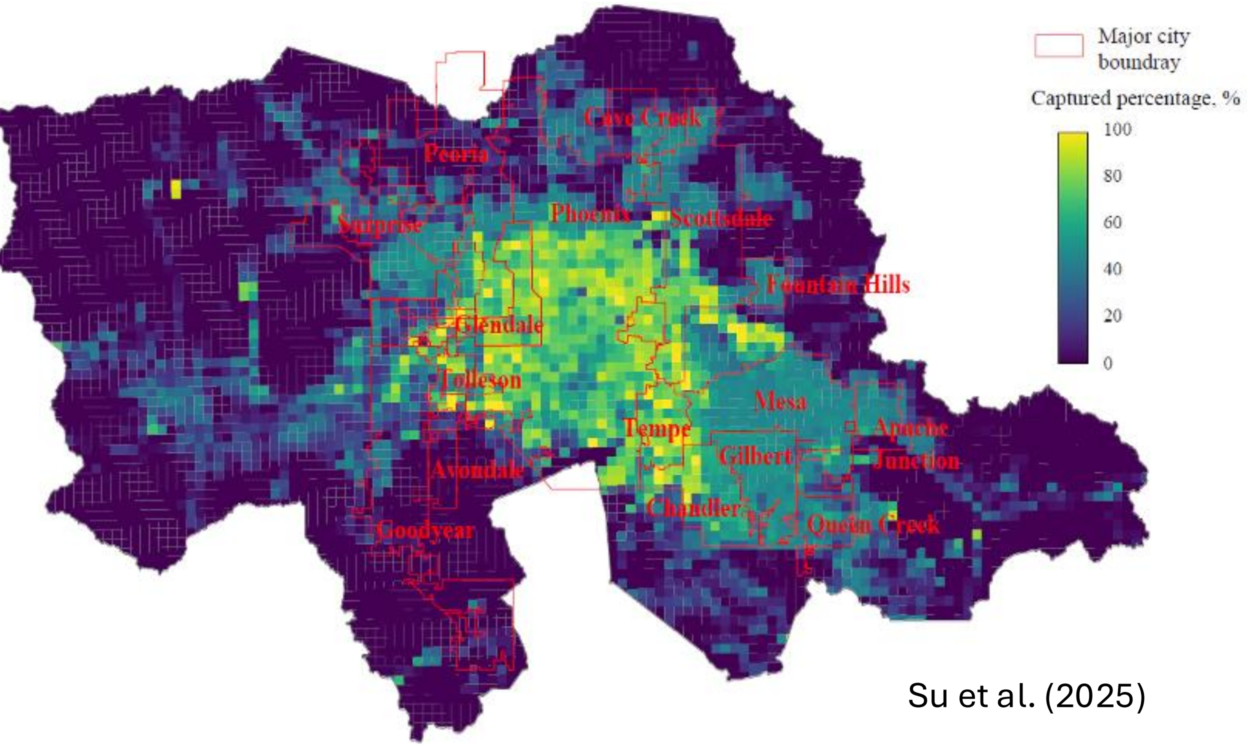
- 94,300 acre-ft/yr captured and infiltrated by existing drywells and RDPs (roughly 13% of groundwater pumpage) in the Phoenix AMA
  - ~20% captured by >40,000 registered in the Phoenix AMA
  - ~80% captured by 12,326 mapped from LiDAR across the Phoenix AMA (Yao, 2024)



Capture grows with urbanization

35.4%

average capture of
generated runoff, current condition



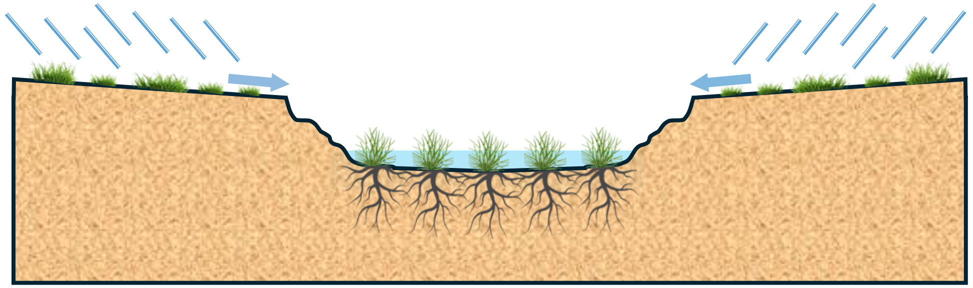
Su et al. (2025)

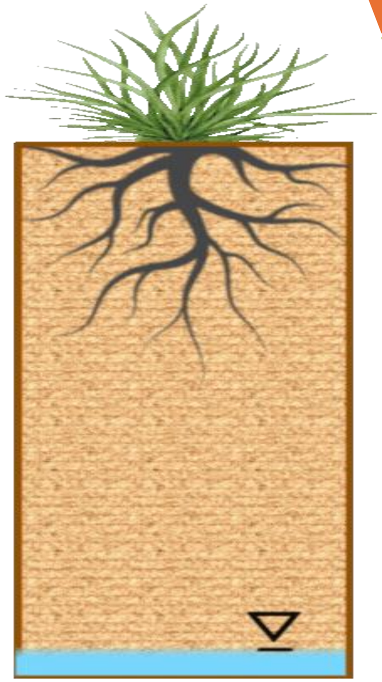
- By 2058, capture could reach 165,000 acre-ft/yr, an additional ~70,700 acre-ft/yr over today
- New impervious surface generates the runoff and triggers the stormwater management requirements that capture it

Values in acre-ft/yr; future shown for the A1B urbanization scenario.

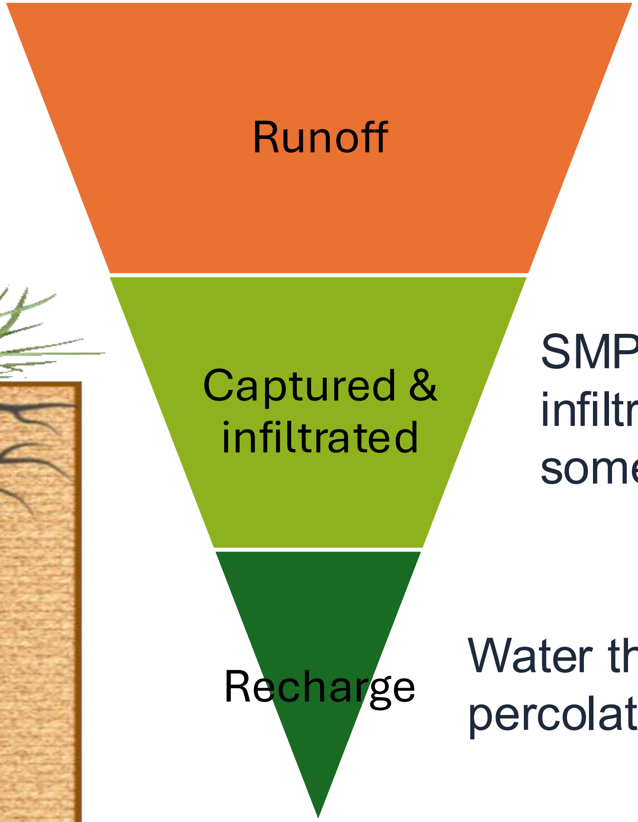
How much of captured runoff recharges the aquifer?

- Factors: soil texture, variation, water input (ponding)
- Hydrus-1D to simulate vadose zone processes over time
  - Infiltration
  - Water uptake by plant roots
  - Deep percolation (recharge)





Strom (2025)



Rain falls on the city, generating stormwater runoff from impervious surfaces

SMPs capture some runoff and infiltrates water into the soil, but some is lost to ET

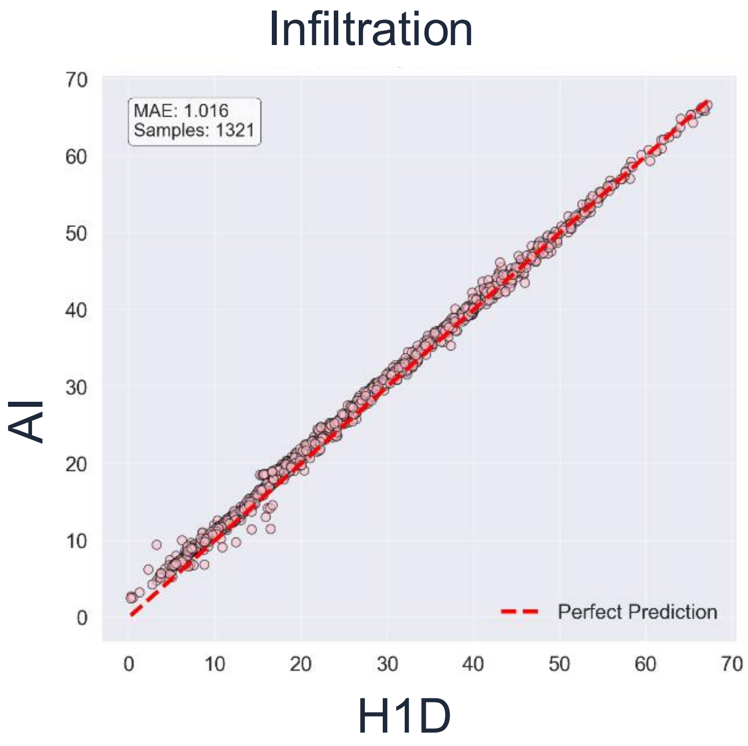
Water that becomes deep percolation

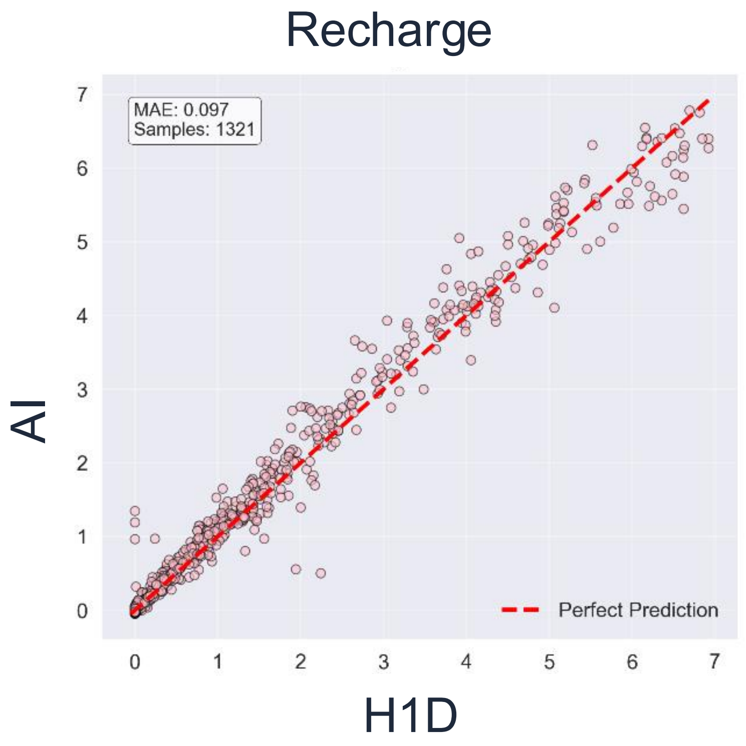
From Capture to Recharge: An AI Surrogate

- HYDRUS-1D needs domain expertise to configure, and one run takes 1~10 minutes
- AI surrogate is trained to reproduce HYDRUS, using adaptive sampling
- One inference: <<0.001s, fast enough t sit behind a fast, accessible screening tool

R^2 = 0.99
RMSE = 1.182 mm

R^2 = 0.98
RMSE = 0.195 mm





Guiding Principles for Enhancing Recharge and Habitat

- Maintain and enhance natural hydrologic system functions
- Support healthy forests and limit high-intensity wildfires
- Encourage recharge in naturally suitable areas
- Acknowledge and account for water and maintenance requirements of enhancing environmental/habitat quality

In Section 3 of final report!

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Decision-Support Tools

ARIZONA STATE UNIVERSITY

THE UNIVERSITY OF ARIZONA

NORTHERN ARIZONA UNIVERSITY

Decision Support Framework

- 10-step flow chart to help natural resource managers navigate to relevant ATUR findings
- Available as a PDF and interactive StoryMap

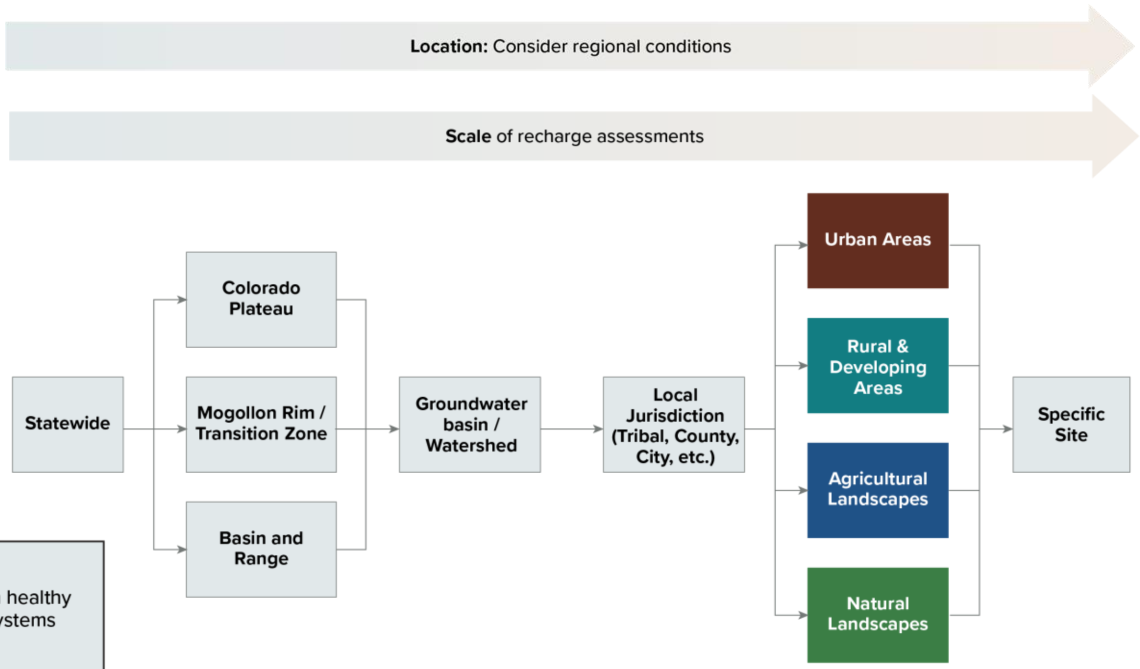
1. Water Management Objective
2. Location and Scale of Solution
3. Water Sources Inventory
4. Source Characterization
5. High-Level Threshold Criteria
6. Capture and Recharge Opportunities
7. Suitability Analyses
8. Priority Options
9. Cost/Benefit Analysis
10. Implementation

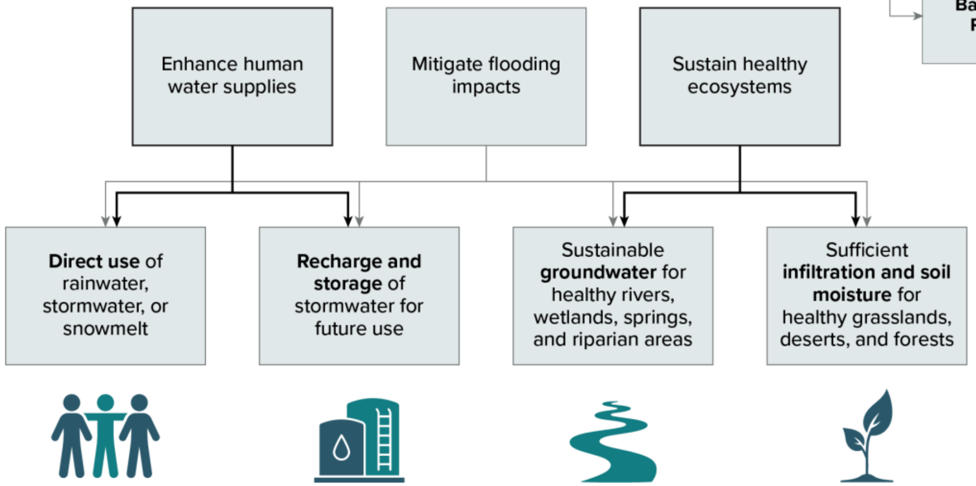
ARIZONA TRI-UNIVERSITY RECHARGE AND WATER RELIABILITY PROJECT REPORT

APPENDIX E: DECISION SUPPORT FRAMEWORK

Right Strategy for the Right Context

- Actions will vary across the state based on primary objectives and regional context
- Important to consider the strengths and limitations of your focus area
- Flexible framework to present "menu" of options





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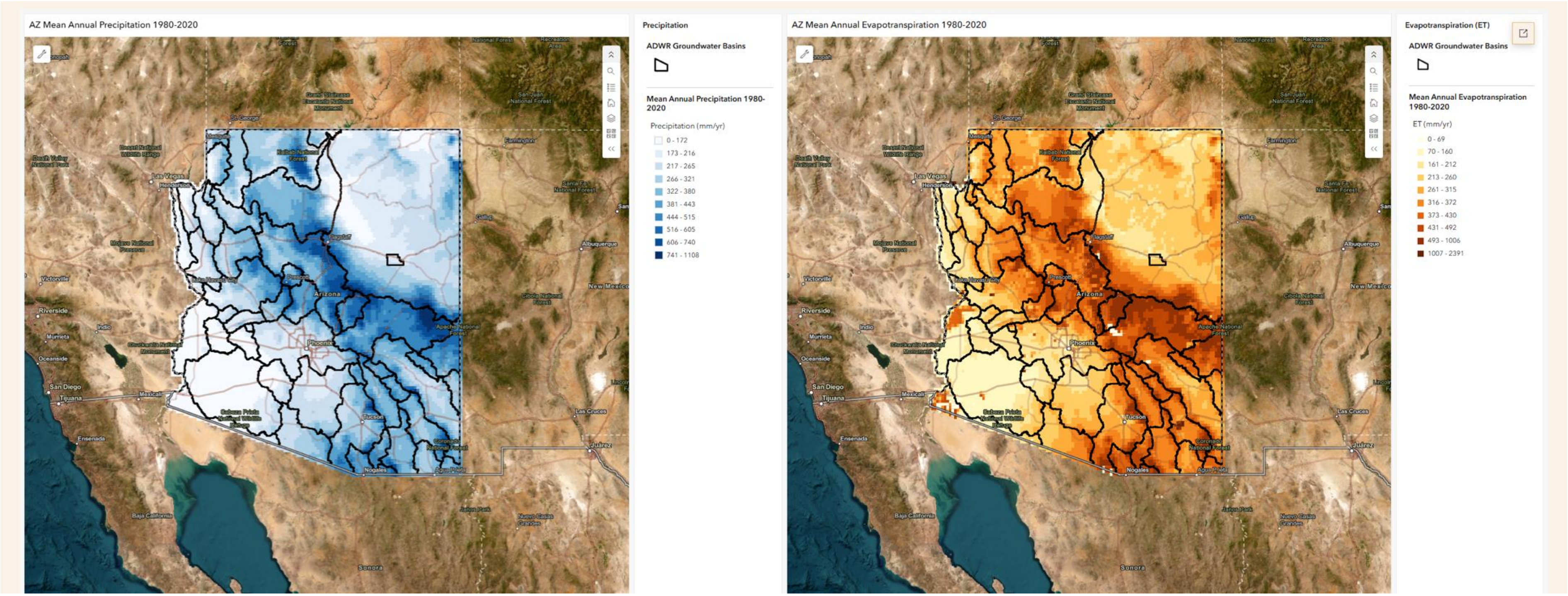
APPENDIX E: DECISION SUPPORT FRAMEWORK

Decision Support Framework

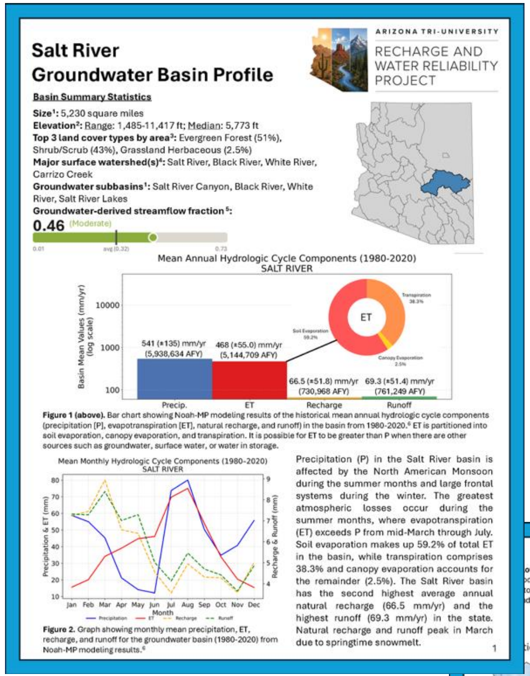
- StoryMap includes interactive dashboards where you can explore the *hydrologic cycle, surface & subsurface properties,* and our *statewide suitability analyses* for your area of interest



Groundwater Basin Profiles

<u>Page 1 + 2</u>: ***when*** and ***where*** recharge occurs

- Basin summary statistics
- Mean annual and monthly water balance
- Maps of water balance components



Salt River
Groundwater Basin Profile

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<u>Basin Summary Statistics</u>

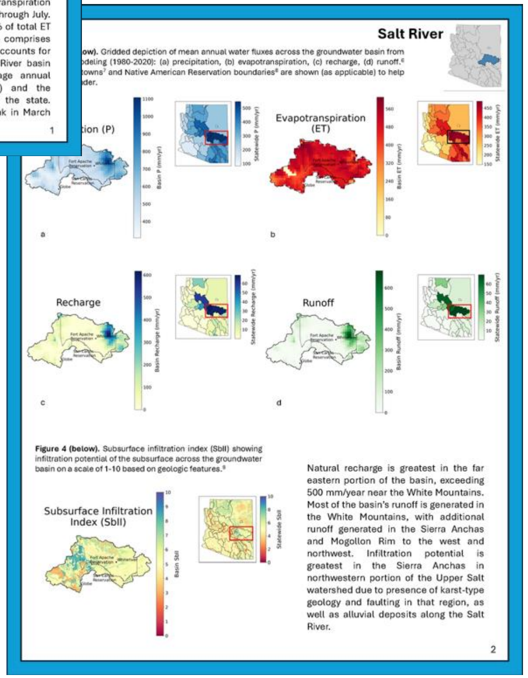
Size[1]: 5,230 square miles
Elevation[2]: <u>Range</u>: 1,485-11,417 ft; <u>Median</u>: 5,773 ft
Top 3 land cover types by area[3]: Evergreen Forest (51%), Shrub/Scrub (43%), Grassland Herbaceous (2.5%)
Major surface watershed(s)[4]: Salt River, Black River, White River, Carrizo Creek
Groundwater subbasins[1]: Salt River Canyon, Black River, White River, Salt River Lakes
Groundwater-derived streamflow fraction[5]:
0.46 (Moderate)

Figure 1 (above). Bar chart showing Noah-MP modeling results of the historical mean annual hydrologic cycle components (precipitation [P], evapotranspiration [ET], natural recharge, and runoff) in the basin from 1980-2020.[6] ET is partitioned into soil evaporation, canopy evaporation, and transpiration. It is possible for ET to be greater than P when there are other sources such as groundwater, surface water, or water in storage.

Figure 2. Graph showing monthly mean precipitation, ET, recharge, and runoff for the groundwater basin (1980-2020) from Noah-MP modeling results.[6]

Precipitation (P) in the Salt River basin is affected by the North American Monsoon during the summer months and large frontal systems during the winter. The greatest atmospheric losses occur during the summer months, where evapotranspiration (ET) exceeds P from mid-March through July. Soil evaporation makes up 59.2% of total ET in the basin, while transpiration comprises 38.3% and canopy evaporation accounts for the remainder (2.5%). The Salt River basin has the second highest average annual natural recharge (66.5 mm/yr) and the highest runoff (69.3 mm/yr) in the state. Natural recharge and runoff peak in March due to springtime snowmelt.

1



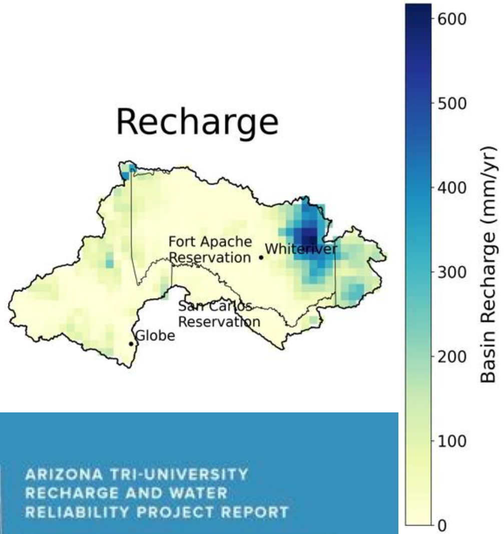
Salt River

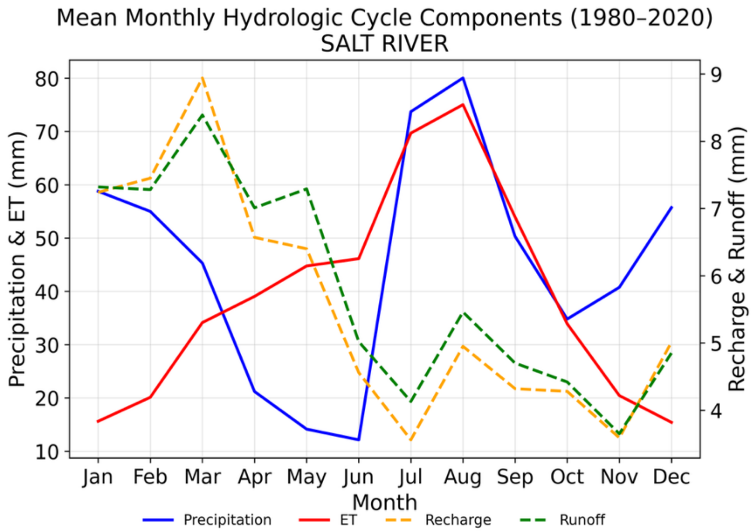
ow). Gridded depiction of mean annual water fluxes across the groundwater basin from odeling (1980-2020): (a) precipitation, (b) evapotranspiration, (c) recharge, (d) runoff.[6] towns[7] and Native American Reservation boundaries[8] are shown (as applicable) to help der.

Figure 4 (below). Subsurface infiltration index (SbII) showing infiltration potential of the subsurface across the groundwater basin on a scale of 1-10 based on geologic features.[9]

Natural recharge is greatest in the far eastern portion of the basin, exceeding 500 mm/year near the White Mountains. Most of the basin's runoff is generated in the White Mountains, with additional runoff generated in the Sierra Anchas and Mogollon Rim to the west and northwest. Infiltration potential is greatest in the Sierra Anchas in northwestern portion of the Upper Salt watershed due to presence of karst-type geology and faulting in that region, as well as alluvial deposits along the Salt River.

2

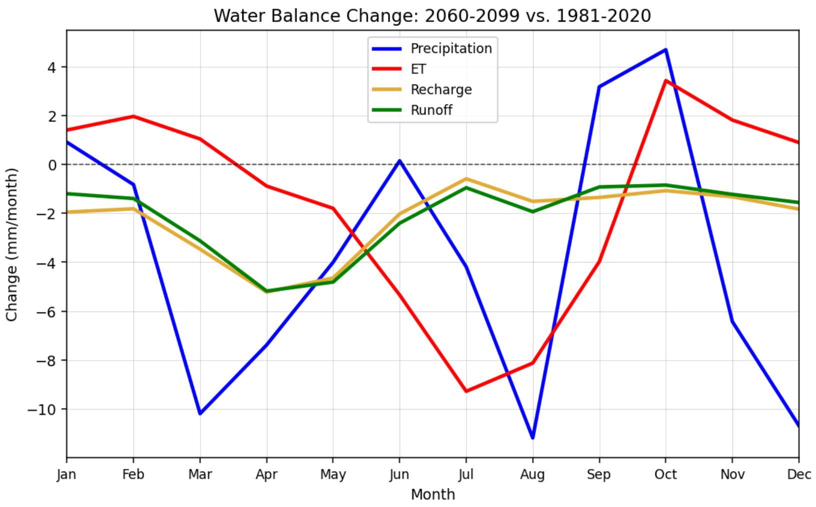


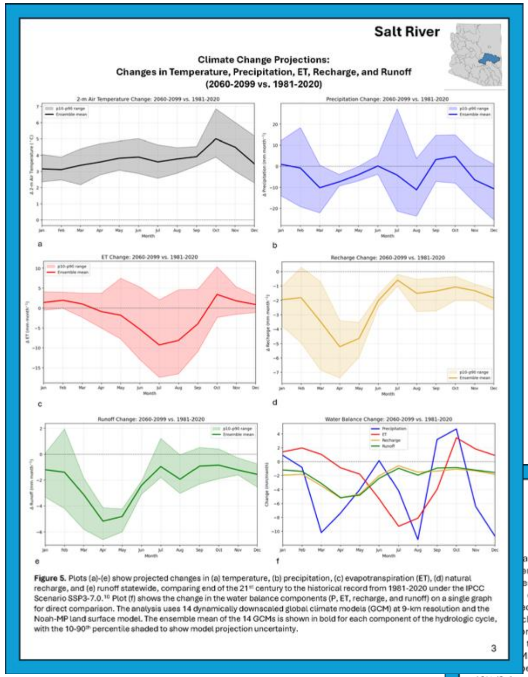


Groundwater Basin Profiles

Page 3 + 4: ***how*** might recharge change

- Graphs of projected changes in water balance components resulting from climate change
- Narrative interpretation of climate change projections





Salt River

Climate Change Projections:
Changes in Temperature, Precipitation, ET, Recharge, and Runoff
(2060-2099 vs. 1981-2020)

Figure 5. Plots (a)-(e) show projected changes in (a) temperature, (b) precipitation, (c) evapotranspiration (ET), (d) natural recharge, and (e) runoff statewide, comparing end of the 21st century to the historical record from 1981-2020 under the IPCC Scenario SSP3-7.0.[10] Plot (f) shows the change in the water balance components (P, ET, recharge, and runoff) on a single graph for direct comparison. The analysis uses 14 dynamically downscaled global climate models (GCM) at 9-km resolution and the Noah-MP land surface model. The ensemble mean of the 14 GCMs is shown in bold for each component of the hydrologic cycle, with the 10-90th percentile shaded to show model projection uncertainty.

3

Salt River

...ange projections across the Salt River basin show drier springs (21-38% drier March through ...er July-August (6-13%), and a drier November-December (17-19%). September and October ...ed to be 6-13% (2.9-4.9 mm/month) wetter on average, which is consistent with a projected ... extreme events associated with hurricane and tropical cyclone activity by the end of the ...eclines in natural recharge are projected for all months of the year, with projections in the ...charge months (February-May) showing declines of 30-71% (-1.9 to -5.3 mm/month). ...projections are slightly negative (-0.25 mm) in July.* Runoff is projected to decrease in all ... the year, with 27-71% (-1.5 to -5.2 mm/month) declines in the highest runoff months ...May). Projected increases in temperature range from approximately 3.1 °C in February to 5.0 ...ber. Higher temperatures and greater water availability from precipitation lead to a projected 10% (3.4 mm) increase in evapotranspiration (ET) in October compared to the baseline period.

*Projected negative recharge values are attributed to increased capillary rise from the aquifer through the vadose zone due to climate factors, resulting in water loss from the system. Because the Noah-MP model does not include groundwater pumping, this indicates that climate-driven factors play a significant role in groundwater storage decline in Arizona.

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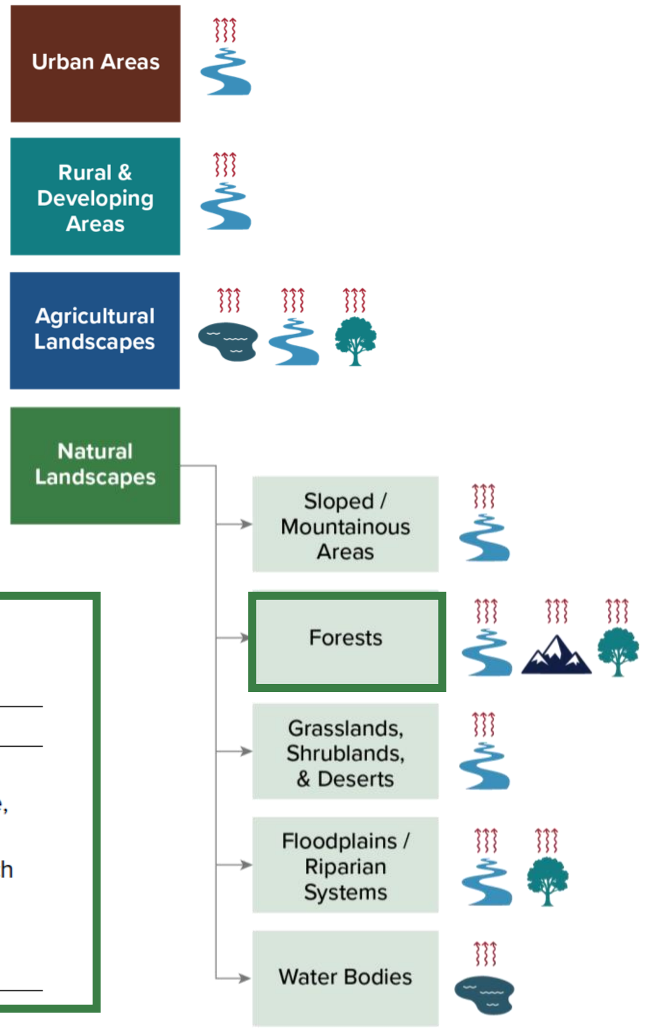
4

Recharge Opportunities Matrix

- Over 50 strategies for enhanced capture and recharge
  - Includes opportunities and possible constraints
- Organized by landscape type



Strategy Code	Management Strategy by Landscape Type	Key Opportunity	Major Constraints/Limiting factors? Unintended Consequences?
E	Forests		
E1	Fuels reduction, forest thinning and/or prescribed fire can be designed to maximize recharge of water that would otherwise be lost to evaporation e.g. in vicinity of karst areas, certain forest types that promote large gains in infiltration and recharge interventions	If capture of water otherwise lost to evaporation results in infiltration or surface runoff that leads to recharge there may be benefits in terms of downstream water flows as well as enhanced soil moisture to support forest productivity. ATUR's forest thinning suitability mapping focuses on these issues	Local characteristics including elevation, slope, aspect, canopy cover and forest type, hydrogeology, floodplain connectivity and other factors may limit utility of this approach

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Conclusions & Next Steps

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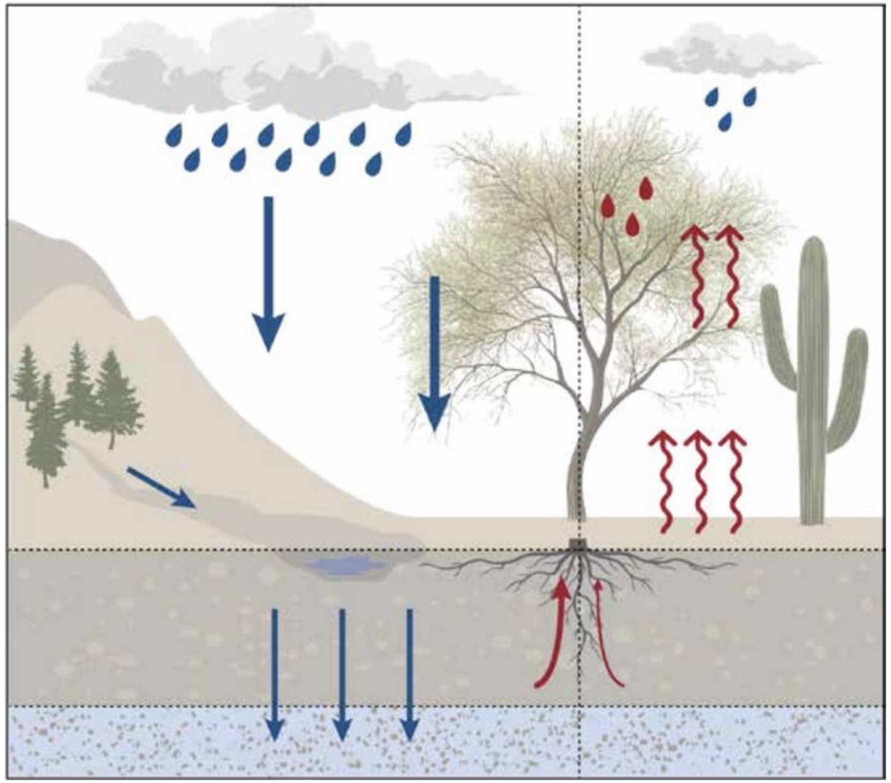
High Level Conclusions

- Warming is having a profound effect on water in storage
- Extreme events are consistently predicted to intensify, and can provide recharge opportunities
- 32% of surface flows in the state originate with groundwater
- Recharge as co-benefit can provide relatively low-cost solutions (ORE)
- Urban development can include capture opportunities
- Environmental assets need pro-active protection



Recommendations

1. Investment into expanding monitoring network expansions

   e.g. GW, ET, pumping

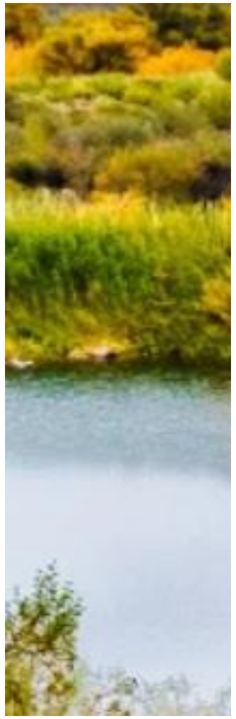
2. Include opportunities related to karsts, mountain fronts, flood/floodplain management into regional reviews
3. Incorporate opportunities in urban regions

   e.g. protect high recharge areas from development, consider drywell installation in urban retrofit, deep(er) retention basins, long(er) retention times

4. Experiment with ORE application into management activities
5. Expand partnerships related to topics above

Planned Next Steps and Opportunities

1. Explore and develop opportunities to expand monitoring networks, including community scientists and ML methods
2. Increase assessment and prediction of recharge opportunities due to extreme events
3. Increase volumetric quantification of recharge strategies
4. Incorporate ATUR findings into regional planning efforts
5. Continue to communicate and disseminate ATUR Phase 1 products



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Questions

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