ARIZONA TRI-UNIVERSITY RECHARGE AND WATER RELIABILITY PROJECT REPORT

APPENDIX D: KEY MESSAGES SUPPORTING INFORMATION

Arizona State University

The University of Arizona

Northern Arizona University

Key Message	Primary Contributors	Key Message Summary (Unedited)	Supporting Information
2.1	Moiz, A., Gupta, A., Qiu, Y., Niu, G., Mascaro, G., Behrangi, A., Mohsenzadeh Karimi, S.	Current water balance information has been estimated using a suite of high-resolution models and confirmed through observations for the 51 ADWR-designated groundwater basins and HUC-8 surface sub-basins in the state.	**Relevant Literature**: Moiz & Mascaro (2026); Niu et al. (2011); Cosgrove et al. (2024). **Datasets/Observations**: AORC; CONUS404; IMERG; USGS stream gauges; Eddy covariance flux towers; SNOTEL snow telemetry stations. **Appendix C Sections**: National Water Model; Noah-MP Model.
2.2	Qiu, Y., Moiz, A., Gupta, A., Broxton, P., Nab, A., Behrangi, A., Mascaro, G.	Evapotranspiration (ET) is the dominant water loss in Arizona's water balance, accounting for more than 95% of annual precipitation statewide. Consequently, even modest reductions in ET could translate into meaningful increases in water availability for direct use or groundwater recharge.	**Relevant Literature**: Moiz & Mascaro (2026); Qiu et al. (2025); Broxton et al. (in press); Glenn et al. (2015). **Datasets/ Products**: OpenET; MODIS ET; ECOSTRESS. **Appendix C Sections**: National Water Model; Climate change and future vegetation.
2.3	Qiu, Y., Moiz, A., Gupta, A., Niu, G., Mascaro, G., Behrangi, A.	Natural groundwater recharge represents a small fraction of Arizona's water budget, accounting for less than 3% of average annual precipitation statewide. However, recharge rates vary substantially across the state's groundwater basins, ranging from less than 1% in the Basin and Range province to more than 10% of annual precipitation in individual basins along the Mogollon Rim.	**Relevant Literature**: Qiu et al. (2025); Chen et al. (2014); Boas & Mallants (2022). **Appendix C Sections**: Groundwater Recharge; Focused vs Diffuse Recharge.
2.4	Qiu, Y., Gupta, A., Moiz, A., Mascaro, G.	Based on modeling results, groundwater recharge generally peaks in early spring in Arizona due to snowmelt in mountainous areas. However, recharge peaks later (May-June) on the Colorado Plateau.	**Relevant Literature**: Eastoe (2023); Chambless et al. (2023); Denver et al. (2025). **Appendix C Sections**: National Water Model; Future Climate Modeling.

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2.5	Qiu, Y., Niu, G., Behrangi, A.	With some exceptions, higher precipitation intensity increases the rate of groundwater recharge, especially during the summer; however, there is an optimum range of precipitation intensity for recharge because on-site recharge can be limited if a large proportion of the precipitation becomes surface runoff.	**Relevant Literature**: Qiu et al. (2025); Asoka et al. (2018); Jasechko & Taylor (2015); Thomas et al. (2016). **Appendix C Sections**: Groundwater Recharge; Focused vs Diffuse Recharge.
2.6	Mroczek, C., Springer, A.E.	Base flow, or the portion of streamflow sustained by groundwater discharge, accounts for approximately 32% of average annual streamflow in Arizona, with substantial variation across the state. Tracking changes in the base flow component of stream flow over time can help water managers understand how changes in climate are affecting groundwater contributions to streamflow and is a particularly useful tool for regions with limited direct groundwater monitoring.	**Relevant Literature**: Mroczek et al. (2025). **Additional Resources**: https://doi.org/10.1016/j.ejrh.2025.102778. **Appendix C Sections**: Baseflow index
2.7	Qiu, Y., Famiglietti, J., Niu, G.	ATUR model estimates show that climatic factors can explain much of Arizona's terrestrial water storage (TWS) declines since 2000 (2000–2020). Our model-based TWS depletions are consistent with GRACE gravity-based observations (which incorporate all reductions in water supplies, including both groundwater pumping and climate-driven depletion).	**Relevant Literature**: Qiu et al. (2025); Abdelmohsen et al. (2025) **Datasets/Observations**: GRACE satellite observations. **Appendix C Sections**: Noah-MP Model; Future Climate Modeling.
2.8	Qiu, Y., Famiglietti, J., Niu, G.	Ensemble modeling of Arizona's water cycle under a relatively high emissions scenario (SSP 3-70*) projects robust and continuing temperature increases, alongside decreasing runoff and groundwater recharge, driven by rising evaporative demand and precipitation declines concentrated in the state's high-elevation water source areas.	**Relevant Literature**: Qiu et al. (in prep.); Rahimi et al. (2024); Cannon et al. (2015); Niu et al. (2011). **Datasets**: WUS-D3 dynamically downscaled CMIP6 dataset. **Appendix C Sections**: Future Climate Modeling; Climate change and future vegetation; Noah-MP Model.

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2.9	Zhang, J., Broxton, P., Qiu, Y., Bromley, F.	Vegetation change alters the hydrologic cycle by modifying evapotranspiration and runoff, with stronger effects on precipitation partitioning at higher elevations. In the future climate–land cover scenario tested, most projected hydrologic changes are driven by climate, while vegetation shifts produce localized impacts, particularly at high elevation.	**Datasets/Scenarios**: SSP3-7.0 climate scenario. **Appendix C Sections**: Climate change and future vegetation; Future Climate Modeling; Noah-MP Model.
3.1	Strom, N., Ferre, P., Gupta, N.	Generally, the controlling factor for inducing recharge is the movement of water vertically, past the root zone. Saturated conditions at the ground surface (surface ponding) lead to much higher vertical water flux. The ponding duration required to initiate recharge depends on local conditions and is challenging to predict and difficult to measure directly. There is a substantial decline in recharge feasibility in soils with greater than 20% clay content.	**Relevant Literature**: Strom et al. (in prep). **Additional Resources**: Thesis: https://repository.arizona.edu/handle/10150/679220?show=full. **Appendix C Sections**: Urban frameworks (modeling boundary conditions)
3.2	Sankey, T., Lima, R., Lewis, R., Broxton, P.	Forest thinning has been shown to reduce both ET and sublimation losses (direct loss of snow to evaporation). It can enhance water availability through increasing the snow water equivalent (SWE), raising the liquid water input (LWI), and/or reducing sublimation. Some post-thinning forest patch size and geometry combinations enhance snow accumulation and persistence more than others. These benefits increase water availability, but the quantity of potential capture and recharge depends strongly on local climate and geology.	**Relevant Literature**: Broxton et al. (2025).. https://doi.org/10.1002/eco.70111. **Appendix C Sections**: Snow Management; Modeling on Forest Thinning; Thinning/High-Elevation Forest Recharge.

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3.3	Lewis, R., Bromley, F.	Ecological disturbances driven by increasingly hot and arid conditions, such as landscape-wide tree mortality and wildfires, are already affecting quantities and locations of capturable water in Arizona's forests. Pre-fire watershed protection and flood control efforts can potentially facilitate water harvesting and limit potential storm damage from post-fire runoff events and associated large-scale erosion.	**Relevant Literature**: Williams et al. (2022). Growing impact of wildfire on western US water supply. Proceedings of the National Academy of Sciences, 119(10), e2114069119. https://doi.org/10.1073/pnas.2114069119. **Appendix C Sections**: Hydrologic Response of In Stream Structures; Post-Fire Hydrologic Response; Climate Change and Future Vegetation.
3.4	Ferrell, K., Korgaonkar, Y., Gupta, N., Xu, T.	Land use changes in watersheds adjacent to and within large cities are projected to result in increased impervious surface due to urbanization through 2100 in the Phoenix, Pinal and Tucson AMAs, with potential to generate greater quantities of urban enhanced runoff (UER), particularly during winter. This increase in UER presents opportunities for capture and recharge because this water is not yet appropriated and the majority of it would otherwise have evaporated.	**Relevant Literature**: Ferrell et al. (in prep). **Additional Resources**: Thesis: https://arizona-ua.primo.exlibrisgroup.com/permalink/01UA_INST/14j263h/alma991050692972903843. **Appendix C Sections**: New urban development runoff/recharge
3.5	Gupta, N., Richter, H., Hinkley, M.	Working with flood managers and exercising the existing authorities of Arizona's Flood Control Districts may allow for increased integration of recharge opportunities into floodwater management practices and provide both community and ecosystem benefits.	**Additional Resources**: Flood Control Workshop Summary brief: https://ccass.arizona.edu/sites/default/files/2025-03/UA-CCASS-ATUR-Flood-Control-Brief.pdf
3.6	Su, X., Xu, T., Gupta, N., Korgaonkar, Y.	Drywells and retention/detention basins are strategies to manage and capture stormwater for recharge in urban regions. In the Phoenix Active Management Area, the ATUR team estimates that over 94,000 acre-ft per year (over 35% of the total runoff generated) on average was captured and infiltrated annually from drywells and retention basins from 2010-2020.	**Relevant Literature**: https://doi.org/10.1016/j.cacint.2025.100190. **Appendix C Sections**: Existing stormwater runoff/recharge; Green stormwater infrastructure

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3.7	Reynolds, J., Korgaonkar, Y., Gupta, N., Xu, T.	Research linking green stormwater infrastructure (GSI) to groundwater recharge is limited. However, models and studies show that GSI practices such as roof runoff harvesting, rock detention structures, and retention basins in semi-arid and arid regions can reduce peak flood flows while increasing infiltration and/or providing water for landscape irrigation demands.	**Additional Resources**: Capstone Paper: https://arizona-ua.primo.exlibrisgroup.com/permalink/01UA_INST/14j263h/alma991050633167103843. Visualization: https://juliannareynolds919.github.io/GSI-visualization/. **Appendix C Sections**: Green stormwater infrastructure
3.8	Lima, R., Sankey, T.	Statewide mapping shows that forest thinning in Arizona's ponderosa pine forests can enhance recharge and provide a water-capture co-benefit. Of the 1.4 million hectares of ponderosa pines statewide, about 46% (588,992 ha, 1.45 million acres) is highly suitable and 2.4% (30,920 ha, 76.5 million acres) is very highly suitable for thinning with recharge enhancement as co-benefit.	**Relevant Literature**: Lima et al. (in prep); https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5219156. **Appendix C Sections**: Modeling on forest thinning; Thinning/high elevation forest recharge
3.9	Zalesky, T., Gupta, N., Lima, R.	The statewide suitability tool for the use of floodwaters to enhance recharge allows identification of regions with high recharge potential. It can provide justification for more targeted local surveys to quantify actual recharge and inform local management practices.	**Relevant Literature**: Zalesky et al. (in prep); **Additional Resources**: Statewide floodwater recharge suitability tool. **Appendix C Sections**: Floodwater recharge
3.10	Lima, R., Springer, A.E.	Karst aquifers (including limestone and related rock types) are critical to Arizona's water resources; they support municipal water supplies, sustain base flow in rivers and streams, and feed ecologically important springs. Karst landscapes–characterized by internal drainage, rapid infiltration, and direct connection between surface and groundwater–offer unique opportunities for recharge enhancement.	**Appendix C Sections**: Karst recharge, Groundwater recharge

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3.11	Lima, R., Springer, A.E., Sankey, T.	Lineament density (density of fault-related features) is a widely used indicator of enhanced infiltration potential and a common factor or thematic layer used in analyses for recharge suitability and in identifying potential recharge zones in bedrock environments.	**Relevant Literature**: https://doi.org/10.4211/hs.6972730012384cc788bb5b3d0e686083. **Appendix C Sections**: Groundwater recharge; Focused vs diffuse recharge
3.12	Mroczek, C., Combs, C.E., Springer, A.E.	Controlled tracer experiments in karst systems provide critical empirical data for managed aquifer recharge design in semi-arid regions, revealing rapid subsurface connectivity through structural features that concentrate recharge – these same features render these zones vulnerable to contamination, presenting a fundamental trade-off for system design.	**Relevant Literature**: Mroczek et al. (in review). **Additional Resources**: Water tracer study conducted on an ephemeral wash on the Colorado Plateau. **Appendix C Sections**: Karst recharge
3.13	Gupta, N., Lima, R., Jacobs, K., Sankey, T., Springer, A.E., Richter, H.	Groundwater supplies can be supported by integrating groundwater recharge considerations into existing land and water management practices. Opportunistic Recharge Enhancement (ORE) is a cross-disciplinary, scalable framework to augment groundwater supplies by strategically integrating recharge co-benefits into existing land and water management practices such as land use planning, forest thinning and stormwater management.	**Relevant Literature**: Gupta et al. (2026): https://ngwa.onlinelibrary.wiley.com/doi/10.1111/gwat.70070. **Appendix C Sections**: Strategies for capture and recharge

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Appendix A	Hinkley, M., Gupta, N., Mohsenzadeh Karimi, S., Bennett, A., Qiu, Y.	Groundwater Basin Profiles
Appendix E	Hinkley, M., Gupta, N., Jacobs, K.	Decision Support Framework with interactive StoryMap
Appendix F	Jacobs, K., Richter, H., Bromley, F.	Matrix of Recharge Strategies