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Four Climate Scenarios Developed to Explore Adaptation Strategies for the Truckee-Carson River System

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*This fact sheet reports results from **Water for the Seasons,** a collaborative modeling research program that partners an interdisciplinary research team with water managers representing the diverse water-use communities in the Truckee-Carson River System in California and Nevada. The program aims to assess the climate resiliency of the river system to climate-induced stressors. The content of this fact sheet provides an update to SP-17-05 (Dettinger et al., 2017) by reporting additional stakeholder-informed climate scenarios developed to examine hydrologic impacts and identify strategies to adapt water management. This five-year (2014-2019) research program is funded by a Water Sustainability and Climate program from the National Science Foundation (#1360506) and the U.S. Department of Agriculture (#2014-67003-22105).*

What is the significance of climate change on water resources in the Truckee-Carson River System?

Climate change poses critical challenges to water management in river systems dependent on snow for water supply (Dettinger, Udall, & Georgakakos, 2015; Hatchett et al., 2017; McCabe, Wolock, & Valentin, 2018; Mote, Li, Lettenmaier, Xiao, & Engel, 2018). In the Truckee-Carson River System, in the western United States, the majority of water supply originates as snowpack from the Sierra Nevada and flows northeastward (Figure 1). Snowmelt runoff generates a majority of surface water supply for diverse downstream municipal, industrial, agricultural and environmental water-use communities in the Great Basin of northwestern Nevada. Snowpack also recharges groundwater that is relied upon as a supplemental water supply, particularly during drought years.

Warming temperatures alter both the accumulation and melt of snow-derived water resources, leading to shifts in timing of water supply and challenging water-management institutions that are based on historical snowmelt records (Barnhart et al., 2016; Li et al., 2017; Milly et al., 2008). To assess these challenges, a collaborative research approach becomes useful to harness local knowledge to identify the salient climate change impacts and local water-management challenges, and examine the effectiveness of potential adaptation strategies (Sterle & Singletary, 2017).

How is local knowledge used to inform research activities?

A collaborative modeling research program in the Truckee-Carson River System convenes an interdisciplinary research team, including hydrologists and climatologists, with a core group of local stakeholders representing the diverse water-use interests from headwaters to river system terminus (Singletary & Sterle, 2017, 2018). Iterative interactions ensure that research and modeling activities incorporate local stakeholder perspectives and information needs.

Figure 1. The Truckee-Carson River System. Singletary & Sterle (2017).

Figure 2 illustrates the idealized collaborative modeling process for using local knowledge in applied climate science research. An assessment of climate resiliency begins with conversations with local stakeholders to identify climatic conditions and impacts of greatest concern. These narratives are then translated into climate scenarios that are used to model changes to water availability and subsequent consequences under existing and alternative water-management practices.

Conditions may focus on extreme events, such as prolonged drought (Dettinger et al., 2017); specific climate changes, such as warming temperature or increased precipitation variability; or overall changes as depicted in multiple projections of future climate. Regardless, the climate scenarios focus on plausible storylines that reflect the climate change risks that are of greatest concern to local stakeholders.

Impacts of climate scenarios and management alternatives are simulated using hydrologic and operations models tailored to the river system (for additional details on these models, see Sterle et al., 2017). Modeling results are then visualized in terms of performance metrics that serve as indicators of important impacts (e.g., river flows or reservoir stage at a particular location and time of year) and presented back to stakeholders in a workshop setting to identify alternative water management strategies capable of alleviating the simulated impact.

What climate scenarios were developed for the Truckee-Carson River System, and what research questions can be addressed?

Table 1 summarizes the four sets of climate scenarios developed as part of

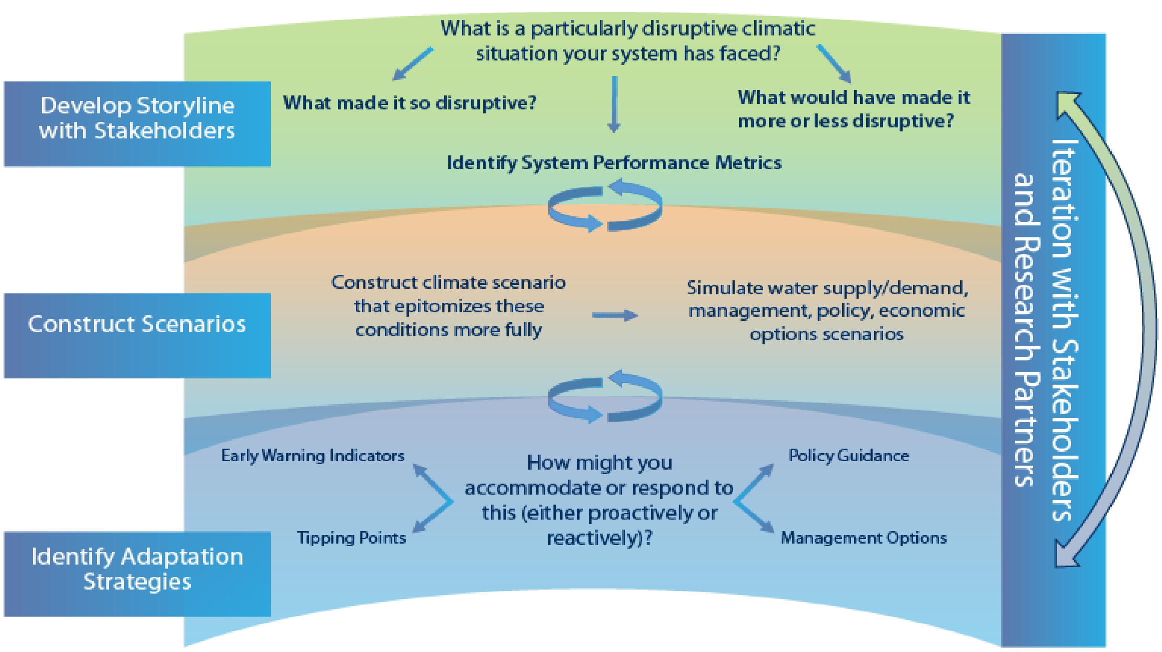

Figure 2. Collaborative modeling to construct and simulate climate scenarios that depict salient impacts described by local stakeholders.

Table 1. Climate scenarios being explored as part of the Water for the Seasons project. Scenarios are developed by translating stakeholders' storylines into model simulations that explore climate impacts and alternative adaptation strategies.

	Climate Scenarios			
	1) Extended Drought + Mid-Century Warming	**2) Late-Century Warming Scenarios**	**3) Low- and High-Frequency Precipitation Variability**	**4) Range of Climate Projections for Lake Tahoe**
Develop Storyline *Stakeholder Input*	The 2012-2015 drought was the worst drought most water-management organizations had experienced, and anything longer could be the "point of no return."	Stakeholders indicate that increased temperature effects on earlier snowmelt runoff and peak streamflow timing would be difficult to accommodate under existing water-management institutions.	The effects of increased precipitation variability are difficult to predict and may differ in the Carson and Truckee Basins due to differences in storage, dominant water uses, and reliance on groundwater versus surface water.	Stakeholders identified Lake Tahoe lake levels as one of the most important indicators of the water supply situation for the system under future climate.
Develop Storyline *Researcher Translation*	Explore implications of continued warmer, severe drought conditions on water supply under current water management and under warmer conditions.	Quantify implications of continued warming on water management prescribed to historical climate records and compared to historical patterns.	Explore sensitivity of water supply under low- versus high-frequency precipitation variability and late-century warming, and implications of alternative water management.	Explore probabilities, frequencies, and durations of Lake Tahoe lake levels under future climate projections and conditions under which they occur.
Construct Scenario	Splice 1987-1994 and 2012-2015 [two "worst-case" droughts] to develop a worse-than-historical scenario; add warming expected by 2050 (2.5 degrees Celsius) to form a second climate-changed version.	Add late-21st century warming (4.3 degrees Celsius) to the 1980-2015 climate record.	Screen large ensemble of climate model projections for 20-year periods with similar precipitation average to historical, 4.3 degrees Celsius temperature increase and 2-year versus 5-year frequencies of precipitation variability.	Simulate eight model ensembles of climate model projections through hydrologic model(s), then screen outputs to identify periods of Lake Tahoe lake levels below (and above) the natural rim.
Indicators	Water levels at Truckee River reservoirs, Lake Tahoe, Pyramid Lake and Lahontan Reservoir; Carson River inflows; and water deliveries to Truckee Meadows agriculture and Truckee-Carson Irrigation District.			Lake Tahoe lake levels
Identify Adaptation Strategies	The above scenarios are being explored to assess the effectiveness of alternative adaptation strategies in comparison to status-quo operations, including: • Agricultural efficiency (water conservation) measures in the Upper Carson Valley, • Managed aquifer recharge in the Carson Valley, • Truckee River reservoir operations that enable the capture and storage of water earlier in the season, and • Truckee River water allocations that could mitigate against future water supply shortages.			The impacts of the full duration and range of climate projections on Lake Tahoe lake levels allow specific episodes of lake level fluctuations and extremes to be explored to assess resulting challenges and impacts in greater detail.

the *Water for the Seasons* research program using local stakeholder input (Albano, 2019). These scenarios include: 1) Extended Drought + Mid-Century Warming, 2) Late Century Warming Scenarios, 3) Low- and High-Frequency Precipitation Variability, and 4) Range of Climate Projections for Lake Tahoe. The degree of warming aligned with projected changes in temperature under two greenhouse gas scenarios, and include 2.5 degrees Celsius (4.5 degrees Fahrenheit) by mid-century (2050) and 4.3 degrees Celsius (7.7 degrees Fahrenheit) by late-century (2080) (IPCC, 2014). The data for each of these scenarios will be freely available through the Consortium of Universities for the Advancement of Hydrologic Science at https://www.hydroshare.org/.

Through simulation of these scenarios, researchers and stakeholders are working together to address the following research questions:

- How are the timing and availability of water supplies affected under each climate scenario at key locations in the system?
- To what extent does earlier capture and storage of water in surface reservoirs help to meet water users' needs under conditions of earlier snowmelt and streamflow timing?
- To what extent does managed aquifer recharge enhance water storage and supplies, and what are the implications of this strategy for diverse water uses?
- How do agricultural water demands change under warmer conditions, and how effective are agricultural efficiency measures at lessening impacts to ground and surface water supplies?

Preliminary results indicate periods of greater-than-historical precipitation variability and warming temperatures introduce challenges to water management, necessitating identification of viable adaptation strategies for the river system.

Collaboratively reviewing modeling results provides an opportunity for stakeholders to gain insights into the potential effectiveness of alternative management strategies. At the same time, researchers are able to further refine their efforts based on additional stakeholder input. The research reported in this fact sheet demonstrates how collaborative modeling provides information useful for stakeholders' climate adaptation planning.

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