



WATER For The SEASONS

"A Program for Sustaining Water Resources in a Changing Climate"



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Adapting to Variable Water Supply in the Truckee-Carson River System: Results of Focus Groups Conducted in 2016 With Local Water Managers

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Water for the Seasons is an integrated research and Extension program that partners researchers with community stakeholders in the Truckee-Carson River System to explore new strategies and solutions for dealing with droughts and floods. Funded by a grant from the National Science Foundation and the U.S. Department of Agriculture, this four-year program uses a collaborative modeling research design that strategically links scientific research with community problem-solving. The goal of this program is to assess and enhance community climate resiliency in snow-fed arid-land river systems. For more information, visit waterfortheseasons.com.

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Introduction

The Truckee-Carson River System supplies water to the high-desert communities of northwestern Nevada through spring snowmelt originating as winter snowpack in the Sierra Nevada. Climate change impacts water management in the region (USGCRP, 2017) by altering the amount of snowpack that accumulates in the mountains (Mote, Hamlet, Clark, & Lettenmaier, 2005; Trujillo & Molotch, 2014), changing the type of winter precipitation that occurs (rain versus snow) (Knowles, Dettinger, & Cayan, 2006), and shifting the timing of snowmelt (Fritze, Stewart, & Pebesma, 2011; Regonda, Rajagopalan, Clark, & Pitlick 2005).

Thus, when we discuss climate change impacts in the region, attention is focused on changes in snowpack storage that directly impact water supply (Li, Wrzesien, Durand, Adam, & Lettenmaier, 2017). Referred to as *snow drought*, such conditions may be the result of either: 1) a period of abnormally low snowpack for the time of year, reflecting either below-normal cold-season precipitation (*dry snow drought*) or 2) a lack of snow accumulation despite near normal precipitation, usually when warm temperatures prevent precipitation from falling as snow or result in unusually early snowmelt (*warm snow drought*) (AMS, 2017; Harpold, Dettinger, & Rajagopal, 2017).

Earlier snowmelt runoff, for example, alters streamflow timing and reduces summer streamflow (Barnhart et al., 2016; Stewart, Cayan, & Dettinger, 2005). Earlier snowmelt reduces surface water supply, particularly during dry periods (Georgakakos et al., 2014), while also affecting groundwater recharge (Harpold, 2016; Jasechko et al., 2014). Warmer spring temperatures further compound dry periods by increasing evaporation from surface water reservoirs and lakes, diminishing soil moisture, and increasing evaporation of irrigated crops (Hatchett, Boyle, Putnam, & Bassett, 2015).

Recent 2012 to 2015 drought conditions experienced in the region remain unprecedented due to decreased snowpack accumulation enhanced by warmer winter temperatures (Belmecheri, Babst, Wahl, Stahle, & Trouet, 2016; Bond, Chronin, Freeland, & Mantua, 2015; Cayan et al., 2016; Cook, Ault, & Smerdon, 2015; Mote et al., 2016). The period 2012 to 2015 was the driest four-year period in California and the 29th driest in Nevada in a 122-year record (CNAP, 2017). Snowpack measured April 1 was three percent of normal in the Carson Basin and 13 percent of normal in the Truckee Basin (NRCS, 2015a), and coincided with record-high January through March temperatures (NOAA, 2015).

The year following (2016) was modestly wet, with April 1 snowpack conditions resembling near-normal snow water equivalence. However, warmer temperatures in April (e.g., 2 F to 4 F) accelerated snowmelt considerably (NRCS, 2016a; b; Nevada State Climate Office, 2016). New snow accumulation in the higher elevations at the end of April 2016, paired with unseasonably cooler temperatures in May, helped to stretch water supply and delay irrigation water demand. Yet by July, agricultural managers at the river system terminus (e.g., Newlands Project) still faced water supply shortages due to previous consecutive years of drought conditions (NOAA, 2017; NRCS, 2016c).

A collaborative research design recruits and uses local knowledge to aid researchers in understanding how local water managers are adapting to continued water supply variability (Klenk et al., 2015; Meadow et al., 2015; Parris et al., 2016). Collaborative research also

strengthens local adaptive capacity in that it requires researchers and key stakeholders to learn together through information exchange (Ensor & Harvey, 2015; McGreavy et al., 2015). Collecting primary data from managers and including their input throughout the research program ensures that research results are useful for decision-making while also advancing applied climate science research.

The collaborative modeling research design implemented to assess drought resiliency in the Truckee-Carson River System relies on researchers' continuous engagement with a *Stakeholder Affiliate Group* comprised of key local water managers (Singletary & Sterle, 2017; Singletary & Sterle, forthcoming 2018; Sterle & Singletary, 2017). Managers represent municipal, industrial, agricultural, environmental and regulatory water-use interests from the river system headwaters to terminus. Figure 1 illustrates the research design implemented in the Truckee-Carson River System case study, highlighting the location of the 12 *Stakeholder Affiliate Group* organizations.

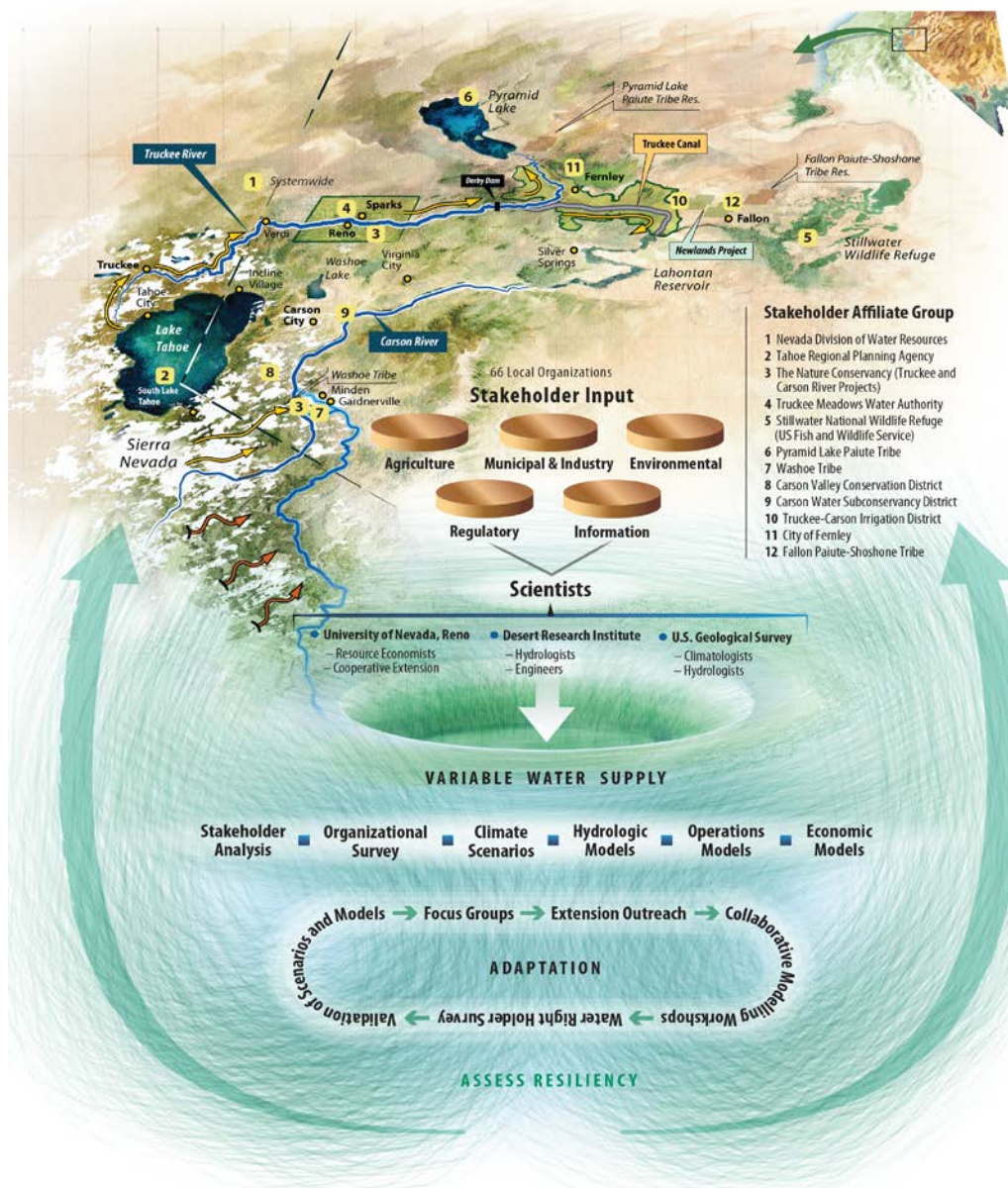


Figure 1. Collaborative Modeling Research Design (Singletary & Sterle, 2017).

As part of the social learning process, interviews and focus groups provide a method of primary data collection to support information exchange. Focus groups served as a second round of primary data collection. The first round of primary data for this case study was collected during face-to-face interviews with 66 local water managers between March and August, 2015. These data allowed researchers to identify baseline water supply challenges during normal versus drought water years (Sterle & Singletary, 2017). During these interviews, managers described *adaptation strategies*, defined as adjustments or actions devised or taken in response to water supply variability due to decreasing or variable winter precipitation, warming temperatures and shifting seasonality (Moser & Boykoff, 2013). Additionally, managers described barriers that impede their ability to adapt, furthering researchers' understanding of information needs across the river system.

Focus groups were conducted during the 2016 summer irrigation season with local managers to determine to what extent continued water supply variability in the Truckee-Carson River System challenged water management and the adaptation strategies managers were planning or implementing. The resulting focus group data furthered a systemwide understanding of how variable water supply, particularly during consecutive drought years, impacts diverse water-use communities that depend on a snow-fed, and highly regulated, river system.

This Extension Special Publication reports the results of the 2016 focus group discussions. It examines, during consecutive drought years, the local water supply challenges faced and subsequent strategies sought to adapt to variable conditions and any barriers encountered. This report does not instruct managers as to which adaptation strategies they should implement, but rather reports the adaptation strategies they identified and implementation challenges faced.

Case Study Area

The Truckee (3,060 square-mile area) and Carson rivers (3,966 square-mile area) originate as snowpack in the Sierra Nevada of eastern California and terminate in the Great Basin of northwestern Nevada. (See Figure 2.) Areas in the headwaters receive over 70 inches of precipitation annually, with 90 percent of the precipitation above 6,000 feet falling as snow between November and April.

The Sierra Nevada typically blocks the passage of precipitation-producing weather systems, resulting in a rain-shadow effect. Due to this rain shadow, the middle reaches of the river system receive less than 15 inches of precipitation annually on average, with lower reaches of the Carson River receiving on average less than 5 inches of precipitation per year.

The majority of river flows are generated by spring snowmelt runoff from April to July, with historical peak runoff occurring in June, sustaining river flows through August. Thirty-year (i.e., 1981-2010) annual average temperatures for the region range from 47.8 F to 68.9 F in the higher elevations in the headwaters, to 67.0 F to 94.5 F in the lower elevations near the system terminus (BOR, 2015).

The Truckee-Carson River System supplies water for urban areas, irrigated agriculture and environmental flows to support habitat for the endangered (Cui-ui) and threatened

(Lahontan cutthroat trout) fish species in Pyramid Lake, a rare natural desert terminus lake located on the Pyramid Lake Paiute Reservation. The *system* aspect of the river results from Truckee River surface flows diverted via the Truckee Canal to join Carson River flows to supply water to the Newlands Irrigation Project area, the nation's first desert reclamation project (1906), and environmental use on the Stillwater National Wildlife Refuge (Wilds, 2014).



Figure 2. The Truckee-Carson River System (Singletary & Sterle, 2017).

Systemwide water use is highly regulated through federal, tribal, state and local water-sharing agreements based on historic prior appropriation doctrine (Wilds, 2014). Local water utilities serving the urban areas of Reno-Sparks and Carson City satisfy water demand through conjunctive use, managing water primarily from surface flows and upstream reservoirs (in the case of the Truckee River) in order to conserve groundwater and reduce use of wells. Municipal water supply for smaller communities in the region, which include Lake Tahoe Basin communities, Truckee, Minden, Gardnerville, Dayton, Stagecoach, Fernley, Silver Springs and Fallon, is provided almost entirely from groundwater aquifers. In contrast, the majority of agricultural diversions depends largely on surface water delivered through networks of earthen ditches constructed in the mid-19th and early 20th centuries.

Method

Twelve focus groups were conducted between April and August 2016 with key water managers representing each of the 12 *Stakeholder Affiliate Group* organizations.¹ These organizations represent municipal and industrial, agricultural, environmental and regulatory water use communities from headwaters to terminus (Table 1). Managers were encouraged to invite staff resource specialists and water right holders to participate, resulting in one to 16 managers per focus group or a total of 59 participants.

Table 1. *Stakeholder Affiliate Group* organizations, type of water use and number of participants per focus group. Numbers in parentheses correspond to the location of the organization indicated on Figure 1.

Water Use	<i>Stakeholder Affiliate Group</i> Organizations	Number of Participants
Municipal and Industrial	Truckee Meadows Water Authority (#4)	1
	Carson Water Subconservancy District (#9)	16
	City of Fernley (#11)	3
Agricultural	Washoe Tribe (#7)	2
	Carson Valley Conservation District (#8)	16
	Truckee-Carson Irrigation District (#10)	1
Environmental	The Nature Conservancy (#3)	4
	Stillwater National Wildlife Refuge (#5)	2
	Pyramid Lake Paiute Tribe (#6)	1
	Fallon Paiute-Shoshone Tribe (#12)	4
Regulatory	Nevada Division of Water Resources (#1)	4
	Tahoe Regional Planning Agency (#2)	5
<i>Total</i>		59

Questions were codeveloped by an interdisciplinary team of researchers and designed to:

- 1) Capture local knowledge and perspectives regarding continued water supply challenges, adaptation strategies and adaptation barriers immediately following the 2012 to 2015 drought period;
- 2) Gather input for hypothetical yet plausible climate scenarios, such as drought or floods (Dettinger et al., 2017), that would resemble future water supply variability useful for managers' adaptation planning purposes; and
- 3) Identify adaptation strategies of interest to managers so that research activities can be prioritized to support local decision-making in the the face of continued water supply variability.

The hypothetical climate scenarios provide precipitation and temperature data as inputs to a suite of hydrologic and operations models tailored to the river system (Sterle, Singletary, & Pohll, 2017). Hydrologic models produce outputs including streamflow and groundwater

¹ The focus group methodology followed a consistent protocol pertaining to human subject research, including participant recruitment, question items included, and data collection and analysis. The University of Nevada, Reno Office of Research Integrity reviewed and approved this protocol.

levels. Operations models produce outputs including reservoir levels, fish flow regimes and water right allocations. When evaluated by local water managers alongside researchers in a structured setting, these outputs are useful in exploring potential future changes in water supply and subsequent operational changes that may be necessary to enhance supply, increase management flexibility, and sustain water resources in the region.

Focus groups were conducted at water managers' offices and lasted approximately 90 minutes. Hydrologists and engineers from the research team joined the authors in these discussions to answer questions specific to the modeling activities. They explained how the models are calibrated to represent the physical aspects of the river system and to predict future water supply availability under hypothetical future climate scenarios. Additionally, they explained *model selection*, including the difference between operations models tailored to the Truckee and Carson Rivers, and *model capability*, including how groundwater and surface water systems are coupled, and the extent to which these water sources can be simulated at the same time (see Sterle, Singletary, & Pohll, 2017).

Discussions were recorded using a laptop computer. Typed transcripts were analyzed using *content analysis* (Krueger & Casey, 2015; Rossman & Rallis, 2016), a method commonly used to compare and contrast qualitative data in order to identify emergent themes. Results are reported by the most frequently stated responses. The direct quotes featured here further illustrate seven emergent themes that reflect local knowledge and perspectives unique to particular water-use communities and/or location on the river system.

WATER CONSERVATION AND UTILITY REVENUE CHALLENGES

"Last year, we asked for 10 percent reduction and we got 20 percent. People are not going to go back to pre-2015 water use levels. People fixed a bunch of inefficiencies that there was no motivation to fix before... The problem here is that the net result is that we are a store. We sell one product. We have a mortgage. The only way to pay the mortgage is to sell that product. The less we sell, the more the average cost of that product goes up. We are in a time period, where that mortgage is going away. We put so much rehab into the system, our repair and replacement numbers are going down. We are offsetting ... we are able to financially manage our reduction in revenue through these offsets." – Truckee River municipal and industrial water manager.

Results

Theme 1: Despite a projected normal water year, drought-associated water supply challenges continue.

Water managers described continued water supply challenges during the 2016 summer irrigation season despite normal winter snowpack accumulation. Following four consecutive years of drought, the projected 2016 normal water year did not provide "enough" water to rebound water supply.

For example, local agricultural water managers described the effects of warmer than normal spring and summer temperatures that resulted in earlier and more rapid snowmelt. That is, given the near 100 percent snowpack in 2015-2016, forecasters predicted a 100 percent allocation for the coming growing season for the Newlands Irrigation Project Area. To recover from drought conditions of the three previous growing seasons, many farmers had based their decisions for operation investments on the projection of a 100 percent water allocation. However, water supply for irrigation was compromised by warmer

temperatures, extremely dry soil conditions compounded from prior drought years, and inability of the current earthen conveyance system to deliver water duties effectively.

Conditions forced some urban water managers to consider locating new sources of water, including potable reuse, and postpone high-water-use development projects. Municipal and industrial water managers explained how increased drought conservation measures had decreased revenue. Water managers representing environmental and regulatory interests described how drought conditions had forced them to revise existing conservation management plans and goals for water quality standards, and to identify monitoring needs to help inform future drought planning.

FARM-SCALE IMPACTS

"We did not choose to deficit irrigate – physically couldn't get the water there. We had no choice. Then we couldn't graze. Perhaps we wouldn't have made this choice because we view this water as having a holistic purpose." – Upper Carson Valley agricultural water manager.

Theme 2: Drought conditions have negative impacts for all water users, with impacts unique to agricultural communities.

All managers, regardless of water-use community, described the negative impacts of consecutive drought years. Those impacts described most frequently included:

- Degraded water quality due to less water in the system concentrating pollutants in groundwater and surface water bodies; these issues are compounded further by warmer air temperatures;
- Diminished river system and watershed health, including surface lakes drying out; degradation of wetlands, meadows and riparian areas; and decline in forest health due to increased disease and wildfire;
- Domestic well users struggle to access water, and many cannot afford to drill deeper wells;
- Destruction of wildlife and migratory bird habitat due to a loss of irrigated wetland vegetation;
- Agricultural impacts, which include fallowed lands becoming infested with noxious weeds; and
- Loss of recreational opportunities.

In response to drought conditions, many agricultural managers responded that they would "absolutely" consider fallowing the less profitable or productive lands. Others explained that fallowing would be a last resort, and instead they would limit irrigation on all fields before fallowing. If forced to fallow or significantly reduce irrigated acreage, agricultural producers requested information about alternative water-efficient crops and how to improve irrigation efficiency.

Use of groundwater to supplement surface-flow-dependent irrigation during drought years is not an option for many producers who either do not have groundwater rights or lack infrastructure to access groundwater for irrigation purposes. The majority of producers explained that increased reliance on groundwater is infeasible given that well permits are unavailable and sustainable aquifer recharge rates are uncertain under a changing climate.

Theme 3: Warming temperatures exacerbate drought impacts.

Consensus emerged across all water managers that warmer temperatures made drought conditions worse. The impacts described most frequently included shifts in seasonality driven by earlier and more rapid snowmelt, changes in timing of runoff, and the failure of winter snowpack to accumulate and provide a substantial reserve of water for use through the summer. Water managers in the Truckee River headwaters noted increased temperature of runoff into Lake Tahoe as a subsequent cause of declining lake clarity.

Earlier snowmelt is particularly challenging for Carson River Valley agricultural water managers who lack upstream storage and depend upon flood irrigation and timing of snowmelt for water supplies. Agricultural water managers in the Newlands Project described how increasingly dry soil conditions since 2012 had prevented effective water deliveries through existing infrastructure, who several described as “antiquated.” In some areas of the river system, cumulative and extremely dry soil conditions prevented water diversions through earthen canal networks. This forced some producers to fallow lands leading to increased noxious weed infestations. Drought impacts for municipal water managers were associated with warmer temperatures and included voluntary conservation measures along with failed wastewater treatment facilities.

CHALLENGES IN WATER CONSERVATION UNDER WARMING TEMPERATURES

“Under increased temperature with long drought, we may not be able to get massive voluntary conservation efforts. What becomes important is accurately predicting demand and managing storage.”
– Truckee River municipal and industrial water manager.

Theme 4: Strategies increase to adapt to water supply challenges associated with drought impacts.

HOW MIGHT WE ENHANCE WATER SUPPLY?

“This is not going to happen in California. The additional reservoir will be in the ground.” – Systemwide regulatory water manager.

“Martis Reservoir is not used for storage. We could change the operations of Martis Reservoir to accommodate storage... that’s right [there are some fairly rigid rules, such as calendar dates, for when you store water and release it]. These systems are not fixed on calendar dates.” – Truckee River environmental water manager.

In response to continued drought challenges, water managers described increased efforts to adapt to future water variability. Managers described comparatively more strategies than in 2015 to overcome water supply challenges. Managers most often emphasized the need to collect science-based information and fund monitoring and research related to addressing issues surrounding: groundwater quality, surface water quality due to increased temperature, groundwater and surface water interactions, habitat and watershed health, riparian restoration, prescribed burns, and declining domestic/private well levels.

Water managers also described increased efforts to explore modifications to existing water-management institutions. While many Truckee River water managers reported drought adaptations through implementation of the Truckee River Operating Agreement (TROA), others sought increased management flexibility under existing water law. This includes seeking additional storage water rights and exploring managed aquifer recharge or aquifer storage and recovery.

Municipal water managers across the system frequently noted the need for such institutions to support longer-term and collaborative water management planning on a regional scale.

Ways to improve regional collaboration noted include increasing systemwide communication and coordination through more frequent meetings, field visits and collaborative monitoring efforts. Also noted was the need for educational programs to enhance community awareness of drought conditions and impacts, particularly in rural areas.

Additional adaptation strategies described by municipal water managers included efforts to enhance water supply by identifying and accessing new sources of groundwater. The

BARRIERS TO ADAPT TO WATER SCARCITY

"We try to take our old system – let's call it what it is – it's a museum. We can't do anything, it's all subject to cultural review – National Environmental Policy Act (NEPA), we deliver water in a museum. That's a fundamental problem we have. We could probably do a whole lot more if we got back into a cycle of normality." – Agricultural water manager below the Truckee Canal.

majority noted that building new surface water reservoirs was not feasible, referring to that idea "as a dream." Instead, managers recommended other strategies to increase supply. These included: construct underground storage including development of induction wells and rapid infiltration basins; change the purpose of existing reservoirs (i.e., Martis Reservoir not currently used for storage); utilize natural systems (i.e., Mud Lake or meadow/wetland restoration); increase the official storage capacity of existing reservoirs (i.e., add

another acre-foot of storage at Lahontan Reservoir); and build reservoir storage outside the basin (i.e., Virginia Hills in Storey County).

Strategies to manage water demand frequently mentioned by agricultural water managers at the farm scale included: explore alternative low-water-use crops; prioritize cultivating comparatively more productive lands; negotiate costs of pump upgrades with local energy utilities; obtain crop insurance; and maintain infrastructure to improve delivery during low-flow years.

Theme 5: As managers increase adaptation efforts, adaptation barriers emerge.

Climate uncertainty was identified as the greatest single barrier when managers described strategies to adapt to drought. Observed earlier and more rapid rate of snowmelt, diminishing aquifer recharge, and lack of water availability comprised considerable barriers.

Managers noted that a lack of accuracy in predictions for annual water supply under shifting climate regimes inhibits adaptation planning and action.

When discussing water supply enhancement as an adaptation strategy, managers described several barriers. These included: lack of water available for reservoir storage; lack of water rights (all water rights are fully adjudicated); loss of reservoir surface water to evaporation; lack of water delivery infrastructure and funding to import water from outside the basins; and costs associated with treatment of any newly identified water sources.

BALANCING DIVERSE WATER DEMAND

"When the municipality needed water during times of drought, fish were least likely to spawn (i.e. fish spawn in spring and water is needed late summer). The whole idea here is to store water for drought and if it's not used, then go ahead and turn it over to fish and wildlife. Everybody wins in those scenarios. If it's not a drought, then wildlife and the environment benefit. During times of drought it is reversed. The people take priority, and the wildlife and environment are secondary." – Truckee River municipal and industrial water manager.

Additional drought adaptation barriers included:

- Existing water-management institutions, including prior appropriation-based water law, which some managers described as inflexible;
- Increasing numbers of competing and diverse uses for scarce and already fully allocated water supply;
- Challenges with domestic well water users and rural communities adopting science-based information concerning drought adaptation planning and action;
- Loss of revenue to water utilities under metered rates (versus flat rate), particularly if conservation is mandated;
- Storage, conveyance and delivery of water during drought and the absence of sufficient force of water flows to physically push the water down delivery ditches; and
- Poor communication and lack of coordination across county and state lines.

Theme 6: Plausible climate scenarios are most useful for adaptation planning.

As part of the focus group discussions, managers described the types of hypothetical climate scenarios of interest and use in their adaptation and planning efforts. Managers

SIMULATE A FLOOD EVENT

"You could also look at atmospheric rivers. If the water is continually delivered in atmospheric rivers, can meadows handle 10 inches of rain given surrounding conditions?" – Carson Valley environmental water manager.

"A flood that would fill Lahontan and the reservoirs in the upper catchments of the Truckee River." – Carson River municipal and industrial water manager.

generally agreed that plausible climate scenarios, such as droughts about 10 years in duration, were more useful than "extreme" scenarios, such as mega-droughts of greater than 50 years.

Managers expressed interest in research that examines the extent to which a major flood or rain-on-snow event (i.e., Atmospheric River storm event) ends drought, or what it would take for the

Truckee-Carson River System, and its diverse users, to recover from the current drought.

In particular, Carson River water managers emphasized concern over increased occurrence of earlier snowmelt and earlier peak stream flow which could force managers to increase their reliance on groundwater. This includes agricultural producers relying more on supplementary wells to irrigate during the summer growing season, which might affect groundwater supplies available for municipal and industrial use. Thus, the majority of water managers agreed that a hypothetical climate scenario that demonstrates warmer temperatures would be very useful for planning.

A RETURN TO NORMALCY

"Actually, the interesting approach would be to determine how many average years would it take to recover? Just assuming a return to average conditions, how many years would it take to recover?" – Truckee River environmental water manager.

"Snowpack is the key to normal years. It doesn't need to be an extreme scenario. We just need normal." – Carson River municipal and industrial water manager.

Theme 7: Prioritize research activities that examine adaptation under a new climate future.

For planning purposes, managers requested science-based research information related to *future climate projections*. This includes: understanding the consequences of projected Lake Tahoe and Truckee River reservoir levels; impacts on diverse users of changes in seasonality; and changes in groundwater perennial yield under a shift in climate regime away from winter snow to rain. During focus group discussions, managers asked the research team the following questions:

- Should we plan for annual climate fluctuations or a new climate equilibrium altogether?
- How does temperature change seasonality?
- What is the worst-case climate scenario that worsens wildfire threats to the region?
- How is perennial groundwater yield affected by changing precipitation trends?
- Does current groundwater pumping exceed the long-term aquifer recharge rate?
- Do we need new water-management approaches to inform changes to policy?
- What is happening to water quality – specifically groundwater quality at the river system terminus, Lake Tahoe clarity, and resulting impacts of effluent from industrial discharge?

Managers expressed interest in identifying, with scientists, adaptation strategies that would improve water management during drought years, such as increasing and sustaining Carson River groundwater recharge and shifting Truckee River reservoir operations to capture earlier snowmelt runoff.

Location-specific research questions that managers posed included:

- Do we have enough storage to support increased population growth in the Truckee Meadows?
- How might future increases in residential demand change groundwater recharge in the Carson Valley?
- How does upstream pumping on the Carson River affect flows downstream?
- Is managed aquifer recharge possible in areas of the Carson River where we have greatest loss?
- How could we enhance existing storage (i.e., add space to Lahontan Reservoir or allow for earlier storage in Truckee River reservoirs)?

INFORMATION AND MODELING TO SUPPORT ADAPTATION PLANNING

“With those simulations, you could show us how bad things got in the Carson River – that is, who’s being impacted and how severe the impacts are. Are wells drying up? Whose water rights are threatened?” – Systemwide regulatory water manager.

“What should our planning horizon be? If the [Truckee] canal goes dry or is lined, how long do we have?” – Truckee River municipal and industrial water manager.

“Somehow need to cater this to the schools and the different educational groups because teachers are the ones that are going to have to deal with that.” – Environmental water manager below the Truckee Canal.

Water managers indicated that routine *Stakeholder Affiliate Group* workshops featured in this project play an instrumental role systemwide in enhancing adaptive capacity. However, they agreed that continued focus group discussions could serve as an important forum to examine stakeholder-specific water supply challenges and adaptation needs based on location in the river system.

Summary

An ongoing collaborative modeling case study in the Truckee-Carson River System continues to examine local water supply challenges coincident with variable climate conditions. Focus groups conducted in 2016 with local water managers comprising the *Stakeholder Affiliate Group* improved researchers' understanding of how continued variability led to enhanced adaptation and subsequent barriers encountered. Seven themes emerged from these discussions.

Theme 1: Despite a projected normal water year in 2016, drought-associated water supply challenges continued. The four consecutive years of drought and warmer spring temperatures compromising the normal snowpack were responsible for these continued challenges, as it was not enough water to rebound water supply. Municipal and industrial managers continued conservation efforts, and environmental and regulatory managers continued discussion around drought planning. Agricultural managers continued to face dry soil conditions, making water delivery and conveyance impossible in some places.

Theme 2: Drought conditions have negative impacts for all water users, with impacts unique to agricultural communities. All managers, regardless of water-use community, described the negative impacts of consecutive drought years. Degrading water quality, declining groundwater levels and diminishing river system health were among some of the impacts. Agricultural communities described negative impacts to crop production and water delivery, forcing some to fallow less productive fields.

Theme 3: Warming temperatures exacerbate drought impacts. Consensus emerged across all water managers that warmer temperatures made drought conditions worse. Impacts described most frequently included shifts in seasonality driven by earlier and more rapid snowmelt, changes in timing of runoff, and the failure of winter snowpack to accumulate and provide a substantial reserve of water for use through the summer.

Theme 4: Strategies increase to adapt to water supply challenges associated with drought impacts. Comparatively more strategies were described than in 2015 to better understand and plan for future water supply variability. Managers described efforts to monitor and collect science-based information to quantify change in the groundwater system, water quality and riparian health. Managers also described efforts to examine existing water-management institutions that impede their ability to adapt. They looked at ways to enhance water supply in existing surface water reservoirs or enhance groundwater recharge through aquifer storage and recovery. Managers emphasized that in order to adapt, collaboration and communication among river system managers was essential, particularly to revisit existing water institutions and collectively share information needs and findings. Inevitably, enhancing water supply through exploring new sources of water or treating previously untapped resources would be considered to sustain supplies for current and future demand.

Theme 5: As managers increase adaptation efforts, adaptation barriers emerge. Managers typically described barriers encountered in conjunction with adaptation. That is, as they increased their efforts, barriers became more apparent. Climate uncertainty emerged as the greatest barrier to adapt. Managers noted that a lack of accuracy in predictions for annual water supply under shifting climate regimes inhibits adaptation

planning and action. Additionally, as managers examined potential changes to existing water-management institutions, they were faced with barriers of these very institutions themselves, as well as lack of coordination across the system. Similarly, as managers increased efforts to enhance water supply, they were faced with water scarcity and water delivery barriers needed to convey new sources to customers and/or agricultural lands.

Theme 6: Plausible climate scenarios are most useful for adaptation planning.

Managers emphasized the importance of developing plausible climate scenarios for the region that parallel observed climate changes to date, including weaker winter systems resembling snow drought periods and warmer winter and spring temperatures. Given the severity of the recent drought period (2012-2016), managers requested scenarios that illustrate the amount of water, either from a flood event or extremely wet year, that it would take to rebound from a drought of this severity.

Theme 7: Prioritize research activities that examine adaptation under a new climate future. For planning purposes, managers requested science-based research information related to *future climate projections*, such as understanding change in reservoir storage, impacts to particular water-use communities, and changes in groundwater perennial yield if more rain than snow is observed in years to come. Given the capabilities of the research team, managers requested that hydrologic, operations and econometric models explore how changes in water supply manifest spatially across the system, and particular operational changes that may alleviate those impacts. Water managers indicated that focus groups, in addition to routine *Stakeholder Affiliate Group* workshops featured in this project, play an instrumental role systemwide in enhancing adaptive capacity.

Conclusions

Preliminary results of the focus groups were presented during a *Stakeholder Affiliate Group* workshop (Oct. 4, 2016) that served as a “third iteration” of information exchange between researchers and key informant local water managers in support of collaborative research and local problem-solving. Discussions during this workshop centered on locally identified adaptation strategies to forward an assessment of drought resiliency in the Truckee-Carson River System and efforts to strengthen local adaptive capacity to drought. The coproduction of new knowledge from these structured workshops, involving researchers and local water managers, supports science-based decision-making toward balancing diverse water demand with variable water supply.

Specifically, hydrologic and operation models simulate benefits and consequences of identified adaptation strategies to date. These include: revisions to operating rules for the four federally managed Truckee River reservoirs in order to enhance surface water supply under earlier snowmelt regimes (Sterle et al., 2017); construction of a Carson River headwaters reservoir to store earlier snowmelt for downstream agricultural irrigation (Morway, Niswonger, & Triana, 2016); and agricultural managed aquifer recharge (Ag-MAR) in the Carson River Valley through canal seepage and off-season flood irrigation (Niswonger, Morway, Triana, & Huntington, 2017). Coincidentally, since some water managers described an interest in investigating revisions to water law to enhance water supply, econometric models are being developed that examine the performance of prior appropriation doctrine in allocating water to highest valued uses historically and today (Lee, Rollins, & Singletary, 2017).

As part of the collaborative modeling research design, researchers continue to engage with local water managers to better understand adaptation strategies and barriers coincident to real-time conditions. Subsequent Extension publications will report the results of these discussions. This includes 2017 historic wet-year impacts on water-management adaptation strategies co-identified by managers and simulated by researchers in assessing climate resiliency across the river system.

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