WATER For The SEASONS

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

University of Nevada Cooperative Extension

PEER REVIEWED

**Special Publication 17-05**

# Climate Scenarios for the Truckee-Carson River System

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***Water for the Seasons*** *partners scientists with community stakeholders in the Truckee-Carson River System to explore new strategies and solutions for dealing with extreme climate events such as droughts and floods. Funded by a grant from the National Science Foundation and the U.S. Department of Agriculture, this four-year research and outreach 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.*

**A partnership of Nevada counties; University of Nevada, Reno; and U.S. Department of Agriculture**

## Introduction

Water for the Seasons partners scientists with a 12-person community-based *Stakeholder Affiliate Group* of representatives from all sectors of the water community in the Truckee-Carson River System, to collaboratively investigate options for improving water sustainability and climate resiliency through an in-depth analysis of climate scenarios. A climate scenario is a hypothetical but scientifically realistic representation of an extreme climate event, such as an extended drought or a severe winter storm.

In this study, the scenarios ultimately take the form of gridded, daily (maximum and minimum) temperatures and precipitation totals spanning the entire Truckee-Carson River System, from which meteorological inputs to various hydrologic, water-balance and water-management models can be extracted by other parts of the Water for the Seasons project and by other studies and stakeholders.

Climate scenarios are constructed using: 1) survey data from interviews with 66 Truckee-Carson River System water-management and water-interest organizations to identify plausible drought and high-flow events that could stress the system irreparably; 2) input from the *Stakeholder Affiliate Group* and other modelers on the Water for the Seasons team to gain additional key stakeholder input with regard to organizational survey results and to identify the most pressing water-management issues being faced in the system; and 3) historical climate datasets used to simulate possible future conditions.

These stakeholder-informed climate scenarios provide inputs into a suite of models that aim to represent hydrologic conditions and operations within the Truckee-Carson River System (as illustrated in Figure 3), to explore potential impacts of climate extremes on the watershed and its communities.

The purpose of this fact sheet is to provide background information on how Water for the Seasons climate scenarios are constructed. Information on the hydrologic modeling process, study results and analyses of individual climate scenarios will be explored in subsequent publications and technical reports.

## Climate in the Truckee-Carson River System

Annual precipitation totals within the Truckee-Carson River System are highly variable and dictated in large part by the presence or absence of *atmospheric rivers,* or ARs, which are narrow bands of water vapor in the atmosphere that transport warm, moist air from the tropics. Along the West Coast of the United States, atmospheric river storms often result in heavy precipitation and flooding. Occasionally, atmospheric rivers reach further inland and bring heavy rain or snowfall to the Truckee-Carson River System and eastern slope of the Sierra Nevada (Albano et al., 2014; 2016; Rutz & Steenberg 2014).

In the Truckee-Carson River System, large floods and high-flow events occur during years with large numbers of atmospheric river storm events. About three-quarters of all peak-flow events greater than 5000 cubic feet per second (cfs) on the Truckee River at Reno, Nevada, have occurred during atmospheric river storms (see Figure 1; Albano et al., 2016). In this system, atmospheric rivers occur approximately 12 days per year (Dettinger, 2015).

When atmospheric rivers are less frequent, the Truckee-Carson River System experiences droughts. Long periods with few atmospheric rivers can result in multiyear droughts, such as the 2012-2015 drought in California and Nevada (Dettinger, 2015; 2016). During this period, above-average temperatures and below-average snowpack depleted water storage reserves and created resource-management challenges for many water-management agencies and water users. Because of unprecedented uncertainties and challenges related to the 2012-2015 drought, representatives from water-management organizations and the *Stakeholder Affiliate Group* indicated that climate scenarios involving long-term drought were of primary interest.

In the Truckee-Carson River System, multiyear droughts (including the 1987-1994 drought-of-record) have sometimes been punctuated with wet years or periods of flooding, creating additional challenges for water managers and water users. In addition to exploring the effects of long-term drought, this program's climate scenarios incorporate possible periods of heavy precipitation.

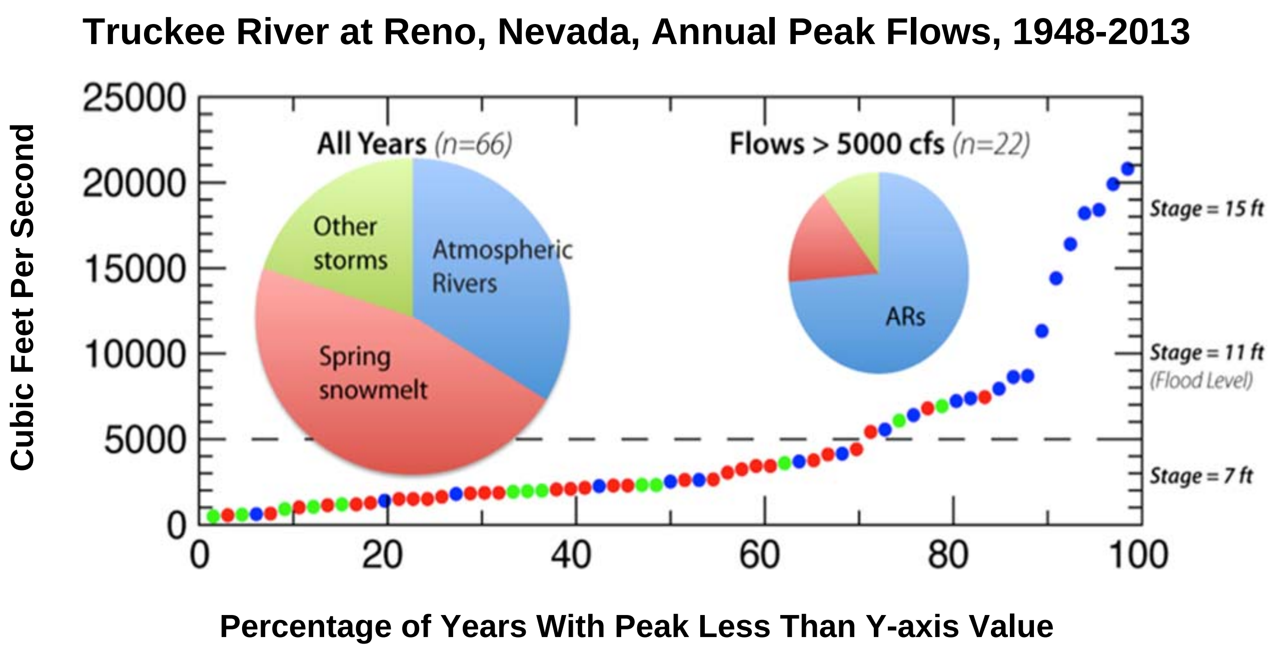


**Figure 1. The majority of large peak flow events (greater than 5000 cubic feet per second) on the Truckee River at Reno, Nev. are associated with atmospheric river storms (Albano et al., 2016).**

## Why use climate scenarios?

By focusing in-depth on a small number of stakeholder-informed climate scenarios, the research team shares with the *Stakeholder Affiliate Group* a set of plausible hydrologic conditions and challenges that are best suited to uncovering realistic and informative vulnerabilities and management options to respond to and explore. *Stakeholder Affiliate Group* and project team members brainstorm realistic responses and options for enhancing the climate resiliency of their organization or greater community in adapting to drought and other climate extremes. Limiting the number of scenarios allows for more detailed analyses of geographically specific data.

## Building a scenario

Researchers use a five-step process to develop climate scenarios. Iterations and adjustments help to ensure that results are useful and relevant to *Stakeholder Affiliate Group* participants in planning for greater climate resiliency.

**Step 1: Develop a storyline.**
Each climate scenario begins with a storyline – a description of a scientifically plausible sequence of climate events in the Truckee-Carson River System, such as a series of drought years or a sequence of wet-year to dry-year transitions that can be explained in terms of realistic sequences of large-scale climatic conditions and variations. The research team and *Stakeholder Affiliate Group* participants collaboratively select storylines to produce scenarios that will be as scientifically informative and useful as possible for the group.

**Step 2: Compile and adjust data.**
Once a storyline has been developed, program scientists compile corresponding weather data. In storylines based on historical scenarios, data are compiled by piecing together historic climate records to create sequences of appropriate duration and severity. Data are adjusted as needed to account for rising air temperatures or other projected future change (see Figure 2).

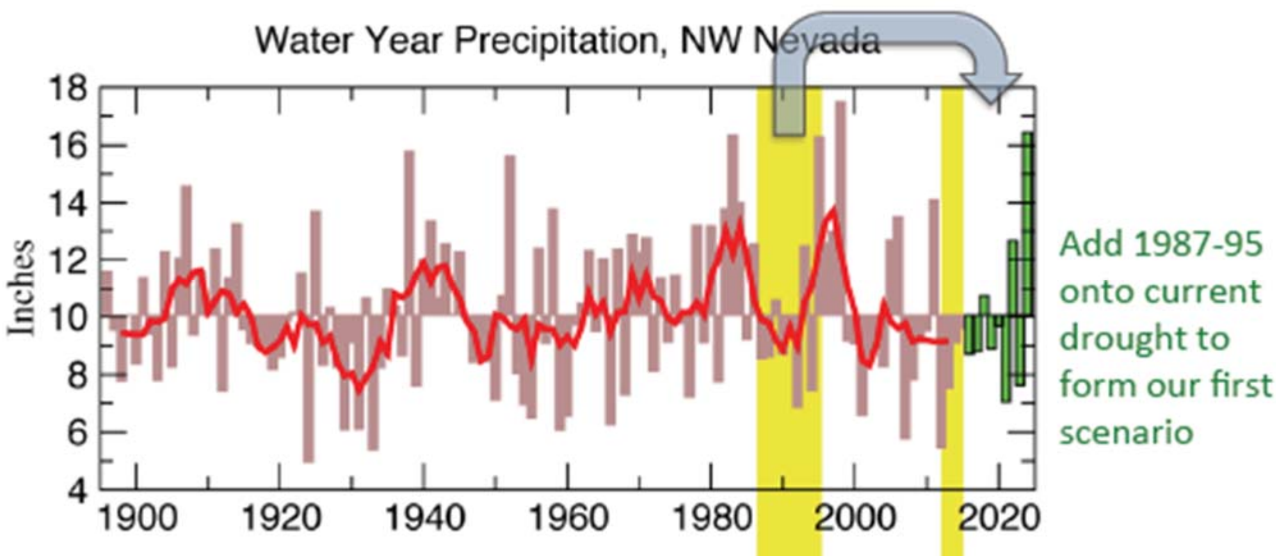


**Figure 2. Data are compiled by piecing together historic records to create sequences of the appropriate duration and severity (Dettinger, 2015).**

In storylines based on projected future conditions, data are obtained from global climate-model outputs that have been downscaled to represent the corresponding detailed conditions in the Truckee-Carson River System. Downscaling is a statistical process that converts large-scale climate variations varying over hundreds of miles into highly resolved (discerning features 3 to 5 miles across) weather data (Pierce et al., 2014). In storylines reflecting prehistoric events (such as the megadroughts of the medieval period), historical records are modified to reflect plausible ways that those past conditions could have happened, allowing those past events to be represented in great and plausible detail.

**Step 3: Integrate climate scenario data into physical and operations models.**
The meteorological events are run through a series of models (see Figure 3) to assess potential impacts of each scenario, including:

- Watershed models that show the effects on high-altitude runoff generation in the headwaters;
- Flow models that show the effects on interactions between surface water (SW) and groundwater (GW); and
- Operations models that show the effects of drought on lake levels and reservoir storage, and simulate decision-making by water users and others.

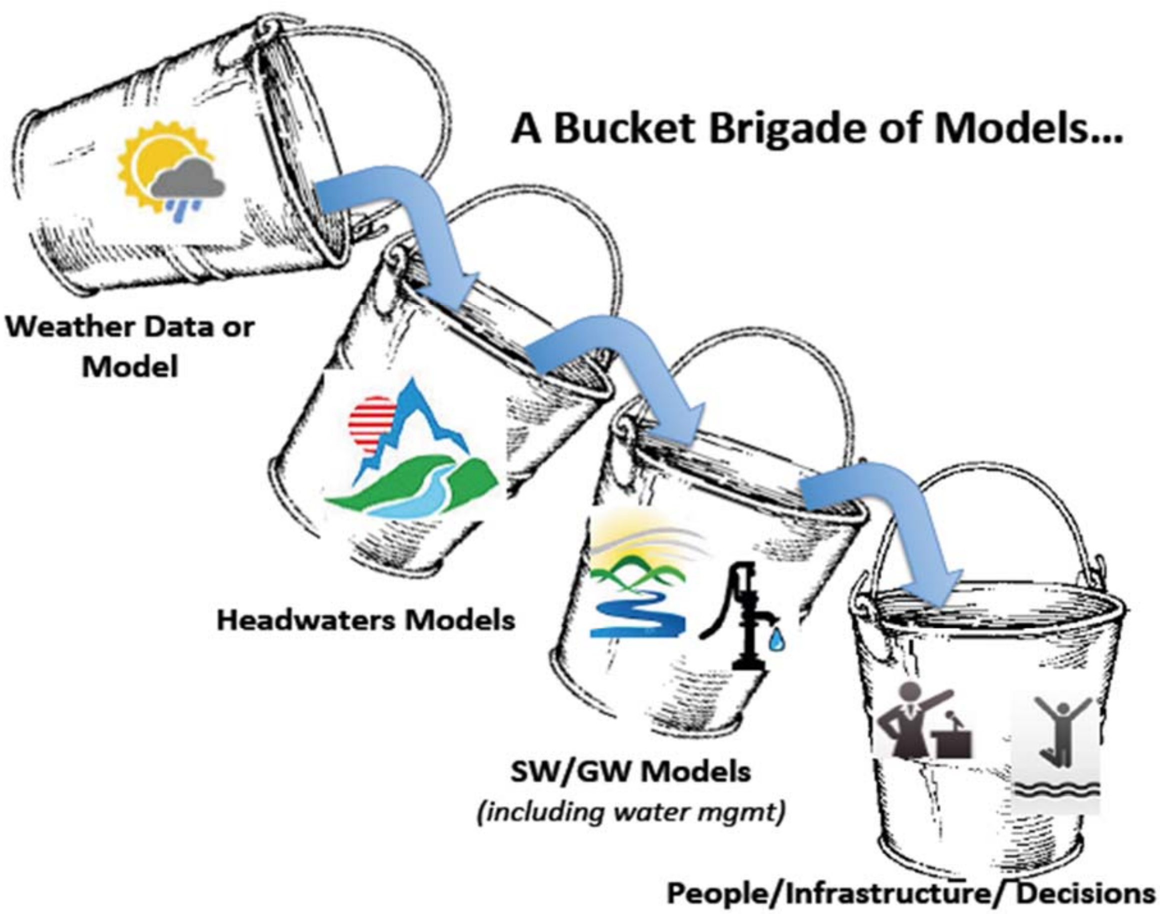


**Figure 3. Climate scenario data is run through a suite of models to assess potential impacts on the Truckee-Carson River System.**

**Step 4: Analyze results.**
The potential impacts of each stakeholder-informed climate scenario are assessed and discussed with *Stakeholder Affiliate Group* participants. Scenarios are used to explore how the impacts of modern droughts differ from historic droughts, and how increasing air temperatures might influence water resources and environmental conditions during future drought situations. The goal of this collaborative modeling activity is to come away with an improved understanding of water resources in a changing climate, and to explore water management options available for coping with or adapting to extreme climate scenarios.

**Step 5: Adjust and iterate.**
Feedback from the *Stakeholder Affiliate Group* is used to adjust climate scenarios as needed, reiterating through any steps that participants recommend revisiting. When a particular scenario has been addressed to the satisfaction of the scientists and *Stakeholder Affiliate Group*, **Step 1** may be revisited to address additional situations that may present future stressors for water managers and users.

## Proposed Climate Scenarios

Members of the *Stakeholder Affiliate Group* collaborate with the project research team to select climate scenarios to explore during the course of this project. Proposed scenarios include:

**1. THIRTEEN-YEAR MODERN DROUGHT**
*How will the Truckee-Carson River System fare if the 2012-2015 drought continues, and what will it take to end this drought?*

During the summer of 2015, the Water for the Seasons team interviewed 66 organizations within the Truckee-Carson River System, and learned that many organizations considered the 2012-2015 (current) drought to be the worst drought they had experienced (Singletary, Sterle & Simpson, 2016). Many reported that conditions during this four-year drought were already as bad as they could imagine. However, in the Truckee-Carson River System, the longest drought in recent decades lasted for eight years (1987-1994). A similar, more severe, eight-year drought occurred from 1928-1936 (Horton, 1997).

Per the requests of the organizations interviewed and the *Stakeholder Affiliate Group*, the first climate scenario explored the potential consequences of a continuation of the 2012-2015 drought. To model this scenario, researchers linked together conditions from the 1987-1994 drought to the end of the 2012-2015 drought. The drought of 1987-1994 included two above-average water years (1989 and 1993), and ended with an extremely wet year (1995). All together, this scenario constitutes a 13-year drought interspersed with a near-normal, a slightly above normal, and then a very wet year to allow the research team and *Stakeholder Affiliate Group* to evaluate how wet things would have to be to break a drought as persistent as this current drought.

Air temperatures during the current drought have been higher than they were during the 1987-1994 drought. To better represent the temperatures of what a repeat of the 1987-1994 drought might look like today, the Water for the Seasons team modeled two versions of this scenario:

**1a)** Temperature for the 1987-1995 drought was nudged upward to bring the mean (historical) temperature closer to that which was experienced during the 2012-2015 period. Data from 2012-2015 were not altered.

**1b)** All temperatures were adjusted for future warming, reflecting the average temperature changes in projections for 2051-2070 climate by 31 different climate models under low and high-greenhouse gas emissions in the future.

These scenarios were made by piecing together the observed sequences of daily precipitation, and minimum and maximum temperatures on a 4-kilometer grid over the study area for the selected water years in daily PRISM fields (PRISM datasets are gridded historical estimates of basic surface-meteorological elements – precipitation, minimum temperature, maximum temperature, and several measures of humidity – covering the conterminous U.S., produced by the Northwest Alliance for Computational Science & Engineering (NACSE) at Oregon State University (DiLuzio et al., 2008; prism.oregonstate.edu). Temperatures were then adjusted uniformly in time as described above.

The temperature adjustments for Scenario 1a were just the differences between average temperatures during the 2012-2015 and 1987-1994 periods, and were computed and applied on a grid-cell-by-grid-cell basis. The temperature adjustment for Scenario 1b was computed as the average amount of warming by 2050 over the Truckee-Carson River System area as a whole in simulations by 31 global-climate models responding to high- and low-greenhouse gas emissions scenarios. The area-wide amount of warming was applied uniformly over the entire study area in Scenario 1b.

## 2. DUST BOWL DROUGHT (1928-1936)

*How would the Truckee-Carson River System fare today under Dust Bowl drought conditions?*

Organizational survey results showed that the Dust Bowl drought of 1928-1936 also stood out in some stakeholders' memories as one of the region's worst droughts (Singletary, Sterle & Simpson, 2016). The Dust Bowl drought lasted eight years and was more severe than recent droughts, but occurred under conditions where air temperatures were lower than they are today and fewer people lived in the region.

Thus the second proposed scenario, the Dust Bowl scenario, might allow the program team and *Stakeholder Affiliate Group* to investigate how today's system would fare under Dust Bowl drought conditions, incorporating challenges related to higher air temperatures, greater water demand, existing water law and aging infrastructure.

Daily PRISM data sets are only available since 1981, so the data source used for Scenario 1 cannot be used to construct the Dust Bowl scenario. However, Livneh et al. (2013) have produced a related data set of daily temperatures and precipitation over the conterminous U.S. for 1915-2011, but on a 6-kilometer grid instead of the 4-kilometer PRISM grid. Data from the Dust Bowl era in this data set can be used as the source of this second drought scenario, with temperature adjustments applied (as in Scenarios 1a and 1b) to construct a "modern" and "future" version of that earlier drought.

## 3. MEGADROUGHT SCENARIO

*How severe could a Truckee-Carson River System drought be?*

Tree ring records from northern Nevada show evidence of megadroughts, which are droughts that lasted from decades to centuries (Cook et al., 2004). In the Tahoe Basin, the most well-known megadrought occurred between 800 and 1250 A.D. During that time, precipitation was less than 60 percent of normal, and the surface of Fallen Leaf Lake dropped 130-200 feet below its present-day elevation (Kleppe et al., 2011). In consultation with the *Stakeholder Affiliate Group*, the Water for the Seasons team may investigate the effects that a similar modern-day megadrought would have on the Truckee-Carson River System.

The tree ring record shows that in 98 percent of megadrought years, precipitation deficits were within the range of modern dry years (e.g., for California's Central Valley, reported in Malamud-Roam et al., 2007). These ancient droughts became megadroughts because drought years came so frequently (almost nonstop), not because the years individually were so dry.

To model the effects of a modern-day megadrought, researchers must construct a plausible version of daily weather events that might result in the tree ring-estimated annual precipitation totals observed during historic megadroughts. Ninety-eight percent of the time, the precipitation total estimated from a tree ring that grew during each year in these megadrought periods is similar to the total in at least one historical year. The detailed meteorological data from that historical year with approximately the same precipitation total can be concatenated (e.g., linked from the same historical-data source used in Scenario 2) to construct a highly detailed and plausible representation of what the details of the meteorology during that year in the megadrought era could have looked like. To represent the remaining 2 percent of megadrought years that fall below the range of historical totals, adjustments to the historical data will need to be made, either by uniformly scaling down daily precipitation amounts throughout the record from a randomly selected historical year or by deleting randomly selected large storms (Dettinger, 2016) from a historical year to achieve an annual precipitation total that mimics the especially dry megadrought precipitation total.

There is no reason to expect that daily precipitation (or temperature) sequences during the ancient megadrought years were precisely the same as during the similar historical years, but the constructed sequences based on historical years would be a plausible way that the precipitation totals during the ancient megadrought period could have occurred. The aim of this scenario is to explore how a plausible megadrought sequence would impact the Truckee-Carson River System, not to try to reproduce exactly (at daily and 6-kilometer resolutions) what happened in those distant past events. The latter is impossible; we will never know the day-to-day events that led to these megadroughts. However, the plausible example, constructed from historical sources, will provide a reasonable basis for exploring what the challenges and potential solutions to a megadrought event under modern water-management conditions would be.

Temperatures would be those observed on the same historical days selected to construct the precipitation scenario to ensure that weather events in this scenario are internally consistent (e.g., wet days generally remain cooler than dry days, largest storms are mostly also warm storms). However, the temperatures used in a scenario intended to be a modern version of one of the ancient megadrought episodes would probably need to be adjusted much as in Scenarios 1 and 2 were adjusted in order to represent the effects of recent and future warming trends.

## 4. CLIMATE CHANGE PROJECTION SCENARIO

*How do historical droughts compare with droughts of the future?*

To assess the specific risks associated with projected future drought scenarios, a fourth climate scenario might examine the impacts that specific examples of droughts from amongst recent climate change projections might cause. A few dozen projections of global climate change have been downscaled to fit the climatic conditions in the Truckee-Carson River Basins on a 6-kilometer grid (Pierce et al., 2014) in a form that is consistent with the Livneh et al. (2013) gridded historical data sets mentioned for Scenario 2 above. A particular drought episode can be extracted from those downscaled projections and used to investigate the characteristics and impacts of a long-term drought under climate change.

For example, Figure 4 (next page) shows an inventory of the driest and wettest decades found in recent climate-change projections by 10 global-climate models. Depending on whether the study chooses to explore an example of a very warm future drought, a very severe (precipitation deficient) but only moderately warm drought, or some mix of the two, the model and decade that offers that combination can be readily identified from the collection of projections presented there.

## 5. WET SCENARIO

*How does a wet climate scenario impact the system?*

Early on, the *Stakeholder Affiliate Group* indicated that the project would want to be sure that the project's modeling and recommendations for addressing droughts don't inadvertently reduce its capacity for accommodating floods and wet periods. Thus, Water for the Seasons is likely to include at least one wet scenario.

One strategy for developing a wet scenario could parallel the selection process (and utilize the same downscaled-climate data sets) described in Scenario 4. Figure 4 shows the inventory of the wettest decades in climate-change projections by 10 climate models. As with Scenario 4, a wet scenario could be constructed from some preferred combination of future warming and extreme wetness by selecting one of the episodes shown, and then extracting that decade's climatic conditions from the downscaled projections.

Alternatively, a historical, or even prehistorical, wet epoch could be selected from one of the data sources used in any of the preceding scenarios to construct a suitable wet scenario for evaluation. Pursuance of this wet scenario depends on the particular aims of the Water for the Seasons team and *Stakeholder Affiliate Group*.

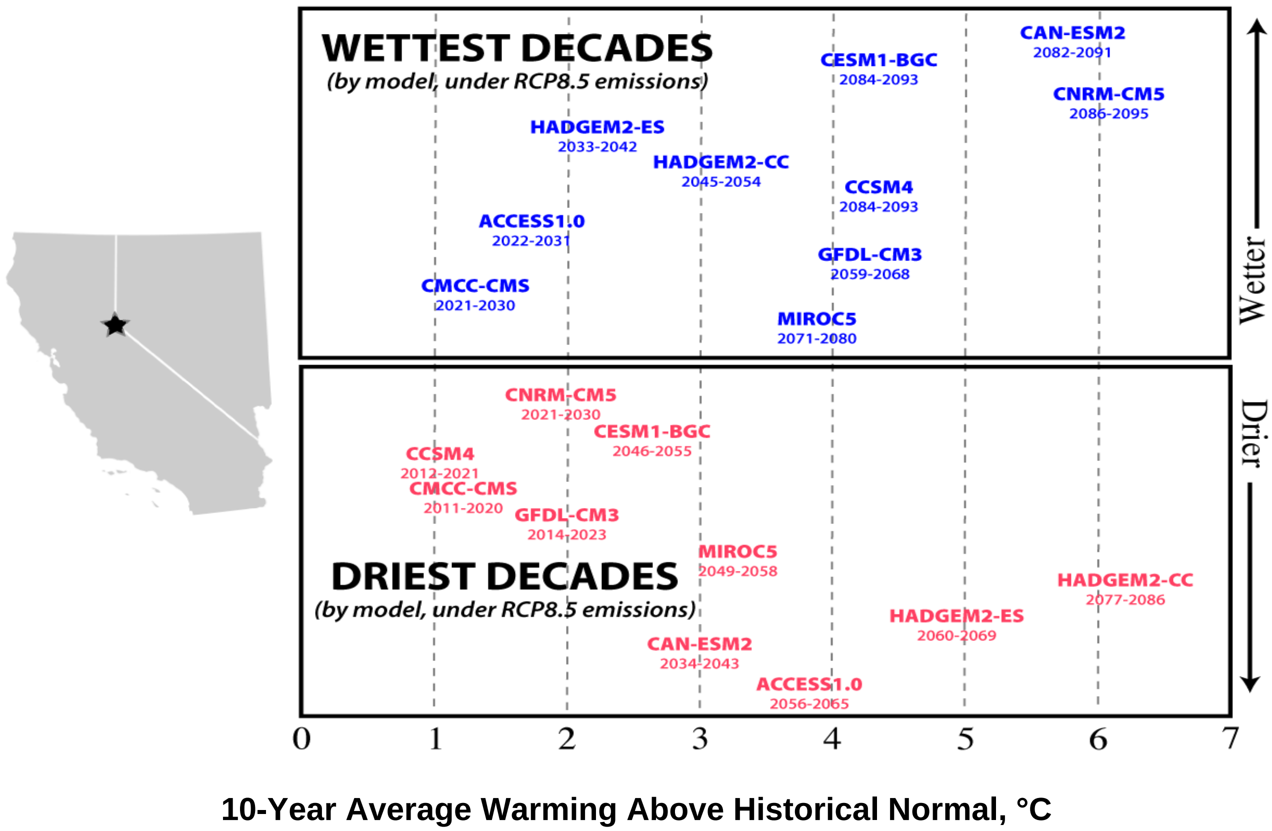


**Figure 4. An inventory of the wettest (top) and driest decades found in projections of 21st century climate over the headwaters of the study area by 10 global climate models responding to rapidly increasing greenhouse-gas concentrations in the atmosphere throughout the 21st century (the so-called RCP8.5 scenario), ranked by how warm the decades are relative to historical (1951-2000) simulated temperatures by each model, on the horizontal axis, and by how wet or dry (in relative terms) the simulated decades are, on the vertical axes.**

## Conclusion

The strategy of developing and exploring the kinds of extreme climate scenarios described here is a fundamental part of the Water for the Seasons study plan. By focusing on the relatively short-term but extreme climate episodes that have been chosen, under guidance from stakeholders and scientists, the study can address problems, responses and adaptations of the water-resources systems of the Truckee and Carson River Basins in more detail, spending less effort on near-average situations than in other studies that spread efforts across many more and much longer climate scenarios. In order for this strategy to work, however, the climate-extremes scenarios need to be well targeted (with the help of stakeholders) and physically defensible and plausible.

Outputs from these climate scenarios are used as inputs to the whole range of water models that the Water for the Seasons project has developed to simulate change across the Truckee-Carson River System (Figure 3; Sterle, Singletary & Pohll, 2017). These methods described above reflect our study's responses to the often-competing need of Water for the Seasons to select scenarios that stress the Truckee-Carson River System in new and (generally) different ways than the most extreme situations in the modern historical period, while maintaining scientific defensibility.

## References


Albano, C., Cox, D.A., Dettinger, M.D., McCarthy, M., Schaller, K. and Wellborn, T. (2014). Arkstorm@Tahoe -- Stakeholder Perspectives on Vulnerabilities and Preparedness for an Extreme Storm Event in the Greater Lake Tahoe, Reno, and Carson City Region. University of Nevada Cooperative Extension Special Publication: Reno, NV, USA, (SP-14-16). Retrieved from: https://www.unce.unr.edu/publications/

Albano, C.M., Dettinger, M.D., McCarthy, M.I., Welborn, T.L. and Cox, D.A. (2016). Application of an extreme winter storm scenario to identify vulnerabilities, mitigation options, and science needs in the Sierra Nevada mountains, USA: Natural Hazards, 80, 879-900, DOI 10.1007/s11069-015-2003-4.

Cook, E.R., Woodhouse, C.A., Eakin, C.M., Meko, D.M. and Stahle, D.W. (2004). Long-Term Aridity Changes in the Western United States: Science, 306, 1015-1018.

Dettinger, M. (2015). Large Storms, Droughts and the Tahoe Environment - Past & Future. Professional Presentation, 2015 Tahoe Science Conference. Reno, NV.

Dettinger, M.D. (2016). Historical and future relations between large storms and droughts in California: San Francisco Estuary and Watershed Science, 14(2), 29 p.

DiLuzio, M., Johnson, G.L., Daly, C., Eischeid, J.K. and Arnold, J.G. (2008). Constructing retrospective gridded daily precipitation and temperature datasets for the conterminous United States: Journal of Applied Meteorology and Climatology, 47: 475-497.

Horton, G. A. (1997). Truckee River Chronology. (N.D. Resources, Producer) Retrieved Aug 26, 2015, from State of Nevada Division of Water Resources: http://water.nv.gov/mapping/chronologies/truckee

Kleppe, J. A., Brothers, D.S., Kent, G.M., Biondi, F., Jensen, S. and Driscoll, N.W. (2011). Duration and severity of Medieval drought in the Lake Tahoe Basin: Quaternary Science Reviews, 30 (23-24), 3269-3279.

Livneh B., Rosenberg, E.A., Lin, C., Mishra, V., Andreadis, K.M., Maurer, E.P. and Lettenmaier, D.P. (2013). Extension and spatial refinement of a long-term hydrologically based dataset of land surface fluxes and states for the conterminous United States: Journal of Climate, 26, 9384-9392.

Malamud-Roam, F., Dettinger, M.D., Ingram, B.L., Hughes, M. and Florsheim, J. (2007). Holocene climates and connections between the San Francisco Bay estuary and its watershed—A review: San Francisco Estuary & Watershed Science, 5(1), 28 p.

Pierce, D.W., Cayan, D.R. and Thrasher, B.L. (2014). Statistical downscaling using localized constructed analogs (LOCA): Journal of Hydrometeorology, 15, 2558-2585.

Rutz, J.J. and Steenburgh, W.J. (2014). Climatological Characteristics of Atmospheric Rivers and Their Inland Penetration over the Western United States: Monthly Weather Review, 142, 905-921.

Singletary, L., Sterle, K., and Simpson, K. (2016). Assessing the Climate Resiliency and Adaptive Capacity of the Truckee-Carson River System: Results of a Survey of Local Organizations. University of Nevada Cooperative Extension Special Publication: Reno, NV, USA, (SP-16-03). Retrieved from: https://www.unce.unr.edu/publications/

Sterle, K., Singletary, L. and Pohll, G. (2017). Collaboratively Modeling Water Resources in the Truckee-Carson River System. University of Nevada Cooperative Extension Special Publication: Reno, NV, USA, (SP-17-04). Retrieved from: https://www.unce.unr.edu/publications/