EXTENSION
College of Agriculture, Biotechnology & Natural Resources

PEER REVIEWED

Fact Sheet 19-10

Managed Aquifer Recharge in Snow-Fed River Basins: What, Why and How?

Kelley Sterle, Assistant Research Professor and Water Resources Outreach Specialist,
Global Water Center and University of Nevada, Reno Extension
University of Nevada, Reno

Wesley Kitlasten, Hydrologist,
U.S. Geological Survey Nevada Water Science Center,
Carson City, Nevada

Eric Morway, Hydrologist,
U.S. Geological Survey Nevada Water Science Center,
Carson City, Nevada

Rich Niswonger, Research Hydrologist, U.S. Geological Survey,
Menlo Park, California

Loretta Singletary, Professor and Interdisciplinary Outreach Liaison,
Department of Economics and University of Nevada, Reno Extension
University of Nevada, Reno

__Water for the Seasons__ is a collaborative modeling research program that partners researchers with water managers representing the diverse water-use communities in the Truckee-Carson River System in California and Nevada. Through systematic and iterative engagement, key water managers and researchers work together to assess climate resiliency and examine local strategies to adapt to climate-induced water supply variability. Fact sheets generated as part of this research program are intended to educate readers about ongoing research activities and share findings from interactions among researchers and local water managers. The intent is not to provide recommendations for water management, but rather generate science information useful to managers' climate adaptation planning. *This five-year (2014-2019) research program is funded by the National Science Foundation (#1360506) and the U.S. Department of Agriculture (#2014-67003-22105) through the Water Sustainability and Climate program.*

What does climate change mean for snow-fed river basins?

Climate change poses unique challenges in snow-fed river basins across the western United States because the majority of water supply originates as snow (Dettinger, Udall, & Georgakakos, 2015). In the Sierra

Nevada, recent observations include changes in snow accumulation and snowmelt, and shifts in peak streamflow timing (Barnhart et al., 2016; Hatchett et al., 2017; Kim & Jain, 2010; McCabe, Wolock, & Valentin, 2018; Mote, Li, Lettenmaier, Xiao, & Engel, 2018). Such changes upstream alter surface water deliveries downstream, as well as groundwater recharge utilized as both primary and supplemental water supply (Godsey et al., 2014; Harpold, 2016; Jasechko et al., 2014).

The Carson River Basin typifies such a basin where snowmelt runoff produces substantial water supply to meet diverse agricultural, environmental and urban water demand (Figure 1). The East and West Forks join at the confluence of the Carson River near the north end of the Carson Valley, a rich agricultural region (40,000 acres) that grows primarily alfalfa hay. The majority of irrigators rely on surface water delivered through a network of earthen ditches constructed in the mid-19th and early 20th centuries. Flow through these earthen networks and the practice of flood irrigation contribute significantly to groundwater recharge.

Because no upstream surface water reservoirs exist, snowpack that accumulates through winter and melts slowly through spring has acted as a "natural" reservoir, providing ample supply through the summer irrigation season. Some irrigators have permitted access to supplemental groundwater that is useful during periods of drought for augmenting shortfalls in surface

Figure 1. The Truckee-Carson River System, including boundaries for the hydrologic models used in the Water for the Seasons research program. Graphic design by Kelley Sterle and Ron Oden.

Copyright © 2019 University of Nevada, Reno Extension

water delivery. Groundwater is the primary source of municipal and industrial water supply for surrounding communities (e.g., Carson City, Minden, Gardnerville, Dayton).

Across the basin, water use is highly regulated through federal, tribal, state and local water-sharing agreements based on prior appropriation doctrine (Wilds, 2014). Carson River surface water allocations follow the Alpine Decree, initiated by the United States Department of Interior in 1925 and signed into law in 1980, following 55 years of litigation, to adjudicate surface water rights to individual parties (NDWP, 1999). The Alpine Decree acknowledges return flows to lower river segments, and thus each river segment is distributed autonomously. This means that the most junior water right on an upper segment can be fulfilled before considering the most senior water right on a lower segment. Ultimately, the ruling is at the discretion of the Federal Water Master to satisfy the needs of each water right.

Downstream of Carson Valley, surface water flows are stored in Lahontan Reservoir, the nation's first desert reclamation project (est. 1906), where releases are managed to meet the Newland's Project irrigation water demand and for environmental use on the Stillwater National Wildlife Refuge. Flows from the Carson River are supplemented through diversions from the Truckee River via the Truckee Canal, resulting in a trans-basin water supply system.

How is the *Water for the Seasons* research program informing snow-fed river basin communities?

In the Truckee-Carson River System, researchers and local water managers are working together to assess climate change impacts to water supply and explore how model simulations can produce useful information to support local climate adaptation. Twelve key water managers represent agricultural, environmental, urban and regulatory water-use communities, and bring to the table diverse input and perspectives on how to adapt to climate change. [1]

Hydrologists use this input to craft scenarios and simulations that meet the information needs of local water managers. Biannual workshops provide an opportunity for information exchange, where researchers and key water managers generate new knowledge of river system function. That is, researchers share results of models that examine the physical potential, and managers validate the on-the-ground potential, further informing the research process.

Coincident to this research program, the region faced a prolonged drought period (2012-2016) with historically low snowpack, followed by a historic wet year (2017) that brought winter and spring flooding as a result of atmospheric river storm events (Sterle et al., 2019). For the Carson River, an important observation made by managers was that peak streamflow that had traditionally coincided with peak irrigation demands, had shifted to earlier in the spring, with summer baseflow also

[1] For further details on this research program, see Extension publication, *Assessing the Climate Resiliency and Adaptive Capacity of the Truckee-Carson River System: Results of a Survey of Local Organizations (SP-16-03)* (Singletary, Sterle, & Simpson, 2016).

Copyright © 2019 University of Nevada, Reno Extension

decreasing (Sterle & Singletary, 2017). Managers shared with researchers concerns over potential future impacts that changing snowpack will have on surface water deliveries and reliance on groundwater, as the region's population and economy continue to grow.

During workshops that occurred over this period, local water managers and researchers discussed ways to evaluate water distribution and use that honors the existing legal framework and accounts for changing snowpack regimes (amount, rain versus snow, timing). In response to managers growing interest, researchers introduced the concept of ***managed aquifer recharge*** as one potential strategy to adapt and enhance regional water sustainability.

What is managed aquifer recharge?

Simply stated, managed aquifer recharge is the intentional recharge of water into the groundwater system (Dillon, 2009). This differs from the incidental recharge that may occur as part of normal irrigation practices. Managed recharge may occur by injection into the aquifer through existing wells, or by using existing conveyance structures to spread water over agricultural lands, allowing water to naturally infiltrate into the groundwater system (Bouwer, 1999; Niswonger et al., 2017). The latter may occur during the irrigation season by applying excess water, or during the nonirrigation season when evapotranspiration losses are low.

Figure 2 illustrates managed aquifer recharge in a snow-fed river basin, where streamflow generated from snowmelt runoff is diverted to agricultural lands to recharge the aquifer. Such flood irrigation practices, including water delivery through earthen ditch networks, provide incidental but significant aquifer recharge through seepage and deep drainage beneath fields (Niswonger, Allander, & Jeton, 2014).

The effects of managed aquifer recharge can vary depending on the location and intensity of practice. For example, implementing managed aquifer recharge adjacent to/along the river's floodplain has the potential to enhance late-season instream flows due to increased return flows, resulting in greater downstream deliveries as well as improving ecological conditions (Niswonger et al., 2017). Implementing managed aquifer

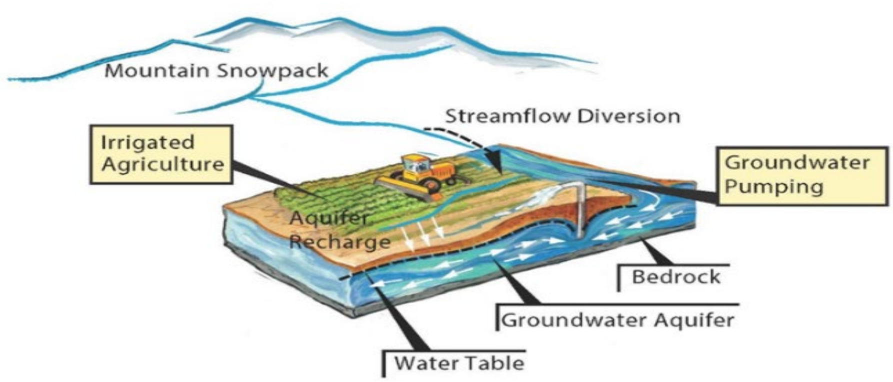

Figure 2. Managed aquifer recharge on agricultural lands in a snow-fed river basin. Graphic design by Kelley Sterle and Ron Oden.

Copyright © 2019 University of Nevada, Reno Extension

recharge away from the river's floodplain has the potential to enhance groundwater supply which is increasingly relied upon during surface water shortage (Green et al., 2011), by storing water in available aquifer space in the deep aquifer. At the basin scale, managed aquifer recharge may lead to regional groundwater sustainability.

While in theory the process may seem straightforward, in practice several challenges exist. For example, in most snow-fed river basins in the western United States and in the case of the Carson River Basin, surface and groundwater resources are fully appropriated. This includes floodwaters resulting from high water years and rain on snow events. Currently all surface water in Nevada is allocated for beneficial use, resulting in no "excess water." Thus, diverting additional surface flows away from downstream users to irrigate agricultural lands is currently prohibited. In addition, diverting water before the start of the irrigation season (approximately April 1) would require permission from the Federal Water Master. Additional challenges include identifying areas suitable for deep aquifer storage and quantifying long-term benefits at the basin scale.

Is the Carson River Basin a candidate for managed aquifer recharge?

The physical limitations to implementing managed aquifer recharge in the Carson River Basin hinges on three key factors. The first factor relates to the physical connectivity between rivers and streams, and the irrigation delivery network of canals and ditches that divert water to agricultural lands (Niswonger et al., 2017). In the Carson River Basin the mechanisms for getting water to fields is already in place. Thus, intentionally routing high flows that occur in wet years through this system during the nonirrigation season would mimic what occurs naturally during the irrigation season.

The second factor relates to the occurrence of atmospheric river storm events that deliver large amounts of precipitation to the region, much greater than average (Dettinger et al., 2015). With increased frequency and intensity projected under a warmer climate, such events have the potential to produce excess water over short periods of time that could be stored through mechanisms such as managed aquifer recharge (Niswonger et al., 2017).

The third factor relates to the change in snowpack accumulation and shifts in snowmelt timing observed elsewhere in the Sierra Nevada (e.g., Godsey et al., 2014; Mote et al., 2018). Having a mechanism in place to maximize use of earlier snowmelt and shifts in streamflow timing could be advantageous and enhance regional groundwater sustainability.

As part of the Water for the Seasons study, a hypothetical scenario was developed to determine the feasibility of managed aquifer recharge in the Carson River Basin, assuming no legal constraints. During "wet" or above-average water years, irrigators in the Upper Carson Valley would divert high flows and spread water over agricultural lands during the nonirrigation season. Assuming flows are abundant and "early," diversions would begin prior to the growing season, when water would otherwise flow downstream to the Lahontan Reservoir. During "dry" years or drought periods, when surface water

Copyright © 2019 University of Nevada, Reno Extension

availability is less, irrigators in the Upper Carson Valley could augment surface water shortages with groundwater, allowing available surface water flows to flow downstream. Researchers hypothesize the amount of water has the potential to boost baseflow to support environmental instream flows, for example.

What concerns have local water managers expressed?

The hypothetical managed aquifer recharge scenario was presented to water managers in a workshop setting. Presentations included an overview of the hydrologic and operations modeling tools used to evaluate managed aquifer recharge by simulating the timing and distribution of water in the upper watershed. Specifically, in the Upper Carson Valley, a hydrologic model (GSFLOW) simulates streamflow driven by snowmelt, and surface and groundwater interactions, while a river basin operations model (MODSIM) allocates water according to the prior appropriation doctrine in the basin (see Figure 1) (Morway, Niswonger, & Triana, 2016; Niswonger et al., 2017). Integrating these two modeling tools advances the evaluation of climate impacts on water availability in agricultural communities and the resulting impacts of alternative management strategies (Morway et al., 2016).[2]

When asked about the viability of managed aquifer recharge, the perspectives of 11 managers varied (Figure 3). Regardless of rating, all managers questioned, "How would this *really* work?" Several managers questioned whether models could simulate the connectivity between surface and groundwater to accurately quantify changes to instream flow. Others raised concerns that managed aquifer recharge violates the Alpine Decree and Nevada Water Law. Still others requested researchers consider alternatives that could work within the confines of current (2019) water law.

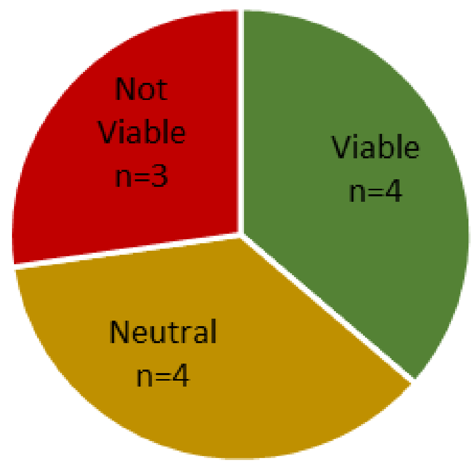

Figure 3. Water managers' responses when asked "How viable is managed aquifer recharge in the Upper Carson Valley?

Managers posed specific questions that should be considered when evaluating the potential for managed aquifer recharge. For example:

- **What triggers implementation of managed aquifer recharge?** *How "high" or "low" must annual flows be to initiate managed aquifer recharge? When in the water year is this determined?*
- **Where exactly in the Carson Valley is managed aquifer recharge possible?** *For example, what areas away from*

[2] For a more detailed description of the models, see Extension publication *Collaboratively Modeling Water Resources in the Truckee-Carson River System (SP-17-04)* (Sterle, Singletary, & Pohll, 2017).

Copyright © 2019 University of Nevada, Reno Extension

the floodplain could ensure long-term storage?

- **Can model simulations quantify potential benefits and consequences system-wide?** *Would this information support decision-making, such as permitting of additional supplemental groundwater rights?*

How are researchers going to address managers' research questions?

Managers' perspectives help to validate the on-the-ground potential of particular strategies and further refine alternative management scenarios. For example, understanding that managers are concerned with oversaturated fields helps researchers to define conditions in the model, such as what defines a wet versus "too" wet type of year and where to focus irrigation for managed aquifer recharge. Incorporating these nuances provides more accurate quantification of the potential benefits and consequences for users across the basin.

Modeling is underway to simulate managed aquifer recharge scenarios and explore basin-wide implications. Researchers and local water managers will convene to collaboratively review results and further assess whether this or other strategies could work under the confines of existing water law. Subsequent fact sheets will present these findings.

Acknowledgements

The authors acknowledge local water managers of the Truckee-Carson River System who contribute to this research program. We especially thank Ed James with the Carson Water Subconservancy District, and three anonymous reviewers for helping to improve the content of this fact sheet.

References

Barnhart, T.B., Molotch, N.P., Livneh, B., Harpold, A., Knowles, J.F., & Schneider, D. (2016). Snowmelt rate dictates streamflow. *Geophysical Research Letters*, *43*: 1–8. Visit the link to above publication here.

Bouwer, H. (1999). *Artificial Recharge of Groundwater: Systems, Design, and Management.* In Hydraulic Design Handbook. L.W.Mays (eds.). McGraw-Hill Education.

Dettinger, M.D., Udall, B., & Georgakakos, A. (2015). Western water and climate change. *Ecological Applications*, *25*(1): 2069–2093. Visit the link to above publication here.

Dillon, P. (2009). Water recycling via managed aquifer recharge in Australia. *Boletin Geologico y Minero*, *120*(2): 121–130. Visit the link to above publication here.

Godsey, S.E., Kirchner, J.W., & Tague, C.L. (2014). Effects of changes in winter snowpacks on summer low flows: Case studies in the Sierra Nevada, California, USA. *Hydrological Processes*, *28*(19): 5048–5064. Visit the link to above publication here.

Green, T.R., Taniguchi, M., Kooi, H., Gurdak, J.J., Allen, D.M., Hiscock, K.M., Treidel, H., & Aureli, A. (2011). Beneath the surface of global change: Impacts of climate change on groundwater. *Journal of Hydrology*, *405*(3–4): 532–560. Visit the link to above publication here.

Harpold, A. (2016). Diverging sensitivity of soil water stress to changing snowmelt timing in the Western U.S. *Advances in Water Resources*, *92*:

Copyright © 2019 University of Nevada, Reno Extension

116–129. Visit the link to above publication here.
Hatchett, B.J., Daudert, B., Garner, C.B., Oakley, N.S., Putnam, A.E., & White, A.B. (2017). Winter snow level rise in the Northern Sierra Nevada from 2008 to 2017. *Water*, *9*(11): 1–14. Visit the link to above publication here.
Jasechko, S., Birks, S.J., Gleeson, T., Wada, Y., Fawcett, P.J., Sharp, Z.D., McDonnell, J.J., & Welker, J.M. (2014). The pronounced seasonality of global groundwater recharge. *Water Resources Research*, *50*(11): 8845–8867. Visit the link to above publication here.
Kim, J.S., & Jain, S. (2010). High-resolution streamflow trend analysis applicable to annual decision calendars: A western United States case study. *Climatic Change*, *102*: 699-707. Visit the link to above publication here.
McCabe, G.J., Wolock, D.M., & Valentin, M. (2018). Warming is Driving Decreases in Snow Fractions While Runoff Efficiency Remains Mostly Unchanged in Snow-Covered Areas of the Western United States. *Journal of Hydrometeorology, 19*(50): 803-814. Visit the link to above publication here.
Morway, E.D., Niswonger, R.G., & Triana, E. (2016). Toward improved simulation of river operations through integration with a hydrologic model. *Environmental Modelling and Software*, *82*: 255–274. Visit the link to above publication here.
Mote, P.W., Li,S., Lettenmaier, D.P., Xiao, M., & Engel, R. (2018). Dramatic declines in snowpack in the western US. *Npj Climate and Atmospheric Science*, *1*(2). Visit the link to above publication here.
Nevada Division of Water Planning (NDWP). (1999). *Nevada State Water Plan*. Carson City, NV. Retrieved from from here.
Niswonger, R.G., Allander, K.K., & Jeton, A.E. (2014). Collaborative modelling and integrated decision support system analysis of a developed terminal lake basin. *Journal of Hydrology*, *517*: 521–537. Visit the link to above publication here.
Niswonger, R.G., Morway, E.D., Triana, E., & Huntington, J.L. (2017). Managed Aquifer Recharge through Off-Season Irrigation in Agricultural Regions. *Water Resources Research*, *53*(8): 6970-6992. Visit the link to above publication here.
Singletary, L., Sterle, K., & Simpson, K. (2016). *Assessing the Climate Resiliency and Adaptive Capacity of the Truckee-Carson River System: Results of a Survey of Local Organizations (SP-16-03)*. University of Nevada Reno, Extension, Reno, Nevada. Retrieved from here.
Sterle, K., Hatchett, B.J., Singletary, L., & Pohll, G. (2019). Hydroclimate Variability in Snow-fed River Systems: Local Water Managers' Perspectives on Adapting to the New Normal. *Bulletin of the American Meteorological Society*, *10*(6):1031-1048. Visit the link to above publication here.
Sterle, K., & Singletary, L. (2017). Adapting to variable water supply in the Truckee-Carson River System, Western USA. *Water*, *9*(10). Visit the link to above publication here.
Wilds, L.J. (2014). Water politics in northern Nevada: A century of struggle. Reno, NV: University of Nevada Press.

The University of Nevada, Reno is committed to providing a place of work and learning free of discrimination on the basis of a person's age, disability, whether actual or perceived by others (including service-connected disabilities), gender (including pregnancy related conditions), military status or military obligations, sexual orientation, gender identity or expression, genetic information, national origin, race, or religion. Where discrimination is found to have occurred, the University will act to stop the discrimination, to prevent its recurrence, to remedy its effects, and to discipline those responsible.

Copyright © 2019 University of Nevada, Reno Extension