The De-Aging of Water Resources in the Northern Sierra Nevadas

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Abstract

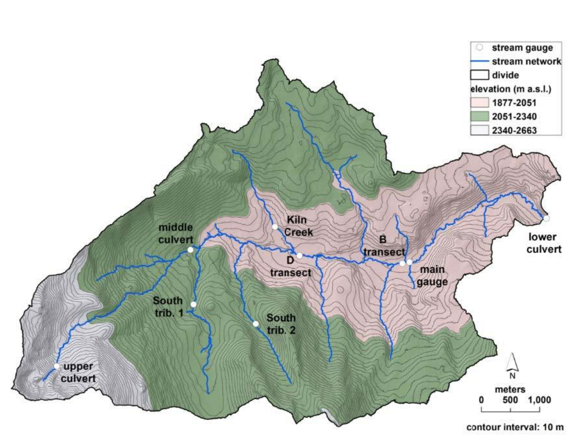
As climate change continues to exacerbate the severity of weather patterns, the majority of the state of California has come to suffer from longer periods of drought and shorter, but more intense rainy seasons. With multi-year droughts comes a decrease in snowpack in the mountains. Alpine watersheds within the Sierra Nevada mountain range are a vital source and storage of water for California and Nevada. Snow water equivalent from snowpack feeds riparian systems that function as California's primary sources of water, which in the northern region of the state predominantly come from local resources. Baseflow conditions are seen earlier in the season and last longer than they used to due to decreased snowpack as a result of climate change. Sagehen Creek, a montane watershed just north of Truckee, CA, follows this behavior.

Background

Sagehen Creek is a perennial stream that is part of a montane watershed in the Northern Sierra Nevada mountain range. The creek, after flowing through both Stampede and Boca reservoirs, feeds into the Truckee River. The Truckee is used as water source for the Reno-Sparks metropolitan area before it reaches its final destination at Pyramid Lake.

A picture of Sagehen Creek taken July 2022.

Hydrologists have monitored Sagehen Creek since 1952, with stream gauges, wells, piezometers. More recent research of Sagehen has focused on a series of springs throughout the watershed, S1 through S14. While the majority of these spring produced water each time they were monitored, some springs would have water some years and be dry in others, especially after particularly dry years. These springs are one of the sources of water that support base flow in the creek. By monitoring changes of age in groundwater sources in the watershed using gas tracers such as SF_6, CFCs, and Rn we can begin to analyze the resilience of the creek and its watershed.



A map of the Sagehen Creek watershed with notable areas listed (Kirchner et. al 2020)

This research was primarily concerned with the 14 groundwater springs through the watershed as well as the reach of the creek between Kiln Meadow and the main stream gauge.

Determining Age of Groundwater Using Chlorofluorocarbons (CFCs) and Sulfur Hexafluoride (SF_6)

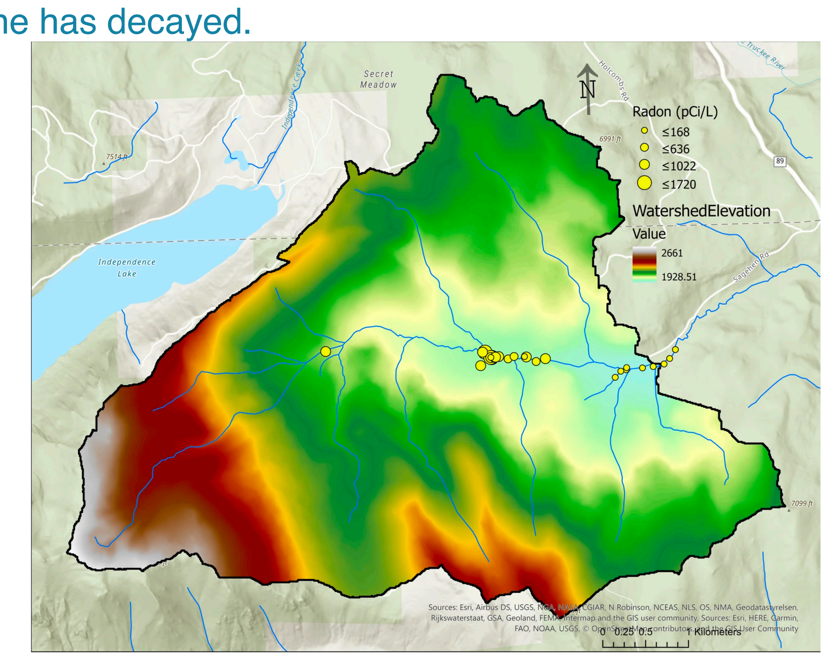
Dissolved gases are useful tools for determining the age of groundwater. CFC is used as an age tracer for groundwater because it is a stable gas that was introduced to the atmosphere by the use of refrigerants and aerosol sprays. Older groundwater will have lower concentrations of CFCs because CFCs were used heavily between 1950 through 1990.

SF_6 was used in conjunction with radon to determine the age of groundwater based on estimated gas velocities and the geometries of different parts of the stream (Gleeson et al. 2017).

Both gases were analyzed with different groundwater flow models to determine accuracy.

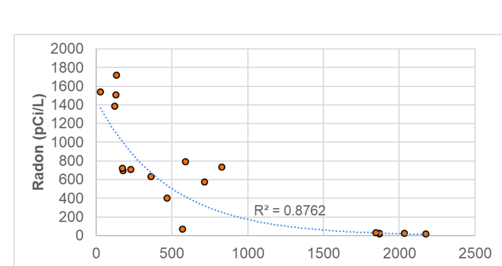
Using Radon to Locate Points of Groundwater Discharge to Sagehen Creek

Radon is used as a groundwater tracer. This is because it is produced as part of the radioactive decay series of uranium, which is found in old geologic formations such as the underlying volcanics and is primarily release from the glacial till and alluvium thereof throughout much of the Sierra Nevada mountain range. Radon is produced and contained within the water in an aquifer as a dissolved gas which is lost quickly when the water is introduced to the atmosphere. It also has a short half life of about 4 days, so younger groundwater sources typically have higher radon activity than old groundwater sources where the has decayed.



Map of the Sagehen Creek watershed showing elevation and radon activity levels (Moran et al 2022).

Above is a map that shows observed radon activity levels at points along the creek based on samples that were collected and analyzed later. The highest radon activity in the creek was observed in the Kiln Meadow area.

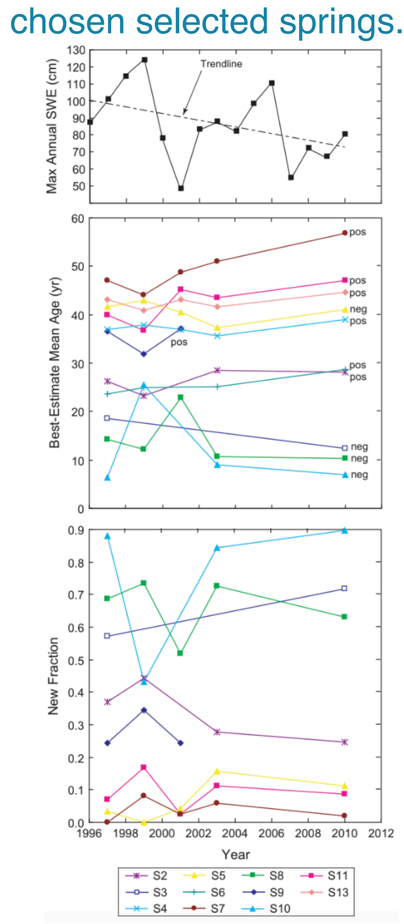


Graph showing radon activity levels at points along Sagehen Creek (Moran et al. 2022)

Radon levels decrease more or less exponentially down the reach of the stream that was sampled, suggesting that the highest groundwater discharge to the creek is found within Kiln Meadow and that there is less groundwater discharge to the creek further downstream.

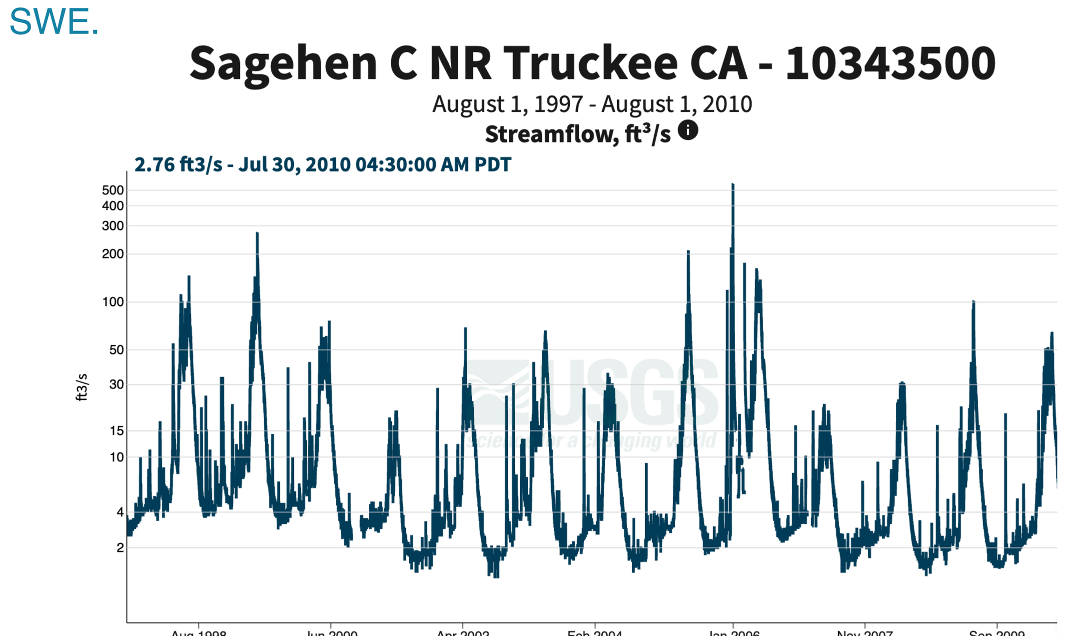
The Process of De-Aging

There is a now 26 year record of best-estimate ages of water from groundwater sources throughout the Sagehen Creek watershed which began in August 1997. The most consistent data is from August 1997 to August 2010. By using a combination of age data gathered from SF_6 and CFC analysis and through the determination of piston flow and bimodal modeling, best-estimate mean ages were produced for groundwater from chosen selected springs.



Graphs from Manning et al. showing snow-water equivalent, best-estimate mean ages, and fraction of young water in monitored springs.

There is a seven year gap between the point from July 2003 and August 2010. Average streamflow is higher between 1997 to 2003, correlating with a higher average snow-water equivalent (SWE). While there is a gap in best-estimate mean age, there is still SWE data showing a decrease of average SWE from 1997 to 2010. While there are drought and heavy precipitation events visible in 2001 and 2006 respectively, streamflow decreases overall with a decrease in SWE.



A graph showing average discharge from August 1997 to August 2010 (USGS).

Include graph from Meyers et al., another paragraph

De-aging means that groundwater is losing old water; that there is a smaller fraction of old water compared to a larger fraction of modern water. There is then, theoretically, less water as time progresses. This increases the sensitivity of the system to change. Water is consistently discharged from springs and other sources throughout the year. Younger water, as it is higher in the aquifer, is preferentially discharged first before old water. When data for calculating best-estimate mean ages is taken in base flow conditions, groundwater will be older overall, but there will be less old water as it is being discharged.

Conclusion

Groundwater supports the base flow of Sagehen Creek. Throughout years of drought, which has caused the melt of snowpack to occur earlier in the year and the snow season to begin later, base flow conditions persist for longer portions of the year. At the same time, the water contained within aquifers is becomes more modern after snowmelt and precipitation is introduced. This suggests that the old fraction of water is being depleted as the groundwater is being discharged consistently while younger water is only added to the aquifers during snowmelt and sporadic precipitation events that are heavy enough to produce enough water to infiltrate into aquifers and is not lost to evaporation.

The unpredictability that comes with climate change also presents an uncertainty for the future of alpine creeks. More frequent analysis of the age groundwater sources throughout the basin in different seasons will help provide better insight to the resilience of water sources throughout the watershed.Monitoring when base flow conditions occur each year will also help determine the effects of climate change upon Sagehen Creek. Using age data from both the beginning and end of base flow each year will provide better information about the overall age of groundwater based on estimated quantities of old and new water.

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