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Meadow Restoration for Downstream Water Supply: Snowmelt Timing in the Tuolumne

Background

The Tuolumne River watershed transports thousands of acre-feet of pristine water from the Sierra Nevada using a system of reservoirs and pipelines. Water is primarily transported to the Turlock and Modesto irrigation districts or is sent to San Francisco to support its population of nearly one million. Large reservoirs including Hetch Hetchy and New Don Pedro help hold some winter precipitation but the Sierra snowpack provides the greatest natural reservoir. High elevation snow-pack formed during the winter eventually melts, providing reliable summer flows for the Tuolumne. Summer snowmelt timing affects downstream users who rely on snowpack as an reservoir for water supply (Essaid & Hill, 2014). The climatic shift toward a rain dominated system intensifies the need for sustained summer flows upstream of New Don Pedro. Downstream, the earlier delivery of precipitation could mean flood preventative dam releases, resulting in decreased levels in the reservoir (Kiparsky *et al.* 2014). Snowmelt runoff can be attenuated by Sierra meadows, which have natural hydrologic characteristics and vegetation that promote recharge and rerelease of groundwater. However many meadows in Tuolumne are impaired, limiting the previously stated benefits.. The restoration of these meadow systems not only provides valuable habitat but also supports reliable summer flows.

Snowpack Storage

California's Mediterranean climate consists of annual precipitation patterns with the majority of rain and snow falling between November and March (Lundquist *et al.* 2005). This leaves a large section of the year with no additional rainfall for water supply. Water supply in the summer months primarily comes from the Sierra snowpack. Come spring, winter snowfall begins to melt, releasing water into the surrounding landscape. The amount and timing of the water released from snowpack impacts the Tuolumne watershed and those who rely on it.

The upper section of the Tuolumne River watershed reaches its peak elevation at around 13000 feet, and areas above 8500 feet can spend half the year covered in snow (Mount *et al.* 2010). Longer spring days with higher temperatures begin to melt this snow, producing substantial volumes of runoff in the tributaries to the Tuolumne River. However, not all of the snowmelt flows directly downstream.

Meadow Systems

Scattered at high elevations of the Sierra are meadows, unique ecosystems characterized by shallow groundwater and herbaceous vegetation. Along with providing habitat, functioning meadow systems support groundwater storage. A portion of the snowmelt infiltrates into groundwater via cracks in surrounding bedrock, talus slopes, or in low sloped meadows (Lowry *et al.* 2010). Meadow systems, unlike the thin soils and granite surrounded groundwater areas, provide short-term groundwater storage that can serve as a water source during summer droughts.

Acting as wetlands, these high elevation systems can store snowmelt runoff and offer filtration that improves water quality (Viers *et al.* 2013). When high flows from snowmelt runoff encounter a meadow, the meadow acts as a mini floodplain. As the water flows over the meadow's wide surface, the now shallow water begins to infiltrate into the organic rich soil. The shallow groundwater, characteristic of Sierra meadow, is eventually released into the downstream channels during late summer drops in groundwater (Lowry *et al* 2010). Loheide et al found that groundwater in these systems stays typically within 30 cm of the surface for 90 days. By keeping the water just below the surface, the meadow's groundwater serves a storage purpose, eventually rereleasing flows. With these characteristics, meadows serve as a useful first reservoir for high snowmelt flows.

Meadow Degradation

Research shows successful meadow systems can attenuate high flows and act as an additional reservoir, but more than half of meadows within the Sierra Nevada National Forest are altered or impaired (Loheide *et al.* 2009). Meadow impairment is typically attributed to human interference, including practices like livestock grazing, road building, and the building of water regulation infrastructure (Essaid & Hill, 2014 , Mount *et al.* 2010). The ability of a meadow to maintain near-surface groundwater relies on shallow, relatively slow-moving river channels, which promote overbank flooding. When stream banks erode due to either anthropogenic or natural causes, the incision of the channel prevents overflow, decreasing groundwater repletion and sending water directly downstream (Viers *et al* 2012). Once a channel has been carved, runoff no longer flows across the entire meadow. Bank erosion can be caused by a loss in vegetation, particularly of fibrous root systems that provide bank stabilization (Mount *et al.* 2010). Furthermore, increases in bank erosion create a feedback loop that intensifies meadow degradation. Eroded banks cause a decrease in groundwater flooding, which in turn eliminates the physical conditions needed to support meadow vegetation (Viers *et al* 2012). Wetland plants like sedges, rushes, and grasses are adapted to meadow flooding and cannot grow without it. Loss of native meadow vegetation in the Tuolumne can also lead to a decrease of organic matter in the soil. Organic rich soils drive the functional benefits of the meadow systems, by increasing water filtration and flood retention (Poore *et al*, 2003). Meadow degradation perpetuates loss of habitat for plants and animal species and impedes slow release of snowmelt through groundwater.

Promoting Functioning Meadows

A fully functioning montane meadow can slow snowmelt pulses, keeping water in its natural reservoir longer, and ultimately provide steady flows through the summer. Restoration of degraded systems can help return Tuolumne's meadows to the groundwater recharge assets they once were. Meadow restoration refers to the return of a meadow to its natural state. This can include the reversal of incised channels and reestablishment of bank stabilizing vegetation leading to increased flooding and increased groundwater storage (Hammersmark *et al*. 2008). Essentially, meadow restoration aims to reverse the cycle of degradation, and restore the ecosystem services montane meadows provide. Field studies as well as modeling efforts have shown how meadow restoration increases groundwater storage, a result of the relationship between ground water table depth, vegetation, and erosion control (Essaid & Hill, 2014; *Loheide* et al. 2009). Coupled with high flow attenuation, meadow restoration could change the timing of summer streamflow to maximize the storage (Lundquist *et al.* 2005).

Climate Change

The Tuolumne is and will continue to be strongly affected by the Earth's changing climate. As a result, the hydrology and water resources management of Tuolumne are undergoing a shift. As temperature increases, snow dominated watersheds such as the Tuolumne River face decreased snowpack storage, shifting towards a rain dominated system (Viers *et. al* 2013). This shift has significant implications for water supply, as current reservoir operation relies on predictable snowmelt pulses to fill the reservoir for the rainless summer months. Downstream users rely on a full reservoir to meet summer water demands, and a precipitation shift threatens that reservoir storage. With increased winter storm runoff due to climate change, reservoir operators must partially empty their storage to make room for potential flood events. This shift in precipitation leads to unpredictable streamflow pulses, which limits the storage capacity of reservoirs such as the New Don Pedro. This will affect the entire water supply system of the Tuolumne.

Modeled climate warming scenarios indicate that the upper Tuolumne will experience earlier timing of snowmelt and peak flows. Additionally, models show that temperature warming of two to six degrees Celsius reduced water supply reliability and overall average reservoir levels (Viers *et. al* 2013). Shortages in water supply can mean huge revenue lost in agriculture or city restrictions in urban use, as well as habitat loss for the Tuolumne's native species (Mount *et al.* 2010). Snowpack and snowmelt runoff are the two of the most important indicators for species presence. Thus, climate driven changes in snowpack and snowmelt will have substantial impacts on Tuolumne ecosystems (Mount *et al.* 2010).

Current predictions of climate change effects on the Tuolumne River watershed indicate the need for adaptive management in water security issues. Water resource decision makers should be considering all options, especially ones that can benefit water supply while supporting ecosystems. Meadow restoration presents a promising pathway for responsible, successful water management in the Tuolumne.

Conclusion

Water in the Tuolumne is an important resource for agricultural and urban use. In order to ensure reliable flows during the dry season, meadow restoration should be considered. Restoring the natural hydrologic system of the meadows in the upper watershed can help attenuate snowmelt flows, keeping the runoff from immediately flowing downstream. By reducing channel incision and increasing vegetation, the meadow can act as a “sponge”, holding snowmelt as groundwater in its organic rich soil until it naturally drains later in the summer. This lag time is becoming more critical in light of climate change. With higher temperatures and rain dominated precipitation, peak runoff times are likely to come earlier in the season, impacting the ecological benefits of instream environmental use as well as the water demand of downstream users. Meadow restoration of the Tuolumne can help provide water security to downstream users and support threatened or damaged ecosystems.

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