Management of the Tuolumne Watershed In Extreme Drought Conditions

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Introduction

Droughts are an integral part of California's historical stream ecology, as native species have adapted to hydrologic heterogeneity. Summer low-flows and multi-year water shortages require effective drought management strategies. Since 2012, the Tuolumne River has experienced an extreme drought, causing low stream-flows, increased heat stress and susceptibility to severe wildfires. These changes affect the structure and function of aquatic and terrestrial ecosystems, as well as how the water supply of the Hetch Hetchy system is managed. By investigating the effects of drought on the ecosystems in the Tuolumne River watershed, managers can properly allocate human water use while maintaining aquatic and forest communities.

Flow Changes

On the Tuolumne River, the drought severely decreased the total runoff for water years 2012 through 2015. Figure 1 shows the discharge in the Tuolumne from October 2009 through May 2016, measured at a USGS monitoring site above the Hetchy Hetchy Reservoir.

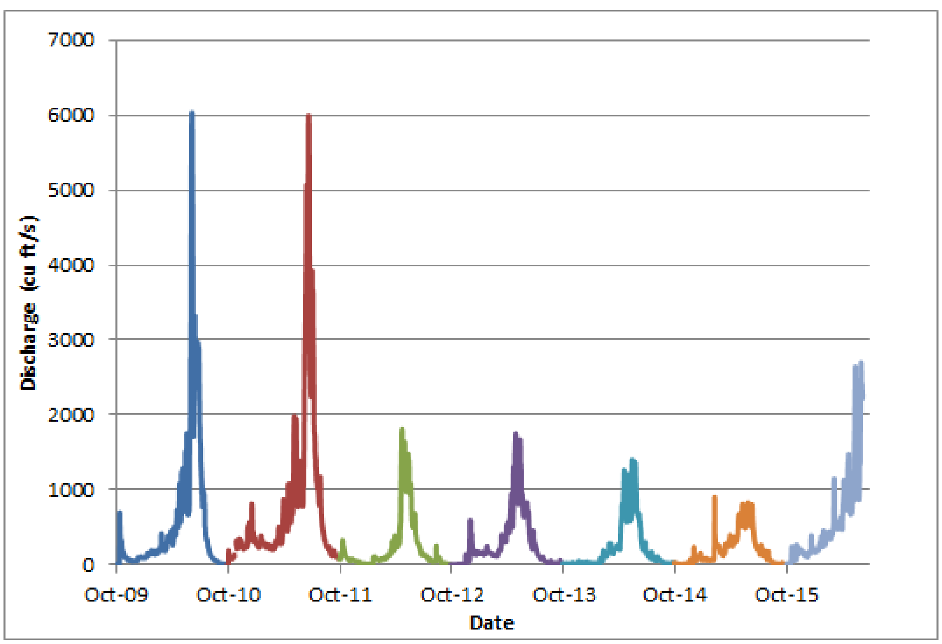

Figure 1. Tuolumne discharge for 2009 to 2016 at Grand Canyon Tuolumne

The hydrographs for each water year show the responses of the river to precipitation patterns isolated from most human flow alterations. There is a minimal snowmelt runoff peak for these years, indicative of the small snowpack the watershed received. 2015 was a critically dry year while 2016 is projected to be an average flow year. This four year drought has caused declines in ecosystem health and changed the way humans utilize their water supply.

Ecosystem Responses

Fish

Several native fish species are adapted to specific water temperatures and are adversely affected by the changes drought conditions induce. Optimum juvenile Chinook salmon (*Oncorhynchus tshawytscha)* temperature is within 13-16 °C water, while juvenile Chinook in 21-24 °C water show significant decrease in growth rate, impaired smoltification, and increased predation risk (Marine and Cech 2004). Data collected in June 2016 on the Middle Fork Tuolumne ranged from 12.1 °C to 15.6 °C, temperatures within optimum range for Chinook. Surveys in June 2015 in the mainstem Tuolumne and tributaries below Preston Falls reported temperatures between 18.1-25.9 °C, far above the optimum threshold.

Additionally, drought alters habitat for native fish species via declining flows. The geomorphological unit first to be affected as stage drops are riffles (Freeman and Marcinek 2006, Kanno and Vokoun 2010). Species that utilize riffles are more susceptible to negative impacts of drought conditions, while generalists and those that thrive in pools have a higher chance of survival (Walters 2016). Brook trout (*Salvenlinus fontinalis)*, a non-native, stream and lake generalist, thrive in both deep and shallow pools, suggesting they would not be as vulnerable to decreasing flow levels (Mollenhauer et al. 2013, Robillard et al. 2011). Native Chinook heavily utilize riffles, and therefore may be more sensitive to a decreased abundance of riffles and subsequent refugia, relative to brook trout.

Drought conditions can result in increased deposition of fine sediment throughout the system (Collins and Walling 2007). Spawning Chinook adults require coarse-bedded substrate free of embedded fine sediments for successful recruitment to the population (Overstreet et al. 2016). Depending on salmonid life stage, wildfires resulting from drought can have both negative and positive impacts on populations-- increased fine sediment from hillslopes is detrimental to egg and fry habitat, while increased loads of large woody debris benefit adults by providing habitat cover (Flitcroft et al. 2016).

Aquatic Ecosystem

New extremes in flow regime will alter the assemblage and abundances of aquatic organisms. Low stream-flows alter habitat types and induce more aggressive resource and niche competition, resulting in a decline in both fish and macroinvertebrate populations (Bunn and Arthington 2002). Above Hetch Hetchy Reservoir, changes to aquatic communities are minimal because the consistent supply of cold water and bedrock substrate in the headwaters are not drastically affected by drought. At lower elevations, drought-induced changes in aquatic ecosystems impair the water quality, making conditions less favorable for native species. Benthic algae populations increase as temperatures rise and more light reaches the streambed. A higher influx of detritus from perishing algal blooms increases microbial consumption, depleting dissolved oxygen in the stream and increasing the level of dissolved organic carbon (Lake 2003). Low levels of dissolved oxygen and increased DOC concentrations are responsible for declines in fish, macroinvertebrate, and macrophyte populations.

Forests

Forested vegetation in water-limited regions such as the upper Tuolumne watershed can provide important ecosystem services by promoting a local community with high plant biomass, diversity and structural complexity (Vose et al. 2016). However, high tree density, fire suppression, increased drought conditions, and increased pathogen and insect attack have increased tree mortality in the region creating widespread impacts on the Tuolumne watershed (Mantgem et al. 2009). Although fires are one of the dominant drivers of ecosystem succession in the Sierras, large and more severe fires caused by fire suppression policies and increased drought conditions have impacted mature conifers that dominate the upland zone (Epke et al. 2010). The newly exposed soil following severe fire increases the likelihood of nutrient leaching, increasing runoff and turbidity of the waterways. Furthemore, vegetation loss from tree mortality shifts nutrient cycling while increasing melting rates of snow, leading to higher peak flows during the spring runoff (Cristea et al. 2013). Reduced canopy cover alters evaporation, transpiration, and canopy interception which can indirectly alter infiltration, runoff, groundwater recharge, and streamflow rates of the watershed (Adams et al. 2012).

Management Responses

Fish

The Tuolumne river watershed is a specialized and complex system, therefore transferability of management tactics from other systems is insufficient. Biases within other systems need to be accounted for proper management. For example, Hakala and Hartman (2004) documented low flow events decreasing abundance and body condition of salmonid populations, but James et al. (2010) showed drought reduced salmonid abundance but did not significantly change body condition. Both studies showed differing impacts of flow reduction on water temperature and resource availability. Therefore, in order to properly manage the Tuolumne river watershed for adequate fish habitat under drought conditions, site specific research needs to be done.

Water Supply

Managing the Tuolumne River to adequately supply water to its users in times of shortage requires an understanding of an equitable allocation for the needs of both ecosystems in the watershed and water users. San Francisco Public Utilities Commission [SFPUC] operates a reservoir in the Hetch Hetchy Valley, collecting clean stream-water for San Francisco and other Bay area residents. Good water quality in Hetch-Hetchy reservoir has persisted during drought conditions and even through the Rim fire. Water releases are based on the rights of the Turlock-Modesto Irrigation District and the demand from SFPUC's customers. During the drought, higher-flow events have been released to maintain habitat for native species adapted to the historical flow regime of the river, though these events have been scaled down or released less often. Despite increasing human populations relying on Hetch Hetchy, the demand for water is declining due primarily to conservation measures, allowing increased availability of water for environmental flows.

Forests

Forest managers in the Tuolumne watershed must strike a balance between maximizing forest productivity while minimizing impact on water supply, quality and habitat in the stream. For instance, thinning overcrowded timber stands can increase individual tree growth while strengthening resilience to droughts, insects, and disease while requiring less water. Placing a priority on minimizing sediment input to the stream with during low-flow periods and in vulnerable areas is also critical (Vose et al. 2016).

Understanding the effects of drought on the upland vegetation assemblage is necessary for predicting community shifts and for designing mitigation strategies. Remote sensing can track the composition changes of the forest to further understand the effects of drought on the forest. Using satellite imagery, managers can monitor changes in forest cover, vegetation density and tree mortality in the Tuolumne watershed, and identify which areas are most affected by drought. Over time, they can also monitor whether or not mitigation measures are successful or adequate (Vose et al. 2016).

Conclusion

The widespread effects of the current drought requires an interdisciplinary approach in research and management in order to adequately supply water for both human use and functional ecosystems. Drought can negatively impact water quality and habitat conditions, and thus aquatic ecosystem health. Drought conditions are detrimental to a majority of stream salmonids, greatly decreasing their overall carrying capacity by altering natural habitat conditions. Long-term declines in stream flows can alter benthic algae and macroinvertebrate assemblages, change carbon flux into the system, and decrease dissolved oxygen levels. Prolonged drought can also led to increased tree mortality in the higher elevation alpine zone. Higher frequency and severity of drought conditions calls for understanding the impacts on hydrologic processes, and linking forest and aquatic ecosystem responses across spatial and temporal scales to effectively manage the Hetchy Hetchy System and the Tuolumne River.

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