Influence of Climate Change on Hydrology in Tuolumne Meadows

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Introduction

Climate is a dominant control on hydrologic patterns and vegetation community structure within the Tuolumne River watershed. Water availability is irregular throughout the watershed due to changes in elevation and local variables, such as density of vegetation, geomorphology, and precipitation variability. The Tuolumne River is characterized by low infiltration and complex topography, and the range in elevation creates unique ecosystems along the elevation gradient. One ecosystem of particular importance is Tuolumne Meadows. The meadows provide many ecosystem functions such as flood control, habitat for riparian vegetation, improvement of water quality and habitat for both aquatic and terrestrial organisms downstream (Null 2010). Due to the meadow's dependence on groundwater, changes to the hydrological cycle have a large impact on the ecological integrity of the system. Variability in timing, rate of change, and magnitude of flow are key factors which alter the abiotic and biotic systems in the meadows (Yarnell 2010). The groundwater-dependent meadow ecosystem relies on a consistent shallow water table to have base flow through the dry summer that is primarily sourced from late spring snowmelt (Loheide 2008). Climate change is expected to create warmer temperatures, which results in more precipitation falling as rain than snow at high elevations (Null 2010). The warming temperatures will lead to earlier stream flows in the spring and lower flows into summer. Longer periods of drought and increased low summer flows will place further stress on aquatic ecosystems, and lack of intervention in impaired meadows will exacerbate meadow degradation (Yarnell 2010). Climate change will have direct impacts on the hydrological cycle within the Tuolumne Meadows, but through active ecosystem management stable ecological conditions can be monitored and maintained.

Impacts of Climate Warming on Flow Regime

Native plant and animal communities living in the Tuolumne River watershed have adapted to living with distinct dry and wet seasons. In the Sierra Nevada, precipitation falls as rain and snow, with the snowline at approximately 1,000 m (Null 2010). The most significant variables that impact the annual growth are winter precipitation and summer temperature (Potter 2015). As air temperatures warm, there is a shift to increased precipitation falling as rain, causing increased runoff and reduced diel snowmelt fluxes (Viers et al 2013). Timing, magnitude, and rate of change of stream flow are dependent on the amount of precipitation and in what form it falls in. The Tuolumne River flows through the meadows and is the primary source for the meadow aquifer (Lowry 2010). Snowmelt is the primary hydrologic driver of this system, creating feedbacks between riparian vegetation and other biotic conditions (Yarnell 2010).

During dry years, warmer temperatures, fewer storms, and early snowmelt recessions are seen (Confluence 2010). Though California summers are often associated with a summer drought, climate change is increasing the duration of low summer flows and delaying the environmental cues for recruitment of local flora and fauna (Kiparsky 2014). For example, the smaller volume of cold snowmelt water can lead to warmer temperatures and low magnitude of discharge into the meadows. This leads to elevated rates of conifer encroachment and growth rates of vegetation, due to the lower flows being unable to scour seedlings along banks (Yarnell 2010). Reduction in water tables can cause a state shift to non-meadow conditions, promoting channel incisions and placing stress on surrounding biota.

During wet years, conditions are more variable. Groundwater reservoirs recharge, and there is a high chance of surface flooding, as well as increased productivity within the river systems. Additionally, with more frequent storms and precipitation falling as rain, there is increased potential for winter floods. The expected mid-to-late spring snowmelt recession leads to higher magnitude flows and increased hydraulic variability (Yarnell 2010). As a consequence of frequent floods, there will be increased loads of debris and sediments, increased erosion and incision events, causing potentially significant degradation of meadow habitat (Viers et al. 2013). Meadows ability to attenuate floods will be impacted as increased magnitude and duration of flows will reduce infiltration of groundwater in the system (Viers et al. 2013).

The unpredictable nature of climate change leaves the Tuolumne Meadows ecosystem with an unknown future. Changes in rate of change, timing, magnitude of discharge will have large implications on the abiotic and biotic factors of Tuolumne Meadows. During wet years, there are signs of scouring and pool formations where cobble bars once stood (Yarnell 2010). Alternatively, dry years promote riparian vegetation encroachment and decline in diversity surrounding the river banks (Yarnell 2010). In the same vein, altering the timing of the snowmelt recession has large implications for the vegetation that have adapted a stable period of recruitment in response to the native flow regime. Earlier start of recession leads to a decrease in suitable conditions for seedling recruitment of woody riparian species (Yarnell 2010). Shifts in the vegetation communities, due to changes in hydrological cycling, will impact meadow functioning and should prompt management efforts to restore natural processes.

Management to Maintain and Restore Functionality of Tuolumne Meadows

Higher frequency and severity of destabilizing events, such as floods and droughts, requires development of suitable monitoring techniques designed to predict changes to hydrological processes and, consequently, impacts on vegetation across spatial and temporal scales. Integrating current management policies with more robust ecological survey methods can help to identify ways in which to plan for future climate stressors. This would involve a collaborative effort between state, federal, and regional entities towards a common goal. An assessment of potential vulnerability can draw connections between the physical process of meadows and changes in response to varying hydroclimatic drivers (Viers et al. 2013). Through active ecosystem management, the ecological integrity of Tuolumne Meadows can be maintained under hydroclimatic changes in the future (Viers et al. 2013).

Active management requires maintenance and implementation of long-term monitoring programs that take measurements of hydrological patterns, water quality, and vegetation community structure. Monitoring water table patterns can be used to predict how the site and species present may change, based on the complex relationship between the physical and biological components of meadow ecosystems (Allen-Diaz 1991). Beginning with vegetation composition and structure monitoring, for creating a model that can then predict and identify how vegetation will respond to these changes (Lowry 2011). Predicting the patterns in terms of mean annual flow, runoff centroid timing, and low flow durations, can give a broader understanding the hydrologic response and susceptibility to climate change (Null 2010). With this collected data, direct modifications can be made to the meadow channel or floodplain with the intention to improve ecosystem functionality.

As an example, a study in Tuolumne Meadows sought to link hydrologic alterations with vegetative response, leading to the ability to predict vegetation dominance. Through monitoring groundwater processes, snowmelt processes and vegetation surveys, models were able to predict and simulate the impact of water table fluctuations on vegetation communities (Lowry 2011). This evaluation can be used to support improvement of meadow functionality, pushing towards restoration of natural ecosystem function and resilience across variable water year types. Accordingly, such models can aid in saving time and money by predicting which meadows will be most affected by climate change (Lowry 2011). Similarly, these models can also inform what restoration techniques will make the most impact based on the predicted changes to ecological function.

With this knowledge, decision-making can involve both ecological and social issues of concern. Collaborative efforts will help to maintain the biodiversity and ecosystem functions of the meadows by aiming to reduce stressors across management efforts, and thus promoting resiliency. Though general trends are expected due to climate change, it should be noted that changes due to warming are region specific, and thus hydrological management should take in such factors (Viers et al. 2013).

Conclusion

Understanding the hydrological cycle of the Tuolumne River, specifically through the meadows, is crucial in order to prioritize restoration efforts as well as informing effective water management decisions. While the extent to which climate change will impact the area is unknown, there are environmental cues that can be monitored to give clues to what expected shifts may occur. Far from being able to prevent climate variability, future decisions must encompass scientific background to ensure decisions are comprehensive and targeted towards reinstating ecosystem functions. Through incorporation of monitoring protocols and vulnerability assessments, restoration efforts can be implemented to increase ecosystem resilience (Viers et al. 2013). The removal of stressors and reduction in vulnerability relies on active ecosystem management. Understanding the relationship between the hydrological function and those physical functions of meadows that are impaired by climate change, will lead to better hydrological and ecological management for the maintenance of these meadows. These widespread effects require an integrative understanding of the hydrological cycle and ecosystem responses across spatial and temporal scales, in order to effectively manage and sustain meadow habitat in the Tuolumne River Watershed.

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