Impacts of Climate Change on Natural Functional Flows

By

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Introduction

Most watersheds in the Sierra Nevada are regulated, having been significantly altered by the mass introduction of dams during the hydraulic era of the 20th century. The Tuolumne River, with Hetch Hetchy Reservoir, is one of the most iconic watersheds within the Sierras (Figure 1). The Tuolumne watershed also serves as a good reference for how Sierran watersheds may respond to climate warming. With the decline of the hydraulic era of water infrastructure in California, water agencies are now learning adaptive management strategies to reconcile impacted environments. As implementation of functional flow regimes are analyzed, the consequences of climate change must also be considered. This paper discusses potential impacts of climate warming on the Tuolumne River and suggests how such change will affect management of a functional flow regime. Flow patterns from before and after the completion of O'Shaughnessy Dam are identified and climate models for the Sierra Nevada are evaluated to describe the benefits and future challenges of enabling a functional flow regime. This analysis relies on publicly available databases, published climate model results, and field results from along the Tuolumne River.

Figure 1. The Tuolumne River watershed with headwaters in Yosemite National Park and mouth at the San Joaquin River[1].

Methods

Determining the potential impacts of climate warming on managing a functional flow regime requires identifying expected changes. First, the historical and current hydrology must be reviewed for context. USGS streamflow gage 11274790, located in the Grand Canyon of the Tuolumne, has been in operation for eight years. Important to note is that this site is located above O'Shaughnessy dam and records unimpaired flow data. This period of data informs trends in discharge and establishes a reference for comparison of what the various climate models predict for the future. USGS gage 11276900, located below early intake, has a longer period of record at 47 years, however this site represents impaired flow data and is not used for this analysis. Discharge trends for the 2014 water year are illustrated in Figure 2. Also plotted are the mean daily values over the period of record which reinforces the expected flow trends. Although a dry water year type, storm peaks are still observed in the beginning of the water year and a recession limb is visible in late spring to early summer. These observations are characteristic of natural flow regimes and represent what functional flow regimes are modeled after.

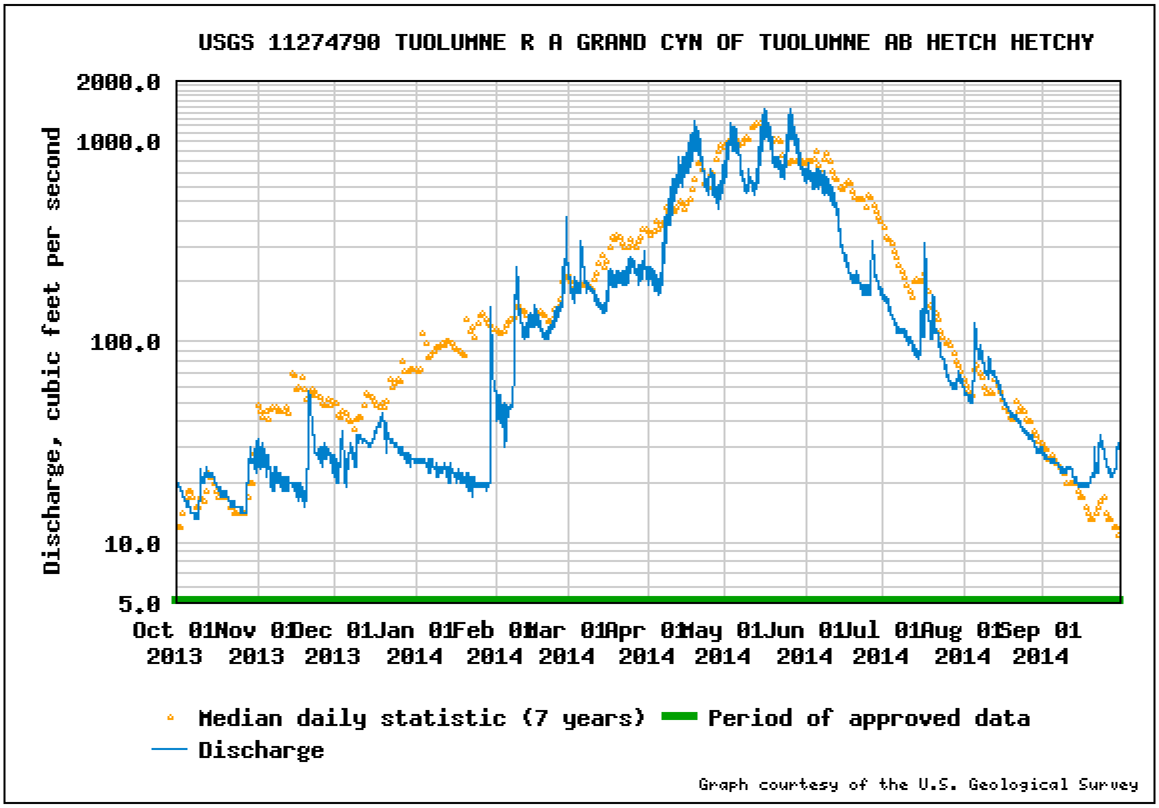

Figure 2. Discharge in English units for water year 2014 within the Grand Canyon of Tuolumne. Mean value over period of record is also plotted[2].

The natural unimpaired flows observed in the Grand Canyon of the Tuolumne, and at other sites above Hetch Hetchy, will change with climate warming according to various models. Consequently, the downstream management will be altered as well. Figure 3 demonstrates the results of the Water Evaluation and Planning (WEAP) model, a comprehensive model of hydrology with agricultural, urban, and environmental uses (Kiparsky, Joyce, Purkey, & Young, 2014). The WEAP21 version of this model is beneficial for evaluating subwatersheds to provide greater resolution within the Sierra Nevada range (Young et al., 2009). Thus, Figure 3 details the expected trends under three warming scenarios of 2°C, 4°C, and 6°C within 50-100 years (Young et al., 2009). The shifts and associated impacts illustrated by the various scenarios are described in the discussion below.

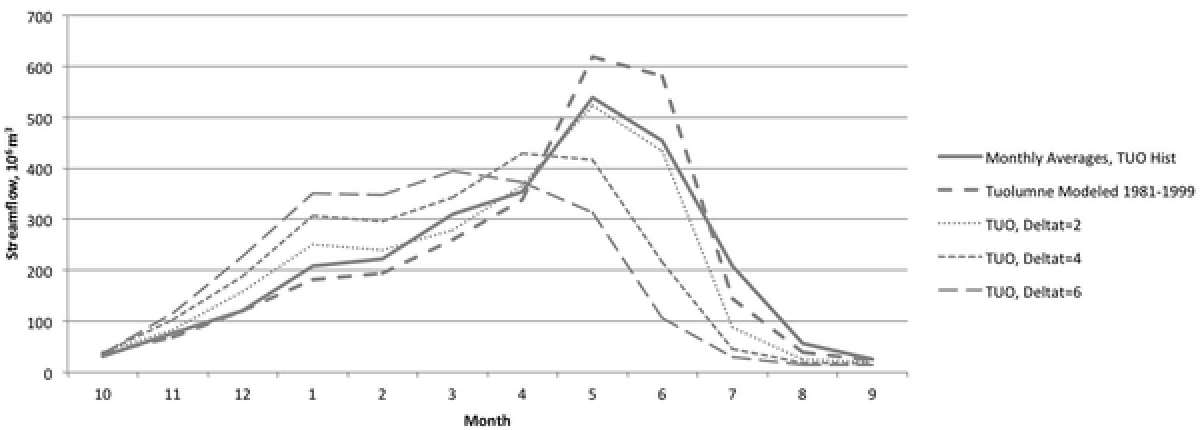

Figure 3. Monthly discharge averages within the Tuolumne River from historical data and models representing 2°C, 4°C, and 6°C climate warming[3].

In addition to public databases and climate models, Tuolumne field data characterizes the current abiotic and biotic conditions for further informing expected responses. Specific data gathered includes channel morphology, discharge, water quality, sediment characterization, bug surveys, and fish surveys. These current stream conditions were compared to warming projections to imply future impacts and thereby inform key areas for adaptive management.

Results:

Across the various climate models, there is consensus that the snowmelt-dominated Sierras will undergo significant hydrologic alterations (Vicuna, 2007). Among those results, the timing of the snowmelt recession is expected to occur earlier in the year. The exact change in timing depends on the climate model scenario, but ranges in shifts of 5-21 days (Kiparsky et al., 2014) to one to two months (Young et al., 2009). Other factors such as carbon dioxide concentrations affect these estimates (Young et al., 2009), but the general concept is that the recession will occur sooner. The magnitude of the recession is also predicted to decrease since more precipitation will fall as rain, thereby decreasing the snowpack storing much of the freshwater used in summer. The rate of change of the snowmelt recession is also expected to vary. As rate of change of the snowmelt recession only decreases slightly, the overall duration of the snowmelt recession is still expected to be shorter (Yarnell, Viers, & Mount, 2010). Thus, over the water year there will be a longer period of low, warm summer flows.

Current abiotic and biotic characteristics vary throughout the Tuolumne watershed. Field results from the Tuolumne indicate the distinct differences below and above regulations. For example, within Tuolumne Meadows the sediment characterization included more gravel but near early intake the sediment was more cobbles and boulders. This indicates supply limitations due to the dam.

Discussion:

Magnitude, timing, rate of change, duration, and frequency are the primary components of flow regimes. Expected results with climate change are mentioned above, and a discussion of implications follows.

With earlier timing and decreased magnitude, flows will be warmer for longer. This is beneficial for some aquatic species such as amphibians, but does not support the native species who have adapted to the historic natural flow regime (Yarnell et al., 2010). Sierra Nevadan species have developed their lifecycles to correspond with the snowmelt recession. Historically, the snowmelt recession has been predictable, but climate warming alters the pattern as seen in Figure 3. This creates the potential for species life cycles to grow out of synch with the changing environment. Flow management from reservoirs such as Hetch Hetchy has the potential to restore the natural flow regime. This will benefit species surveyed such as EPT diversity within riffles of streams, native trout species, as well as species that were not specifically surveyed such as the western pond turtle. Warming temperatures however will increase suitability for invasive species such as bullfrogs and bass observed in high quantities within the lower reaches.

Limitations:

From the results described above, implementing functional flow regimes will be a challenge. Water resource managers will need to consider the increased rainfall and decreased snowpack. This requires modeling and managing for flood flows to protect infrastructure and downstream communities while also maintaining enough capacity in the reservoirs for supply during extended low summer flows. One tool to help satisfy the variety of water interests is hedging. Hedging is a reservoir management technique that induces smaller shortages earlier in order to prevent substantial shortages later in the water year. This is beneficial for a number of anthropogenic water uses, but does not aim to satisfy a functional flow regime. The Looking Downstream document by the San Francisco Public Utilities Commission has made significant progress in establishing what a functional flow regime may look like from O'Shaughnessy Dam. This document has required extensive research and monitoring. The associated effort reflects the complexity of mimicking natural flows while meeting usage demands.

Conclusion:

Climate warming will alter the hydrology of the Sierras since the region is snowmelt-dominant. Reservoirs within the Tuolumne watershed provide an opportunity to adjust flows to create the natural functional flow regimes that species have evolved to. This will require an interdisciplinary approach among biologists, hydrologists, engineers, and government agencies. Achieving successful functional flows will require optimization tools, but may preserve the historic snowmelt recession. Rather, the functional flow regime is not meant to perfectly mimic full natural flows, but induces the necessary signals that species have adapted to and that are required to allow the abiotic environment to adapt as well.

References:

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Figures:

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