Impacts of the Flow Regime of Tuolumne River Following the Rim Fire

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Abstract

Wildfires have grown substantially over the past several decades in the United States; California in particular is highly susceptible to these natural disasters because of patterns in the state's climate that cause increased drought and extreme heat, combined with overgrown forests and improper fire management within them. In 2021 alone, California had approximately 8,835 fires that burned up 2,568,948 acres (CalFire). Forest fires can cause increased surface water runoff, degrade water quality, and impact the hydrology of watersheds in a multitude of ways. The 2013 Rim Fire occurred in the Stanislaus National Forest and burned approximately 257,313 acres of the Tuolumne River Watershed. This study analyzes impacts to the flow regime of the Tuolumne River from the Rim Fire, by analyzing streamflow data of the Tuolumne River near Modesto located downstream from the fire's location. A hydrologic and flow regime analysis was conducted of the Tuolumne River before and after the fire by utilizing University of California Davis Functional Flows Calculator. An analysis of the different functional flow components was conducted on two sets of data – pre-fire data ranging from 1980-2012 and post-fire data from 2014-2021 – as well as an independent analysis of two dry water years within each data that occurred pre- and post- fire, 1990 and 2014, respectively. This study analyzed any changes to magnitude, timing, frequency, duration, or rate of change in the Tuolumne River flow regime. It is concluded that post-fire wet-season flow cycles were elongated compared to pre-fire cycles and had a greater magnitude of about 1.5x that pre-fire flows. Dry-season flows post-fire we're observed to be shorter in duration and lower in magnitude, though not significantly. For individual years, 2014 saw a large increase in peak flow compared to 1990, despite a larger decrease in precipitation and runoff in 2014. Though this suggests a positive correlation for hydrological impacts from wildfire resulting in increased flows, more data needs to be incorporated to enhance the studies robustness.

Introduction

Wildfires, among other natural disasters, have grown in frequency and in scale in recent years due to climate change as well as the decreasing boundary in the Wildlife Urban Interface. With this increasing frequency comes a growing concern for impact on surface waters; wildfires have a large potentially to significantly change the conditions of watershed hydrology. Depending on the forest's terrain, a wildfire can increase peak-flow magnitude due to the lack of vegetation in burned watersheds. Lack of vegetation from a fire impacts the forest-floors ability to "intercept precipitation, moderate infiltration, and protect mineral soil [resulting] in decreased evapotranspiration and infiltration, and increased runoff" (Neary et al. 2011). Increasing wildfires add unpredictability to our water supply by impacting hydrology via risks like flooding and sedimentation following fires. The United States (US) relies on forests to provide and ensure reliable water quality; 80% of all freshwater resources in the US come from forests and about 50% of the water supply in southwestern US come from forests. The 2013 Rim Fire was located in the Stanislaus National Forest in California; it began on August 17, 2013 and lasted under November 4, 2013, burning approximately 257,313 acres of the Tuolumne River Watershed in its path. The Tuolumne River begins in the Sierra Nevada Mountain range at a higher elevation, eventually flowing down to join the San Joaquin River near Modesto. It supplied San Francisco with approximately 85% of its water and 17% of its electricity; therefore a negative impact to this watershed would have consequences for the entire region.

Objective

The main objective of this project is to compare the flow regime of the Tuolumne River at Modesto (Figure 1) before and after the Rim Fire by conduction a hydrologic analysis with flow data. I will compare the overall flow regime for the river from 1980-2012 with 2013-2021 to analyze if there have been long term impacts to different functional flow components including dry-season low flows, wet-season base flows, and spring recession flows.

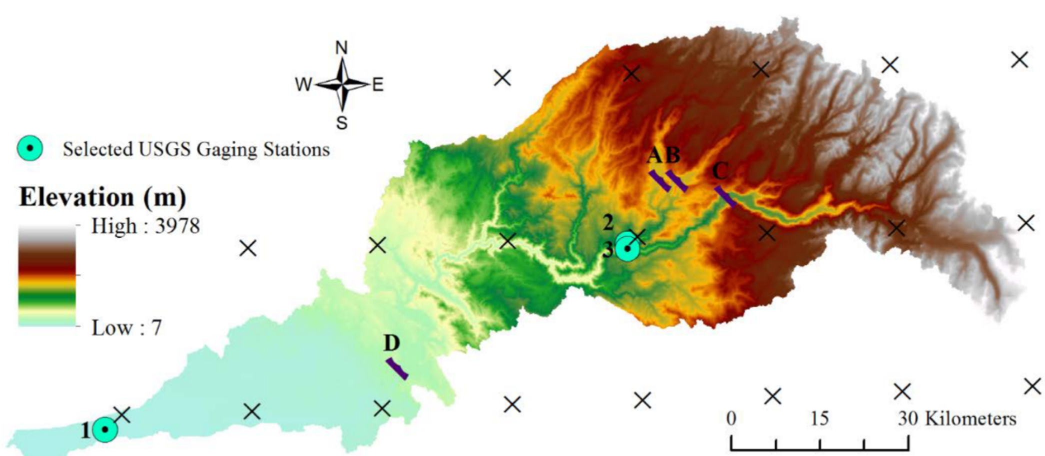


Figure 1. Location of the USGS Gaging Station analyzed. Site 1. (Blasco 2020)

I will compare individual water year hydrographs pre and post fire to analyze changes in annual flow immediately following the fire. I will produce a series of hydrographs for different dry and wet water years, before and after the fire, to compare accordingly. I will also produce two graphs to compare the natural flow regimes of the Tuolumne River before and after the fire. I will specifically select Water Year 1990 as a pre-fire year, and Water Year 2014 as the post-fire year immediately following the drought. According to the California Water Science Center, the 1987-1982 drought compares to the 2012-2016 drought due to its duration and severity of lack of precipitation and runoff (USGS). Therefore these years will be the most accurate comparison of available data.

Hypothesis

I hypothesize that the Tuolumne River experienced increases in streamflow immediately following the fire, compared to hydrograph of an equivalent pre-fire water year.

Data Sources

- Stream gage flows (daily mean) for USGS 11290000 – Tuolumne R A Modesto
  - USGS online gage data (USGS, 2022).
- Annual Flow Result and DRH .CSV File – Obtained via USGS data
  - University of California Davis Functional Flows Calculator.
- California State Annual Precipitation Data 1900-2020
  - National Weather Service. *Year in Review 2020 (v2).* National Ocean and Atmospheric Administration.
- Map of USGS Site Location
  - Blasco, C. (2020). "Assessing Impacts of 2013 Rime Fire on Tuolumne River Watershed." Bowling Green State University. 193.

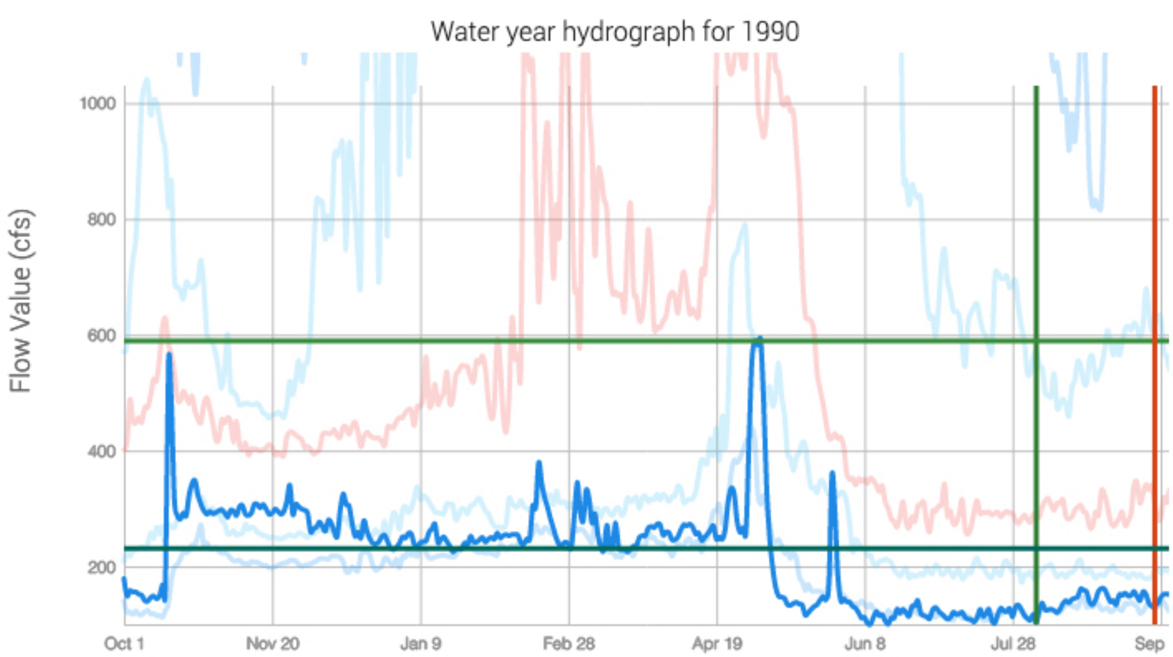
Methods and Assumption

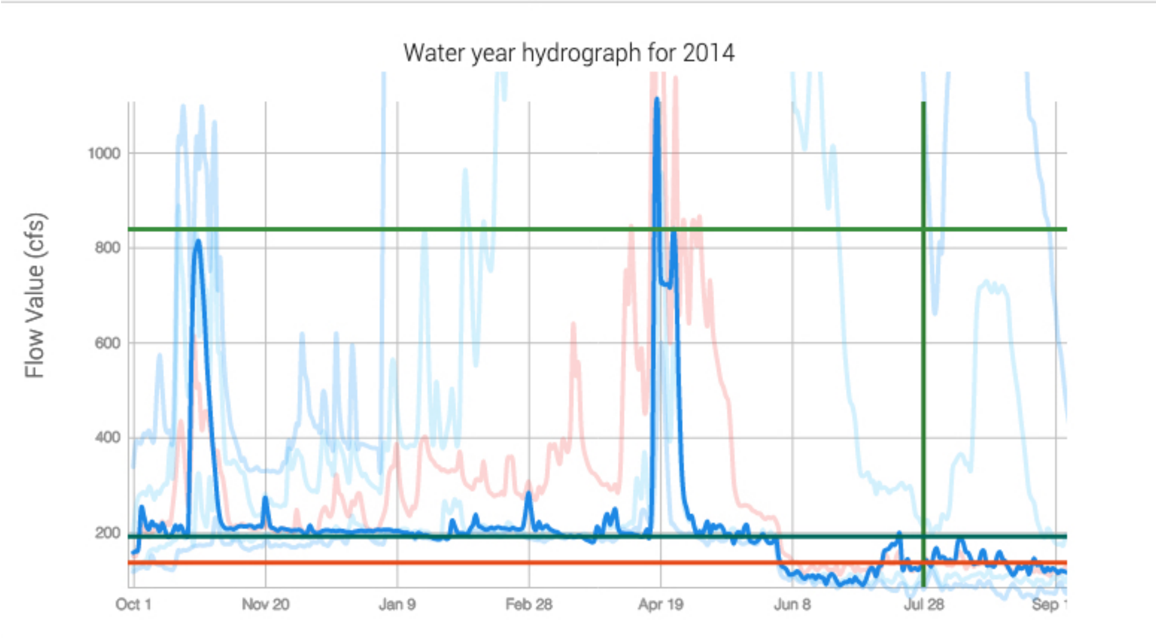
- I downloaded daily stream flow data, making sure to only use complete water years, from USGS of Tuolumne River from 1980-2012 and 2013-2021 and properly formatted it, then imported it into a CSV file.
- I then uploaded it into the UC Davis Functional Flows Calculator (FFC) and began evaluated the Dimensionless Reference Hydrograph (DRH) for pre and post fire data. In analyzing this, I viewed the seasonal and interannual variation in the river's flow regime, with day 1 marking the start of the water year on October 1st.

- In the FFC, I explored the Annual Flow Plot and compared how different functional flow components and metrics changed before and after the Rim Fire; including dry-season low flows, wet-season base flows, and spring recession flows.
- I overlaid different annual flow plots with the DRH to see how they compared.
- I downloaded CSV filed from the FFC of the DRH and Annual Flow Results, then imported them into the HYD 243 “FFC_Master.xlsm” to calculate functional flow metrics.
- I assumed from USGS data that 2014 had 27.24 acre-feet of annual runoff and 12.39 inches of rainfall. 1990 has 34.71 acre-feet of annual runoff and 15.02 inches of rain.

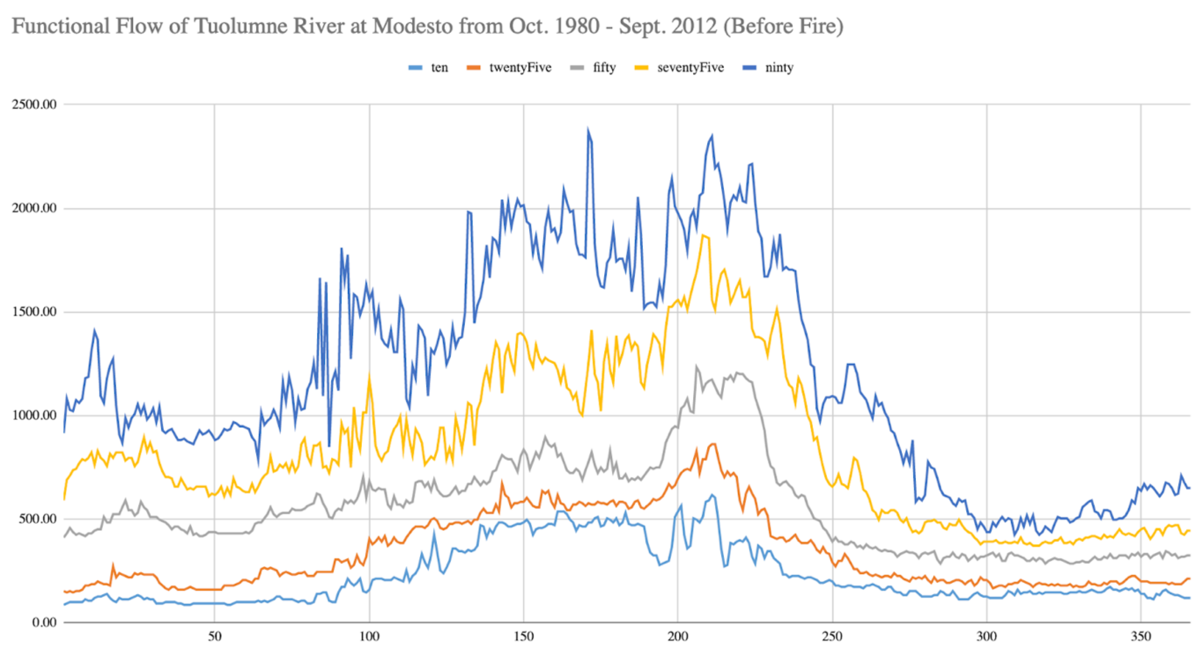
Calculation/Results

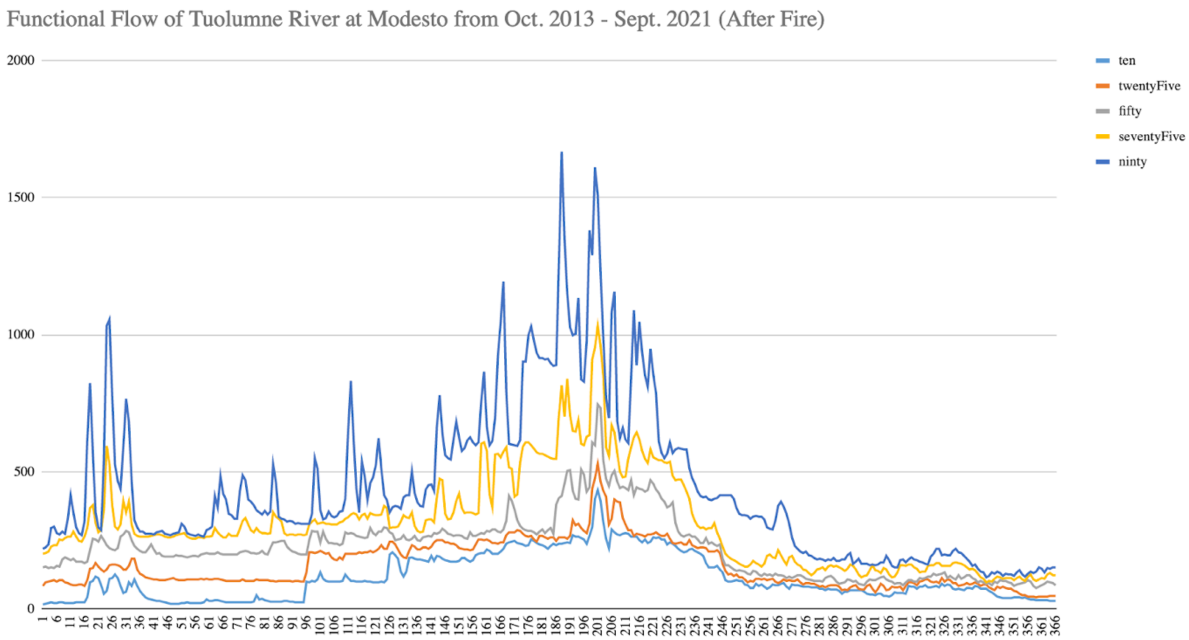
A hydrograph was obtained for water year 1990, which occurred before the fire, and water year 2014 which occurred after the fire. Both of these years were the driest year on record during two historic droughts. The Hydrograph for 1990 is overlain with the DRH, which maps the river’s flow regime. Vertical lines indicate timing of functional flow components including start of dry-season low flows (indicated in red), wet-season base flows (indicated in gold), fall pulse flows (indicated in orange), spring recession flows (indicated in green), and peak flows (indicated in purple). Horizontal lines indicate magnitude of corresponding functional flow components. Spring recession magnitude is indicated in green, low flow magnitude is indicated in red, fall pulse magnitude is indicated in orange, baseflow magnitude for wet seasons are indicated in turquoise.





Both of these years faced drought, therefore understandably there was a lack of precipitation and neither water year experienced a fall pulse flow, as would have been depicted by an orange vertical line on the hydrographs. Spring recession flow timing, as indicated by a green vertical line, remains consistent between pre and post fire drought years, however in the post-fire year, 2014, the magnitude of spring recession is approximately 130 cubic-feet-per-second (cfs) higher than in 1990. Notably this occurs right around the end of October 2013, which is when the Rim Fire was almost fully contained. There is also a noticeable increase in flows around April 19. Base flows remained consistent at 200 cfs for both pre and post water years.





The peak flow for pre-fire flow regime is 2,366.89 cfs and the peak flow post-fire is about 1,668.38 cfs.

Additional values estimated for pre-fire functional flow metrics include:

	Dry-season	Wet-season	Spring-recession	Mid point
Median				
Start Date	264	92	216	239.75
End Date	92	202	240	264
Magnitude	91.5	2.0	13.0	603.2

Additional values estimated for post-fire functional flow metrics include:

	Dry-season	Wet-season	Spring-recession	Mid point
Median				
Start Date	264	50	211	237.25
End Date	50	203	237	264
Magnitude	50.0	3.5	18.5	252.8

Dry Season flows post-fire ended about 40 days earlier than pre-fire flows, indicating a shorted dry season flow along with decreased magnitude at a rate of almost double. Wet season flows post-fire started about 40 days earlier than pre-fire, elongating the cycle and having a greater magnitude, of about 1.5x. Spring recession did not see noticeable changes, started and ending only a few days earlier. Mid-points also saw a large decrease in post-fire functional flow metrics, of almost 3 times less.

Conclusions

In comparing the Tuolumne River's hydrology for two dry water years pre and post fire, 1990 and 2014, respectively, and observing the functional flow components, it was observed that an unusual peak in streamflow occurred immediately following the fire in October 2013. Spring recession flows stayed consistent, although post-fire magnitude was greater by about 130 cfs. This was the only significant change. In comparing the flow regime for pre-fire flow data from 1980-2012, and post-fire data from 2013-2021, and analyzing the functional flow components of those hydrographs, it is observed that dry season flows after the fire were shorter and lower in magnitude. In contract, wet-season flow cycles were elongated post-fire and had a greater magnitude of about 1.5x than pre-fire flows. There seems to be some data indicating increases in flows and peak flows immediately following the fire but this cannot be concluded without increasing the sample size of data.

Recommendation/Limitations (one paragraph)

Limitations of the study included the range of available streamflow data from USGS. Daily flow data for the Tuolumne River is available as early as 1980. However there was a historic drought in the 1970s that had more comparable precipitation and runoff metrics to the 2014 drought; this would have made for a more accurate and robust comparison, assessment and study. Similarly, evaluating additional USGS stream flow gages along the river, particularly at higher elevations near the origin of the Rim Fire, would have informed the study and shed light on the immediate hydrologic impacts from a burned watershed.

References

- Blasco, C. (2020). "Assessing Impacts of 2013 Rime Fire on Tuolumne River Watershed." Bowling Green State University. 193.
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