AN ANALYSIS OF THE IMPACT OF FOREST FIRES IN YOSEMITE VALLEY WATER SYSTEMS

This Independent Study Project is Submitted in Partial Fulfillment of the Requirements of the Multidisciplinary Academic Program in Energy Studies at Yale College.

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May 2022

Abstract

This project takes a data-driven approach to analyze how Yosemite Valley water quality and quantity has varied over the past 10 years in relation to the pervasive forest fires of north and central California. Human activity over the past century that has accelerated climate change, and in addition to frequent human-caused ignitions, has led to an increase in the spread, magnitude, and duration of wildfires in California. Previous research has shown that in the wake of a forest fire, the burning of local vegetation pollutes water sources and leads to myriad short- and long-term water system issues (EPA). These negative consequences strain local ecosystems as well as municipal water resources.

This research uses qualitative and statistical techniques to uncover relations between the US Geological Survey's (USGS) Hydrology and Weather service datasets and the National Interagency Fire Center's (NIFC) Wildland Fire Locations Full History datasets. The data analysis stage will consist of exploration and visualization to portray trends across time and locations. This research and analysis aims to yield an objective report on how Yosemite Valley's current water systems have been impacted by regional forest fires to highlight the effects they have on whole ecosystems.

The analysis aims to answer the following key research questions:

1. How has Yosemite Valley's water quality and quantity changed in the past decade?
2. How much change in Yosemite Valley's water quality and quantity can be attributed to forest fires in the Pacific Northwest?

3. How do our conclusions regarding the impact of forest fires on water quality and quantity in Yosemite Valley extend to the greater California region?

Background on Forest Fires and Hydrology

Human activity in past centuries has led to environmental shifts and climate change that have increased the frequency and severity of natural disasters. One of the most powerful and unpredictable natural disasters is forest fires. While some forest fires are prescribed burns and are necessary for ecosystems to reset after periods of prolonged vegetation growth, the majority of wildfires are unplanned and, once ignited, extremely difficult to extinguish. These unplanned fires often spread hundreds of acres and wreak havoc on the humans, animals, and plants in their way. Wildfires burn trees and plants, decimating the shelters and food supply of many animals, and often pose life-threatening dangers to humans living in proximity to the fires.

To label wildfires as "natural" disasters would not paint a complete picture of the cause of many ignitions. The U.S. National Park Service concluded that "nearly 85 percent of wildland fires in the United States are caused by humans… from campfires left unattended, the burning of debris, equipment use and malfunctions, negligently discarded cigarettes, and intentional acts of arson" (Wildfire Causes). Population growth and, in turn, increased density in suburban areas with lots of vegetation has increased the prevalence of human-instigated wildfires.

No other region in the United States has been scorched by forest fires and has as high a risk of future wildfire damage as the dry, yet heavily vegetated, as the populated state of California. California's semi-arid climate coupled with its sprawling forest and powerful winds have made it susceptible to have wildfires spread over hundreds of square miles in less than a day.

In 2021, California experienced one of its most widespread and destructive fire seasons with more than 2.6 million acres being burnt across the state (2021 Incident Archive). These wildfires have caused uncountable consequences, such as the destruction of property, crops, andn ecosystems.

Wildfires are inextricably linked to human public health. One of the most damaging repercussions of wildfires has been the polluting effect on regional air quality. Smoke from wildfires has been shown to lead to long term respiratory and optical damage (How Smoke). As both the population of California and the greenhouse gas emissions of the world continue to increase, it does not appear that wildfires will relent in the state.

The regions that California residents, environmentalists, and politicians are most concerned about are the heavily-wooded regions in the north and along the Sierra Nevada in the center of the state. The western edge of the Sierra Nevada is home to many world-renowned protected natural areas, including Yosemite National Park.

Yosemite Valley is a seven and a half mile long valley in the heart of Yosemite National Park. The park stretches more than 1,000 square miles along the western Sierra Nevada mountain range in central California. It is one of the United State's most visited and recognizable National Parks, hosting more than 3 million recreational visitors annually (Visitation Numbers). Tourists, hikers, mountaineers, researchers, and families flock to Yosemite to marvel in the natural beauty of its towering Giant Sequoia trees, crashing waterfalls, and daunting granite boulders.

Yosemite lies in a high-risk region of the state and has experienced some of the most destructive fires in California's history. In the past 10 years, Yosemite's has endured the Rim Fire of 2013 in which 255,000 acres were burned and the El Portal Fire of 2014 during which 4,689 acres were burned (Fire History). This past calendar year has provided no reprieve. By the end of September 2021, Yosemite had already experienced 62 fires in the nine months of the year (National Park Service).

Forest Fires Impact on Regional Water Quality and Quantity

An often overlooked result of wildfires is the effect they have on local and regional watersheds, harming the quality of life for both humans and the entire ecosystem of the region. Wildfires transform watersheds in multiple ways over a span of durations. During the active burn period, particles and ash are released into the air and often eventually settle onto bodies of water. These particles contaminate the water in which freshwater fish and insects live. These particulates often cause unwanted algae growth that eats up the oxygen in the water system, "clogging the gills of fish and invertebrates, or smothering corals and submerged aquatic vegetation" (Harmful Algal Bloom). Additionally, eroded soil and larger organic matter can pour into waterways, blocking rivers and streams and compromising the movement of marine animals and amphibians.

Wildfires disintegrate the trees, shrubs, and herbs and scorch the soil that these plants rely on. As the soil breaks down under extreme heat, it is less able to retain moisture and even develops an increased water repellency (Neary). As water flows more quickly over and through soil because of these changes in characteristics, soil and rock are more likely to be displaced–causing erosion. EPA researcher Mussie Beyene, along with his coauthors, in their research "Parsing Weather

Variability and Wildfire Effects on the Post‐Fire Changes in Daily Stream Flows: A Quantile‐Based Statistical Approach and Its Application," commented that "intense storm or snow-melt events following extensive, severe burns in upland basins can trigger massive flash floods and sediment and nutrient flow, which impair downstream water supplies (Bladon et al., 2014; Emelko et al., 2011), human life and property (Jordan & Covert, 2009), and aquatic ecology (Rieman et al., 2005; Silins et al., 2014)" (Beyene). This increases water flow during periods of precipitation, but also drying of watersheds in the long term, as well as changes the composition of the water.

Additionally, as fires become more prevalent close to dense urban areas, there are additional chemicals and particulate matter that are released into the water system. When fires burn manmade structures, they dislodge materials and chemicals from the structures and subsequent rain carries these toxins through and into bodies of water.

Water Systems Effect on Municipal Water Supplies and Ecosystem

Changes in hydrology at watersheds and in water's path to its destination affect the water systems that humans depend on. Water systems in California are specifically affected by forest fires because, according to the U.S. Geological Survey, "approximately 80 percent of the freshwater resources in the U.S. originate on forested land" (California Water). The San Francisco Water Power Sewer branch of the San Francisco Public Utilities Commission cites the following adverse effects of fires on water treatment:

1. "increase in erosion, causing increase in sediment and turbidity at treatment plants,…
2. increase in metals, such as, iron, manganese and other heavy metals from ash washing into the reservoir,… [and]

3. short-term effect from fire-fighting retardants used by aircraft" (San Francisco Water Power Sewer).

In extreme cases, wildfires can damage the water processing infrastructure. For example, wildfires reach temperatures that can melt plastic and even aluminum at high temperatures, which would melt water meters.

Water infrastructure is of paramount importance, especially during periods of drought. As California's population continues to grow, water infrastructure will likely be further strained.

Yosemite Valley Hydrology

Visitors from across the country and the world come to Yosemite Valley because of the striking views towering granite boulders, the intricate ecosystem populated with exotic flora and fauna, and the pristine waterways flowing throughout the park. Yosemite's hydrology shapes the geography and ecosystem of the park and evolves from season to season. In the fall and winter months, rain pours down on the land and snow settles atop the boulders' peaks. And as spring comes, the packed snow on top of granite mountains slowly melts and passes through the park, coursing down from the waterfalls to the numerous rivers that service the entire ecosystem.

The Tuolumne River and Merced River Watersheds are the two main sources of water that wind through Yosemite Valley. Both of these water systems begin in the upper-reaches of the western Sierra Nevada and flow dozens of miles through the park before dispersing to different parts of the state.

The Tuolumne River plays a significant role not only in the ecosystem of Yosemite but also in the water and food supply of central California and the Bay Area. The water of the Tuolumne River passes passes from Tuolumne Meadow in east of the Park to the west before irrigating Stanislaus County, which is one of the nation's largest producers of almonds, milk, eggs, chicken, and many other consumer staples (Stanislaus County). From there, the Tuolumne River “provides fresh water to the Modesto Irrigation District and Turlock Irrigation District, and provides water to the city of San Francisco and several other Bay Area communities through the city’s Hetch Hetchy Reservoir” (Tuolumne River).

Because of its profound impact on both Yosemite Valley’s hydrology and the water system of central California and the Bay Area, I selected Tuolumne Meadows as the location from where recordings were taken for discharge and turbidity data for this study. The National Parks Service commented that the water in Tuolumne Meadows is “so clean, that it is one of the few urban reservoirs in the United States to require only minimal water treatment” (Tuolumne Meadows). This site is representative of a pristine baseline of water quality, so it is hypothesized that deviations from the norm will be noticeable.

Data Collection and Processing

Description of US Geological Survey's (USGS) Hydrology and Weather service Datasets

Through California’s Department of Water Resources, the California Data Exchange provides open-access to hydrologic and climate information. For this analysis, we accessed hydrological data from the past 9 year (May 8, 2013 to May 8, 2022) from the Tuolumne Meadow collection point. We extracted data for the two variables below that represent water quantity and quality.

1. Turbidity is a measure of “presence of suspended material, such as clay particles, plankton or other microorganisms” (Smith). Turbidity can be thought of as a rough approximation of water quality as there can be deleterious “health risk is associated with suspended material that may carry disease-causing microorganisms or particles that have adsorbed toxic organic or inorganic compounds” (Smith). In this research, Turbidity was measured in the Nephelometric Turbidity Unit (NTU), which measures the concentration of suspended particles in a fluid.
2. Flow is a measure of the quantity of water passing through a designated point in a second. Doctor Beyene and co-authors in the same paper mentioned above noted that “high severity fires can alter key catchment hydrological processes (e.g., infiltration, evaporation, and interception) such that the water yield is substantially enhanced (DeBano, 2000; Kunze & Stednick, 2006; MacDonald & Huffman, 2004)” (Beyene). Flow was measured in Cubic Feet Per Second (CFS).

The California Data Exchange Center does not provide turbidity or flow data before 2013, which limited the scope of the data we could examine.

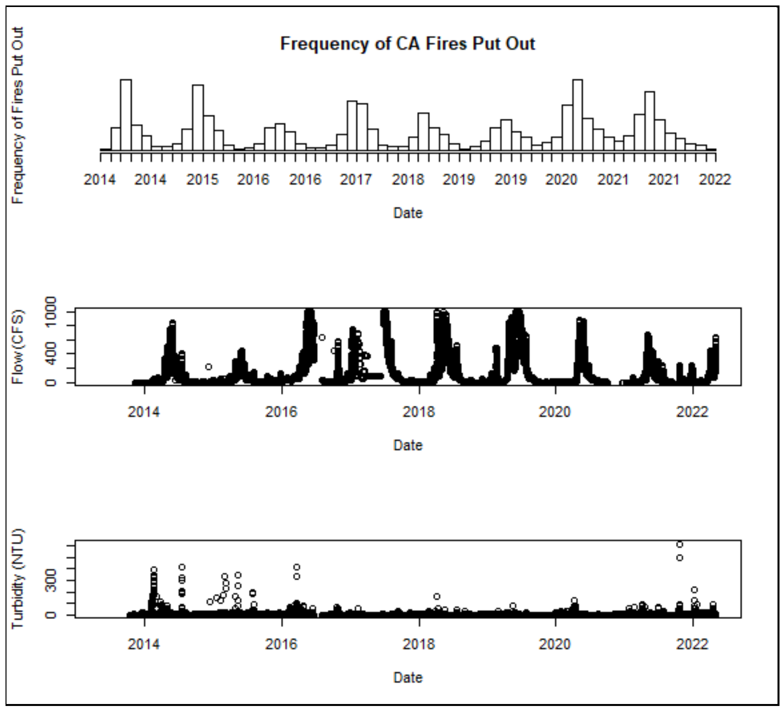
Description of National Interagency Fire Center's (NIFC) Wildfire Perimeter and Behavior Datasets

To investigate the impact of wildfire on the hydrologic systems of the Tuolumne River, data was taken from The National Interagency Fire (NIFC), which is the self-described “nation’s support center for wildland fires” (Fire Information). I subsetted our data to include the following variables: *Calculated Acres, Fire Cause, Fire Discovery Date, Fire Out Date, Incident Name, Fire Behavior, Latitude,* and *Longitude*. The distance between a fire and the Tuolumne Meadow was then calculated by computing the Haversine distance, or the distance between points on a sphere, between each fire's latitude and longitude and the coordinates of the Tuolumne River.

Wildfires can spread hundreds of miles, so we included all forest fires that occurred in the whole state of California.

Methods and Results

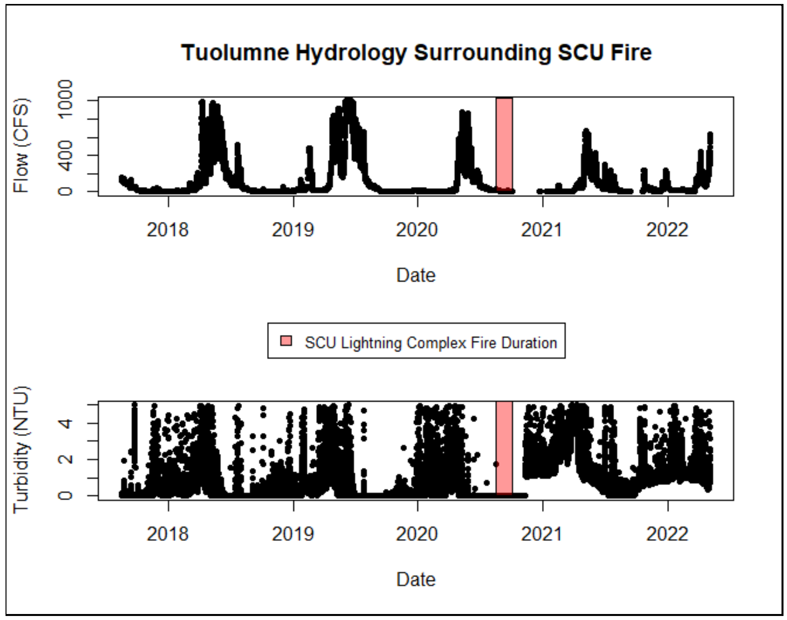
First, we visualize turbidity and flow at Tuolumne River, as well as the frequency of fires being discovered over a nine year period. We can see that for each of these metrics, there are seasonal effects, which was expected. The frequency of fires extinguished peaks in the dry summer and early fall and then declines in the winter and early spring months. The



water flow peaks in the spring months as snowbeds melt and flow through down to Tuolumne Meadow. It is difficult to interpret Turbidity as there is high variance and many large values that obscure the plot.

Next, we sought to investigate the relationship of the SCU Lightning Complex Incident fire on water quality and quantity in the Tuolumne Meadows. The SCU Fire was first discovered on

August 18, 2020, only 110 miles from Tuolumne Meadows, and burnt almost 400,000 acres in the five counties surrounding Yosemite (California Department of Forestry). In the figure I created on the right, we can see the hydrology data of Tuolumne Meadows surrounding the period of active fire, which is shaded in pink. By narrowing the duration of our plot and superimposing a significant wildfire event, we can delineate the hydrological characteristics before and after the fire in Yosemite. We can see that in the two years after the fire, water flow does not reach as high levels as it did before the fire. Furthermore, there appears to be an increase in water turbidity in late 2020 and early 2021 immediately after the fire.



We cannot make causal statements about the SCU Lightning Complex Fire and water hydrology in Yosemite Valley because of myriad confounding variables that we did not control for. Namely, precipitation levels would be a helpful explanatory variable to include in our analysis.

It should be noted that in the second plot, we restricted the maximum turbidity in our dataset to be less than 5 NTUs in order to create a more readable time series plot. This only decreased the size of the subset of our dataset by 2,079 observations, which is less than a 10% change in size.

Study Limitations

Hydrological data was only available from 2013 to 2022 from California's Department of Water Resources. Though almost a decade of hourly data certainly contains valuable information, it is a relatively limited period to investigate. The scope does not allow us to factor in pivotal events in Yosemite's history, such as having a baseline for the Rim Fire in 2013. Though we can see the patterns in hydrology during and following the fire, we do not have the data to analyze how this data compares to the years before the event.

Additionally, a decade is a relatively short period of time in comparison to the lifespan of the relative to the Great Sequoias of Yosemite that live to be thousands of years old or to the Sierra Nevada mountain range itself which is tens of millions of years old. There have been anthropogenic factors that have changed the forests and water systems not just in the past decade but in the last centuries. Therefore, we are comparing water quality only between years within a single era. One of the key factors that researchers have identified for the increased acreage fires traverse in the past decade has been the containment of fires in decades prior. They hypothesize that a more sparse vegetated forest was likely the state of the Sierra Nevada hundreds of years ago, which was less susceptible to burning (University of California).

Conclusion

The growing population of California and the inundation of visitors continues to strain the natural resources of the land. The current water practices of the state to meet the demands of its residents are unsustainable, as droughts plague the state and fires become seemingly omnipresent to residents of the northern and central region. Forest management and the creation of sustainable forest ecosystems play a key role in the mitigation of these environmental risks.

The start of 2022 paints a similar concerning picture: the first three months of 2022 in California constituted the driest months in 100 years, putting all 58 counties in the state “under a drought emergency proclamation” (Current Drought Conditions). Though an alleviation from drought by increased precipitation is foreseeable, this would only be a temporary reprieve from the issue of water scarcity in California. There are long-standing water demand and supply issues that the state and nation must reckon with.

California’s dry period is trending to start earlier each year due to climate change, now starting in January through to the springtime. The dry conditions are forecasted to continue and will be complemented by the increased temperature to further fuel wildfires.

Though there are apparent negative consequences from wildfires on watershed, research of naturally-ignited forest fires, such as Scott Stephen’s 2021 paper “Fire, water, and biodiversity in the Sierra Nevada: a possible triple win”, have also indicated that letting forest fires blaze could result in ecological benefits, “including boosting plant and pollinator biodiversity, limiting the severity of wildfires and increasing the amount of water available during periods of drought” (Manke).

In decades to come, water scarcity may be the most pressing issue that California and the United State southwest faces. Policy-makers, researchers, and citizens must keep in mind the inextricable relationship between fires and water quality and quantity to create a sustainable water system for the American West.

Appendix

Please visit https://github.com/hgill123/Yosemite_wildfire_hydrology/ to view code that processed data and created the above plots.

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