Examining the Impact of Wildfires on Northern California Water Quality

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Introduction

On October 8, 2017, Northern California experienced the worst wildfires in the area's history, as 250 different fire incidents combined to devastate the region. More than 200,000 acres were burned, more than 100,000 people have been displaced, and there have been 44 confirmed deaths, as a result of the wildfires. Dozens are still missing. According to the state of California, property insurance claims have amounted to $3.3 billion so far, with that number expected to climb. Among the properties damaged are more than two dozen wineries in the worst-hit areas, Napa County and Sonoma County. An estimated 9,000 structures have been destroyed, leading to this billion-dollar disaster. All fires were finally contained on October 31, 2017 (Nix, 2017). This grim picture helps set the scene for a tragedy that has cost people so much and has left them with many questions.

Figure 1. Extent of major wildfire incidents

Causing more than half of the burn damage were five of the major incidents – the Atlas, Nuns, Redwood, and Tubbs fires (Figure 1), with the Tubbs fire accounting for 22 of the confirmed 44 deaths. As mentioned, Sonoma County and Napa County were sustained the most damage of any area in Northern California, with a large amount of destruction occurring in the city of Santa Rosa (Figure 2). Here, three fairly large streams – Sonoma Creek, Napa River, and Santa Rosa Creek, which all flow into the critical San Francisco Bay – are all adjacent to areas that were heavily burned.

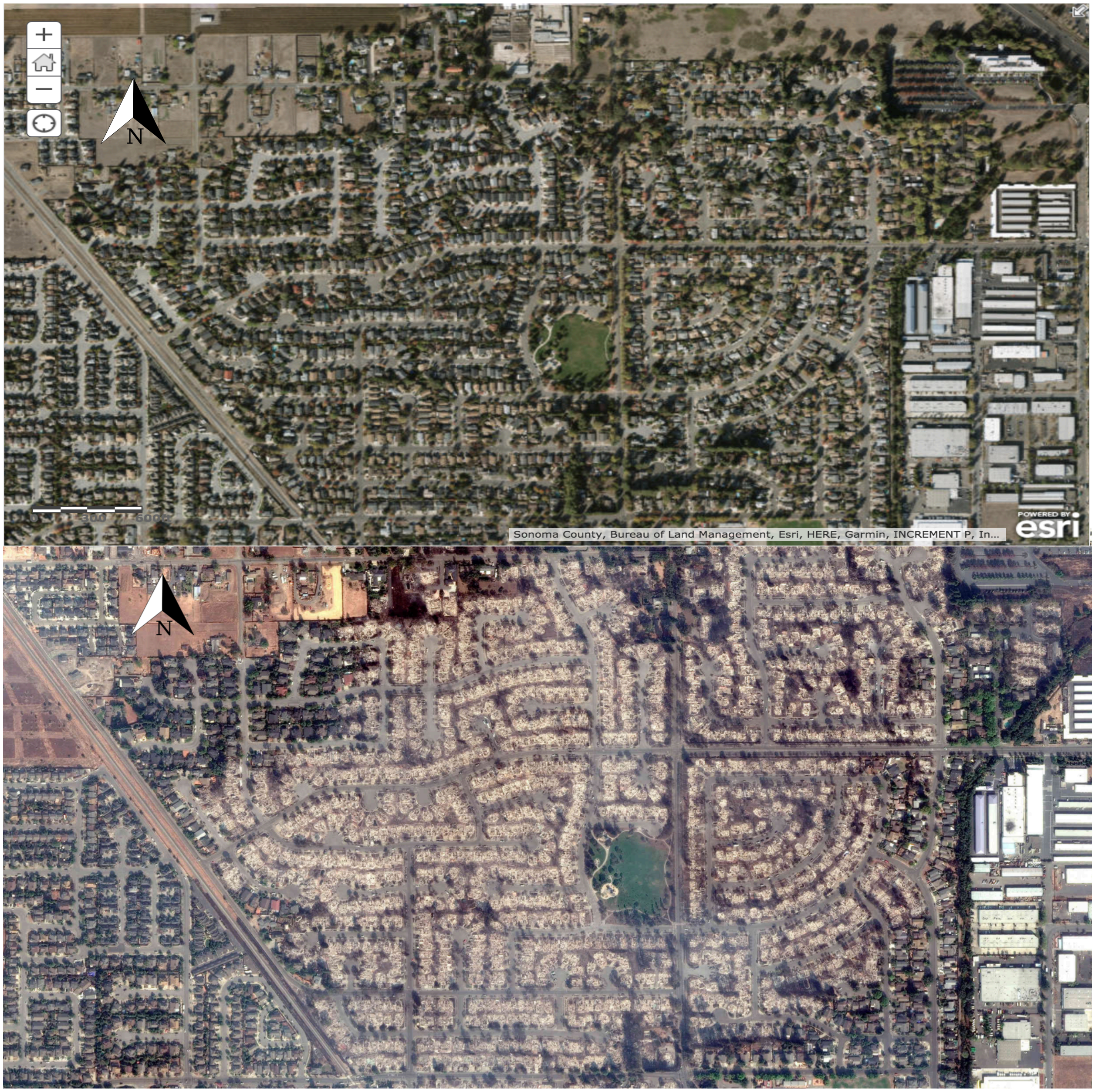

Figure 2. Before (top) and after (bottom) the Tubbs fire ravaged a northern Santa Rosa neighborhood

Fire can substantially reduce interception on land ground cover by destroying both the vegetation canopy and organic material on the soil surface. This can expose underlying soil to rain impact and subsequent erosion and runoff. The hard, smooth, water-repellent soil layer will increase runoff flow velocity. In addition, increased streamflow over a burned area will occur due to decreased transpiration losses as a result of the missing vegetation. This heightens the potential for flooding and landslides, which is a major concern for flat, open land cover after wildfires have burned (DeBano, 2009). Due to Sonoma Creek, Napa River, and Santa Rosa Creek, all being located adjacent to heavily burned areas and upstream of San Francisco Bay (Figure 3), it was decided that the Bay's water quality, too, should be analyzed. Not only is the Bay important to the region but it serves as the West Coast's largest estuary. Millions of residents and tourists and plentiful wildlife rely on San Francisco Bay for livelihood.

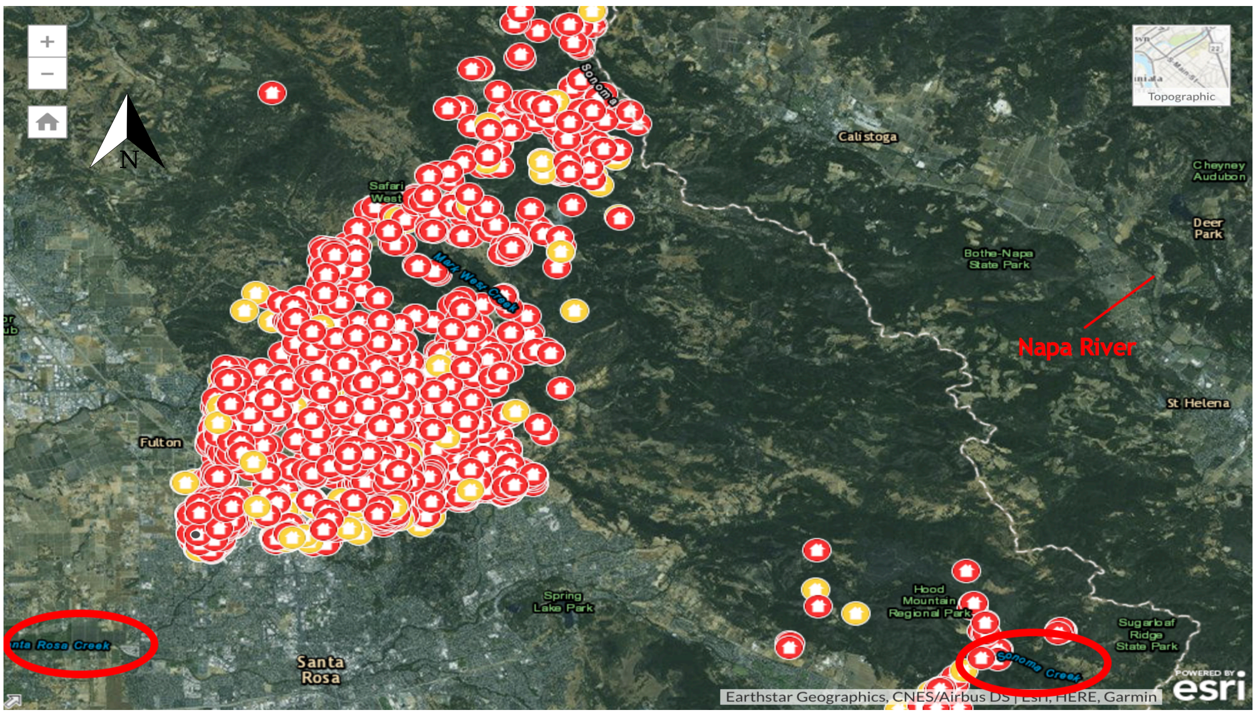

Figure 3. Proximity of wildfires to the three identified streams

This report attempts to analyze the potential effect that the October 2017 Northern California wildfires had on important bodies of water in the region to explore if data presented by USGS water gage data and analysis tools in ArcGIS Pro show an observable relationship between the fires and water quality in the area. In addition, potential for subsequent events following wildfires, such as flooding from excessive rainfall, will be looked at to further explain water quality results.

Methods

Study Area

The San Francisco Bay Hydrologic Region covers approximately 4,500 square miles and contains 28 groundwater basins, including the Napa-Sonoma Valley. The region includes all of San Francisco and large portions of Sonoma, Napa, Marin, Alameda, and Santa Clara counties, among others. Even though it is the smallest of California's ten hydrologic regions, it comprises a population of more than seven million people (Figure 4).

Source: Department of Water Resources, CWP 2013

Figure 4. Alluvial Groundwater Basins and subbasins within the San Francisco Bay Hydrologic Region

The San Pablo Bay watershed (HUC 8 ID: 18050002) was chosen as a study area because it encompasses the Napa-Sonoma Valley. The watershed covers about 1,227 square miles and contains a large chunk of the Napa River subbasin as well as the San Francisco Bay subbasin (Figure 5).

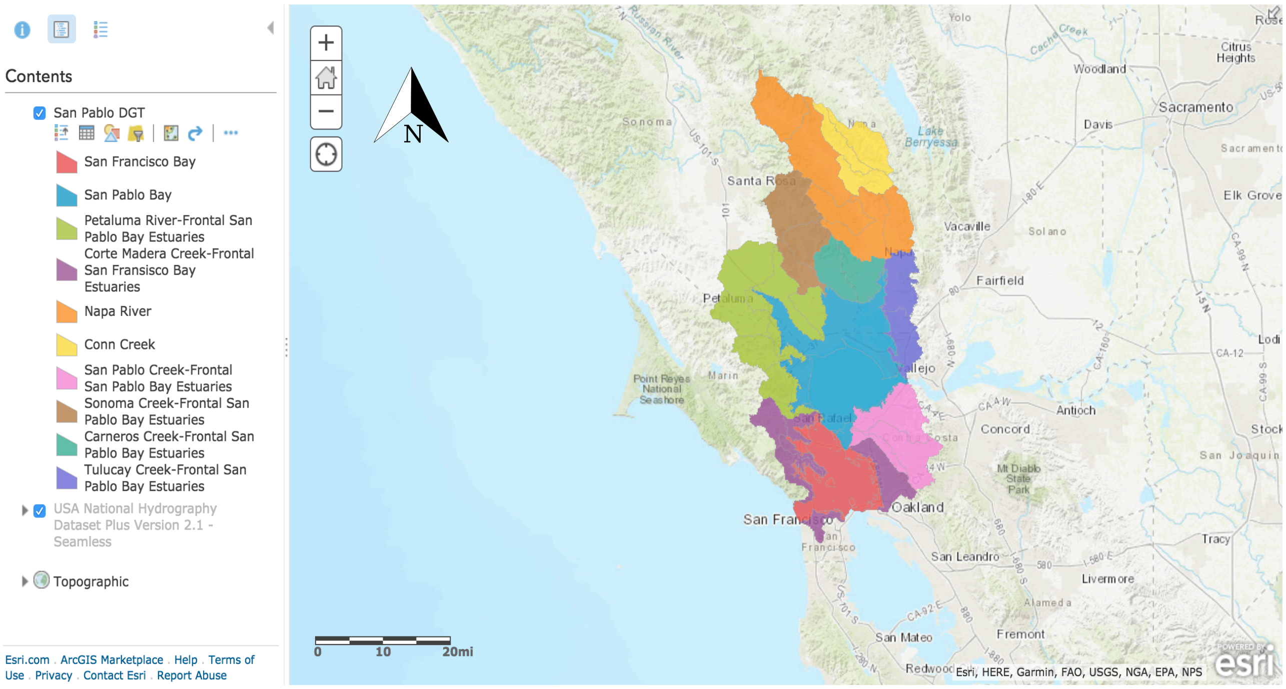

Figure 5. HUC 10 watersheds within HUC 8 San Pablo Bay subbasin

This data was obtained from the National Hydrography Dataset (NHD) Plus Version 2.1 – Seamless Layer Living Atlas within ArcGIS Online. The San Pablo Bay subbasin was chosen as a study area to be examined because it not only contains a large area of land that burned in the fires but also because it contains the three streams of interest in the vicinity. A flowline and catchment extraction using ArcGIS Online was attempted, but the request to create a raster layer to find all existing streamflows within the 18050002 HUC 8 subbasin was denied due to insufficient credits, and this issue could not be resolved before submission of the study. Therefore, to demonstrate the wildfire burn scar locations in relation to current Northern California flood risk data, a topographic map was generated using ArcGIS. The burn scar data for this map was provided by Cal Fire and converted into a spatial burn scar area for each of the three main fires. The flood risk raster layer was provided by FEMA. To provide a control for comparison, a November 2016 FEMA flood risk map for the same area, generated in ArcGIS, was analyzed to show that severe wildfire burns highly increase flood susceptibility over burnt land cover. The visualization of the stream locations and their proximity to the wildfire burn scars should give insight on the decision to examine the four specific bodies of water, with the expectation to find a correlation between an observable change in their water qualities and the October 2017 wildfires.

Soil Impacts

Before the water quality impacts of the wildfires could be examined, soil impacts were observed as a precursor to the water data. Soil impact data and maps were obtained from the Soil Agricultural Groundwater Banking Index (SAGBI) app, developed by the California Soil Resource Lab at the University of California, Davis and the University of California Division of Agriculture and Natural Resources (UC-ANR). SAGBI is a real-time suitability index for groundwater recharge on agricultural land, based on five factors that are critical to groundwater infiltration: deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. Deep percolation factor is essential to successful groundwater discharge but can be significantly reduced by wildfires, as previously penetrable soil pores can get plugged by burnt ash. Root zone residence estimates the likelihood of maintaining good drainage within the root zone shortly after water is applied. The chemical conditions factor takes characteristics, such as salinity into account because it is a threat to groundwater and soil sustainability. This is quantified using the electrical conductance of the soil, which is a measure of soil salinity. The level topography factor is ideal for water infiltration across large land areas, so SAGBI uses ranges in soil slope percentages to categorize them into five classes. The two soil properties employed to diagnose surface condition are sodium absorption ratio, used to identify soils prone to crusting, and the soil erosion factor, used to estimate potential soil susceptibility to erosion and disaggregation. Because of the comprehensive features of the SAGBI index, it was determined that for the purposes of this paper's soil impact data, SAGBI is an effective study measurement. SAGBI-generated maps were then analyzed to determine if the wildfires affected the water quality in Sonoma and Napa counties.

Precipitation

The U.S. Climate Database was consulted to obtain daily precipitation data on the Sonoma, Napa, and San Francisco areas. Rain events are needed to deposit sediment and ash from wildfire burns into susceptible water bodies, increase water turbidity, and contribute to increased streamflow. These measured data are all points that were observed in this study. From the daily precipitation data given, rainfall graphs for the month of November were generated for Napa, Sonoma, and Santa Rosa in order to provide a visual analysis of the major contributor to potential water quality and flooding impacts. November was chosen as the month to be studied because all fires were 100% contained by October 31, indicating that consequences of the wildfires most likely would not show up until at least a few days after. This data was provided to give more insight into explaining the water quality data measurements.

Water Quality

In order to obtain daily water data starting from October 1, 2017 to December 9, 2017, the USGS National Water Quality Information System was consulted. October 1 was chosen as the start date for examination because it was a week before the wildfires began. Water quality data in Sonoma and Napa counties from the week prior to the start of the fires was seen as an effective baseline to compare with water quality data from the end of October into the beginning of November. Water quality data was obtained during the desired time period for Sonoma Creek, Napa River, Santa Rosa Creek, and the northeast part of the San Francisco Bay Hydrologic Region near San Pablo Bay subbasin at the Richmond-San Rafael Bridge. The chosen data to analyze were discharge, for the three streams and the control stream, and turbidity and suspended sediment concentration, for the Bay and the control stream. These were chosen because they were the available data points taken by the USGS gages in the specified locations. According to the California Water Science Center and USGS, wildfire burns have typically resulted in increased discharge, turbidity, and suspended sediment concentrations, in bodies of water downstream from burned land. In order to provide a control to the data acquired, the same water quality data were taken from the Sacramento River since this stream is within 100 miles of the aforementioned bodies of water. This ensures that the Sacramento River experiences similar climate patterns as the others. Additionally, the Freeport area, where the Sacramento River USGS gage is positioned, was not ravaged by the wildfires in Northern California like Napa and Sonoma Counties. Therefore, it was assumed that the Sacramento did not and will not experience the observable water quality changes that the water bodies adjacent to and downstream of Napa, Sonoma, and Santa Rosa were expected to.

Results

Potential Flood Impacts

A flood risk map created in November 2016 by FEMA shows the relative risk of a 100-yer flood occurring in the area centered around Napa and Sonoma counties (Figure 6a).

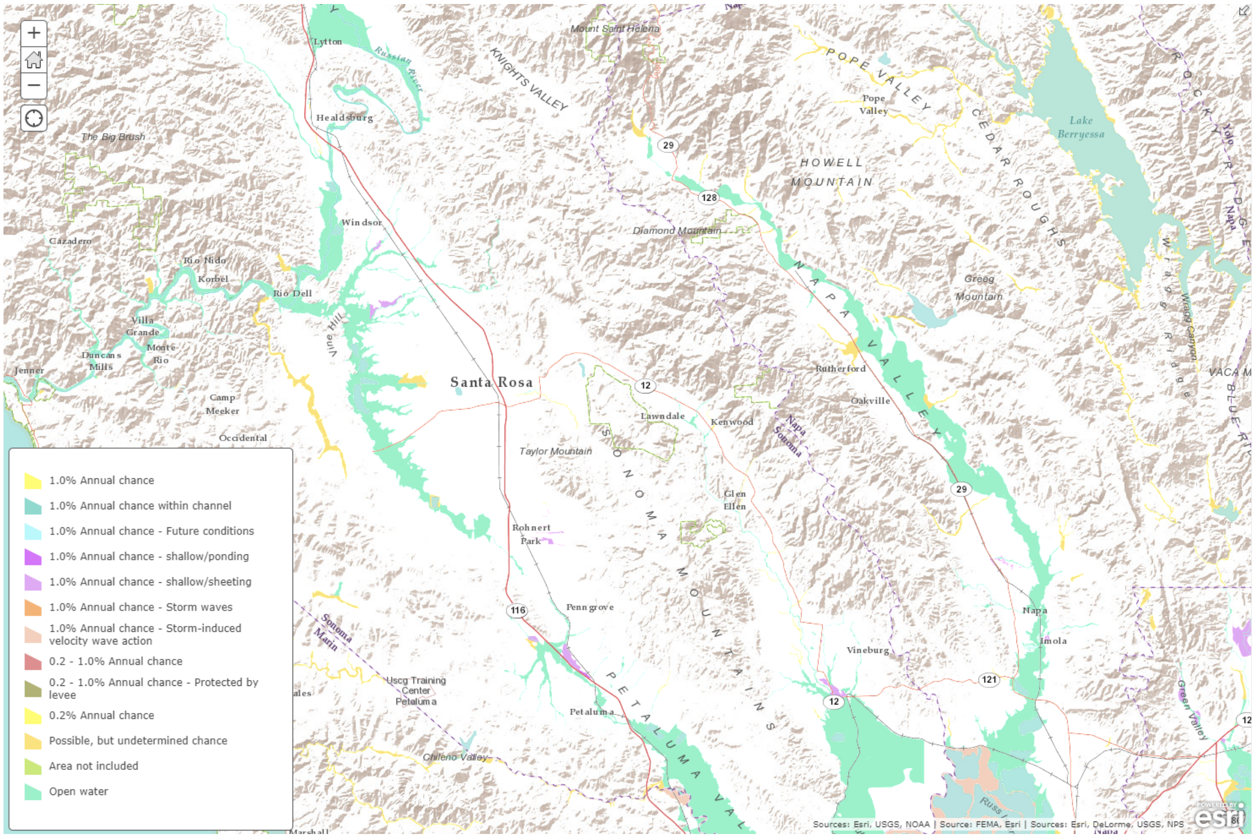

Figure 6a. Flood risk map of Napa and Sonoma counties

The relative risk of a 100-year flood occurring in November 2016 was much less compared with a December 2017, flood risk map, generated in ArcGIS (Figure 6b).

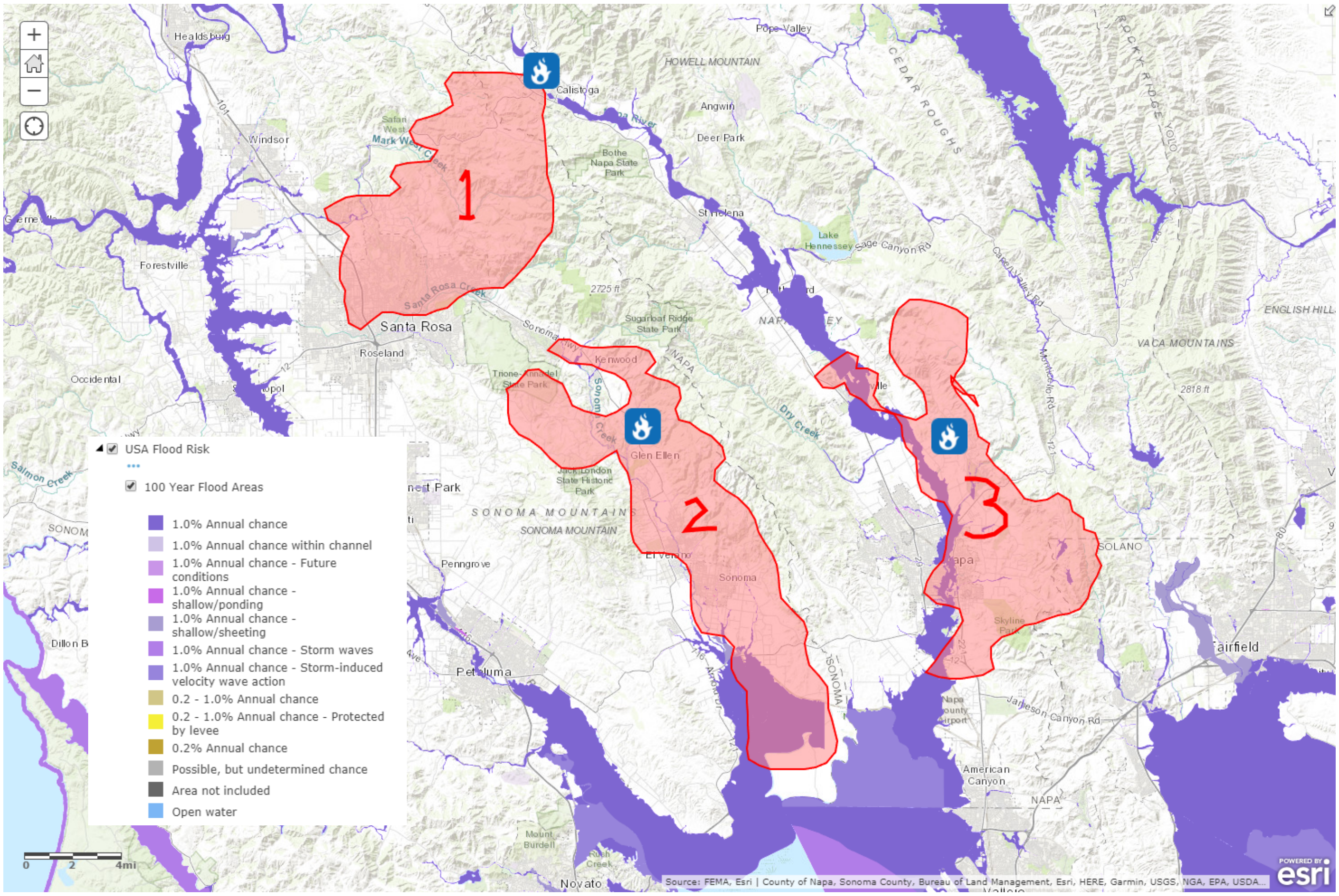

Figure 6b. Flood risk map in Napa and Sonoma counties with burn scar extent of Tubbs (1) Nuns (2), and Atlas (3) fires.

As seen in the flood risk maps, the relative risk of a 100-year flood occurring has significantly increased since November 2016. Other variables than the occurrence of the wildfires may have had an impact on why the relative flood risk increased significantly from 1.0% Annual chance within the channel over a small area of the region to 1.0 Annual chance over a much extensive area of the region. This is especially telling when comparing the approximate locations of the burn scars to the locations of the generated flood risk areas. As discussed, disastrous flooding due to creation of hard-water repellent ground cover layers after wildfires is a large risk to residents of areas impacted by wildfires. This map comparison at the very least holds some potential for wildfire burn relating to much increased flood risk over a heavily burnt area, as expected.

Soil Impact Data

A 2014 map produced by the UC-ANR was presented as baseline data (Figure 7a) and showed that the SAGBI measurement around the 2017 wildfire impact area (Santa Rosa) either rated as Poor or Very Poor.

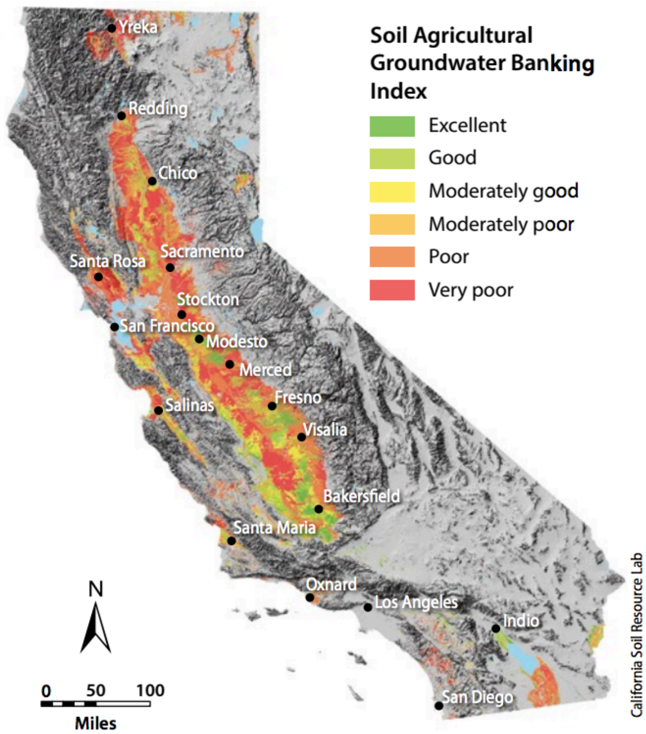

Figure 7a. Spatial extent of SAGBI suitability groups from 2014

The 2014 map and its measurements were then compared with the real-time map from December 8, 2017, generated by UC Davis and UC-ANR (Figure 7b). The figure from 2014 indicates that the soil in and around Napa and Sonoma counties had a poor SAGBI evaluation in 2014.

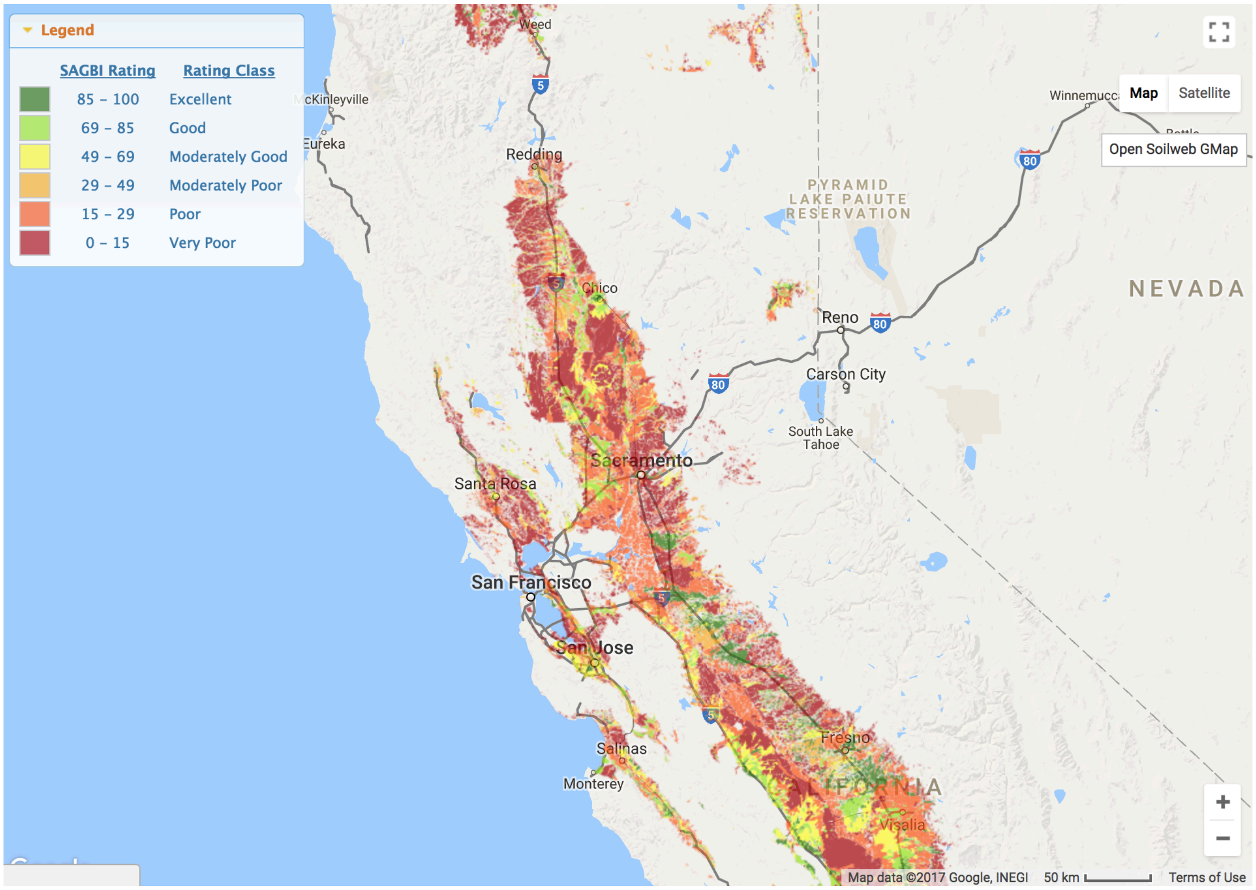

Figure 7b. Spatial map of SAGBI suitability index from Dec. 7, 2017

As seen from the 2017 map data, even after the fires, the Santa Rosa area maintains almost an identical SAGBI rating profile to what it had in 2014, before any major wildfires had hit the area. This may suggest that even before the wildfires occurred, the Napa, Sonoma, and Santa Rosa areas already had a poor soil index, resilient to agricultural groundwater banking. This does not provide insight into the impact of the fires on the soil profile in the wildfire-affected areas. Perhaps alternative soil profiling examinations should have been performed as opposed to the SAGBI method. However, the comprehensive factors that went into creating the SAGBI system were relevant to wildfire-soil impacts.

Precipitation Data

November 2017 precipitation data gathered from the U.S. Climate Database showed that at least 0.04 inches fell in Napa, San Francisco, and Sonoma, every day during the month of November (Figures 8a, 8b, 8c). Additionally, in all three areas, the precipitation totals for the month more than doubled the average monthly rainfall in the specified areas, so that information, as well as the daily rainfall trends will hold some influence, specifically when examining the stream discharge water quality data.

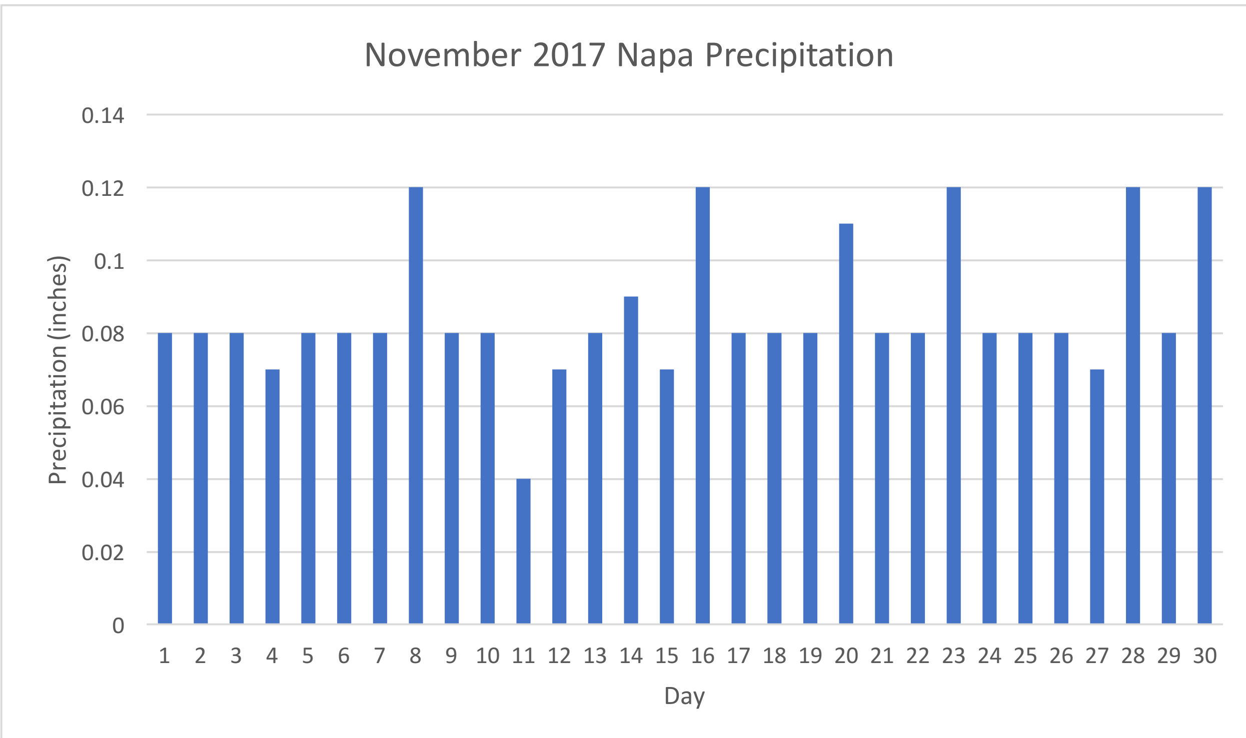

Figure 8a. Daily November 2017 precipitation data in Napa

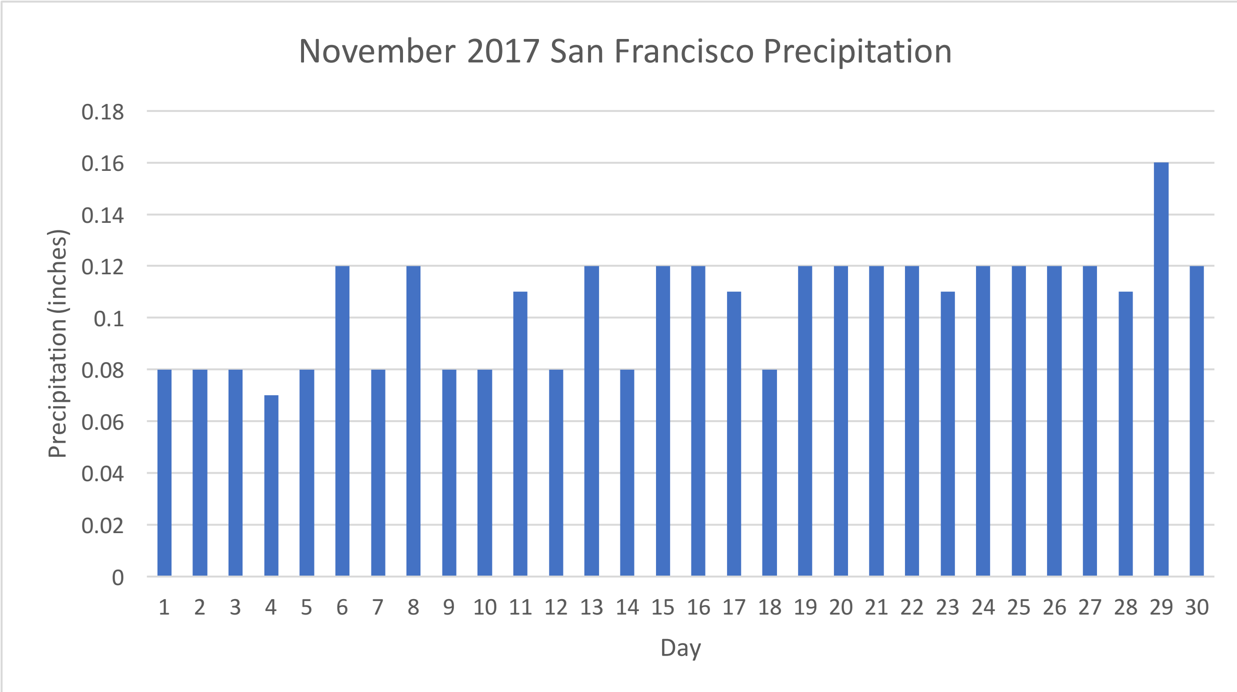

Figure 8b. Daily November 2017 precipitation data in San Francisco

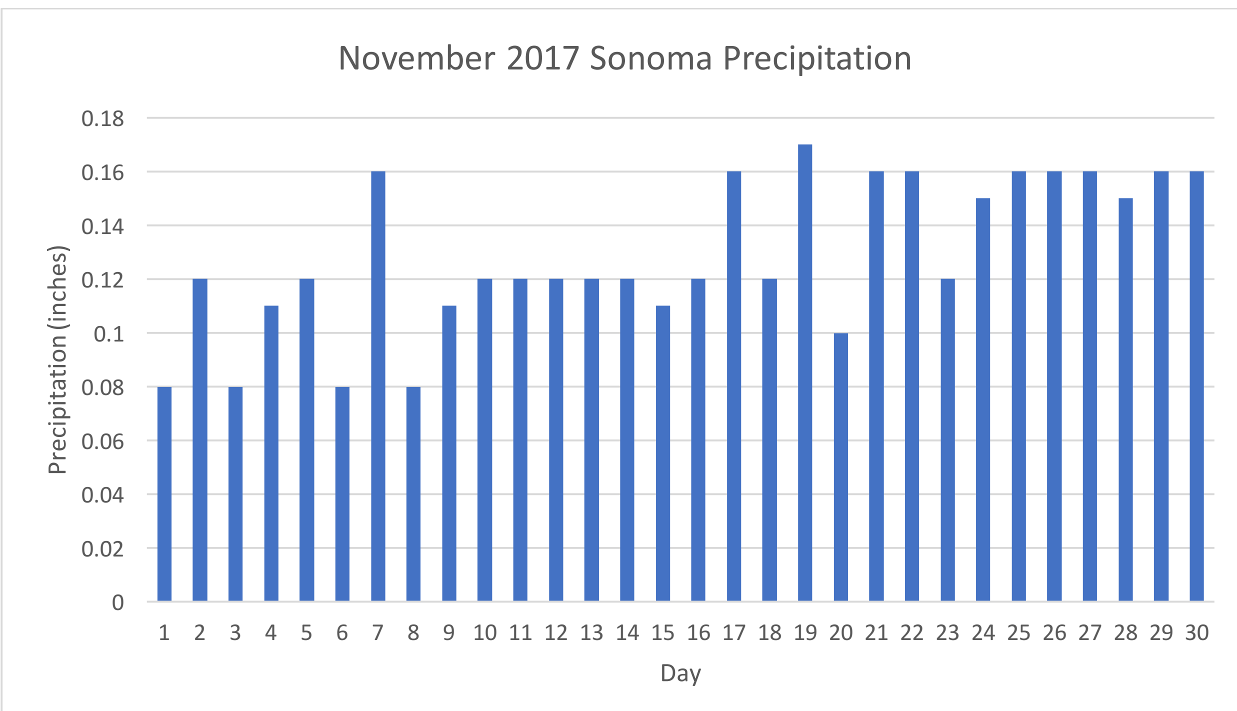

Figure 8c. Daily November 2017 precipitation data in Sonoma

According to the National Weather Service, generally half an inch of rainfall within a 60-minute time period will cause flash flooding in a burn area, but this can also depend on terrain characteristics. However, the November rainfall data indicates that the precipitation in the three areas did not even exceed 0.17 inches in a 24-hour period. Therefore, there were no flood events in the area. The figures do indicate that there was precipitation during every 24-hour period throughout the month, but none of these instances were large enough to produce large-scale erosion or sediment deposition. If anything, this data indicates that it could affect the discharge data in each stream analyzed because however small, the precipitation aggregate exceeded the November monthly average by significant amounts.

Water Quality Data

Water Quality data for the Sacramento River was used as a control in this study. Therefore, for two of the three aforementioned measures, discharge and turbidity, the Sacramento River's data was considered. Daily pH was not considered for any other bodies of water than the Sacramento River in this study, but it was included as a figure to show that the water quality in the Sacramento River remained relatively stable during the examined time period, as the pH remains relatively stable (Figure 9).

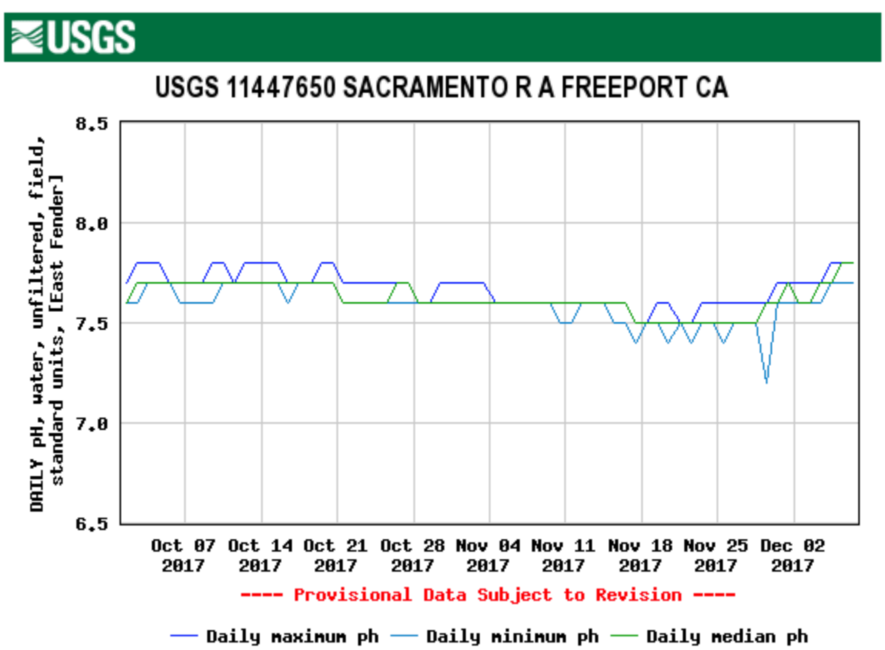

Figure 9. Daily pH readings in Sacramento River from Oct. 1 to Dec. 9

Discharge

The daily stream discharge measurements for the surveyed streams Sacramento River, Napa River Santa Rosa Creek, and Sonoma Creek, are presented below (Figures 10a, 10b, 10c, 10d).

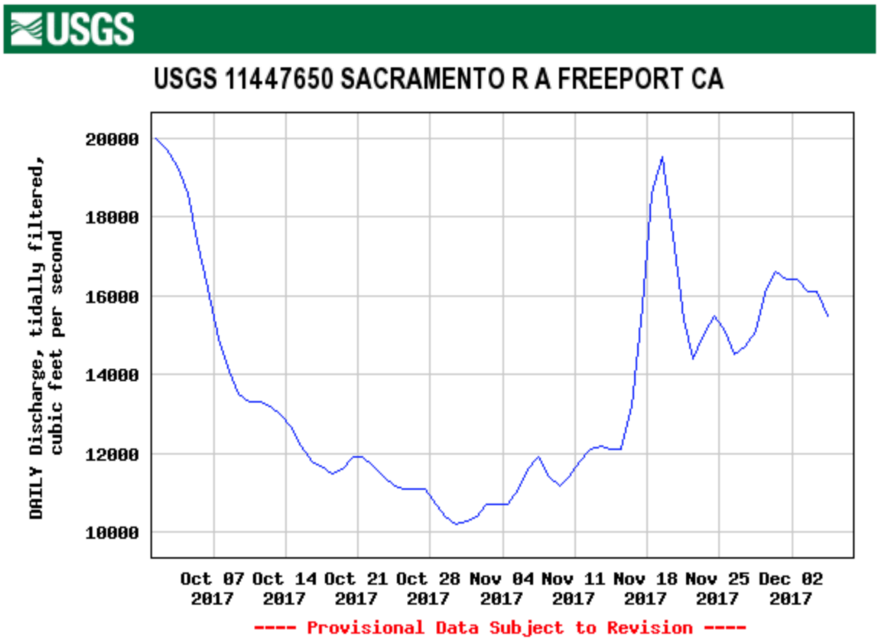

Figure 10a. Daily Discharge measurements in Sacramento River from Oct. 1 to Dec. 9

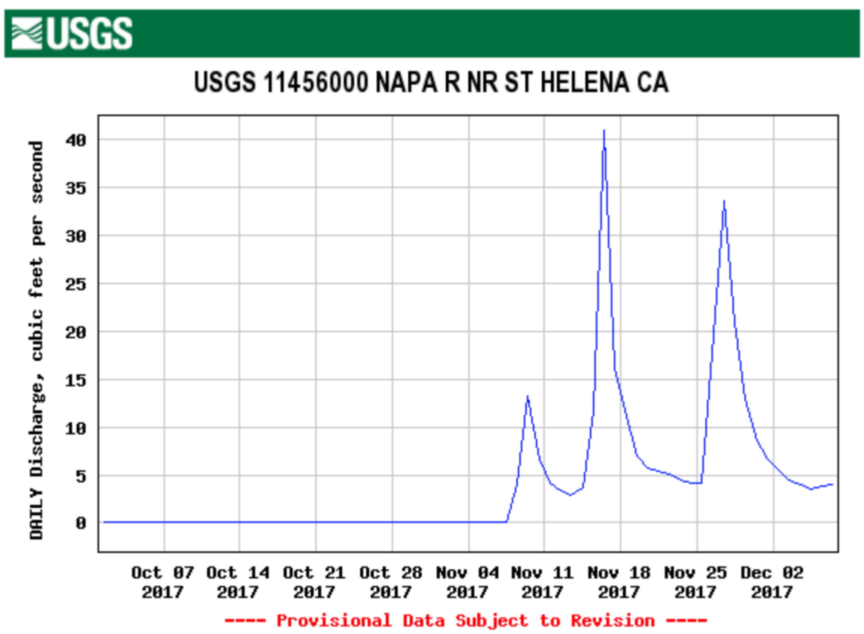

Figure 10b. Daily Discharge measurements in Napa River from Oct. 1 to Dec. 9

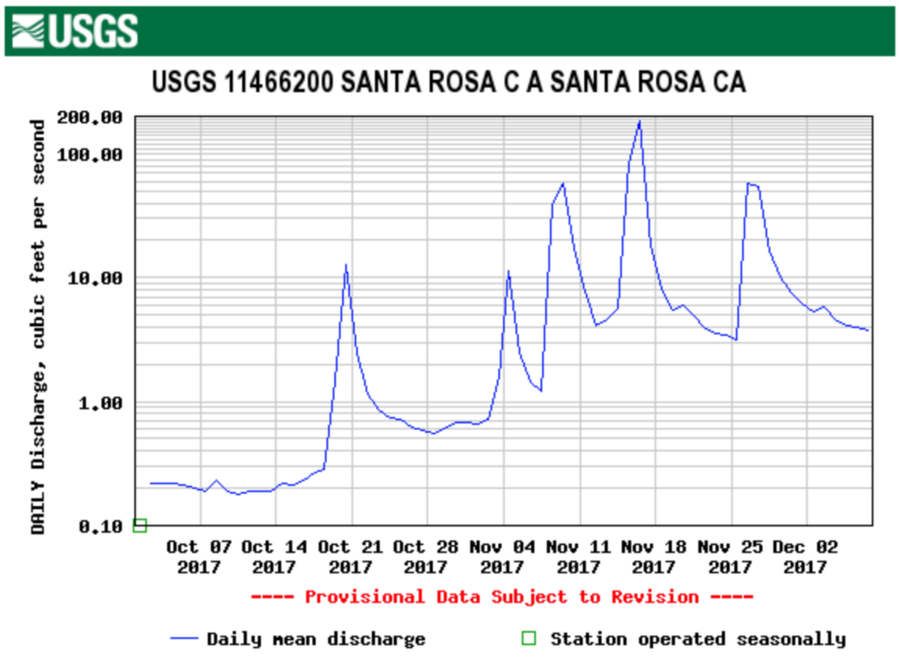

Figure 10c. Daily Discharge measurements in Santa Rosa Creek from Oct. 1 to Dec. 9

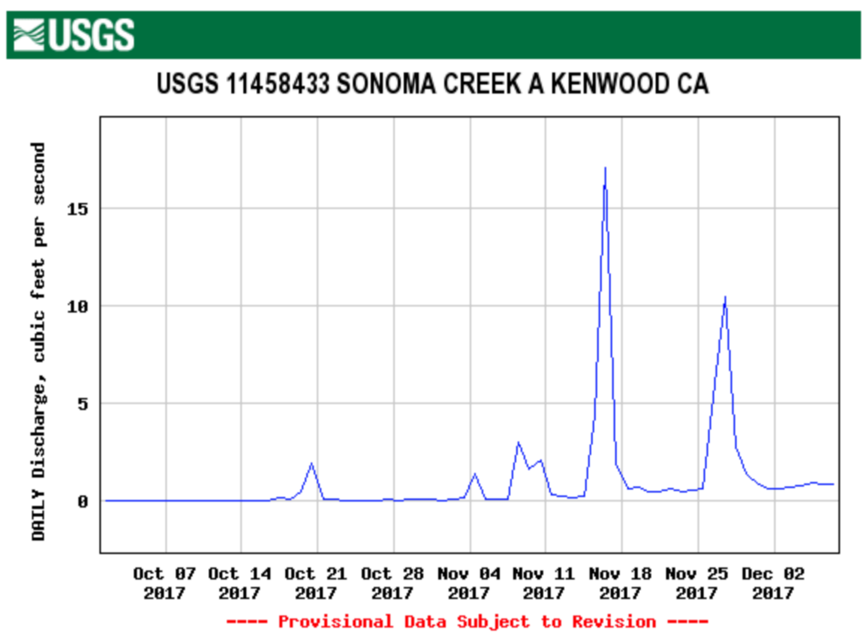

Figure 10d. Daily Discharge measurements in Sonoma Creek from Oct. 1 to Dec. 9

The daily discharge in the Sacramento River compared to the other three streams shows a similar pattern in that it shows a significant spike during mid-November. This indicates that the constant precipitation that has been occurring across Northern California, including in Sacramento, may have some influence on these numbers. However, the charts also show that the magnitudes with which the daily discharges increase in the Napa River, Santa Rosa Creek and Sonoma Creek, are all greater than the magnitude increase experienced in the Sacramento River spikes. Additionally, the large discharge increase that the Sacramento River experiences in mid-November is the only major spike that the stream felt throughout November. The other three streams feel another very large discharge spike after the initial one in mid-November, indicating that another factor than the aggregate precipitation could be in play to generate these results. More time and datapoints are needed to make a more confident judgment as to whether or not these increases can be further studied as potential consequences of wildfire burn.

Turbidity

The daily turbidity measurements for the Sacramento River and the San Francisco Bay, near the San Pablo subbasin, are presented below (Figures 11a, 11b).

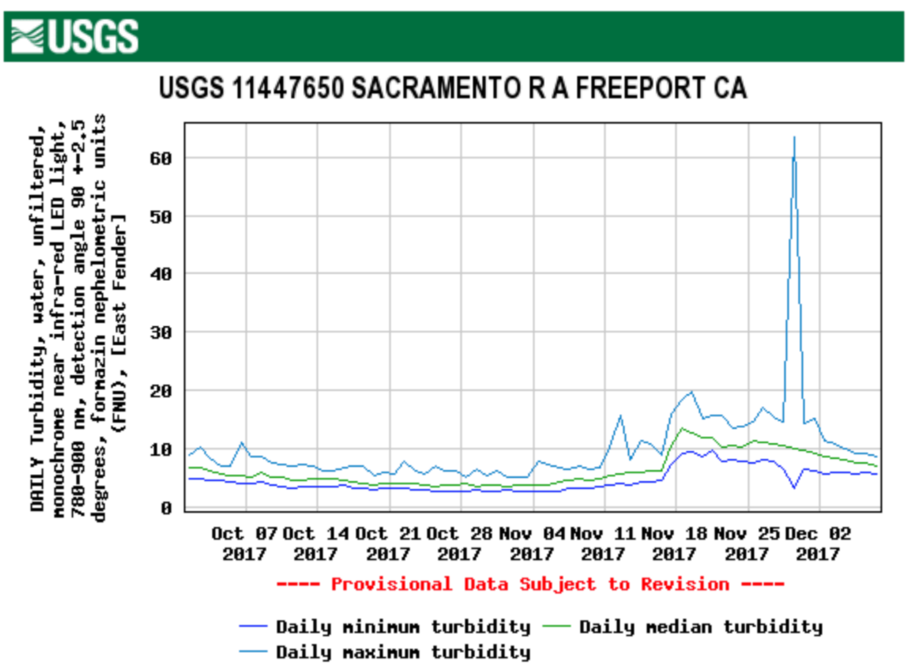

Figure 11a. Daily Turbidity measurements in Sacramento River from Oct. 1 to Dec. 9

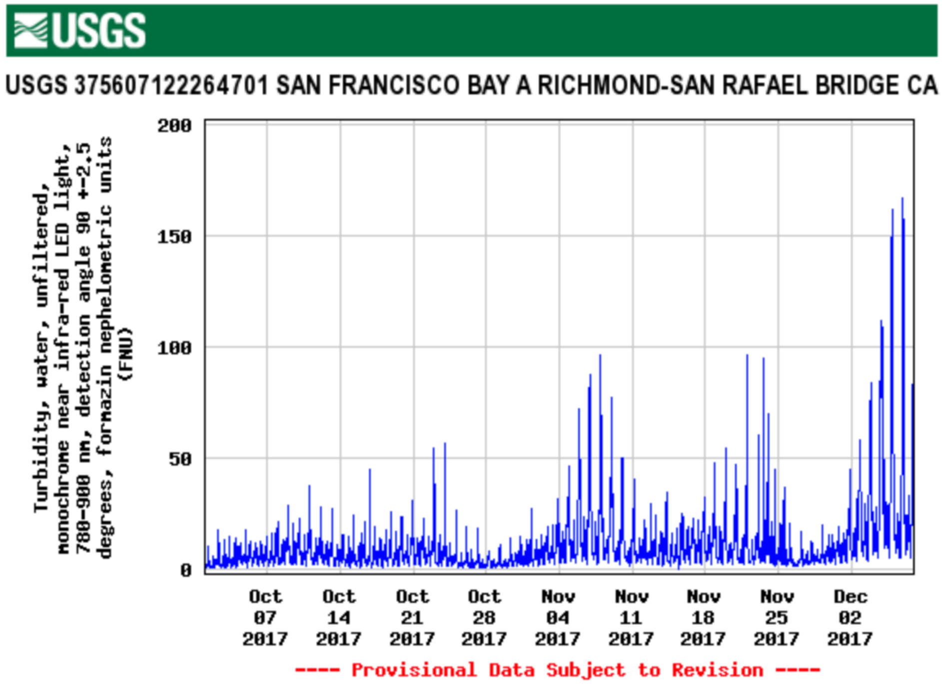

Figure 11b. Daily Turbidity measurements in San Francisco Bay from Oct. 1 to Dec. 9

The stream gages in the Sacramento River show slight, noticeable increases in daily turbidity beginning in mid-November, in addition to a very large spike at the end of November, while the daily discharge shows a major spike at the beginning of November, in addition to a positive trend in spikes through December so far. While the aggregate rainfall in November in both areas most likely is a contributing factor to the increased cloudiness and particle numbers in the water, the differentiating spikes that occur in the San Francisco Bay could be a result of upstream flow into the Bay depositing particles into the estuary and impacting the water quality. Again, more data points over a more sustained period of time would need to be collected to confirm, with greater confidence, that the wildfires are acting forces contributing to these results.

Suspended Sediment Concentration

The suspended sediment concentrations for the Sacramento River and the San Francisco Bay, near the San Pablo subbasin, are presented below (Figure 12).

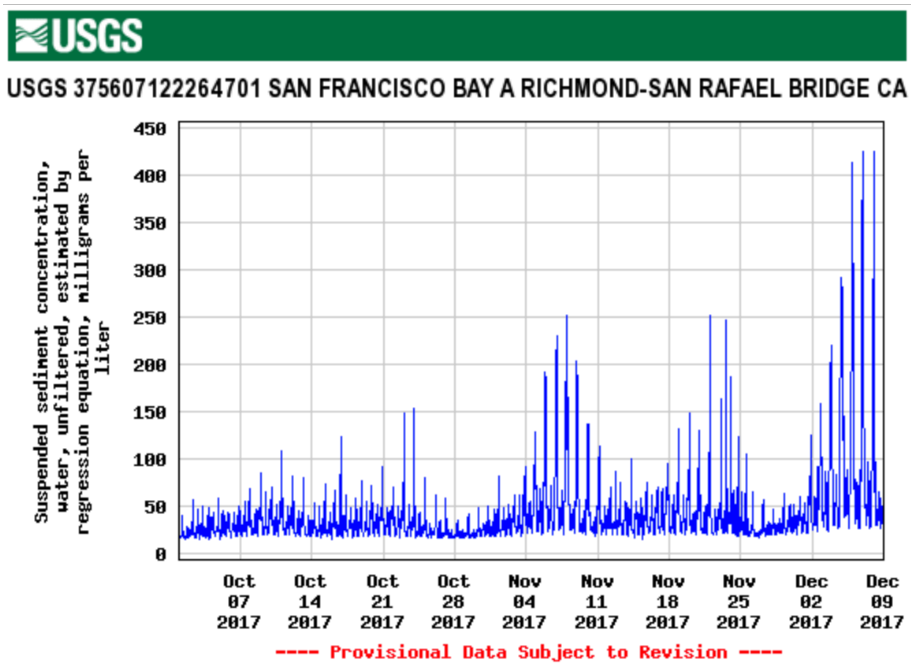

Figure 12. Suspended sediment concentration in San Francisco Bay from Oct. 1 to Dec. 9

The decision to examine suspended sediment concentration data was made for the same reason that turbidity was chosen as a datapoint to study. The suspended sediment concentration is a very telling statistic of water quality after wildfires. Like turbidity, sediment concentrations in water downstream of burned land generally increases significantly from wildfire burn influences. However, the USGS gages only had this data available for San Francisco Bay near the San Pablo subbasin. Even though the Bay was the only water body that had this data available, it still proved somewhat important, since it showed almost an identical pattern as that of the turbidity graphs for the experimentally-examined bodies of water. This gives a similar conclusion as that reached after the turbidity data were assessed – it is possible that the wildfires could be contributing to the increased suspended sediment concentration in a Bay located directly downstream of the burned land, but this cannot be confidently confirmed with only the given USGS water quality data.

Discussion and Conclusion

The results of this study were not contrary to typical findings surrounding the subject of the impact wildfires have on water quality. However, the results did not provide any definitive conclusions that could be drawn based on the stream gage data provided by the USGS. Therefore, at the least, the information presented could provide a basis upon which to build a more technical study with access to better technology for measuring water quality data and access to samples of the water being examined.

When it comes to the soil layer data that was taken using the SAGBI system created by UC Davis and UC-ANR, the generated maps did not necessarily provide proof that the burned landscape's soil was impacted by the wildfire burns, according to factors, such as deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. Had statistics measuring each of these influences, or the information that was used to generate the 2014 and 2017 SAGBI maps of the Northern California area of interest, been presented, then they could have potentially been used to provide more clear-cut data indicating that the soil had been affected. However, this was too concerning considering the primary results of the study did not rest on the presentation of statistical evidence proving that the soil layer had been impacted. It can commonly be assumed that fires as severe as those that burned the Napa-Sonoma Valley had a very substantial impact on the health of burned land's soil.

The water sequestration and presentation of the water quality data presented the most challenging aspect of the study. For one, the USGS water quality database has a limited number of gages in limited locations, and not all locations are going to have the same water quality parameters being studied as other locations. Therefore, I could not present the same datapoints across all chosen locations in the study. This threw off the consistency and experimental integrity of the study. Perhaps the biggest issue with the way the study was constructed is the accuracy of the results shown. When analyzing the results of the USGS gage data, there was no known way to separate potential confounding variables so that it could be confidently said that the water quality effects were or were not a result of the October 2017 wildfires. For example, when looking at the sharp increases in discharge, turbidity, and suspended sediment concentration, there was no way to tell whether or not the results presented were because of the precipitation in the area, the wildfire repercussions, as thought, or whether they were due to some other confounding variables. Perhaps gathering water samples in person and analyzing the chemical composition of these samples, specifically targeting products like ash, nitrates, phosphorus, or manganese, would have been more effective in determining that products of the wildfires were exerting a tangible effect on the water quality. Simply using the data provided by the USGS gages was insufficient, and another method of gathering water quality data would need to be examined when looking at wildfire-water quality impacts.

According to Southwest Hydrology, effects of wildfires felt by water bodies may take several months to manifest in water quality data. Therefore, an extension of this study, perhaps combined with some of the suggestions presented in this discussion, would make for a more accurate and comprehensive report with more impactful findings.

Lastly, several erroneous assumptions may have been made within the structure of this study. One example is the assumption that the Sacramento River was a good control to use for comparing the other streams. This assumption was based on the fact that the Sacramento area experiences very similar climatic patterns that the Napa-Sonoma Valley does as well as the fact that the Sacramento River was not affected by the much smaller fires that burned upstream. The Sacramento River is one of the longest rivers in Northern California, so the gage that was chosen to gather data from could have been at a location where many confounding variables influenced its water quality results. Now, these assumptions were made with logical reasoning based on previous literature and knowledge of wildfire and water quality patterns, but they were not able to be confirmed quantitatively. Another large assumption was that the consistent precipitation led to what was seen in the water quality graphs and that any deviance between the control, the Sacramento River, and the four experimental bodies of water was due to wildfire impacts. While the assumption of significant, deviant water quality results being attributable to the wildfires was not assumed, per se, it was mentioned as a possibility, but the study is missing the proof to confirm or deny this claim.

The ambitious nature of this study was rooted in attempting to tackle a complicated issue. Predicting causation of one natural occurrence as a result of another is very tough to, especially when limited by data access and inexperience using ArcGIS, which no doubt could have been employed to a fuller extent had more experience with the software been had previously. Nevertheless, much found in this study can be applied to future work and a lot was learned by way of researching the subjects involved and a trial-and-error approach to the procedures involved. Should a way to effectively study this subject be demonstrated, the work that results has the potential to prevent serious health effects that could result from contaminated water and save water resources as well as wildlife that relies on these impacted bodies of water.

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