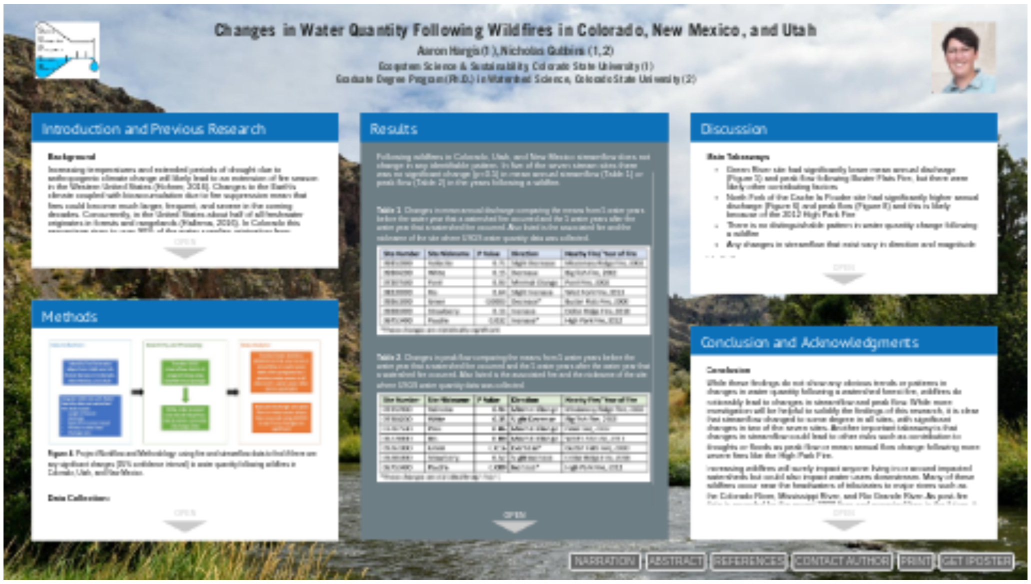
Changes in Water Quantity Following Wildfires in Colorado, New Mexico, and Utah



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PRESENTED AT:

COLORADO STATE UNIVERSITY | CURC 2021 CELEBRATE UNDERGRADUATE RESEARCH AND CREATIVITY

INTRODUCTION AND PREVIOUS RESEARCH

Background

Increasing temperatures and extended periods of drought due to anthropogenic climate change will likely lead to an extension of fire season in the Western United States (Hohner, 2016). Changes to the Earth's climate coupled with bioaccumulation due to fire suppression mean that fires could become much larger, frequent, and severe in the coming decades. Concurrently, in the United States about half of all freshwater originates in forests and rangelands (Hallema, 2016). In Colorado this percentage rises to over 90% of the water supplies originating from forested watersheds (Rhoades et al, 2011). This raises the importance of understanding what an increase in wildfires could mean for watersheds and how water quantity might be affected.

Everyone is dependent on water, so this study impacts anyone from farmers and hydropower companies to municipal and industrial water users. With demand for water increasing as populations grow, being able to predict how the water supply may change in the months and years following a wildfire disturbance is key to managing water resources. This study uses existing fire and streamflow data to find any significant differences in water quantity following wildfires and could be used to help manage water in areas that depend on water from an area that has been burnt.

Previous Research

- Generally, more severe fires show increases in stramflow in the years immediately following a fire
  - Hydrophobic ash layer can lead to reduction in infiltration and an increase in runoff during subsequent precipitation events (Hallema, 2016).
  - The burning of the canopy often leads to a decline in photosynthetic processes that cause evapotranspiration as well as an increase in precipitation that reaches the surface (Hallema 2016).
  - Where the canopy has been burned more snow may reach the ground but will be melted away faster with the lack of shade that forests typically provide (Bladon, 2014).
- Previous Studies on fire impacts on water yields are disjointed and based on just a handful of experimental watersheds (Hallema, 2016).
- Fires are often too unpredictable and variable to allow for accurate predictions of how water supplies will be affected before a fire occurs.

This Study

- Focuses on fires and watersheds in Colorado, Utah, and New Mexico (Figure 1)
- Seeks to identify patterns or trends in water quantity change following wildfires in recent decades
- All data used is publicly available through USGS
- Looks at 7 different stream sites, 2 of which had significant changes in streamflow following their respective fires (Figures 2 and 3)
- Studying disturbance ecology and hydrology may help scientists and water managers to better understand

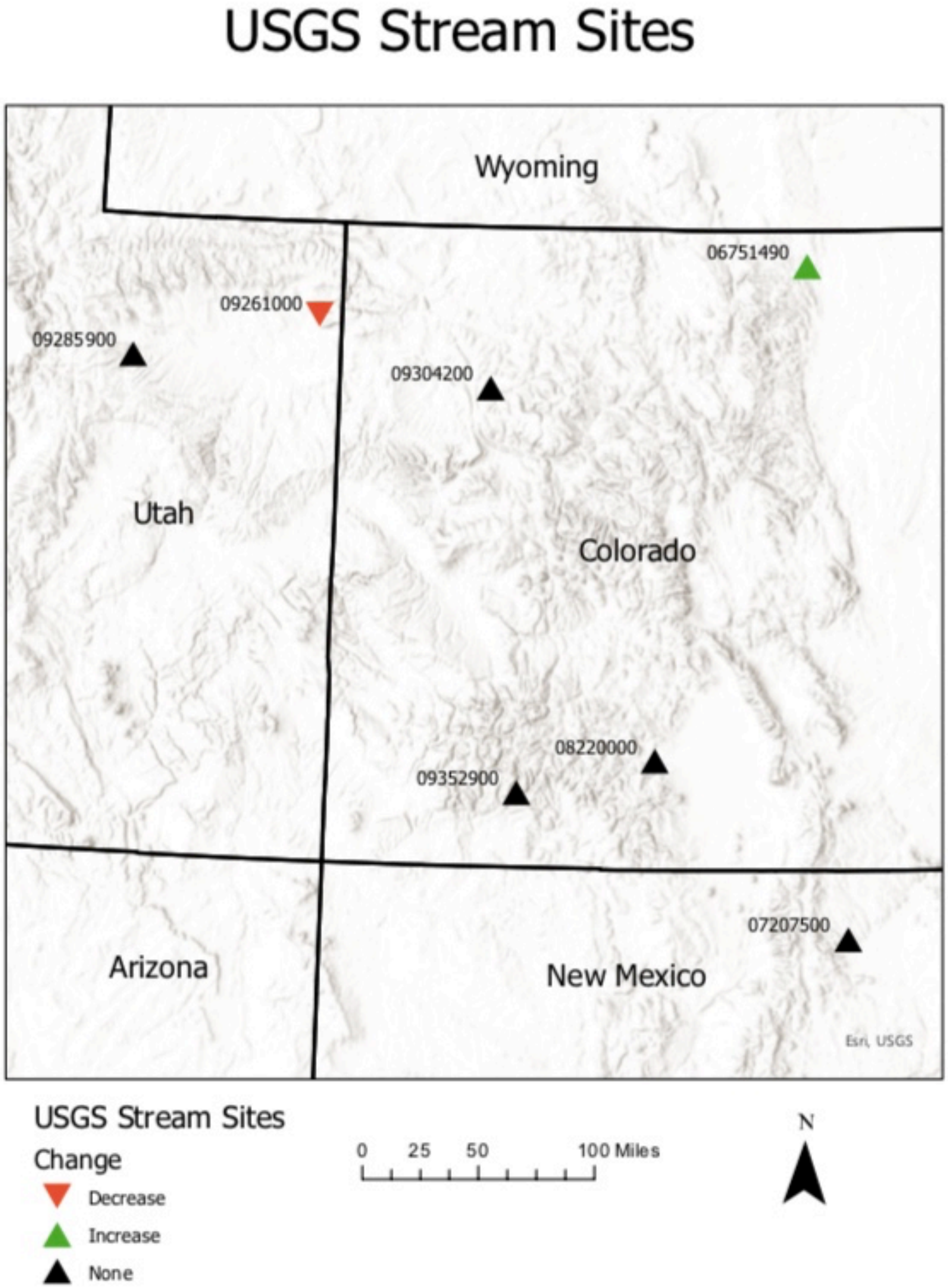

Figure 1. Map showing the seven USGS stream sites across Utah, Colorado, and New Mexico that were used in this data analysis. Each site is labelled by its site number and the color of the triangle determines whether or not that site had a significant increase or decrease in mean annual streamflow.

Research Questions and Hypotheses:

Increased fires in watersheds in the Western United States leads to several important questions. Following wildfires in Colorado, Utah, and New Mexico from 2000-2018, which direction does water quantity move and what is the magnitude of the change? How does that change vary over time following the fire? By utilizing long-term USGS data we are able to explore the answers to these questions as they relate to several watersheds in Colorado, Utah, and New Mexico.

Expected Outcome/ Hypothesis:

There will be a significant change to streamflow and peak flow in watersheds after a wildfire occurs which will depend on size, severity, and location of the associated wildfire.

Null Hypothesis:

There will be no significant changes to streamflow or peak flow in watersheds after a wildfire occurs.

Figure 2. Photo from USGS site 09261000 Green River Near Jensen, UT. This River has a drainage area of 29,660 square miles and is a tributary to the Colorado River which historically emptied into the Sea of Cortez (U.S. Geological Survey, 2021).

Figure 3. Photo from USGS site 06751490 North Fork Cache La Poudre at Livermore, CO. This River has a drainage area of 538 square miles and is a tributary to the Platte River which empties into the Missouri River which empties into the Mississippi River and eventually makes its way into the Gulf of Mexico (U.S. Geological Survey, 2021).

METHODS

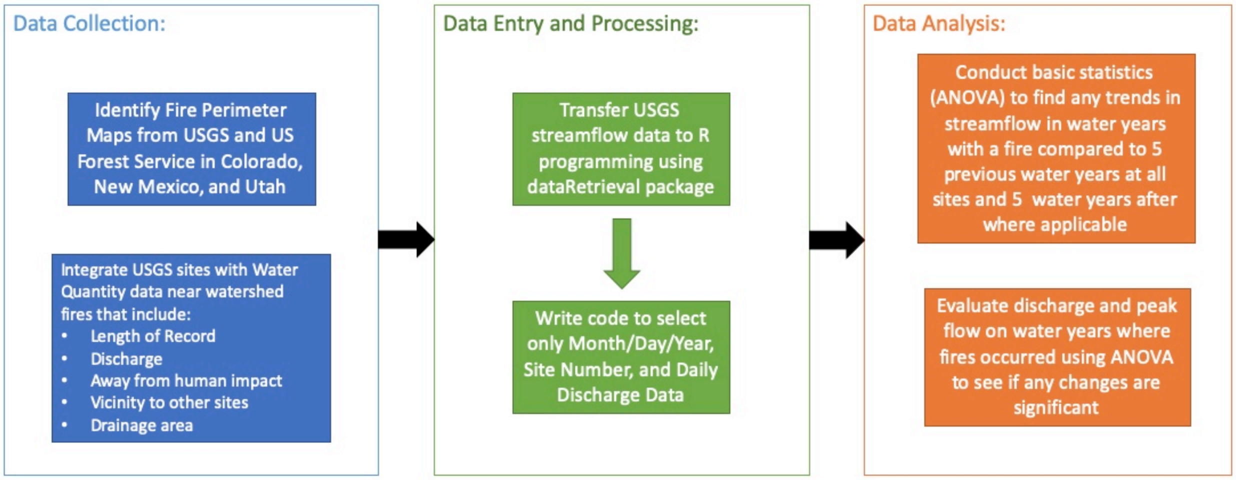

Figure 4. Project Workflow and Methodology: using fire and streamflow data to find if there are any significant changes (95% confidence interval) to water quantity following wildfires in Colorado, Utah, and New Mexico.

Data Collection:

The data collection phase consisted of two primary tasks (Figure 4). I first found major fires near water features and noted the total area burnt. Perimeter maps and other information on the fires were found using USGS (U.S. Geological Survey, 2021) and USFS (U.S. Forest Service, 2021) public information. I then found potential USGS stream sites in or downstream from burnt areas using the USGS mapper (https://maps.waterdata.usgs.gov/mapper/index.html). I only selected sites that were in or around Colorado, and I made sure they included daily water quantity data for at least 5 years before the associated fire. I also noted the drainage area and checked to make sure they were far away from reservoirs or other infrastructure that could impact streamflow.

Data Entry and Processing:

With help from Nicholas Gubbins, data collected was imported into R using the dataRetrieval package (Figure 4). The variables I selected were month/day/year, Site Number, and Daily Discharge. From these 3 variables I was able to see where the data was collected, when it was collected, and how high the discharge was in cubic feet per second. Initially I had over 20 potential sites, all but 7 were discarded due to issues such as missing data or lack of approved data in the years after the fire. I also changed the date from year to water year starting in October

Data Analysis:

The data analysis phase consisted of categorizing data into mean annual discharge for 5 water years before and 5 water years after a fire occurred in each site. I repeated these steps using max peak flow for each site. With help from my mentor I used a paired ANOVA in R to identify if there were any trends in changes to streamflow between pre and post fire using a 95% confidence interval. I did this for both mean annual discharge and peak flow for each site. The ANOVA showed if there were any changes in water quantity before and after a fire, and whether or not any changes were significant. I then created graphs and tables to show any signficant changes visually.

RESULTS

Following wildfires in Colorado, Utah, and New Mexico streamflow does not change in any identifiable pattern. In five of the seven stream sites there was no significant change ($p<0.5$) in mean annual streamflow (Table 1) or peak flow (Table 2) in the years following a wildfire.

Table 1. Changes in mean annual discharge comparing the means from 5 water years before the water year that a watershed fire occurred and the 5 water years after the water year that a watershed fire occurred. Also listed is the associated fire and the nickname of the site where USGS water quantity data was collected.

Site Number	Site Nickname	P Value	Direction	Nearby Fire/ Year of Fire
09352900	Vallecito	0.71	Slight Decrease	Missionary Ridge Fire, 2002
09304200	White	0.15	Decrease	Big Fish Fire, 2002
07207500	Ponil	0.93	Minimal Change	Ponil Fire, 2002
08220000	Rio	0.64	Slight Increase	West Fork Fire, 2013
09261000	Green	0.0003	Decrease*	Buster Flats Fire, 2000
09285900	Strawberry	0.15	Increase	Dollar Ridge Fire, 2018
06751490	Poudre	0.032	Increase*	High Park Fire, 2012

*These changes are statistically significant

Table 2. Changes in peak flow comparing the means from 5 water years before the water year that a watershed fire occurred and the 5 water years after the water year that a watershed fire occurred. Also listed is the associated fire and the nickname of the site where USGS water quantity data was collected.

Site Number	Site Nickname	P Value	Direction	Nearby Fire/ Year of Fire
09352900	Vallecito	0.94	Minimal Change	Missionary Ridge Fire, 2002
09304200	White	0.35	Slight Decrease	Big Fish Fire, 2002
07207500	Ponil	0.86	Minimal Change	Ponil Fire, 2002
08220000	Rio	0.80	Minimal Change	West Fork Fire, 2013
09261000	Green	0.016	Decrease*	Buster Flats Fire, 2000
09285900	Strawberry	0.52	Slight increase	Dollar Ridge Fire, 2018
06751490	Poudre	0.009	Increase*	High Park Fire, 2012

*These changes are statistically significant

The Green River site downstream from Dinosaur National Park near the Utah/Colorado border showed a significant decrease in streamflow in the five years following the 2000 Buster Flats Fire compared to the five years before (Figure 5). The North Fork of the Cache la Poudre River site near Livermore, Colorado showed a significant increase in mean streamflow in the five years following the 2012 High Park Fire (Figure 6), as well as a significant increase in peak flow (Figure 8).

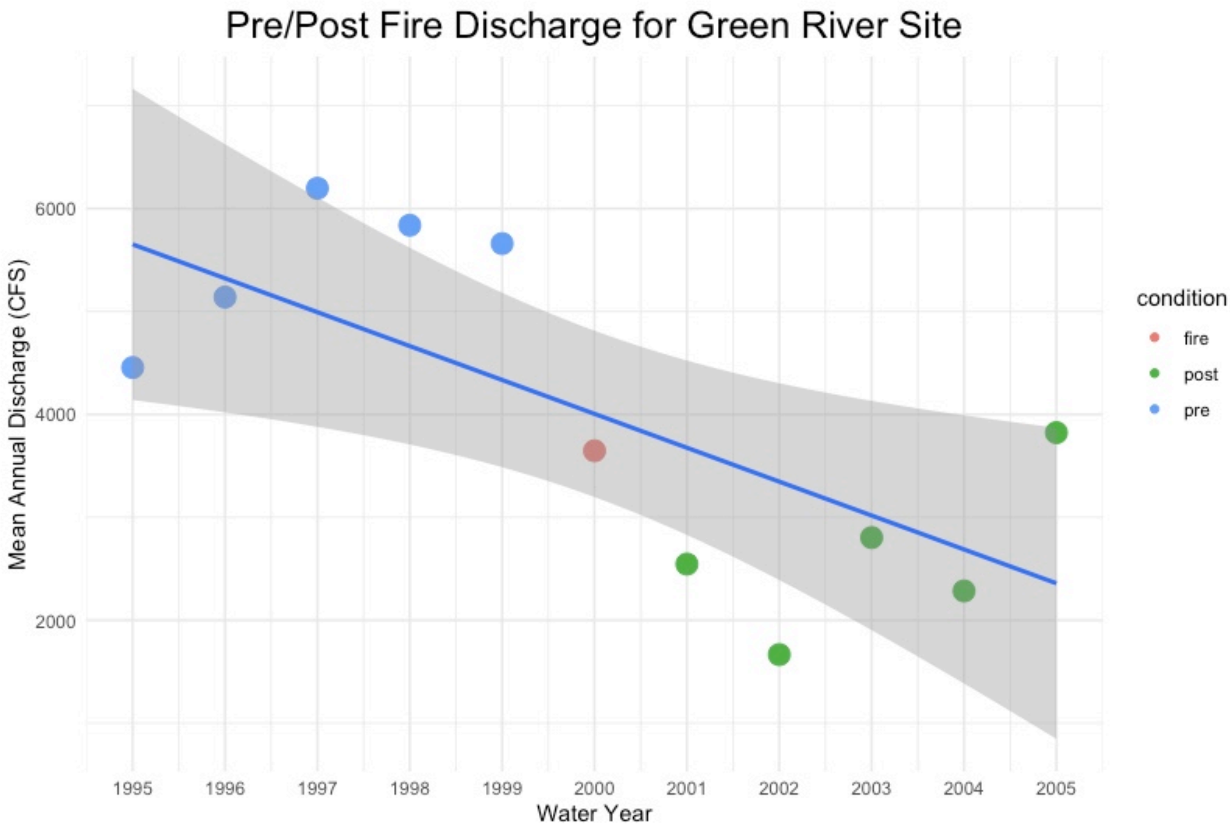

Figure 5. Mean annual discharge for Green River 5 water years before and 5 water years after the Buster Flats Fire in 2000. This USGS stream site is located on the Green River near Jenson, UT.

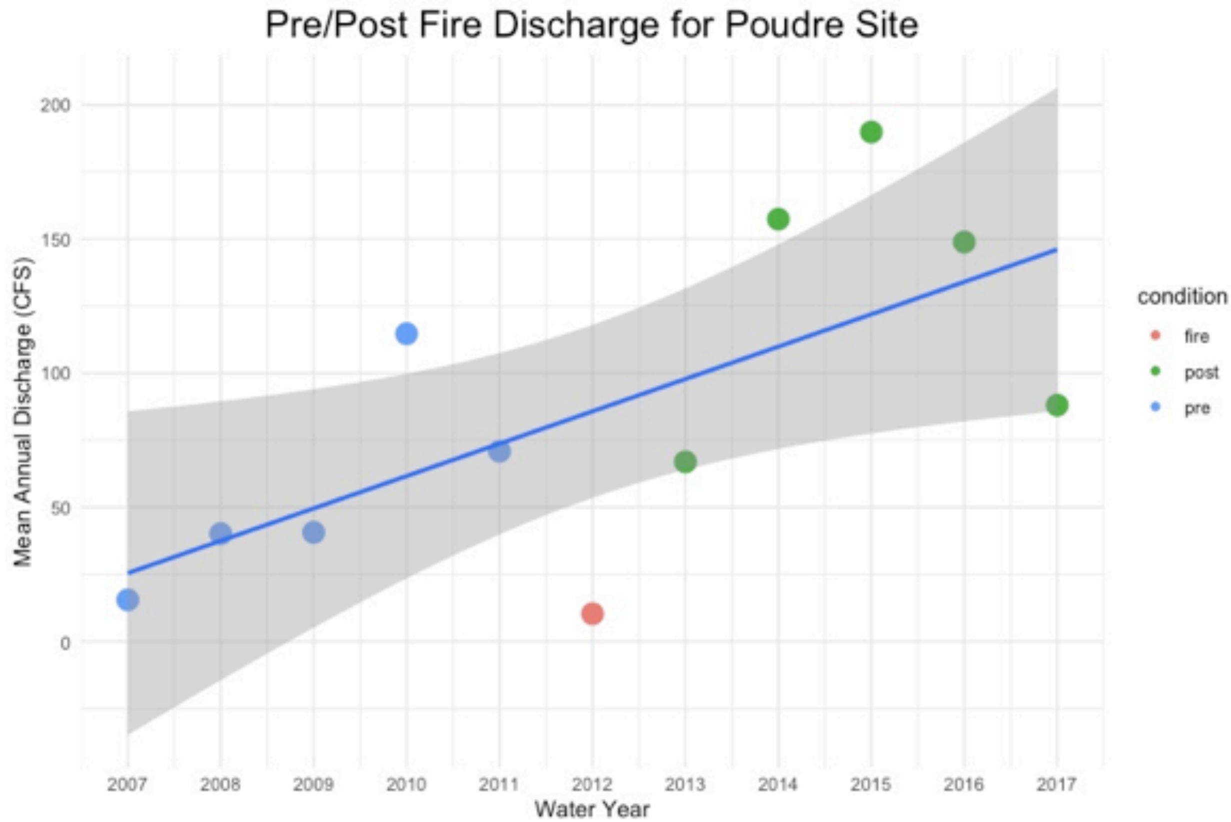

Figure 6. Mean annual discharge for the North Fork of the Cache la Poudre River 5 water years before and 5 water years after the High Park Fire in 2012. This USGS stream site is located on the North Fork of the Cache la Poudre River in Livermore, CO.

The other five remaining stream sites did not show significant changes in streamflow when comparing mean annual streamflow (Table 1) and peak flow (Table 2) from five water years before and after the associated fire occurred. Combining all sites with five years of both pre and post fire data shows that while change is minimal, there is a slight decrease in mean annual streamflow the year of the fire and it stays lower for the next five years (Figure 7).

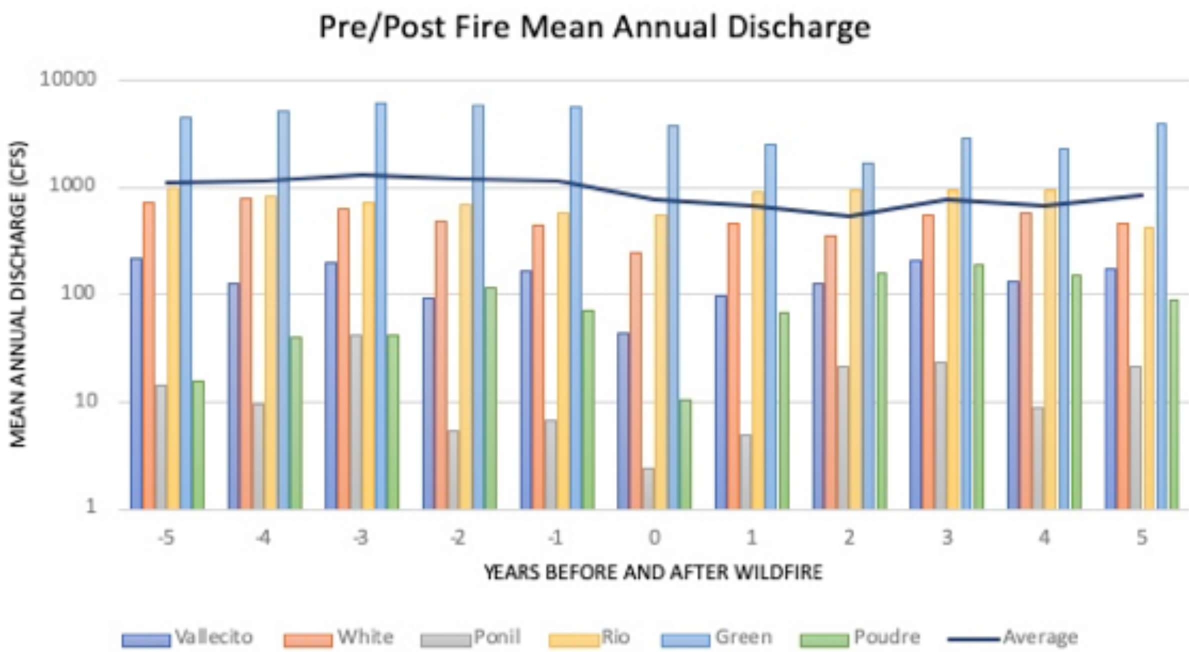

Figure 7. Bar chart showing mean annual discharge in CFS for each USGS stream site with 5 water years of pre and post fire data. The Y axis is in logarithmic scale as these streams vary in size.

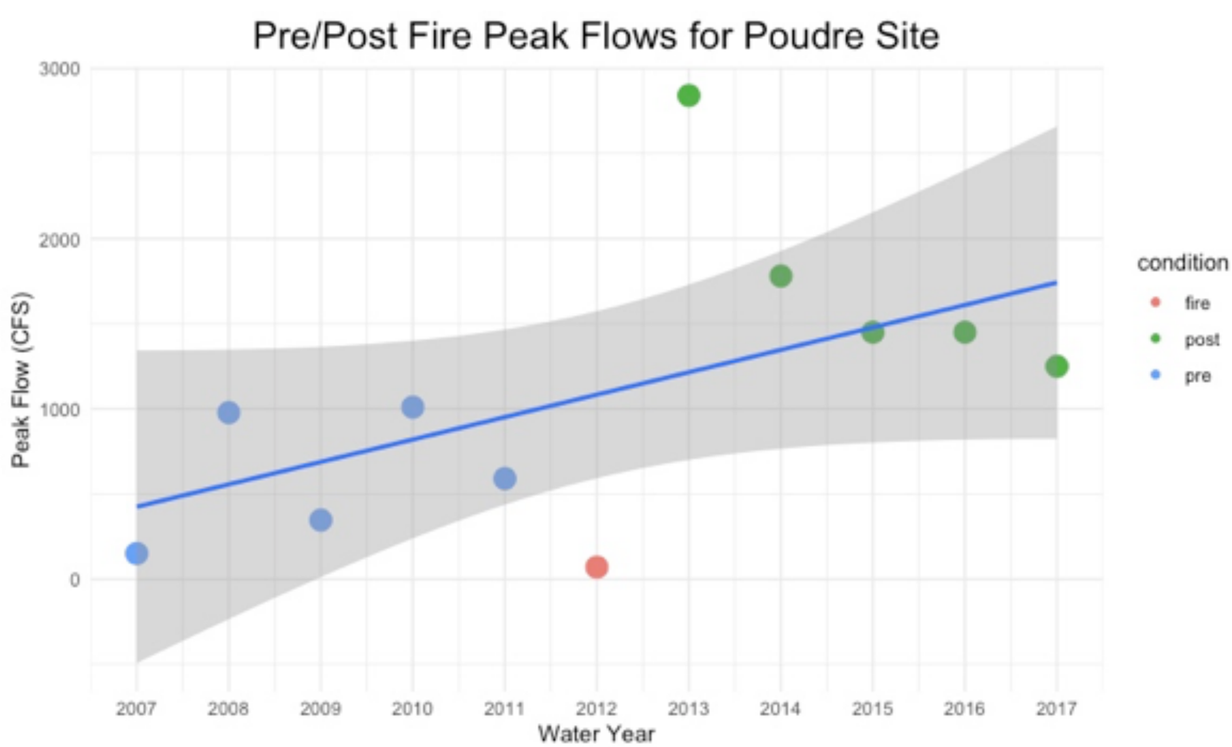

Figure 8. Peak flow for North Fork of the Cache La Poudre River in the 5 water years before and after the High Park Fire in 2012. This USGS stream site is located on the North Fork of the Cache la Poudre River in Livermore, CO.

DISCUSSION

Main Takeaways

- Green River site had significantly lower mean annual discharge (Figure 5) and peak flow following Buster Flats Fire, but there were likely other contributing factors
- North Fork of the Cache la Poudre site had significantly higher annual discharge (Figure 6) and peak flow (Figure 8) and this is likely because of the 2012 High Park Fire
- There is no distinguishable pattern in water quantity change following a wildfire
- Any changes in streamflow that exist vary in direction and magnitude

Limitations:

- Fire data for older fires is limited and doesn't always include components like fire severity, accurate perimeters, and forest ecology
- For more accurate data analysis one would have to normalize for snowpack, soils, and altitude in each watersheds that could help explain changes in streamflow
- Only 7 sites were used in this analysis, this is primarily due to lack of consistent water data for years before and after fire as well as rarity of fires in watersheds that also happen to have USGS stream sites

Future Studies

- Fires are becoming more common, and there is more data on those fires. This will allow for more accurate answers to these questions.
  - There were many fires in 2020 like the Cameron Peak Fire (Figure 9) and Williams Fork Fire that are nearby USGS streamsites that could have been used for this study had there been more years of post-fire data.
- It will be difficult to predict how a fire may impact the water supply until after the fire occurs, but with additional studies it may be possible to find patterns between fire size or severity and changes in streamflow.

Figure 9. Cameron Peak Fire north of Rocky Mountain National Park in August, 2020. Photo Credits: Emily Fischer and Peter Girard Image Link (https://www.atmos.colostate.edu/2020/08/emily-fischer-encounters-cameron-peak-fire-while-backpacking-with-family/)

Full Discussion

Studying the impacts of wildfires can be very complicated due to how various fires each behave differently from each other. Through this data analysis we find that while fires appear to have an impact on water quantity, not every watershed that is impacted by a fire will experience significant changes in streamflow or peak flow. One site that saw a significant change in streamflow in the years following a fire was the Green River site near Jensen, UT (Figure 5). In this case, the years following the fire all had lower streamflow than the previous years. While it is possible that the Buster Flats Fire had something to do with this decline, there could be many other reasons for a decline in streamflow. It should also be noted that this fire occurred upstream on the Green River before the Green and Yampa river combine in Dinosaur National Park. Additionally, this fire burnt only 17.2 square miles, whereas the contributing drainage area for this site is 25,400 square miles (U.S. Geological Survey). Therefore, it is likely that there were other contributing factors to the significant decrease in streamflow in the five years following the fire.

Another site where there was a significant change in streamflow was the Poudre, or more specifically, North Fork Cache la Poudre site. This site is associated with the High Park Fire of 2012. For this site, streamflow was significantly higher overall following the fire (Figure 6). The High Park Fire was much larger than the Buster Flats Fire, burning approximately 136 square miles (U.S. Forest Service). Additionally, the contributing drainage to the Poudre site was 538 miles (U.S. Geological Survey). In this case, we can be fairly certain that the fire contributed to the increase in streamflow as it burnt a large portion of the watershed. Another interesting finding from this site was that the year after the fire occurred the peak flow was 1060 CFS higher than the peak flows in any other year (Figure 8). This is consistent with previous research that shows increases in streamflow and peak flow following severe wildfires.

In Figure 7 a bar chart shows the mean annual discharge for all sites except Strawberry due to its limited post fire data. While the graphic shows the average mean annual streamflow declining, this is likely influenced by the relatively larger size of the Green River. However, it should be noted that in all 6 sites the lowest mean annual discharge either occurred the year of the fire or in the years after the fire (Figure 7). This is likely because fires typically occur on drier years when there would be less streamflow with or without a fire.

The findings in this research are consistent with previous work in that there is no distinguishable pattern in water quantity change following a fire. As expected, changes in streamflow and peak flow following a fire would not always be in the same direction or magnitude. While most sites saw at least some change, only two of these were significant. With more time, additional USGS stream sites, and improved fire data, it may have been possible to relate any observed changes in streamflow to the fire's severity and size, as well as discovering what other unrelated impacts may have led to water quantity changes. Additionally, for more accurate data analysis I would normalize for snowpack, soils, and altitude in each watershed which may help to explain some of the observed changes in streamflow.

While I had hoped to find a pattern that could be helpful for understanding how future fires may impact the water supply, it appears as though the complexity of fires and watersheds limits what I was able to do in this project. However, future studies involving water quantity and wildfires will be able to more accurately answer these questions as fire frequency is increasing and there is more data being collected on those fires.

CONCLUSION AND ACKNOWLEDGMENTS

Conclusion

While these findings do not show any obvious trends or patterns in changes in water quantity following a watershed forest fire, wildfires do noticeably lead to changes in streamflow and peak flow. While more investigation will be helpful to solidify the findings of this research, it is clear that streamflow changed to some degree in all sites, with significant changes in two of the seven sites. Another important takeaway is that changes in streamflow could lead to other risks such as contribution to droughts or floods as peak flow or mean annual flow change following more severe fires like the High Park Fire.

Increasing wildfires will surely impact anyone living in or around impacted watersheds but could also impact water users downstream. Many of these wildfires occur near the headwaters of tributaries to major rivers such as the Colorado River, Mississippi River, and Rio Grande River. As post-fire data is recorded for the recent 2020 fires and expected fires in the future, it may be possible to find patterns associated with fires of different size and severity. This will allow water managers and scientists to better understand how fires impact watersheds and prepare for a future with an increasing amount of climate-related disturbances.

Acknowledgments

This project was completed as part of the Ecosystem Science and Sustainability SUPER Program (Skills for Undergraduate Participation in Ecological Research) at Colorado State University.

Thank you to Dr. Stacy Lynn and Anna Clare Monlezun for their support and feedback throughout this research.

ABSTRACT

In the Western United States, a changing climate combined with historical forest management practices have left many forested watersheds vulnerable to wildfires. With water scarcity becoming an increasingly important issue in Colorado and other western states, understanding how these fires impact water quantity is crucial. Previous studies tend to focus on one or two watersheds and have found that water quantity in burnt watersheds depends heavily on several factors including fire severity, elapsed time since the fire occurred, ecological make-up of the forest, altitude, forest aspect, weather events, soil properties, and more. In this study, USGS National Water Information System data is used to identify USGS stream sites in multiple watersheds that have been affected by wildfires in Colorado and neighboring states. Years of water quantity data from these sites are analyzed using R to determine if there are any general trends in discharge and peak flow on years where a fire occurred compared to averages from the 5 previous years. We hoped to find any significant changes to streamflow in watersheds after a fire occurs, and identify any patterns between the magnitude and direction of these variations with the size, severity, and location of the associated wildfire. These findings can then be used to prepare for water management strategies in burnt watersheds.

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