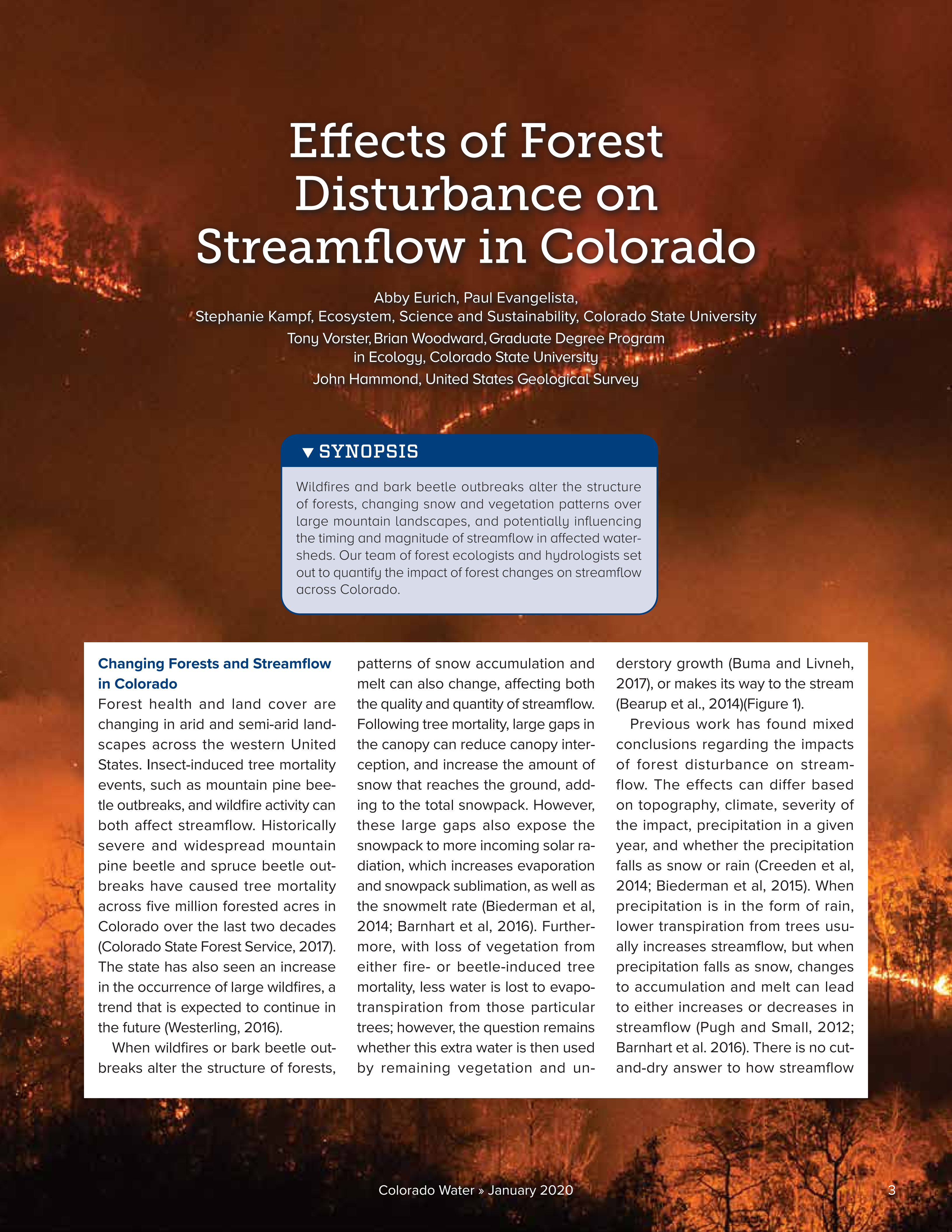

Effects of Forest Disturbance on Streamflow in Colorado

Abby Eurich, Paul Evangelista,
Stephanie Kampf, Ecosystem, Science and Sustainability, Colorado State University
Tony Vorster, Brian Woodward, Graduate Degree Program
in Ecology, Colorado State University
John Hammond, United States Geological Survey

▼ SYNOPSIS

Wildfires and bark beetle outbreaks alter the structure of forests, changing snow and vegetation patterns over large mountain landscapes, and potentially influencing the timing and magnitude of streamflow in affected watersheds. Our team of forest ecologists and hydrologists set out to quantify the impact of forest changes on streamflow across Colorado.

Changing Forests and Streamflow in Colorado

Forest health and land cover are changing in arid and semi-arid landscapes across the western United States. Insect-induced tree mortality events, such as mountain pine beetle outbreaks, and wildfire activity can both affect streamflow. Historically severe and widespread mountain pine beetle and spruce beetle outbreaks have caused tree mortality across five million forested acres in Colorado over the last two decades (Colorado State Forest Service, 2017). The state has also seen an increase in the occurrence of large wildfires, a trend that is expected to continue in the future (Westerling, 2016).

When wildfires or bark beetle outbreaks alter the structure of forests, patterns of snow accumulation and melt can also change, affecting both the quality and quantity of streamflow. Following tree mortality, large gaps in the canopy can reduce canopy interception, and increase the amount of snow that reaches the ground, adding to the total snowpack. However, these large gaps also expose the snowpack to more incoming solar radiation, which increases evaporation and snowpack sublimation, as well as the snowmelt rate (Biederman et al, 2014; Barnhart et al, 2016). Furthermore, with loss of vegetation from either fire- or beetle-induced tree mortality, less water is lost to evapotranspiration from those particular trees; however, the question remains whether this extra water is then used by remaining vegetation and understory growth (Buma and Livneh, 2017), or makes its way to the stream (Bearup et al., 2014)(Figure 1).

Previous work has found mixed conclusions regarding the impacts of forest disturbance on streamflow. The effects can differ based on topography, climate, severity of the impact, precipitation in a given year, and whether the precipitation falls as snow or rain (Creeden et al, 2014; Biederman et al, 2015). When precipitation is in the form of rain, lower transpiration from trees usually increases streamflow, but when precipitation falls as snow, changes to accumulation and melt can lead to either increases or decreases in streamflow (Pugh and Small, 2012; Barnhart et al. 2016). There is no cut-and-dry answer to how streamflow

Tree mortality on Glacier Gorge Trail, Glacier Creek, RMNP. Photo by Abby Eurich.

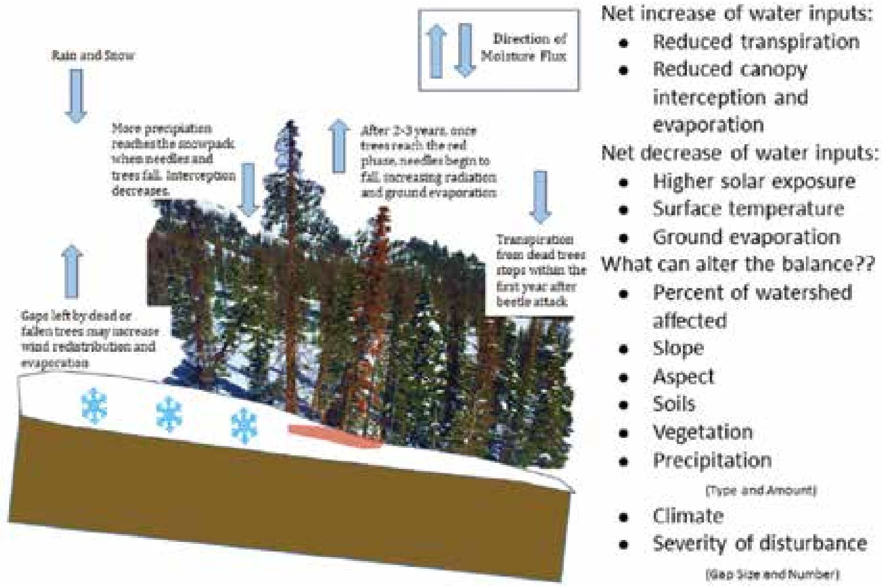

Figure 1. Schematic diagram illustrating the possible effects of Mountain Pine Beetle forest disturbance on snowpack and streamflow.

will respond to forest disturbance, or whether it will respond at all. Additionally, the percent of watershed disturbed, and the severity and dispersion of the disturbance, play key roles in the streamflow response.

Our team of forest ecologists and hydrologists set out to quantify the impact of forest changes on streamflow across Colorado. To do this, we generated forest disturbance maps delineating severity and timing of bark beetle outbreaks (2001-2013), and summarized wildfire data (Monitoring Trends in Burn Severity, 1984-2015). For watersheds that have stream gages with complete annual records for the years of disturbance data (US Geologic Survey, Colorado Division of Water Resources), we analyzed the relationship between streamflow anomalies and disturbance type and severity, while controlling for climatic influences on streamflow, such as precipitation and snow cover.

Mapping Bark Beetle Outbreaks Using New Remote Sensing Techniques

Outbreaks of native bark beetles have caused widespread tree mortality in lodgepole pine and spruce forests across Colorado since 2000. Insect and disease impacts on forests are assessed annually by trained human observers who conduct airplane flyovers to delineate tree mortality and damage. These Aerial Detection Surveys provide valuable information about trends in tree mortality over the last few decades. However, the use of satellite remote sensing offers an opportunity to produce finer resolution maps of forest insect and disease impacts, and to better capture the extent of complex tree mortality patterns, and the heterogeneity of this mortality. We utilized Landsat 5 imagery to map lodgepole pine mortality from 2001 to 2013 across Colorado, Wyoming, Montana, and Idaho. We then merged these maps with the Aerial Detection Surveys to characterize the timing and cause of mortality at each mapped pixel. The maps we produced more accurately represent the dead canopy area across all four states compared to the Aerial Detection Surveys. However, we were able to leverage the aerial surveys to characterize the cause of the mortality and the timing, outbreak details that are typically very difficult with remote sensing (Figure 2). We

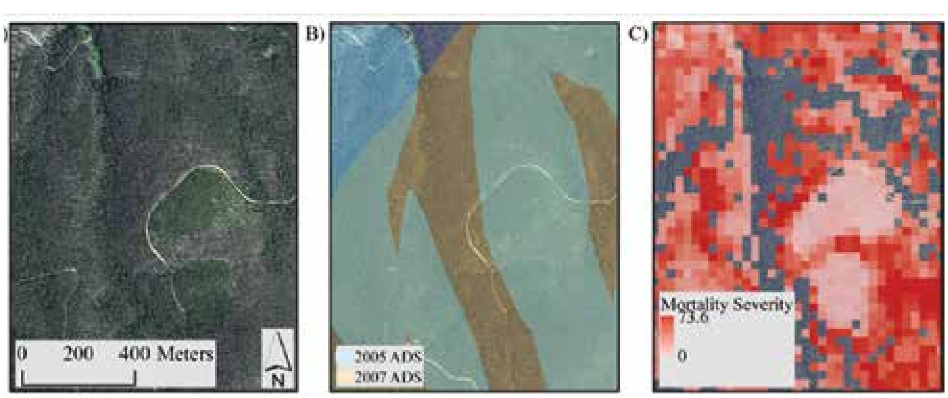

Figure 2. A) Aerial imagery showing mountain pine beetle-caused mortality in a lodgepole pine forest in northern Colorado. B) Aerial Detection Survey data for the same area indicating mortality in this area in 2005 and 2007. C) Mortality shown by our maps within the lodgepole pine forests, with each value representing the proportion of each pixel that is dead canopy. Aerial Detection Surveys are coarser, whereas our products capture heterogeneity in mortality.

Our group monitors streamflow on this snow-fed stream near Copper Mountain, 2018. Photo by Abby Eurich.

found that across these four states, Colorado had some of the most widespread and severe lodgepole pine mortality. These improved tree mortality maps present an opportunity to better investigate linkages between bark beetle outbreaks and streamflow. We summarized the lodgepole pine dead canopy area, and the timing of the outbreaks across each watershed in Colorado to pair with the stream gage data (Figure 3). We also used existing maps of fires across the state (Monitoring Trends in Burn Severity) to summarize annual area impacted by fire, and the severity of these fires in each watershed.

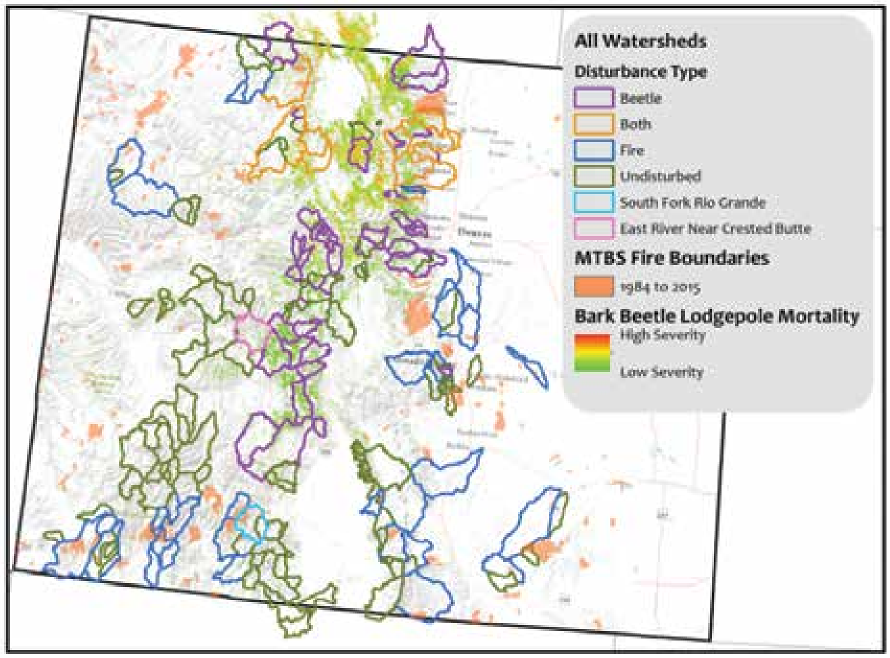

Figure 3. Site Map, illustrating all watershed boundaries, colored by disturbance type, corresponding with the years of streamflow data. South Fork Rio Grande and East River Near Crested Butte watersheds are used as examples in Figure 4.

Table 1. Percentage of stream gages with significant streamflow change post-disturbance (a=0.05), after controlling for precipitation variability.

	Annual Q	Low Flow Q	Minimum 7-day Q	Maximum 7-day Q
Fire	33%	21%	33%	17%
Beetle	5%	5%	2%	4%

Streamflow Response to Disturbance

We compiled a dataset of 200 watersheds across Colorado, using gages with drainage areas less than 1500 km^2 in order to better isolate different disturbance and forest types within a watershed. We excluded all stream gages with transbasin water diversions, leaving 55 watersheds that have experienced beetle mortality in lodgepole pine forests, and 42 watersheds that have experienced wildfire. Of these, 11 watersheds have experienced both beetle mortality and wildfire (Figure 3).

Multiple linear regression and ANOVA were used to determine whether there was any significant difference in annual streamflow response pre- and post- disturbance, while accounting for variability in annual precipitation, by including it as a predictor in the regression model. We used this method for four different streamflow metrics (Total Annual Streamflow, Total Streamflow during Low Flow Months Oct & Nov, Minimum 7-day Streamflow, and Maximum 7-day Streamflow, Table 1).

Significant differences pre- and post- disturbance were found for some sites, showing both an increase and decrease in streamflow. Precipitation is a strong driver of annual streamflow variability. On a plot of annual streamflow vs. precipitation, if the streamflow tends to plot higher in the years after disturbance than the years prior to disturbance, this indicates an effect of the disturbance causing streamflow to be higher, relative to the expected variation with precipitation (Figure 4). Table 1 summarizes the percentage of watersheds with a significant streamflow response for each disturbance type.

For fires, all watersheds with at least 15% of the area burned exhibited a significant change in total annual streamflow. So far, we have not found a similar threshold in the effect of beetle-induced mortality. Fewer watersheds had significant streamflow response to beetle-induced mortality than to wildfire disturbance (Table 1). This is likely because when trees die from beetle attack, they remain in-situ, and the surrounding vegetation is not impacted, sometimes even thriving with more resources and additional water available. This can mute the effects of large canopy gaps and snowpack changes, post-disturbance. Wildfires, however, tend to affect both the canopy and understory vegetation, and therefore are more likely to change streamflow (Table 1).

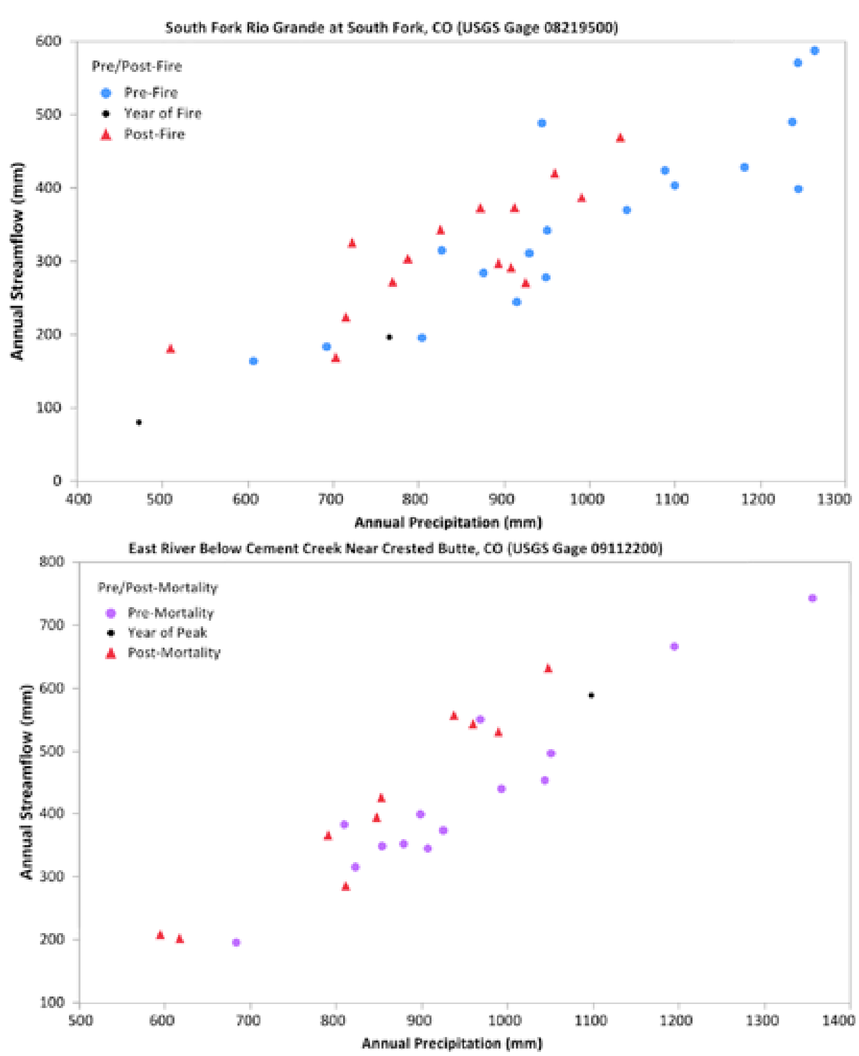

Figure 4. Graphs of annual streamflow vs. annual precipitation, colored by pre- and post-disturbance. Both stream gages shows a significant change in annual streamflow after disturbance (a=0.05).

Tree Mortality at Monarch Mountain Ski Resort, 2019. Photo by Abby Eurich.

Mountain Pine Beetle Mortality at Copper Mountain Ski Resort, 2019. Photo by Abby Eurich.

Continued Research, Lessons, and Challenges

The site-specific nature of streamflow response to forest disturbance begs the questions, what are the main controls on streamflow response, and can we anticipate the way watersheds will respond to future disturbance events across variable conditions? Our team is continuing to explore these questions by using the disturbance severity information from the remote sensing techniques tested in this study, as well as soil, geology, and vegetation information for each watershed with and without a significant streamflow response. We hope to understand why some watersheds respond differently from others, and whether there are clear predictive characteristics for their response. In addition, we plan to assess the impacts of spruce beetle mortality on streamflow, using maps produced by our group (Woodward et al., 2017). This will increase the number of watersheds in the analysis, adding to our overall impact detection.

One of the largest challenges of this work is identifying watersheds with both forest disturbance and stream gage data, where the streamflow is not altered by trans-basin diversions or reservoirs. Many watersheds in Colorado that have experienced large disturbance have reservoirs and water diversions that change streamflow, masking the less pronounced forest disturbance effects on streamflow. Understanding how disturbance events in increasingly-stressed headwater ecosystems impact water supply is vital to land and water managers across Colorado. Continuation of this work will help to identify the most likely impacts to streamflow in these valuable and vulnerable landscapes.

Acknowledgements

This project was supported by funds from the Colorado Water Center Water Research Team Grant, the Colorado Water Conservation Board, and by the Agriculture and Food Research Initiative Competitive Grant (Grant no. 2013-68005-21298) from the USDA National Institute of Food and Agriculture.