LIVING WITH FIRE & WATER

Ben Gannon, Colorado Forest Restoration Institute, Forest and Rangeland Stewardship, Colorado State University;
Stephanie Kampf, Ecosystem Science and Sustainability, Colorado State University;
Codie Wilson, Geosciences, Colorado State University;
Kelly Jones, Human Dimensions of Natural Resources, Colorado State University;
Yu Wei, Forest and Rangeland Stewardship, Colorado State University;
Lee MacDonald, Natural Resource Ecology Laboratory, Colorado State University;
Katherine Mattor, Forest and Rangeland Stewardship, Colorado State University;
Peter Nelson, Civil and Environmental Engineering, Colorado State University;
Tony Cheng, Colorado Forest Restoration Institute, Forest and Rangeland Stewardship, Colorado State University;
Brett Wolk, Colorado Forest Restoration Institute, Colorado State University

SYNOPSIS

Wildfire is considered a critical risk to community drinking water supplies in the western U.S. Our team integrates research from the physical and social sciences to better characterize wildfire risk to water supplies and to evaluate the effects of pre- and post-fire risk mitigation approaches.

Introduction

Recent wildfires in Colorado and other western states demonstrate the vulnerability of community drinking water supplies to wildfire. The removal of ground cover and changes in soil properties can lead to very large increases in surface runoff and erosion that detach and convey ash, soil, and debris into rivers and reservoirs. The increased organic material, sediment, and debris can increase the cost and complexity of water conveyance, treatment, and storage. For example, post-fire erosion following the 1996 Buffalo Creek and 2002 Hayman Fires resulted in 500,000 m^3 of sediment deposition in Denver Water's Strontia Springs Reservoir. Ash and sediment inputs following the 2012 High Park fire prevented the Cities of Fort Collins and Greeley from using water from the Cache la Poudre River for over three months and necessitated shifts to alternative water sources to meet basic demands (Figure 1).

Although Colorado communities have identified wildfire as a critical risk to their water supplies, they have limited tools to evaluate which risk mitigation strategies would be most effective. Possible strategies include reducing fuels in source watersheds, fire suppression, infrastructure improvements, developing alternative supplies or water intakes, and post-fire watershed rehabilitation. Our team is conducting a range of research studies and analyses to help communities predict the magnitude of potential fire effects and evaluate the costs and benefits associated with different management alternatives. Here, we present on recent efforts to improve predictions of post-fire physical processes, increase understanding of social and economic factors that influence wildfire risk mitigation and financing, and deliver locally-relevant decision support tools to land and water managers.

Watershed Research and Modeling

Models are increasingly being used to predict post-fire erosion. Models help assess the benefits of pre-fire mitigation treatments, such as fuel reduction, and post-fire watershed rehabilitation activities, such as mulching. The most prevalent models are the Water Erosion Prediction Project (WEPP; Flanagan and Nearing, 1995) and the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997). These models were developed primarily from observations on small agricultural plots with gentle slopes. Model predictions, therefore, come with considerable uncertainty when applied to steeply forested watersheds, especially when combined with imperfect spatial data used to approximate topography, soil, ground cover, and rainfall. We used field data, a local empirical model, and evidence of erosion from aerial photographs to evaluate the performance of WEPP and RUSLE at hillslope to watershed scales (~0.1-1,500 ha).

We compared the predicted erosion from RUSLE and WEPP to sediment yield measurements from convergent hillslopes after the 2012 High Park Fire (HPF; Figures 1 and 2) to evaluate model performance at the hillslope scale. To assess

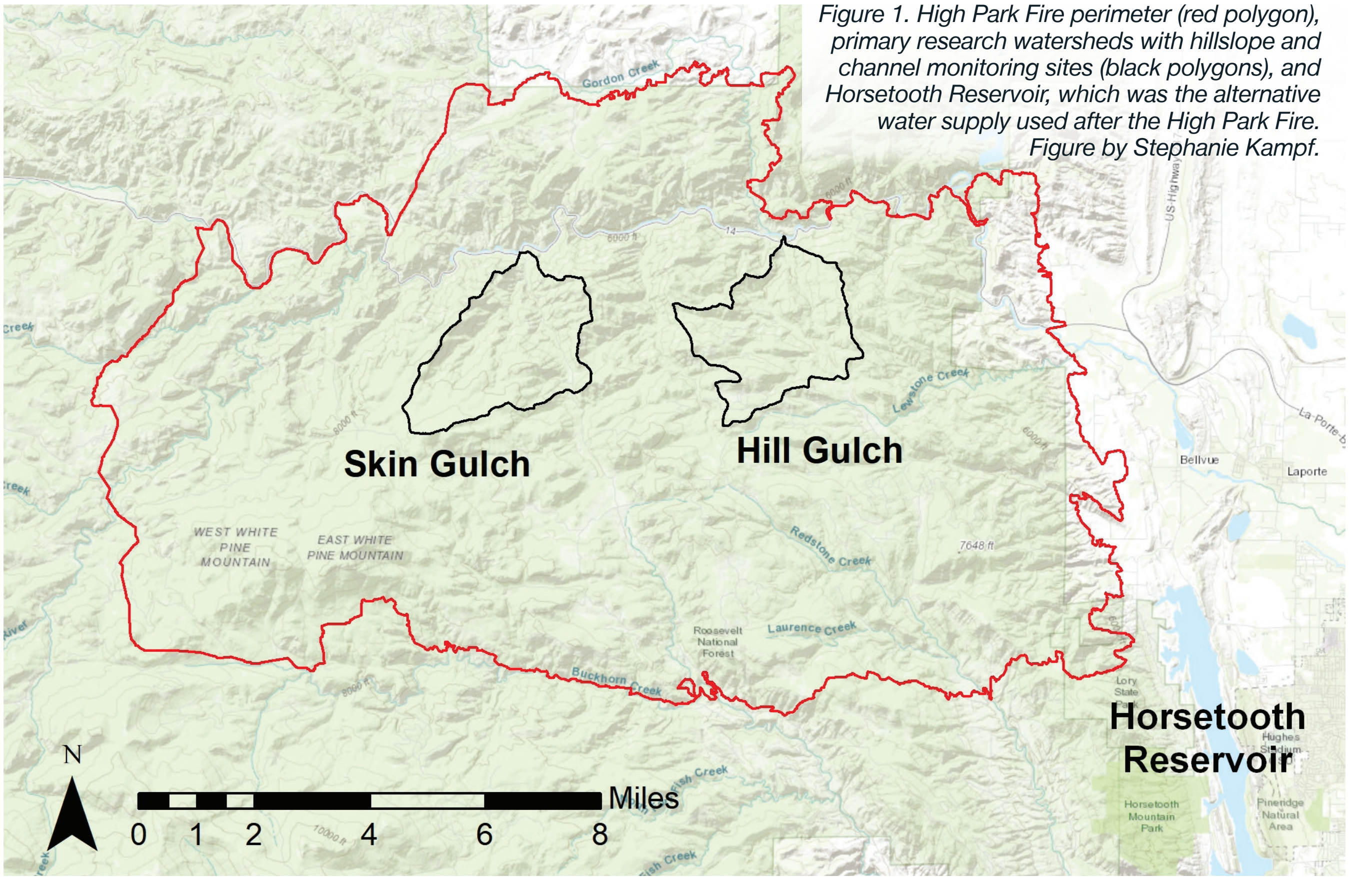

Figure 1. High Park Fire perimeter (red polygon), primary research watersheds with hillslope and channel monitoring sites (black polygons), and Horsetooth Reservoir, which was the alternative water supply used after the High Park Fire. Figure by Stephanie Kampf.

the value of RUSLE and WEPP for prioritizing management activities across larger watersheds, we compared the erosion predictions from RUSLE and WEPP to a local empirical model (Schmeer et al., 2018) applied to the hillslope portions of Hill and Skin Gulches (Figure 1). The local empirical model was developed from measured hillslope erosion rates following the High Park Fire, which related post-fire sediment production to rainfall depth, slope length, and percent bare soil (Schmeer et al. 2018). As an additional test, we compared erosion predictions from RUSLE, WEPP, and the local empirical model to the density of channel head locations in Hill and Skin Gulches mapped from high-resolution aerial photography. Channel head locations indicate where erosional features such as rills and gullies initiate.

Compared to field measurements of hillslope erosion, neither WEPP nor RUSLE represented erosion accurately (R^2=0.00 and 0.05, RMSE 20.4 and 2.8, respectively). Hillslope erosion rates were better correlated with observed erosion for the empirical model (R^2=0.60, RMSE 5.2), which makes sense as this was locally derived and calibrated using the measured HPF data. We also found that the empirical model correlation with observations declined when used with radar-derived rainfall and bare soil estimates from satellite imagery (R^2=0.14), highlighting the importance of accurately characterizing these variables. We are also comparing the erosion model predictions across two watersheds within the High Park Fire, Skin Gulch, and Hill Gulch. The location of channel heads across watersheds were most correlated to the erosion patterns simulated by the empirical models (R^2=0.54-0.75), however, erosion patterns from WEPP and RUSLE also compared favorably (R^2=0.47-0.52 for WEPP and 0.15-0.33 for RUSLE). This is encouraging because even if the models

Figure 2. Sediment fence used to measure erosion after the High Park Fire. After rainstorms, researchers dug out and measured the accumulated mass. These are placed in small convergent hillslopes as indicated by the small rill leading into the sediment fence, indicating significant post-fire overland flow. Photo by Sarah Schmeer.

do not predict the actual amounts of erosion accurately at a given location, they are likely reliable for identifying areas of high erosion (Figure 3).

Social and Economic

Because wildfire impacts rarely stop at jurisdictional boundaries, both proactive fuels management and post-fire rehabilitation efforts require collaborative watershed management. This collaborative effort needs to include diverse stakeholders, ranging from water utilities to non- and for-profit organizations and land management agencies. We are conducting structured interviews and surveys to determine what motivates stakeholders to collaborate, how they participate in different stages of risk mitigation (e.g., planning, funding, and implementing), and what information they need to make better decisions. Risk-based decision making is now used by federal fire and land managers, but we know little about why and how other stakeholders, such as water utilities and private industry, are engaging in wildfire risk mitigation. Hence, we are testing: (1) the role of scientific information in prioritizing and assessing outcomes within collaborative partnerships, and (2) the influence of different factors on participation in collaborative partnerships. Future research will focus on how communicating information on risk and uncertainty influences stakeholders' contributions to these groups and their perception of wildfire risks. Many of these collaborative watershed management groups are still developing, and we anticipate that this research will identify information needs and barriers that can better facilitate stakeholder participation and the development of policy tools and funding for watershed management.

Development of a Decision Support System

We are integrating our work on erosion modeling with our social and economic findings to help stakeholders identify types and locations of pre- and post-fire management activities to reduce wildfire risk to water supplies. We quantify wildfire risk as a function of fire likelihood and intensity and the

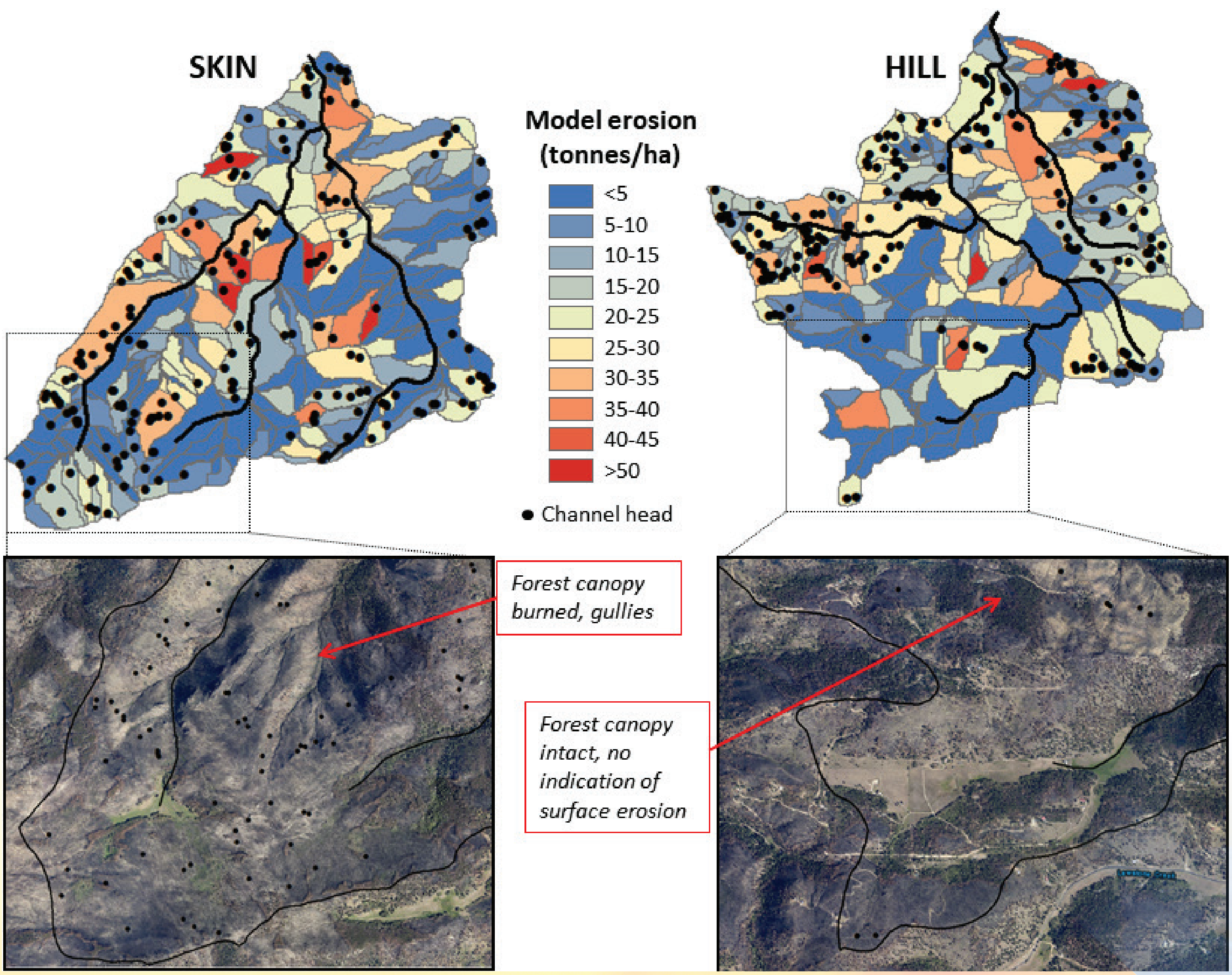

Figure 3. Upper: simulated patterns of erosion from WEPP for Skin and Hill Gulch overlain by post-fire channel heads; Lower: indications of surface erosion in Pictometry air photos from 2012. Figure by Stephanie Kampf.

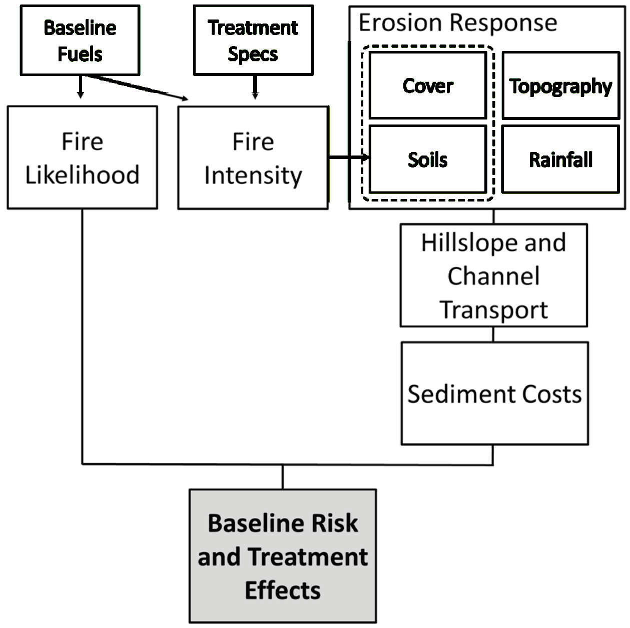

Figure 4. Schematic of our wildfire risk assessment methods. Current vegetation (fuel) conditions determine the likelihood of fire and fire intensity. Post-fire hillslope erosion is controlled by fire intensity. This eroded sediment is then routed downstream to water infrastructure locations, which are assigned sediment impact costs that reflect their importance and vulnerability. Risk is then calculated as the product of wildfire impact costs to water supplies and the probability of experiencing fire. Different fuel treatment scenarios such as forest thinning or prescribed fire can be tested to determine how they modify fire intensity, erosion, and sediment delivered to water infrastructure.
Figure by Ben Gannon.

potential for post-fire erosion to impact water supplies (Figure 4). Fire likelihood and intensity vary across large watersheds due to fuels, weather, topography, and ignition sources. There is also considerable spatial variability in the potential for wildfire to impact water supplies due to biophysical controls on erosion and sediment transport and the locations of water infrastructure. By linking wildfire, erosion, and sediment transport models (Figure 4), we can produce spatially-explicit and locally-relevant wildfire risk assessments for large water collection systems (Figure 5).

We can also test the effects of management by simulating pre-fire fuel reduction and post-fire watershed rehabilitation treatments (Figure 4). With additional information on treatment constraints, it is then possible to optimize treatment type and placement to minimize water supply risk. Priorities are refined by considering constraints on management including land management designations, operability, costs, and social and ecological values. Decision tools like this can support strategic risk management by explicitly considering the spatial distribution of risk on the landscape and the ability to mitigate it with different management approaches. Source water systems are diverse, so it is likely that optimal risk reduction strategies will also vary by community. Using consistent and quantitative approaches for assessing risks and risk mitigation effects can help communities decide what strategies are most appropriate for them.

Conclusions

We found that popular erosion models do not accurately predict post-fire erosion from small hillslopes, but they do have acceptable accuracy for mapping the relative erosion potential across large watersheds. We are working to understand the roles of risk, risk perception, and other social and ecological factors in motivating stakeholders to engage in watershed protection efforts. Our decision support tools provide spatially-explicit measures of wildfire risk in meaningful terms for water management and powerful methods to evaluate and prioritize risk mitigation actions.

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Figure 5. Wildfire risk to water supplies across interconnected source water systems in the Cache la Poudre and Big Thompson Basins of Northern Colorado. Black dots indicate locations of water infrastructure such as pipelines or reservoirs, and the size of the black dot represents the relative importance for water supply. Figure by Ben Gannon.