



Figure 1. High density forests, like this stand in Upper Hill Gulch burned by the High Park Fire (2012), support high intensity crown fires which kill all the trees and consume much of the organic surface cover. Forestry interventions can be used to reduce and/or modify the horizontal and vertical continuity of fuels to lessen fire severity and post-fire erosion.



Connecting Forests and Water

Fuel Treatment Assessment and Planning Tools

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Fire is a natural process in Colorado forests, but recent wildfires are burning hotter, larger, and over a longer season than historical fires, with trends likely to continue increasing for the foreseeable future. Modern wildfires are also burning in watersheds that provide water to growing downstream populations in areas like the Front Range of Colorado. Sedimentation of streams and reservoirs, increased water treatment costs, and damage to infrastructure from floods and debris flows are all undesirable post-wildfire outcomes affecting Colorado watersheds long after the flames are out. The confluence of increased wildfire activity and demand for water resources has motivated water providers and other stakeholders to pursue proactive approaches to enhance source water security, including forest management. The Colorado Forest Restoration Institute (CFRI) at Colorado State University (CSU), along with partners in the Warner College of Natural Resources (WCNR) at CSU and at The Nature Conservancy, are leading an effort to enhance our knowledge of fire and watershed connections through field and modeling research, stakeholder engagement, and by developing pre-fire mitigation planning tools.

Fuel is the one component of the fire behavior triangle (weather, topography, and fuel) we can reliably manipulate to lessen fire severity. Sediment yields from hillslopes burned at moderate or high severity tend to be an order of magnitude higher than those burned at low severity, so it follows that fuel treatments aimed at reducing the footprint of moderate and high severity fire (Figure 1) will avoid the bulk of post-fire sediment. Fuel treatments also provide opportunities for fire fighters to safely engage in suppression efforts, which can lead to avoided impacts if fire is kept from spreading into high value watersheds. Fire historian Stephen Pyne would remind us, however, that over the long run “every wildland fire put out is a fire put off.” When properly managed, natural or prescribed fire can be an effective tool to achieve both fuel reduction and other ecosystem management objectives.

Fire mitigation can be justified in all ecosystems to protect life and property, but there are additional benefits in the montane ponderosa pine-dominated forests of Colorado (~1,800 to 2,700 m ASL) where fuel reduction and forest restoration goals largely overlap. Historical evidence and future climate projections suggest it is appropriate to manage for structural heterogeneity at landscape-scales by reintroducing elements that were common in the historical forest but rare today, like low density stands and openings. Water providers, watershed coalitions, and others interested in source water security have been actively involved with fuel reduction work on the Colorado Front Range since the Buffalo Creek fire in 1996 through collaborative planning with other agencies, as funding partners, and by managing their own lands.

Denver Water spent more than \$26 million responding to the combined impacts of the Buffalo Creek and Hayman Fires, which deposited over 760,000 m³ of sediment in Strontia Springs Reservoir. These direct costs incurred from post-wildfire watershed impacts, and concerns over future operational disruptions from extreme events, have been powerful motivators for water providers to invest in forest management as part of their risk mitigation portfolios. Partnerships between water providers and land management agencies have turned shared goals into significant accomplishments, but fuel treatment costs continue to be a major constraint to achieving landscape-scale forest management objectives. A forest products industry in decline and prescriptions that call for removing primarily small diameter, unmerchantable timber do not help the balance sheet. Costs for mechanical forestry work can range from \$1,500-\$6,800 per acre, which creates pressure to prioritize fuel treatments where they will have the biggest impacts.

CFRI and WCNR faculty are combining expertise in fire and watershed science, economics, and systems engineering to build integrated tools for landscape-scale fuel treatment planning and assessment. The methods for measuring fuel treatment effects on post-wildfire watershed responses necessarily rely on modeling due to the high spatial and temporal variability of wildfire. To address planning and assessment needs,

wildfire, erosion, and sediment transport models can be linked to model the effects fuel treatments have on wildfire likelihood and intensity, to estimate the effects of wildfire on erosion, and to quantify the exposure of water resources and assets to sedimentation. Our approach uses the foundational principles of wildfire risk assessment, i.e. risk is quantified by jointly considering wildfire likelihood, intensity, and susceptibility, but makes necessary advances in the analysis of effects and exposure for water resources and assets.

Spatial wildfire simulation models can be used to estimate burn probability and fire behavior, which together communicate fire likelihood and intensity. A fire modeling fuelscape consists of raster data on fuels, canopy characteristics, and topography, which serves as the primary input to models for stochastic wildfire simulation or for static prediction of fire behavior under specified conditions. Fuel type and canopy characteristics can be modified to reflect the spatial location, type, and intensity of fuel treatment. Fire models can then be run for the untreated and treated fuelscapes to estimate the effects on fire behavior (Figure 2 A-D) and burn probability. In an assessment or planning context, we are generally interested in comparing existing or potential fuel treatment alternatives, which could each be represented by their own modified fuelscape. For fuel treatment prioritization or optimization applications, fuel treatment effects may be modeled for each spatial unit to use as inputs to another decision process or model.

A major challenge is translating metrics of wildfire behavior into variables used in erosion modeling. The link between fire and erosion models is an identified area for improvement, but a reasonable approach is to map fire behavior type (surface, passive crown, and active crown) to categories of fire severity (low, moderate, and high). Erosion models generally require inputs on cover (including vegetation), soils, topography, and climate or weather. Wildfire effects on cover and soils are sufficiently described by categories of low, moderate, and high severity fire in the literature, especially in Colorado, to parameterize erosion models for baseline and various treatment-fire scenarios (Figure 2 E-F).

Much of the wildfire risk assessment work to date has addressed the exposure and effects of fire on municipal watersheds using overlay analysis and expert response functions. This is an acceptable approach for some multi-resource planning applications, but water providers in Colorado are primarily interested in the amount of sediment that can be delivered to their downstream infrastructure and how much pre-fire fuel treatments can reduce it so they can weigh pre-fire mitigation investments against alternative risk management strategies. This necessarily requires a network topology and sediment transport models, which are part of quasi-distributed physical and empirical model frameworks like the Automated Geospatial Watershed Assessment tool and the geospatial interface for the Water Erosion Prediction Project, but can also be added to hillslope erosion models like the

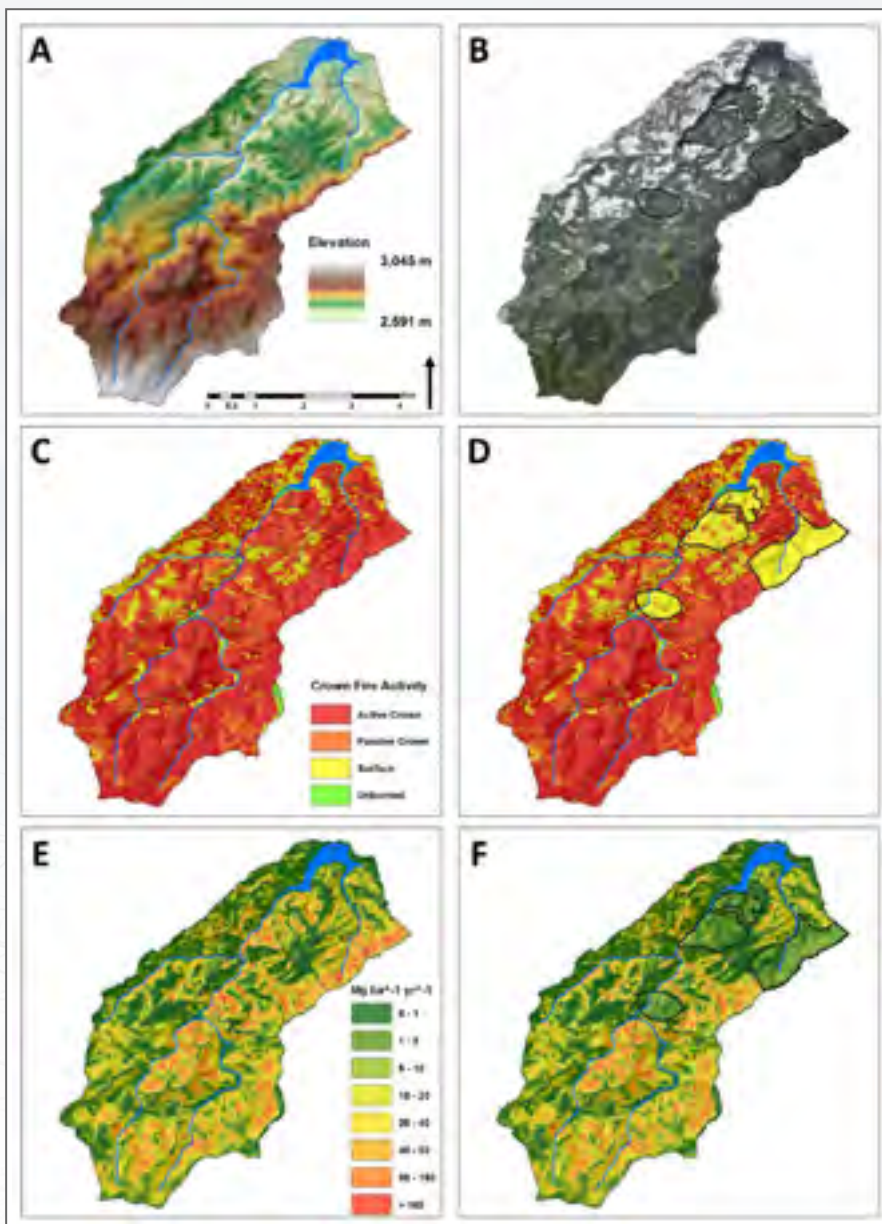


Figure 2. Fire and erosion models can be linked to assess the effectiveness of fuel treatments. A) Watershed contributing to Eaton Reservoir in Northern Larimer County. B) Aerial photography (National Agriculture Imagery Program) showing the distribution of vegetation and hypothetical fuel treatments (black polygons) aimed at reducing risk of post-fire sedimentation. C) Simulated fire behavior for untreated landscape under 97th percentile weather conditions. D) Simulated fire behavior with fuel treatments. E) Estimated erosion given fire in the untreated landscape. F) Estimated erosion given fire in the landscape with fuel treatments. With additional data on burn probability and using models for hillslope and channel sediment delivery, the mean annual sediment delivery to the reservoir can be estimated. Sediment delivery over the expected longevity of fuel treatment effectiveness can be compared between the treated and untreated landscape to estimate fuel treatment effects on sedimentation.

Revised Universal Soil Loss Equation. This is an active area of development and a necessary improvement to bring information to stakeholders at the scale their assets are impacted.

Our team of CSU and TNC researchers are excited to be working with water utilities and other stakeholders to refine a systems model incorporating fire, erosion, and sediment transport components to fill gaps in fuel treatment assessment and planning needs. Past fuel treatments can be assessed relative to baseline fuel conditions (like in Figure 2) or to specified erosion mitigation goals to measure program accomplishments. Alternative fuel treatment scenarios can be compared to see which has best value in avoided post-fire sediment delivery. The power of a systems model is fully realized when integrated with spatial optimization modeling to make the most efficient use of fuel treatment budgets when planning new investments. Optimization models can use inputs like burn probability, effects of treatment on post-fire erosion, costs of

sediment impacts, and management costs and constraints to arrange fuel treatments to minimize the post-fire delivery of sediment to water infrastructure. CFRI is engaging with local and national stakeholders to incorporate these analytical tools into planning and assessment processes.

This project highlights the type of translational research CFRI and WCNR faculty are engaged in to apply research tools from wildfire science, forest ecology, watershed science, economics, and systems engineering to empower science-based decision making. It also reflects the growing interest from regional and national land and water managers in understanding forest and water connections. Increased understanding of the ecosystem services our forests provide can aid in engaging diverse stakeholders and in developing new funding mechanisms to accelerate the pace and scale of dry forest restoration here in Colorado. 