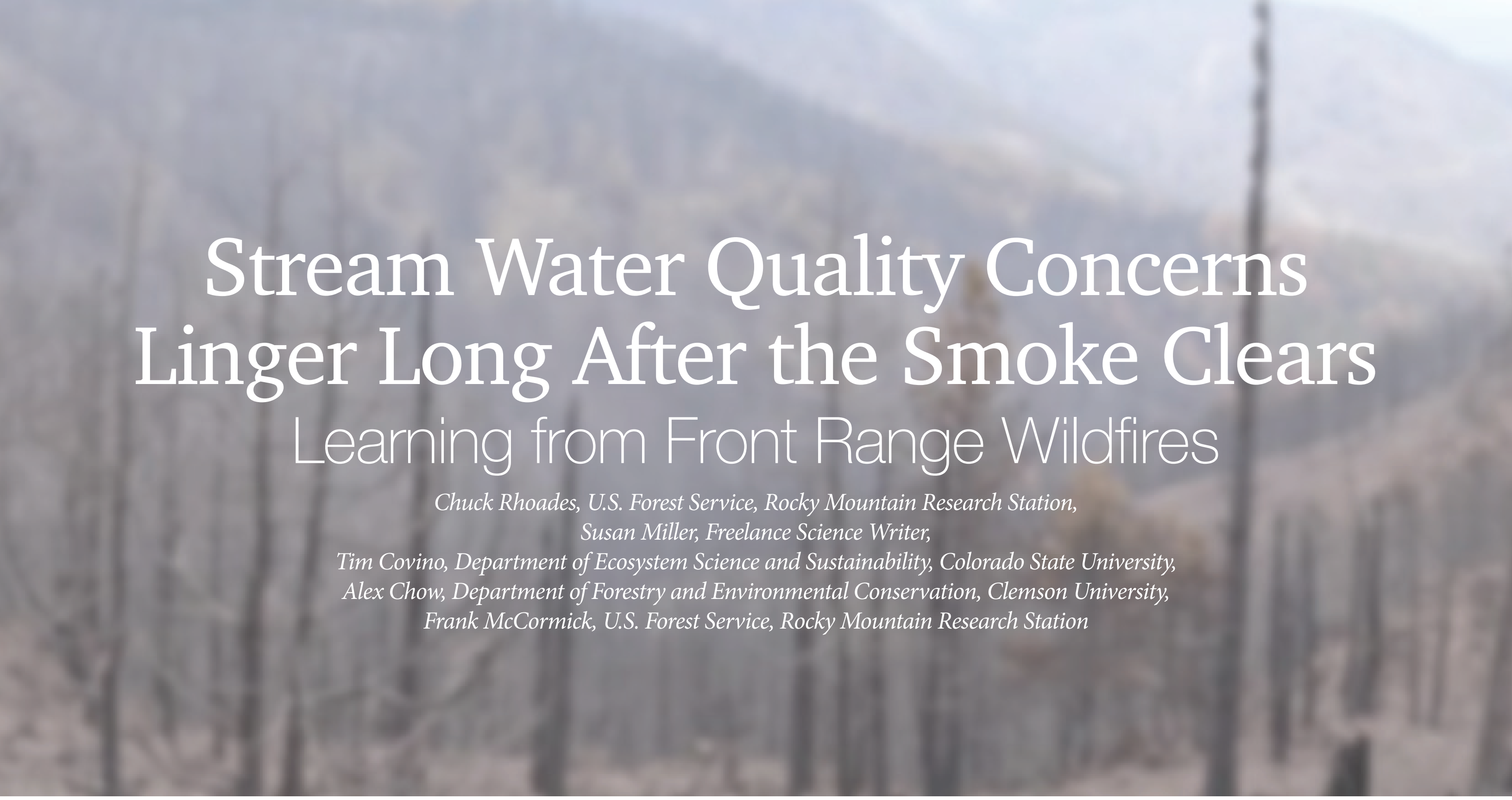

Stream Water Quality Concerns Linger Long After the Smoke Clears

Learning from Front Range Wildfires

Chuck Rhoades, U.S. Forest Service, Rocky Mountain Research Station,
Susan Miller, Freelance Science Writer,
Tim Covino, Department of Ecosystem Science and Sustainability, Colorado State University,
Alex Chow, Department of Forestry and Environmental Conservation, Clemson University,
Frank McCormick, U.S. Forest Service, Rocky Mountain Research Station

Large, high-severity wildfires alter the ecological processes that determine how watersheds retain and release nutrients and affect stream water quality. These changes usually abate a few years after a fire but recent studies indicate they may persist longer than previously expected. Wildfires are a natural disturbance agent, but due to the increased frequency and extent of high-severity wildfires predicted for western North America, it is important to better understand their consequences on surface water.

The close proximity of the Hayman, High Park and other recent wildfires to growing Front Range communities has highlighted the challenges of source water protection in watersheds vulnerable to severe wildfire (Figure 1). The Hayman Fire, for example, occurred in watersheds that supply >70% of drinking water to the Denver metropolitan area. Post-fire erosion impacted the Strontia Springs and Cheesman Reservoirs after the Buffalo Creek and Hayman Fires, leading to costly sediment removal operations. Ash and sediment laden streams compromised the water supply to homes and agricultural producers after the High Park Fire, and water quality concerns forced the City of Greeley to stop using Cache la Poudre River water during both 2012 and 2013. Immediate post-fire response efforts usually address ash and sediment erosion with aerial mulching and seeding, and surface erosion control measures. However, these water quality concerns typically fade after a few years as vegetation recovers.

Changes in post-wildfire stream nutrients, combined with increased stream water temperature, can have longer-term impacts on aquatic biota and water quality. Nutrient enrichment is among the top causes of surface water quality impairment in the continental U.S., affecting 15% of rivers and streams and 25% of lakes. Streams flowing from undisturbed forests supply the nation's cleanest water though activities on those lands can affect water quality. There is a need to evaluate whether more extensive or severe wildfires, especially in areas like the Colorado Front Range where increasing atmospheric nitrogen deposition places additional stress on surface water quality, may impact the sustained supply of clean water and threaten aquatic habitat in forest watersheds.

Front Range Wildfire x Water Quality Monitoring

For the past 15 years, U.S. Forest Service (USFS) researchers and their partners have measured stream chemistry, temperature, and sediment in tributaries of the South Platte River after the 2002 Hayman Fire, the largest wildfire in Colorado recorded history. Following the 2012 High Park Fire, new USFS collaborations with Colorado State University (CSU) researchers, the Fort Collins and Greeley water utilities, and the Coalition for the Poudre River Watershed, expanded investigation of post-wildfire effects on water quality to the Northern Front Range.

Our ability to evaluate the effects of the Hayman Fire benefited from a network of stream monitoring sites established by USFS hydrologists prior to the fire. The extent and severity of wildfire varied across the watersheds (Figure 2). Overall, 35% of the Hayman Fire burned at high severity, creating conditions typically linked to significant ecological change. Across our network of sites, we compared watersheds ranging from 0 to 100% burned and <10 to 81% burned at high severity. Not surprisingly, the extent of a watershed disturbed by high severity wildfire in-

High Park Fire, Lory State Park, 2012.

C. Rhoades

P. Fornwalt and T. Fegel

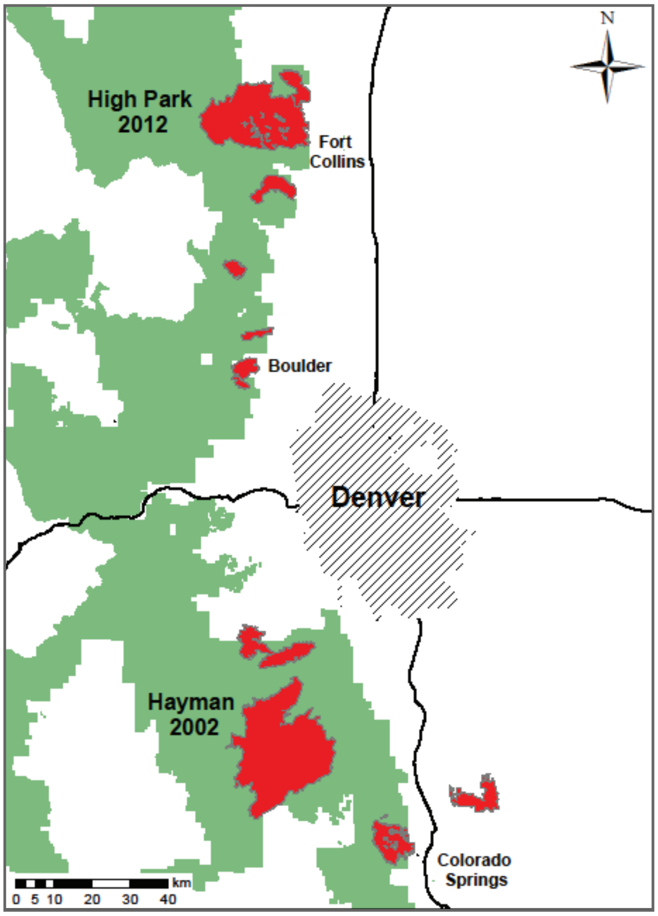

Figure 1. The perimeter of wildfires larger than 6,000 acres that have burned since 1996 and their proximity to Colorado Front Range population centers.

T. Fegel

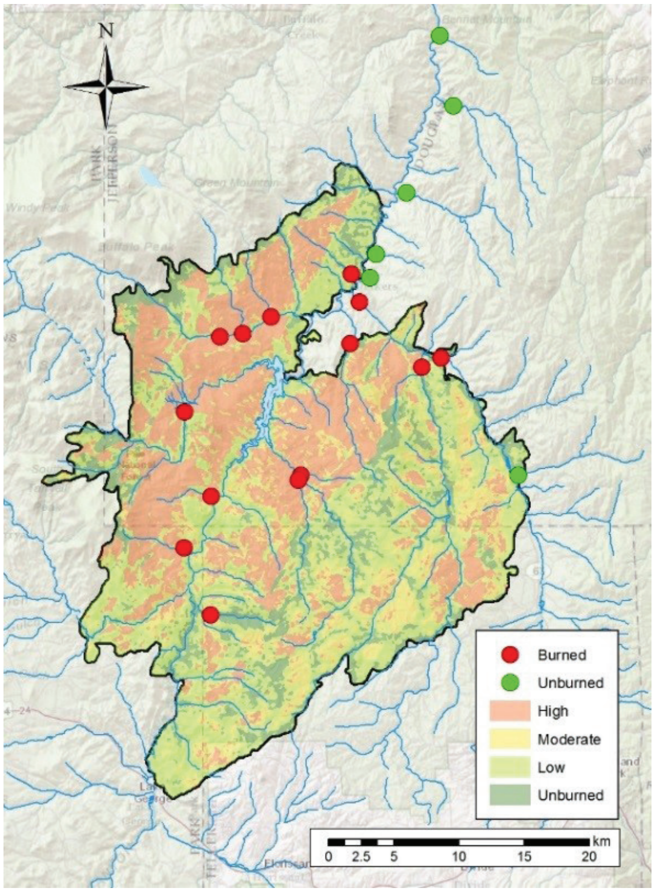

Figure 2. Sampling locations (red and green dots) and the Hayman Fire perimeter in the South Platte River watershed, southwest of Denver. The Fire burned (June 2002) largely on the Pike National Forest and private land surrounding Cheesman Reservoir.

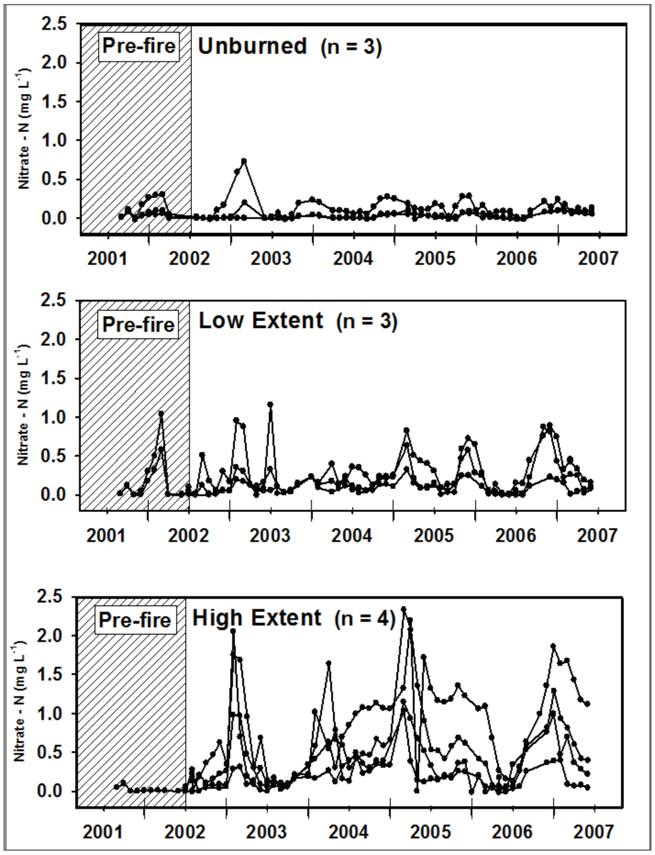

Figure 3. Stream nitrate sampled monthly in tributaries of the South Platte River within and near the 2002 Hayman Fire. Seasonal peak concentrations typically correspond to the spring runoff period.

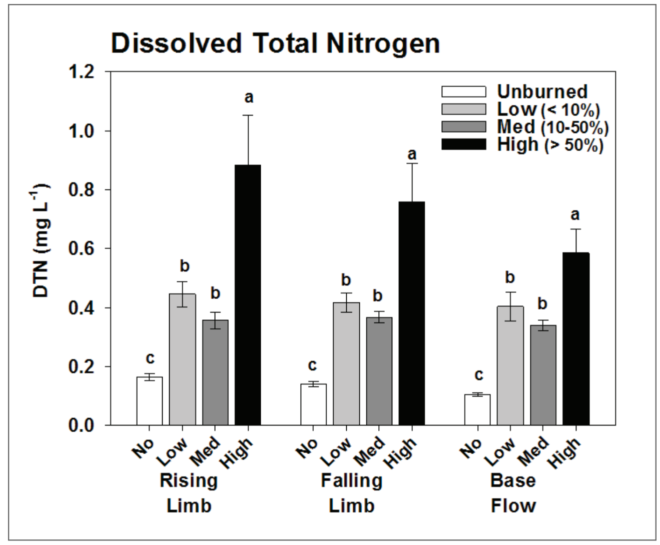

Figure 4. Persistent effect of the Hayman Fire on stream nitrogen concentrations. Bars are seasonal averages from monthly samples collected 13- and 14-years after the fire. Seasonal divisions track the streamflow hydrograph as follows: Rising Limb = March, April, May; Falling Limb = June, July, August; Base = September – February. Different letters denote significant differences among burn severity classes.

Figure 5. A Hayman Fire landscape in 2016 showing the slow forest recovery in areas where high severity crown fire removed forest and organic cover. The downslope forest border delineates areas burned by low severity surface fire.

A. Rhea

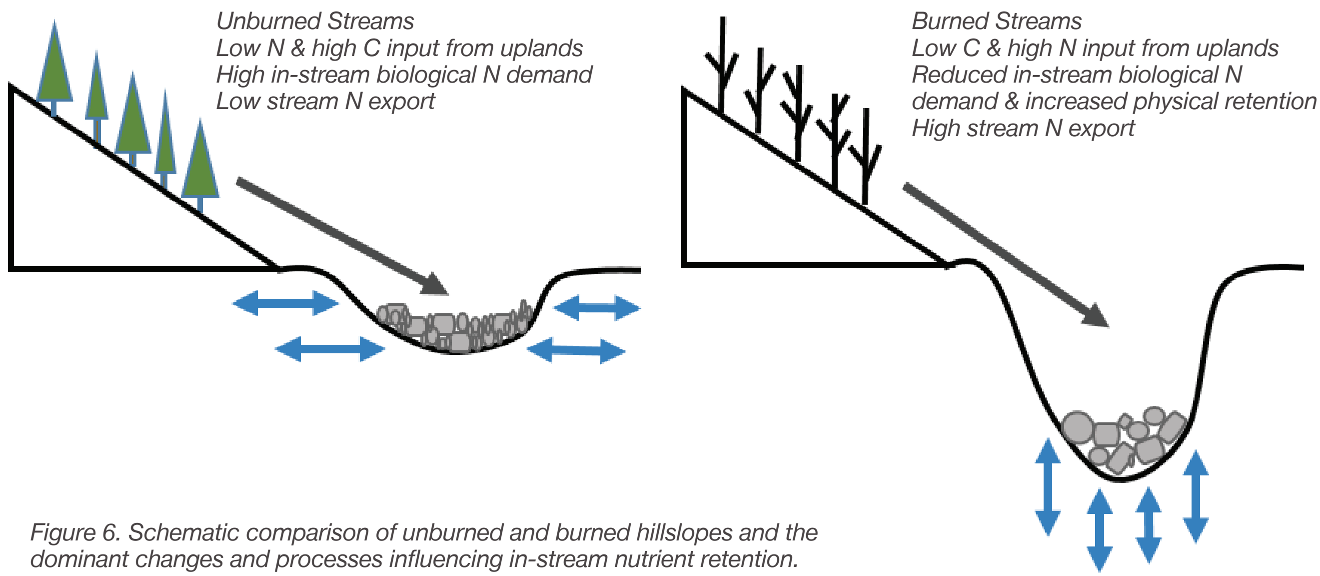

Figure 6. Schematic comparison of unburned and burned hillslopes and the dominant changes and processes influencing in-stream nutrient retention.

fluenced how much post-fire water quality changed. Monitoring conducted the first five years after the fire showed a strong relationship between stream nitrogen and the proportion of a watershed that burned (Figure 3) or that burned at high severity.

Lasting Wildfire Effects – Elevated Stream Nitrogen

Our earlier work showed that high-severity wildfire effects stream nitrate, temperature, and suspended sediment for at least five post-fire years. Recent sampling conducted 13 and 14 years after the Hayman Fire (i.e., 2015 and 2016) found that sediment had largely returned to pre-fire levels. However, stream nitrate remained ten times higher than pre-fire levels in watersheds with extensive high-severity wildfire. Stream temperature and total dissolved nitrogen concentration also remained higher in those streams compared to unburned watersheds (Figure 4). Unburned sites had total nitrogen concentrations typical of unimpaired conditions in forested streams of the Western U.S., according to the Environmental Protection Agency (EPA). Streams in burned watersheds consistently exceeded that threshold.

High severity wildfire consumes nearly all vegetation and surface organic layers (litter, duff), causing nutrient and organic matter losses and changes in soil structure, and soil water infiltration. Moderate severity fires, in contrast, consume up to 80% of organic ground cover, with little effect on soil structure. Foliage may remain in tree canopies after moderate wildfire and subsequent needle cast may add soil cover and mitigate sheet erosion. Surface organic layers are only partially combusted by low severity fire, and soil structure and roots remain unaffected.

Examining How Wildfires Effect Water Quality

High severity wildfires eliminate nearly all vegetation, interrupting plant nutrient demand. The resulting surplus of soil nutrients may then be leached downslope and lost to streamwater. Tree recovery has been slow after the Hayman Fire, though shrubs and herbaceous plants are now relatively abundant (Figure 5). However, our current research in soils and streams suggests that reduced plant demand may not be the only cause of elevated stream nitrogen.

Using a nutrient tracer approach developed by CSU's Dr. Tim Covino, graduate student Allison Rhea began studying nutrient retention and release in watersheds burned by the High Park Fire. Rhea's initial findings indicate that wildfire and subsequent stream channel restructuring have altered both the physical and biological processes that retain nutrients. In general, fire appears to reduce biological uptake, but increase physical retention of nitrogen. Post-fire runoff and erosion alters the geometry and substrate of stream channels, enhancing vertical transport of water and nutrients to the subsurface (Figure 6). Tracer tests also indicate that nitrogen supply exceeds demand in burned streams, unlike the typical low nitrogen concentrations and nitrogen-limited conditions typical of relatively-pristine streams. The decreased nitrogen demand is most likely linked to low stream carbon concentrations in severely-burned watersheds resulting from organic matter combusted during wildfire and compounded by low leaf litter inputs from uplands or riparian zones after vegetation cover is gone.

Additional work carried out in conjunction with Dr. Alex Chow from Clemson University helped characterize the soils charred by Front Range fires and the lasting effects of wildfire on soil nitrogen and carbon cycling. Total soil nitrogen and net nitrogen mineralization (an index of nitrogen supply to plants) were both higher in severely-burned portions of the Hayman Fire than in moderately-burned or unburned areas. This suggests that higher nitrogen supply from soils may contribute to the nitrogen lost to streams. Analysis of the soil char layer indicates that it is comprised of stable, aromatic carbon compounds that resist decay and will therefore have lasting effect on soil nitrogen dynamics.

Spatial patterns of burning within watersheds may further contribute to the water quality responses we have measured. We compared nitrogen in streams whose headwaters emerged in burned vs. unburned forests and found that the highest stream nitrate occurred where the upper watershed burned at high severity. Conversely, so long as the upper watershed remained unburned, wildfire in the lower watershed had little effect on stream nutrients. Post-fire riparian conditions also influence stream water quality. For example, 15 years after the Hayman Fire, streams with sparse riparian vegetation had the highest stream nitrate. Stream temperature was also higher in burned areas especially during spring months and in watersheds with extensive high-severity wildfire.

Restoration Opportunities

Forests and watersheds altered by severe wildfire provide a testbed to increase understanding about ecosystem resilience to disturbance. In recent years, large, high-severity wildfires have helped identify the limits of current knowledge about post-fire responses and recovery of surface water quality and nutrient retention. Our findings regarding persistent nitrogen losses from burned headwaters and exposed riparian zones can help prioritize restoration aimed at mitigating long-term water quality impacts. These areas allow us to test the effectiveness of riparian plantings or other restoration practices at reducing stream nitrogen elevated by severe wildfire (Figure 7). These projects provide numerous opportunities to engage the public as citizen scientists to help monitor post-fire change and contribute to understanding of post-fire recovery.

Fire suppression and emergency post-fire rehabilitation are extremely costly. Wildfire-related activities comprised > 50% of the U.S. Forest Service's 2015 budget and estimates suggest that it could consume 67% by 2025. Fire is a natural process that influences the composition of our forests, but projected increased wildfire size and severity prompt questions about future forest conditions. Much remains unknown about the best ways to manage forests to optimize the ecological benefits of fire and minimize unwanted ecological, human health, and infrastructure consequences. There also remains much to learn about the long term effects of extensive, severe wildfires on stream water quality and aquatic habitat. The persistent post-wildfire effects we found were surprising, but additional long-term studies will help confirm whether they are broadly generalizable. Though future research will reveal more about the factors involved, the implications of our findings have immediate application for using water quality as a tool to identify restoration needs.

J. Kovecsas, Coalition for the Poudre River Watershed

Figure 7. Volunteers planting willows for post-wildfire riparian restoration at the High Park Fire.