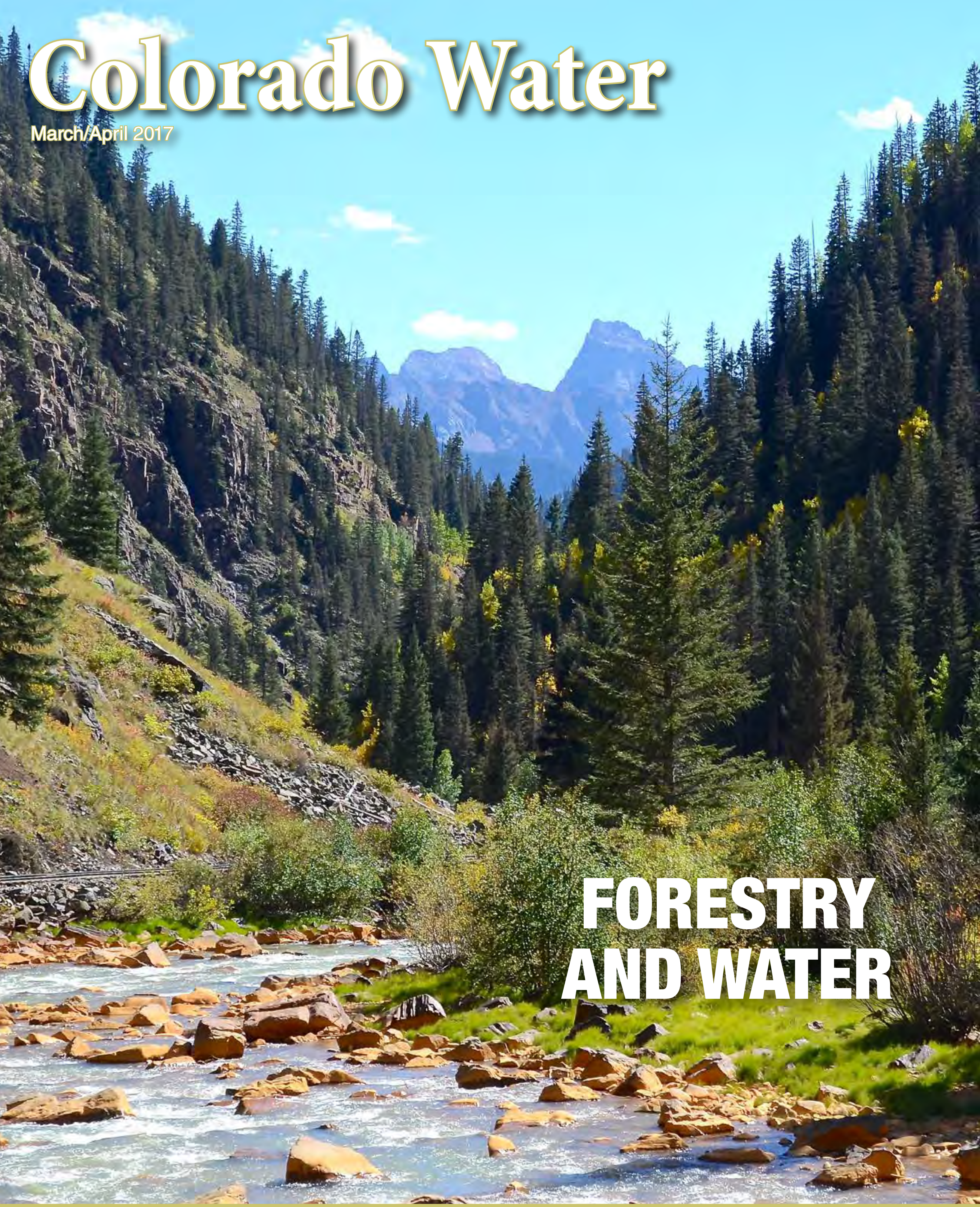
Colorado Water

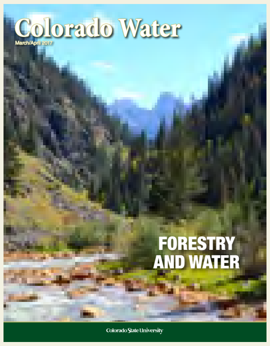
March/April 2017



FORESTRY AND WATER

Colorado State University

Features — Forestry and Water



On the cover: The Animas River. Photo by Woody Hibbard

From our Cooperators

In Every Issue

Cooperators include the Colorado State Forest Service, the Colorado Climate Center, and CSU's Water Resources Archive.

COLORADO **WATER**

Volume 34, Issue 2

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Director's LETTER

Colorado is sometimes called the "Mother of Rivers", other times the "Headwaters State", reflecting our geographic position straddling the spine of the Rocky Mountains and the rivers that originate from mountain snowpack. The Yampa, North and South Platte, Laramie, Arkansas, Rio Grande, White, Gunnison, San Juan and Colorado Rivers all start as trickles of melting snow in the mountains, transforming into rivers as they move through the high country forests that make up the headwaters of our watersheds. These wildlands deliver some of the purest water in the continental United States, yet a legacy of mining, logging, road construction, urban encroachment, and fire suppression underscore that these watersheds are not impervious to human activities and must be properly managed if they are to provide the water quantity and quality we depend on. Literally thousands of miles of streams and millions of acre-feet of water wend their way through our forests before spilling out on the plains and flowing to 18 downstream states and Mexico.

The state of our forests has been at the forefront of policy and research discussions for the past 15 years in Colorado as we suffered the loss of millions of acres of beetle killed trees and catastrophic wildfires followed by devastating floods and debris flows from burn areas. While we periodically hear the call to increase logging to enhance water yield from forestlands, watershed scientists and forest hydrologists agree that our goal should be management approaches that improve the health of our forests, which includes timber harvesting, fire, and other management tools. Healthy forests absorb rainfall and snowmelt and allow it to runoff slowly, recharge aquifers, sustain streamflows, and filter contaminants. In the long run, healthy forests will deliver the optimum water quality and quantity that we rely on.

The consequences of past forest management, human settlement in the forests and attendant fire suppression have become all too apparent across the West. As you will read in this newsletter, the Colorado State Forest Service and the U.S. Forest Service are working with public and private landowners, stakeholder groups, water providers and nongovernmental organizations to better steward these land resources. There will never be enough funding to accomplish all of the needed management, so we have to be efficient, putting our resources where most needed and where the greatest impact can occur. Partnerships are the only way we will achieve the large-scale work needed to protect our forested watersheds.

Colorado's Water Plan clearly recognizes the importance of our forests in the future of our water supply and notes the increased vulnerability that warmer future temperatures could bring by increasing the frequency and severity of wildfire, and making trees more vulnerable to insect infestation. The Water Plan states that approximately 80 percent of Colorado's population relies on forested watersheds to deliver municipal water supplies. Whether we realize it or not, our forestlands are absolutely critical to the well being of all Coloradans.

We are pleased that the Colorado State Forest Service is an ongoing partner with the CSU Water Center and the Colorado Water Institute in the production of the Colorado Water newsletter. This issue of our newsletter is devoted to the link between our forests and our water supplies.

Reagan Waskom
Director, Colorado Water Institute

West Fork Complex Fire, Creede, Colorado

Tech Sgt. Wolfram M. Stumpf

Achieving Healthier Forests for Cleaner Water

Michael B. Lester
State Forester and Director
Colorado State Forest Service

Ryan Lockwood, CSFS

Colorado's headwaters play a crucial role in meeting our nation's need for fresh water. Some 19 states derive at least some of their water supply from our forested high-country watersheds, and Colorado's Water Plan indicates that approximately 80 percent of our population depends on forested watersheds for municipal water supplies.

But these watersheds often suffer the same fate as the forests themselves. When forest health declines, so may the quality of the water yield flowing through those forests. Yet many of our high-country forests have become unhealthy and overly dense. These forests can set the stage for potentially devastating wildfires or insect and disease outbreaks.

Because of the intertwined relationship between wildland fire, forest health and Colorado water supplies, and the need to raise awareness of this relationship, the theme of the 2016 Report on the Health of Colorado's Forests, released by the Colorado State Forest Service (CSFS) in February, was "Fire & Water." Likewise, the theme of this issue of *Colorado Water* is another clear indicator of the recognized importance of the link between healthy forests and clean, reliable water supplies. It also provides a means to continue the necessary work of educating various stakeholders about the forests/water relationship.

How Forests Impact Water

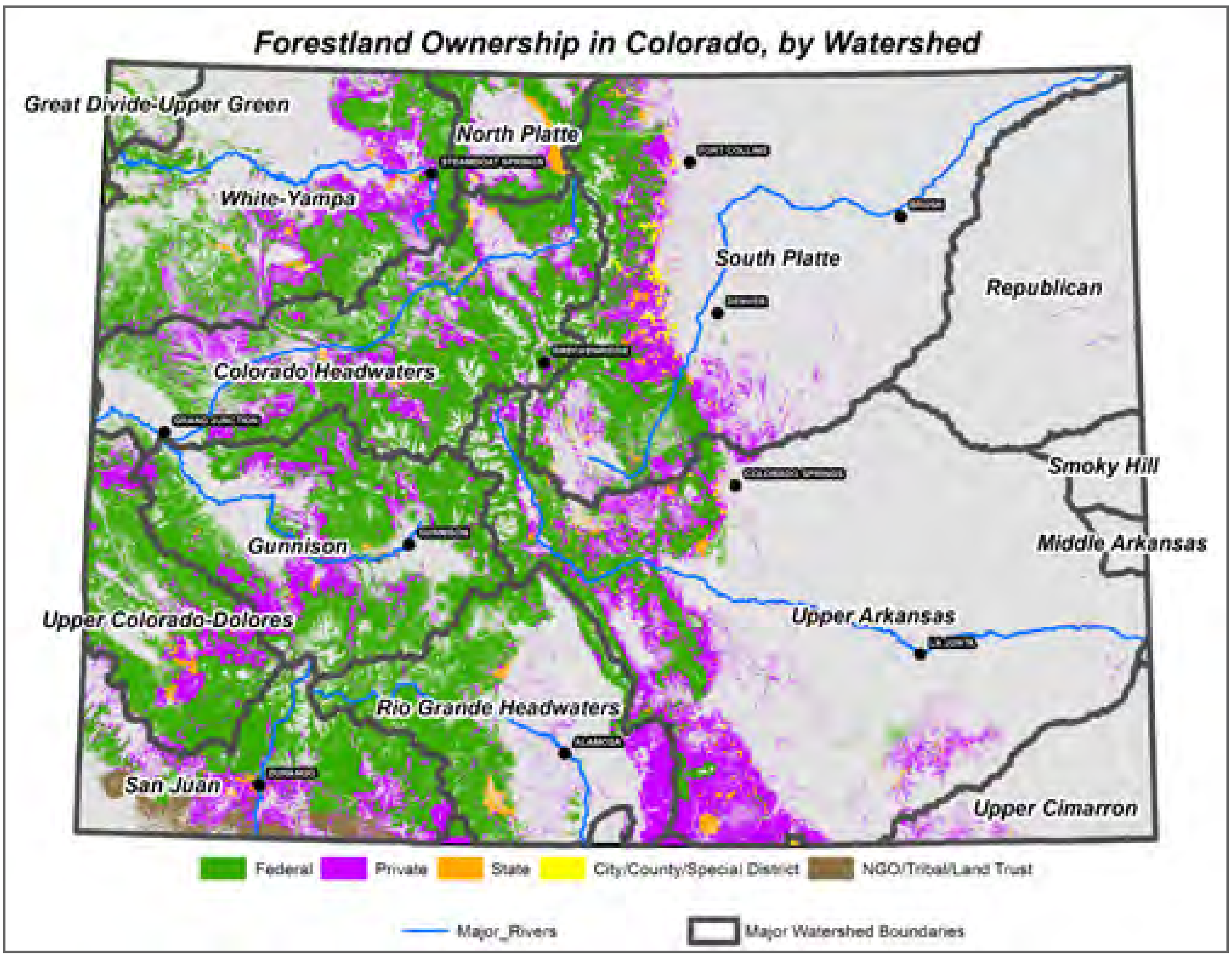
As we have all seen in recent years, intense Colorado wildfires often lead to severe runoff and soil erosion during storms. In areas where a wildfire burns at high intensity, the combustion of vegetation removes cover necessary to protect bare soil from falling and flowing precipitation. It also creates a gas that penetrates the soil profile to form a waxy coating. This coating can make soils water-repellent, or hydrophobic, further increasing water runoff and erosion. The resulting high rates of runoff and erosion during post-fire weather events can greatly lower water quality in nearby streams, and ultimately clog reservoirs downstream with sediment, impacting urban and agricultural interests. Also, the canopy in forests with extensive mortality from insects and disease or wildfire may be altered until the forest is able to regenerate, resulting in changes to the timing of snowmelt and runoff – which also has implications for water users.

Large, devastating wildfires like the Hayman (2002), High Park and Waldo Canyon (both in 2012) fires on the Front Range, and also the 2013 West Fork Complex in southwest Colorado, can greatly increase the potential for flooding, erosion, and water quality concerns. It can take years for soil hydropho-

(Above) Seedlings growing at the CSFS Nursery in Fort Collins, to be used for conservation purposes.

The High Park Fire burning west of Fort Collins, Colorado, June 2012.

Mike Hughes, CSFS



Colorado State Forest Service

Despite a high degree of federal land ownership in Colorado, approximately 30 percent of the state's forestlands are privately owned.


Grace Mirzeler, Council of Western State Foresters

State Forester Mike Lester works with partners at an insect and disease workshop.

bicity to diminish and vegetation to return and stabilize steep slopes; until then, flooding and erosion remain serious concerns to water supplies downhill from burn areas.

Protecting Water Through Forest Management

It is imperative that we manage Colorado's watersheds at a landscape scale to improve their health and resiliency. The High Park Fire provides a good example of the effectiveness of forest management to later reduce wildfire risk. During that event, high-severity fire was prevented within previous fuels treatment areas in Lory State Park, where stand thinning occurred. As a result, the watershed for Horsetooth Reservoir was not as seriously threatened by post-fire runoff. In contrast to these treated areas, none of which burned at high severity, approximately 8 percent of all burned acreage within the 87,000-acre fire area burned at high severity. Those approximately 7,000 acres were much more susceptible to flooding and erosion in later storm events.

It is the role of agencies like the CSFS to ensure that private landowners, who are the stewards of most non-federal lands, have the tools they need to address forest and watershed health, including wildfire risk. Our foresters work with state and federal land managers, water providers, local governments, and private landowners to help protect water supplies through effective forestry practices. Every year, the CSFS helps treat more than 17,000 targeted acres of forestland and assists approximately 2,000 landowners to improve forest health and reduce risks to watersheds. Forest management efforts that thin forests, change vegetative fuel structures and remove fuels on private lands are critical because, according to a 2015 report by the American Forest Foundation, almost 40 percent of important watersheds at high risk to wildfire in the West are private or family-owned.

The CSFS also grows seedling trees and shrubs in its Fort Collins nursery, distributing more than half-a-million each year for conservation goals including reforesting burned or flooded areas, enhancing wildlife habitat, and re-stabilizing stream banks after flooding. Our agency works closely with wildland restoration groups to get these seedlings planted on lands impacted by wildfires, floods, and other disasters. Almost 300,000 CSFS seedling trees have been planted since 2003 to help restore the Hayman Fire burn area, and more than 30,000 additional seedlings have gone into efforts to restore forests impacted by the destructive 2012-2013 Colorado wildfires and areas impacted by the 2013 Colorado floods.

Another way to protect water in forested settings is by addressing erosion risks due to wood harvesting, building roads, and other human activity. The CSFS helps address the risk of this sort of "nonpoint source pollution" to water supplies by providing Forestry Best Management Practices (BMPs) for the state. These guidelines help forest landowners, land management agencies and commercial or other timber harvesters protect water supplies and avoid unintentionally polluting them.

Partnerships, Legislative Support Vital for Success

Watershed issues of a landscape scale cannot be accomplished by a single organization. It takes a team approach. CSFS partnerships with other federal and state agencies, including the U.S. Forest Service (USFS), Colorado Parks and Wildlife, and with water providers like Denver Water and Northern

Ryan Lockwood, CSFS

Mike Hughes, CSFS Fort Collins District, and his son plant seedlings together for forest restoration after the 2012 High Park Fire.

> Every year, the CSFS helps treat more than 17,000 targeted acres of forestland and assists approximately 2,000 landowners to improve forest health and reduce risks to watersheds.

Water, allow stakeholders and land managers to work together to make the greatest possible impacts in the health of the forestlands that supply our water. Active forest management, particularly in critical, high-priority watersheds like the South Platte, Colorado and Big Thompson, can mitigate watershed health risks. Working with our partners, across boundaries, we can take a landscape-level approach to leveraging our limited resources where they will achieve the greatest benefit.

Forest and watershed management would not be possible without the necessary funding and resources. Forestry-related legislation and funding generated by the Colorado General Assembly has had widespread positive impacts on the health and diversity of Colorado's forests. Many crucial forestry-related bills have passed through the State Legislature, enabling community-based forest restoration, protection of watersheds, and the fostering of intergovernmental cooperation. An example is the Colorado Healthy Forests and Vibrant Communities Act of 2009. Through 2017, this legislation will continue to provide resources to the CSFS to address wildfire and watershed risks, increase outreach efforts, and allow for forest treatment solutions.

Also, in 2016, the Colorado General Assembly passed further legislation that will allow for enhanced management of Colorado watershed conditions. House Bill 16-1255 will address management in three ways: through funding pilot Good Neighbor projects under a new Master Good Neighbor Agreement in Colorado (which leverages state resources to most efficiently accomplish work on National Forest System lands); a statewide watershed analysis; and via the establishment of a CSFS-led Forest Health Advisory Council. The bill's watershed analysis in particular requires the CSFS, in conjunction with the Colorado Water Conservation Board, to compile and summarize existing information to quantify and document the relationship between Colorado's Water Plan and the importance of forest management in protecting and managing the state's water resources.

Colorado's forested watersheds and those they serve face many challenges. But these can be addressed through targeted forest management, legislative and public support, and by strengthening key partnerships that have a common goal of ensuring clean, stable water supplies. The complexity of Colorado's forests and the land ownerships within them stresses how important it is that we all work together to bring a broad range of perspectives, individuals and organizations to the table to ensure healthy watersheds.

Legislation to Enhance Watershed Management

Joseph Duda, Deputy State Forester, Colorado State Forest Service

In 2016, the Colorado General Assembly passed new legislation that will allow for enhanced management of Colorado watershed conditions. House Bill 16-1255 will address management in three ways: through funding pilot "Good Neighbor" projects under a new Master Good Neighbor Agreement in Colorado; a statewide watershed analysis; and via the reinstatement of a Colorado State Forest Service (CSFS)-led Forest Health Advisory Council.

The Good Neighbor Authority addressed in this bill promotes greater efficiencies using state personnel and contracting authorities, in combination with project development and expertise from the U.S. Forest Service (USFS), to address forest management work on federal lands. This allows more work to be done, more quickly and for less money. In 2015, Colorado became the fourth state to finalize this type of forest management agreement between state and federal forestry agencies via a Master Good Neighbor Agreement. In the agreement, the USFS and CSFS formalized an expanded federal-state partnership that will indefinitely enable and increase management efforts on federal lands. Eligible projects include those that protect water supplies, reduce wildfire risk, and meet other forest management objectives.

This bill will allow the state and federal forestry agencies to fully explore and develop operating procedures that utilize the Good Neighbor Authority to increase the amount of stewardship work that can occur on federal lands. Additionally, the focus will be on projects that produce wood products that can be used by forest product businesses. The first two Good Neighbor pilot projects funded by this bill are currently being implemented in Colorado. The first project is an 86-acre timber salvage harvest operation in the CSFS Montrose District to help address spruce beetle mortality on the Uncompahgre National Forest. The second project is focused on public permit-oriented wood removal projects in the CSFS Alamosa District, to address beetle-kill in the Rio Grande National Forest. Both projects will supply forest products to businesses and for local use, and reduce the fuels available for wildfire.

USFS and CSFS personnel are meeting early in 2017 to discuss the planning of projects that could be implemented over the next several years using the Good Neighbor Authority. The objective is to fully utilize the expertise of both agencies and to maximize the work being performed on the landscape.

The 2016 House Bill's watershed analysis component requires the CSFS, in conjunction with the Colorado Water Conservation Board, to compile and summarize existing information to quantify and document the relationship between Colorado's Water Plan and the importance of forest management in protecting and managing the state's water resources. The compilation will include a summary of the potential costs and effects on watersheds, communities, water users, and

Joseph Duda, CSFS

The smoke plume from the 2013 West Fork Complex Fire, viewed from South Fork, CO.

infrastructure, if appropriate forest management does not occur in a forested area prior to a wildfire. The Colorado Water Plan provides the ideal means to host this information, as forest health and resiliency has direct and sometimes profound impacts on water supplies. The compilation of information will be completed by July 1, 2017.

The revival of a Forest Health Advisory Council for Colorado will enable the State Forester to receive direct feedback from a broad base of key stakeholders – including nonprofits, water and utilities providers, fire protection professionals, and timber industry representatives – to best identify the leading forestry concerns across the state. Currently, there are many local organizations that serve various constituencies and areas across the state of Colorado. The Forest Health Advisory Council allows a direct mechanism to provide the State Forester with advice and information on forestry, watershed and wildfire issues from a wide range of constituents, and allows new ideas and solutions to be brought forward outside the constraints of current practices and operating protocol.

Joseph Duda, CSFS

The 2013 West Fork Complex Fire left many soils hydrophobic.

With the recent increases in forest fires and insect and disease activity impacting Colorado, it is time to create this forum for a thoughtful dialogue that can provide solutions for forest and water managers to embrace. Ultimately, the state's forests will benefit, which will translate to a multitude of other benefits for those within and outside of Colorado.

Benjamin Gannon

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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Kelly Jones, Assistant Professor, Human Dimensions of Natural Resources, Colorado State University,
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Rob Addington, Ecologist, The Nature Conservancy,
Tony Cheng, Professor, Forest and Rangeland Stewardship, Colorado State University, and Director, Colorado Forest Restoration Institute,
Jeffrey Cannon, Research Associate, Colorado Forest Restoration Institute

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

Benjamin Gannon

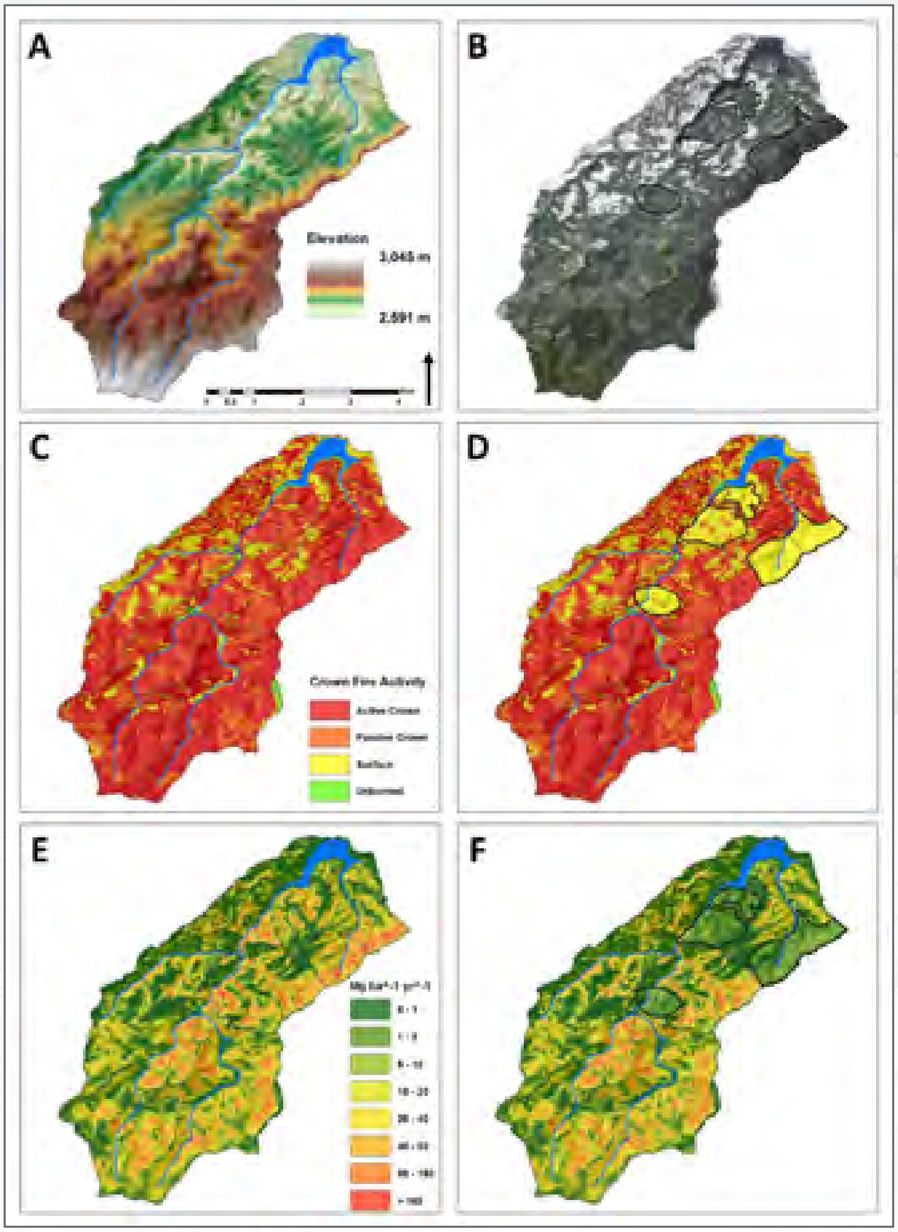


Figure 2. Fire and erosion models can be linked to assess the effectiveness of fuel treatments. A) Watershed contributing to Eaton Reservoir in Northern Larimer County. B) Aerial photography (National Agriculture Imagery Program) showing the distribution of vegetation and hypothetical fuel treatments (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.

From Forests to

Partnerships Treat Landscapes to Protect Denver's Water Supply

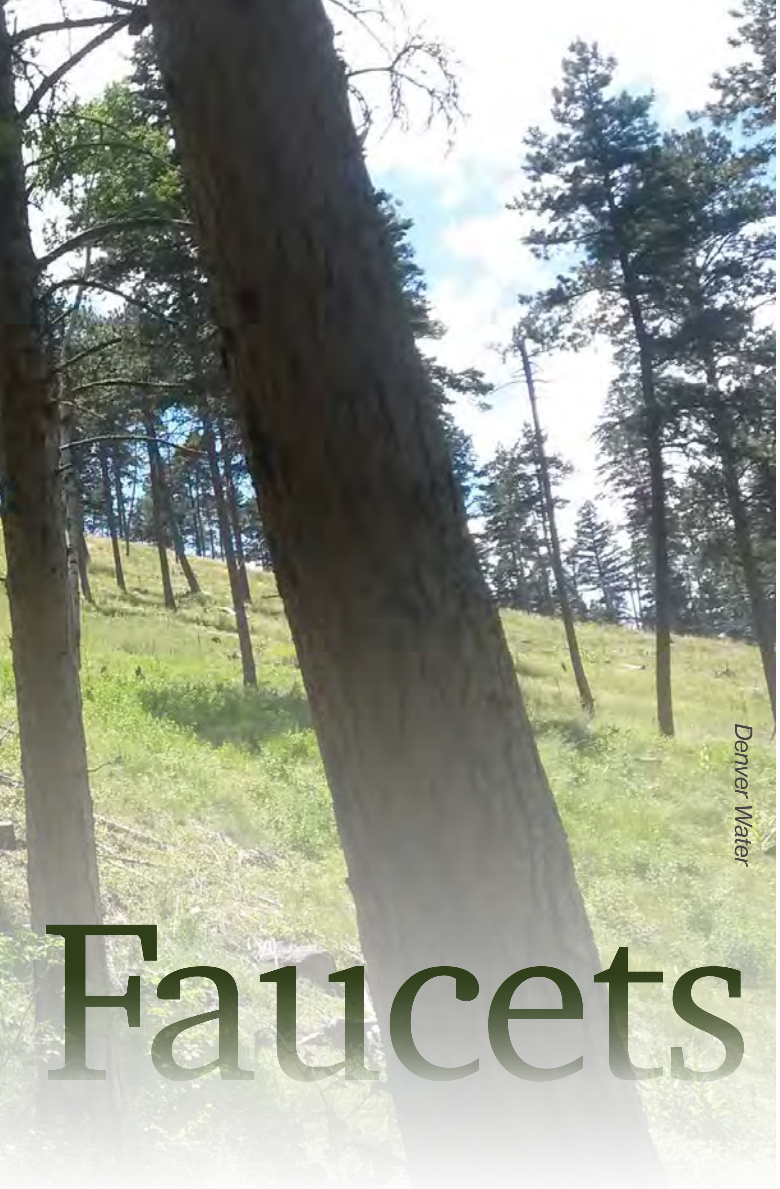
Ryan Lockwood, External and Media Communications Program Manager, Colorado State Forest Service

The forested Upper South Platte Watershed, which provides the majority of Denver's water supply, is no stranger to severe, record-breaking wildfires. The 1996 Buffalo Creek Fire, at the time considered the most damaging and costly fire in Colorado history, occurred 10 miles north of Cheesman Reservoir and burned 11,900 acres. The multi-million-dollar Hi Meadow Fire then burned near Bailey in 2000, and two years later, the 138,000-acre Hayman Fire broke new records as the largest and most destructive blaze in state history, leaving soils sterile and much of the landscape barren.

Runoff from rainstorms that followed these fires carried silt, ash, and debris into creeks, rivers, and lakes critical to Denver's water supply, most notably Strontia Springs Reservoir, where dealing with lost storage capacity and water quality concerns has cost more than $27 million. Besides the fact that the 1.2 million-acre Upper South Platte Watershed provides the Denver Metro area with approximately half of its water, it also is home to hundreds of thousands of residents living in or near the wildland-urban interface (WUI) and is a popular destination for outdoor recreation. And built within it are millions of dollars' worth of utilities, communications, transportation, and other infrastructure that could be impacted by wildfires and post-fire flooding.

While substantial, the impacts of past wildfires here could have been worse. Because for more than three decades, Denver Water – Colorado's oldest and largest water utility – has worked with the Colorado State Forest Service (CSFS), and more recently also with the U.S. Forest Service (USFS) and other agencies and organizations, to ensure that tens of thousands of targeted acres have been treated to reduce wildfire risk and protect the watershed.

(Above) Forestland in Jefferson County thinned to reduce tree densities and reduce wildfire risk.


Denver Water

Faucets

A History of Active Watershed Management

Serving 1.4 million people in the metro area, Denver Water has a long history of making significant investments to mitigate wildfire risk and help prevent damage from post-fire rain events – to protect source water quality, decrease debris flows and erosion, and prevent expensive damage to its reservoirs and infrastructure. To achieve watershed protection measures at a truly effective landscape scale, the utility has for years participated in many public/private partnerships and collaboratives.

One of the earliest was a partnership with the CSFS to treat Denver Water-owned lands beginning in the mid-1980s. Following a mountain pine beetle outbreak erupting in the decade prior, the utility first contracted the CSFS to assist in managing watersheds on its land near high-country reservoirs in Grand County. In 1985, the first formal forest management plan was developed, which later evolved into a multi-year Forest and Land Management Service Agreement (FLMSA) still in use today.

Later, following the Buffalo Creek Fire in the late 1990s, the first official wildfire watershed assessment for the Upper South Platte Watershed was cooperatively completed by the CSFS, Denver Water, U.S. Environmental Protection Agency (EPA), and USFS. The 2002 Hayman Fire resulted in the Upper South Platte Watershed Restoration Project, which has since treated more than 40,000 acres on Denver Water, USFS, and private land through fuels reduction of forest vegetation.

In 2010, Denver Water and the USFS entered into a $33 million, five-year partnership formally known as the “From Forests to Faucets” program. Forest treatments executed through this program were essentially wildfire mitigation efforts on National Forest lands, equally funded by Denver Water and the USFS. Under the “From Forests to Faucets” approach, Denver Water continues to lead efforts with government agencies and NGOs to empower local implementers to install science-based forest restoration projects on private, federal, and other lands to ensure landscape-scale effects.

“From Forests to Faucets is a successful collaborative partnership between Denver Water, the CSFS, U.S. Forest Service, and Natural Resources Conservation Service to implement forest health projects to reduce the risk of catastrophic wildfire in the watersheds that are critical to our water supply,” says Christina Burri, Denver Water’s watershed scientist. “The effort also restores forests impacted by catastrophic wildfires.”

Besides efforts through the “From Forests to Faucets” program, the ongoing CSFS/Denver Water agreement now focuses on forest management across more than 50,000 targeted acres, eight counties, and five CSFS districts. Work is primarily focused on the northern part of the Upper South Platte Watershed, which is largely private land. Annual work planning between the CSFS and Denver Water focuses on activities in high-priority areas, such as: creating and maintaining defensible space around utility infrastructure, forest management planning, noxious weed management, creating shaded fuelbreaks (i.e., areas where forest stands are thinned) along firefighter and resident ingress/egress routes, and timber stand improvement.

“Denver Water has been a leader in getting key agencies and organizations together to address watershed health on Colorado’s Front Range,” says Scott Woods, Assistant Division Supervisor, CSFS Forest Management Division.

The Upper South Platte Partnership

More recently, Denver water worked with government agencies, nonprofits, and academic institutions to form the Upper South Platte Partnership (USPP) to plan, implement and manage forest treatment projects and wildfire mitigation-related community outreach efforts. Developed in early 2015 based on previous and ongoing collaboratives, including the Front Range Fuels Treatment Partnership and the Watershed Wildfire Protection Group, the USPP has a mission to “develop, maintain, and enhance the quality and sustainability of the landscape and watershed." Members include:

- Denver Water
- Colorado State Forest Service
- U.S. Forest Service (USFS)
- The Nature Conservancy (TNC)
- Coalition for the Upper South Platte
- Jefferson Conservation District
- Natural Resources Conservation Service
- American Forest Foundation
- Colorado Forest Restoration Institute (CFRI), Warner College of Natural Resources, Colorado State University

DENVER WATER

Of key importance to the partnership is the strategic prioritization of fuels reduction treatment sites, to maximize the impacts of dollars spent to reduce the watershed's vulnerability to wildfires. Fuels reduction-based forest restoration treatments will include forest thinning and prescribed fire, targeting locations of high risk to wildfire and that would most likely adversely impact water supplies. Prioritization also considers proximity of homes, infrastructure and other values at risk. USPP members are working toward a common goal of implementing private and public land treatments for forest restoration, fuels management and watershed protection.

Just after its development, the USPP recognized the National Cohesive Wildland Fire Strategy as a potential funding source, made available for pilot projects through the USDA Forest Service's State and Private Forestry branch. A result of the 2009 Federal Land Assistance, Management, and Enhancement (FLAME) Act, this "Cohesive Strategy" provides a framework for coordinating and integrating wildfire efforts. These efforts must be based on three main goals: restore and maintain landscapes, create fire-adapted communities and improve wildfire response.

Similarly, the USPP will focus on three top priorities related to goals of the Cohesive Strategy: forest and watershed resilience, fire-adapted communities, and coordinated response to wildfire. To address these priorities, the USPP's focus will include projects that demonstrate potential for impact on:

- Active crown fire potential and forest characteristics that influence forest stand resilience to disturbance
- Community awareness and preparedness, regarding the inevitability of wildland fire and the need for active forest management
- Private and public cooperation and efficiency across fuels mitigation projects
- Options and strategic advantages for fire suppression efforts
- Fire intensity and spread near firefighter access and community evacuation routes
- Firefighting capacity and resources

Seeking funding to address landscape-scale treatments, USPP members submitted a pilot project proposal to the USDA Forest Service in 2015 and received approximately $2 million to be divided between TNC and the CSFS.

"The Colorado State Forest Service is focused on bringing together funders and implementers to improve landscape resilience in the watershed, through proactive fuels and forest management," said Woods. "Landowner and community assistance are two of our core goals for this partnership."

What's Next?

Denver Water, the CSFS, USFS, and Natural Resources Conservation Service recently funded a second round of the "From Forests to Faucets" program to increase treatment activities on federal and private lands within multiple smaller watersheds. Also, after the utility renewed its current forest management service agreement with the CSFS for treatment on its own lands, the organization simultaneously initiated a new, five-year "Denver Water Non-Federal Lands Forest Treatment Partnership" agreement. Starting in 2015, the organization provided a $1.65 million contribution to support the Coalition for the Upper South Platte, Jefferson Conservation District, and CSFS to conduct forest thinning and removal of vegetation in targeted non-federal areas to reduce potential for wildfire. Funding also was directed to the Colorado Forest Restoration Institute to conduct monitoring on these treatment sites.

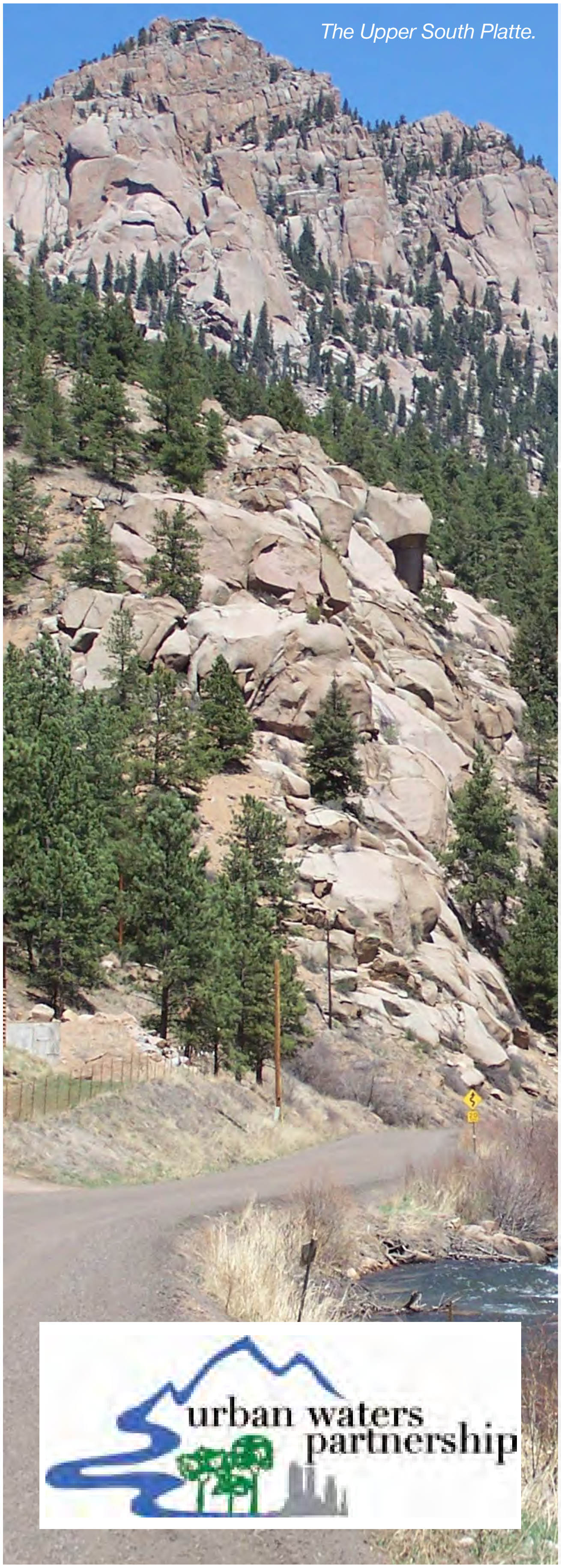
The CSFS continues working with private residents, public land agencies, and USPP partners to design projects that balance landowner objectives and science-based treatment goals in conjunction with the National Cohesive Strategy. Implementation of the first USPP project by the CSFS began in January 2017 and will continue this year.

Woods says that the USFS likewise continues to be a strong supporter and participant in the partnership, and that joint planning on federal and non-federal lands continues to be a focus to leverage USPP efforts and funding for maximum benefit in the Upper South Platte.

Denver Water land near the Upper South Platte River, after forest thinning efforts to reduce the risk of catastrophic wildfire and related watershed concerns.

Ryan Lockwood, CSFS

CSFS



The Upper South Platte.

Partnership Focuses on South Platte's Urban Waters

Keith Wood, Community Forestry Program Manager, Colorado State Forest Service

Recognizing the importance of the South Platte River Watershed and the key role forest management plays from its headwaters to the plains, the Colorado State Forest Service (CSFS) began coordinating a related Urban Waters Partnership in 2013. The purpose is to reconnect urban communities – especially those that are underserved or economically stressed – with their local waterways, and to improve collaboration among agencies striving to improve those waters.

Specific program objectives include addressing waterway protection and restoration, ensuring community involvement and education, and working with local officials and community-based organizations to leverage local expertise and funding. A key effort of the partnership currently being coordinated by the CSFS is the Natural Capital Resource Assessment – a collaborative green infrastructure assessment with funding from the USFS. This assessment will build on existing studies in the South Platte River corridor and watershed to:

- Create an assessment that maps and evaluates the regional network of green/riparian infrastructure.
- Prioritize key areas for conservation and restoration based on the economic value of benefits obtained from natural systems ("ecosystem services").
- Sustain and enhance the sharing of ideas, data and resources across organizations.

For more information, contact Keith Wood, CSFS community forestry program manager, at keith.wood@colostate.edu.

John Twitchell, CSFS Steamboat Springs District, shares how BMPs are used on forest management projects in the Colorado State Forest.

Lisa Mason, CSFS

Best Management Practices Help Protect Water Quality

Ryan Lockwood, External and Media Communications Program Manager, Colorado State Forest Service

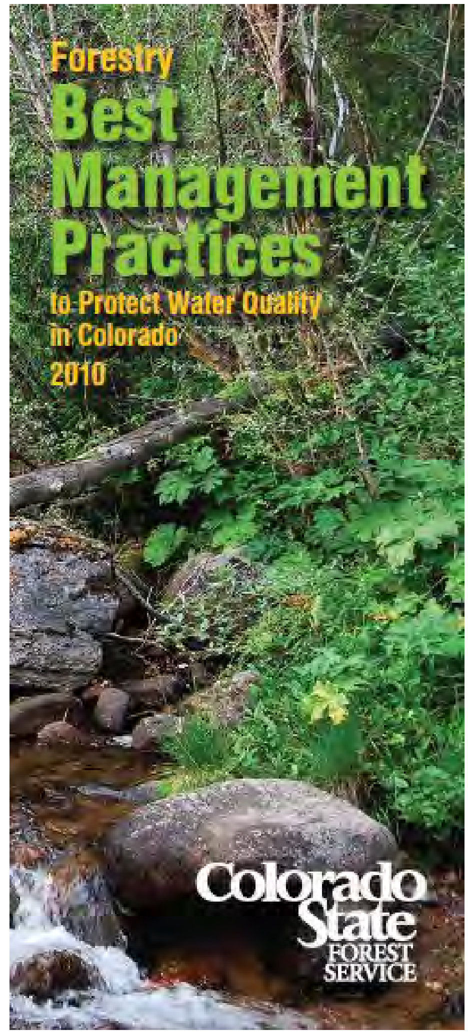
Forests, fish, and wildlife all depend on water that originates as rain and snow over Colorado's high country. Thousands of farms and millions of residents also depend on this water yield. However, the quantity and quality of the state's water yield can be affected by necessary but possibly high-impact human activities like logging and road or bridge construction. These activities disturb vegetation and soil, and have the potential to generate "nonpoint source pollution" caused by precipitation flowing across and filtering into the ground and mobilizing human-generated pollutants, as well as sediments. These pollutants flow downhill and ultimately can impact lakes, rivers, wetlands, and groundwater sources.

To mitigate the risk of nonpoint source pollution to water supplies, the Colorado State Forest Service (CSFS) offers guidelines to protect water quality and minimize erosion in the form of Forestry Best Management Practices (BMPs) for Colorado. These guidelines provide recommendations for implementing these forest activities, which are based on the collaborative experience and observations of natural resource professionals from multiple agencies. They help forest landowners, land management agencies, and the timber industry to protect water supplies and avoid inadvertently polluting them. Federal land management agencies subscribe to these practices, but they are not mandatory on private lands in Colorado.

"These management practices are voluntary," said Rich Edwards, Assistant Staff Forester with the CSFS Forest Management Division. "However, we highly encourage anyone who works in or owns forestlands to use the BMPs whenever constructing roads or trails, establishing streamside management zones, harvesting timber, applying pesticides or fertilizers, or designing stream crossings."

In 2010, the CSFS released the current water quality protection guidelines for individuals and organizations conducting forestry-related activities in Colorado. *Forestry Best Management Practices to Protect Water Quality in Colorado: 2010* represented a thorough revision to previous 1998 guidelines and were condensed from a larger publication on watershed BMPs created by the CSFS, Colorado Timber Industry Association, Colorado Nonpoint Source Task Force, and U.S. Environmental Protection Agency (EPA). The water quality BMPs addressed in the publication apply to all forest management activities, including wood harvesting operations, fuels mitigation projects, prescribed fire, forest health treatments, invasive tree species removal, and road construction. They also apply to other land management efforts, such as applying pesticides to control weeds. Guidelines include specific advice on such topics as designing, constructing and grading roadways, which can potentially produce up to 90 percent of sedimentation from forest activities, and post tree-harvest soil stabilization methods for loggers. The guidelines apply to both forestry professionals and private landowners harvesting timber or extending roads through forested watersheds.

Biennially since 2008, the CSFS, in cooperation with researchers and other state and federal agencies, also has monitored the application and effectiveness of forestry BMPs through audits and field monitoring. The objectives are to determine if the BMPs are being implemented and evaluate their effectiveness in protecting water resources. A total of 79 forestry-related BMP guidelines, which include minimizing the number of access roads necessary per project and retaining sufficient post-harvest woody material on the ground for ecological benefits, are evaluated for each site. Audit results foster adaptive changes to the BMP guidelines, and help identify landowner, logger and forester training needs.



Over the past eight years, BMP audits have been completed in Colorado at 18 field sites representing 26 counties and five National Forests. The data from those audits were analyzed and the field monitoring results show an average of 85 percent implementation and also an 85 percent effectiveness rate to date, for all sites and practices monitored.

All recommendations from the BMP audits and subsequent reports are used for educational and outreach purposes only, with confidentiality provided to contractors and landowners.

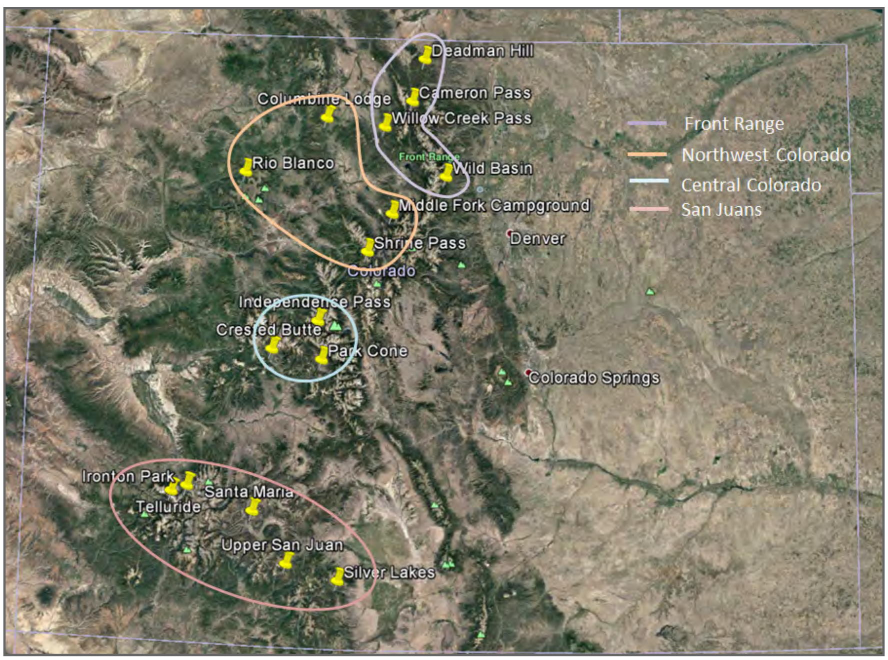
"Forestry-related BMPs set the standard for water resources protection in natural resources management," says John Stednick, Professor for the Watershed Science program at Colorado State University (CSU). "CSFS audits show a high implementation rate of BMPs on forested lands, and their overall effectiveness demonstrates protection of water resources from nonpoint source pollution."

For more information about Colorado's forestry BMPs or to obtain copies of the related CSFS publication with guidelines, contact a local CSFS district office. District locations and contact information are available online at www.csfs.colostate.edu.

Colorado's Climate and Forests

An Update on Snowpack's Developing Relationship with Climate Change and the El Niño Southern Oscillation

Peter Goble, Research Associate, Colorado Climate Center,
Nolan J. Doesken, Colorado State Climatologist, Colorado Climate Center



COLORADO CLIMATE CENTER

Figure 1. The map is a satellite image of the state of Colorado courtesy of Google Earth with the state boundaries marked in white. Each yellow pin indicates the location of a snow course site, and is accompanied by the site name. The four different regions used in this study are outlined as follows: Front Range (light purple), Northwest Colorado (light orange), Central Colorado (light blue), and San Juans (light red).

Introduction

The buildup of snowpack over the winter and spring is a vital part of Colorado's ecosystems as well as the economy. The agricultural sector, forests and parks, mountain recreation, and the general tourist industry all depend upon the buildup of snow from October through April. Subsequently, the rivers, reservoirs, and soils are recharged in the warmer months following snowmelt. Statewide snowpack can easily vary by over a factor of two from year-to-year and may vary more for specific mountain ranges and elevation zones within the state. Two factors that influence Colorado's seasonal snowpack are the warming trend of the climate over time and the state of the El Niño Southern Oscillation (ENSO). The ENSO refers to a cyclical change in eastern Equatorial Pacific Sea Surface Temperatures, which has been shown to have a myriad of impacts on the behavior of the atmosphere around the globe. One full oscillation takes anywhere from one to several years. These relationships have been closely monitored in recent years. This is a brief update to the growing body of literature examining the relationship between seasonal snowpack and these two factors.

Background

A more extensive analysis of snowpack trends in Colorado was completed by the Natural Resources Conservation Service in 2013 (Lukas et al., 2014). In this study 30-, 50-, and 70-year trends were analyzed for the Yampa & White, Colorado, South Platte, North Platte, Arkansas, Gunnison, Rio Grande, and San Juan river basins. The only statistically significant trend realized was a 70-year significant decrease in the South Platte Basin. This study, while not as extensive, provides three years of additional data for the period (2014-2016) and employs a more sensitive statistical analysis, akin to the methodology used in Clow et al. (2010). Their study indicated more statistically significant decreases in snowpack.

Methods

In this study, manually collected snow core measurements were obtained from the Natural Resources Conservation Service Snow Survey Database. Data were examined from 16 sites where measurements were taken consistently each within a week of April 1st from 1940-2016. Seasonal snowpack commonly peaks either before or after April 1st for some snow course sites depending largely on their elevation. Peak snowpack is a critical prognostic tool when assessing the adequacy of the coming warm season's water supply. This, in turn, is a useful predictor for runoff and surface water supplies for April-July. El Niño Southern Oscillation statistics were obtained from the Earth Systems Research Laboratory for the period of 1950-2016.

Some of the stations used did have missing years in the record. If a station was missing data for a given year then a substitute observation was calculated as followed: missing observations were replaced with the average measurement from all other stations in the year missing and are then modified by the ratio between the average April 1st snow core for all non-missing years of the snow course site over the average year for all stations.

1940-2016 trends in the April 1st snowpack were calculated for a composite of all 16 Colorado manual snow course measurement sites used in this study, as well as four clusters of sites that were used, including: Northwest Colorado, Front Range, Central Colorado, and San Juans (Figure 1).

Statistical significance of trends was calculated using a Mann-Kendall test for a monotonic relationship. A Mann-Kendall test for significance checks the sign of one observation minus all of the observations preceding it individually. If there are more positive changes with time than negative changes for the given sample size (in this case, the number of years) then the trend will be identified as significantly positive.

Correlation between Colorado snowpack and wintertime Multivariate ENSO Index (MEI) reading was also tested. This was also performed for a composite of all 16 manual snow course locations and for the four separate regions of the Colorado high country (Figure 1). This test was a simple r^2 test for a linear relationship between April 1st snowpack and wintertime MEI readings. MEI data for the 1940s were not available, so these tests were for the years 1950-2016.

Results

April 1st snowpack averaged across all 16 snow course sites was found to be decreasing with time (Figure 2). This decrease is occurring at an average rate of 0.38 inches/decade, and is statistically significant at 95% confidence but not 99% confidence. While decreases are statistically significant, only 6.1% of the variance in-site-averaged April 1st snowpack can be explained by this downward trend.

April 1st snowpack is decreasing with time across all four of the highlighted sub-regions of the Colorado Rockies including: Northwest Colorado, Front Range, San Juans, and the Central Colorado. In the examination of sub-regions included in this study, site sample size is a valid concern. Snowpack for these four sub-regions is decreasing at rates of 0.26 inches/decade, 0.38 inches/decade, 0.39inches/decade, and 0.49inches/decade respectively (Table 1). These downward trends are statistically significant at 95% confidence for the Front Range and San Juans, and at 99% confidence for the Central Rockies. The downward trend in April 1st snowpack for Northwest Colorado was found not to be statistically significant.

Table 1. Decadal trends in snowpack for each of the four regions of the Colorado Rockies analyzed.

Region	Northwest Colorado	Front Range	San Juans	Central Colorado
April 1st Snowpack Trend	-0.26"/ Decade	-0.38"/ Decade	-0.39"/ Decade	-0.49"/ Decade
Significance Level	None	95% Confidence	95% Confidence	99% Confidence

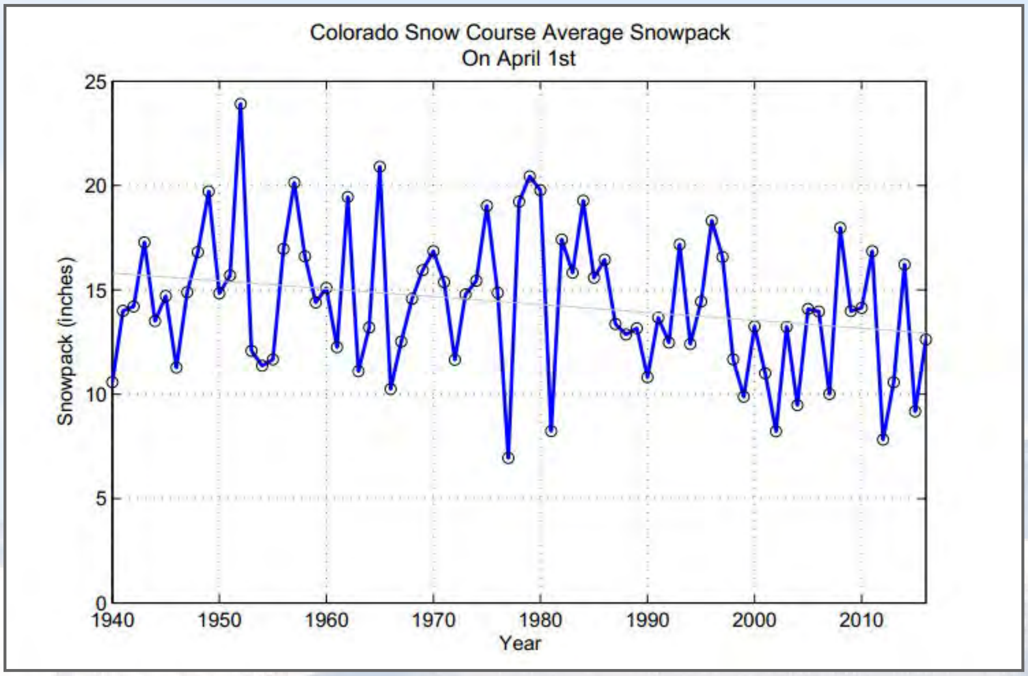


Figure 2. Plot of the snow course-average for April 1st snowpack in the state of Colorado annually from 1940-present. The straight, gray line is a least squares regression line fit to the data.

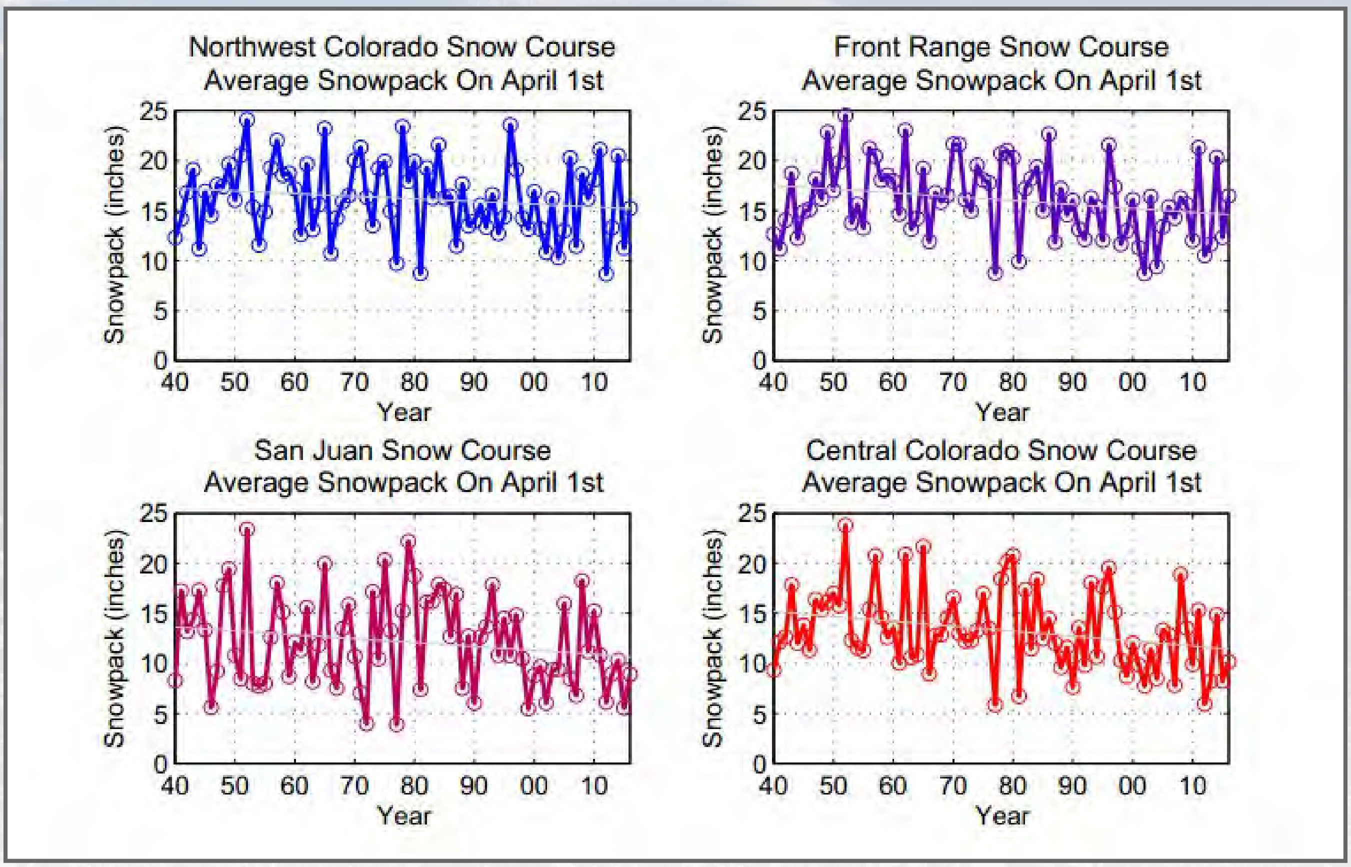


Figure 3. Change in the manually-observed April 1st snowpack over time for four regions of the Colorado Rockies: Northwest Colorado (upper left), Front Range (upper right), San Juans (lower left), and Central Colorado (lower right).

Background: Winter snowpack in the forests of Grand County.

Ron Cousineau, CSFS

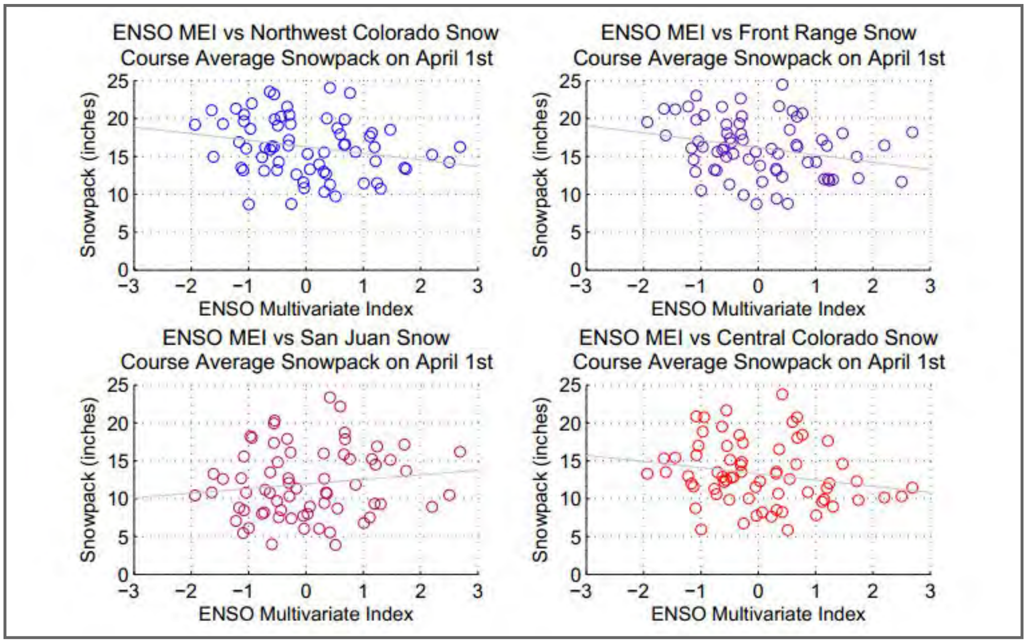


Figure 4. The four scatterplots illustrate the relationship between December-January-average Multivariate El Niño Southern Oscillation Index and manually-observed April 1st snowpack for four regions of the Colorado Rockies: Northwest Colorado (upper left), Front Range (upper right), San Juans (lower left), and Central Colorado (lower right).

The Rocky Mountains of Colorado are favored for increased precipitation in the winter during La Niña and for increased precipitation in the spring during El Niño (Lukas et al., 2014). This relationship is mostly washed out when examining the April 1st snowpack because both these seasons have profound impacts. Wintertime MEI explains only 1.5% of the variance in April 1st snowpack averaged across all 16 snow course sites. When these sites are broken into the four subgroups used in this study, it can be seen that the ENSO-neutral line can be drawn between Central Colorado and the San Juans. The MEI explains 5.4% of variance in April 1st snowpack for the Northwest Colorado subgroup with the La Niña preference for increased snowpack. The index explains 7.0% of the variance for the Front Range with La Niña preferred. La Niña is likewise preferred for greater April 1st snowpack for the Central Colorado subgroup but explains just 4.1% of the variance. April 1st snowpack for the San Juans subgroup is the least impacted by ENSO. Here El Niño conditions are preferred but only 1.8% of the variance is explained.

Conclusions

Since the Natural Resources Conservation Service began recording snow surveys, April 1st snowpack (near the time of peak snow water accumulation) observations suggest high year-to-year variations but with a detectable downward trend for the state of Colorado. All four sub-regions of Colorado used in this study showed decreasing snowpack over time. Decreases in snowpack were significant with at least 95% confidence for the Front Range, San Juan, and Central Colorado regions but was not statistically significant for the Northwest Colorado region. The relationship between Colorado April 1st snowpack and the wintertime phase of the El Niño Southern Oscillation was indicated as very weak. Higher snowpack was weakly correlated with La Niña conditions for the mountains north of Cochetopa Pass and weakly correlated with El Niño conditions for the San Juans. The combination of decreasing snowpack over time and relation to ENSO comes nowhere near a fully sufficient explanation of the inter-annual variability of Colorado snowpack. The forests of Colorado are accustomed to large year-to-year variations in snowpack and water supply, but this variability imposes stresses and subjects forests to occasional extreme events such as floods, drought, insects, diseases, fire, etc. These extreme events can impact the local economies that rely on the forests and snowpack, whether it be in the recreational or agricultural sectors. With so many dynamic variables in place, it is unrealistic to expect a stable and largely unchanging forest ecosystem.

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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

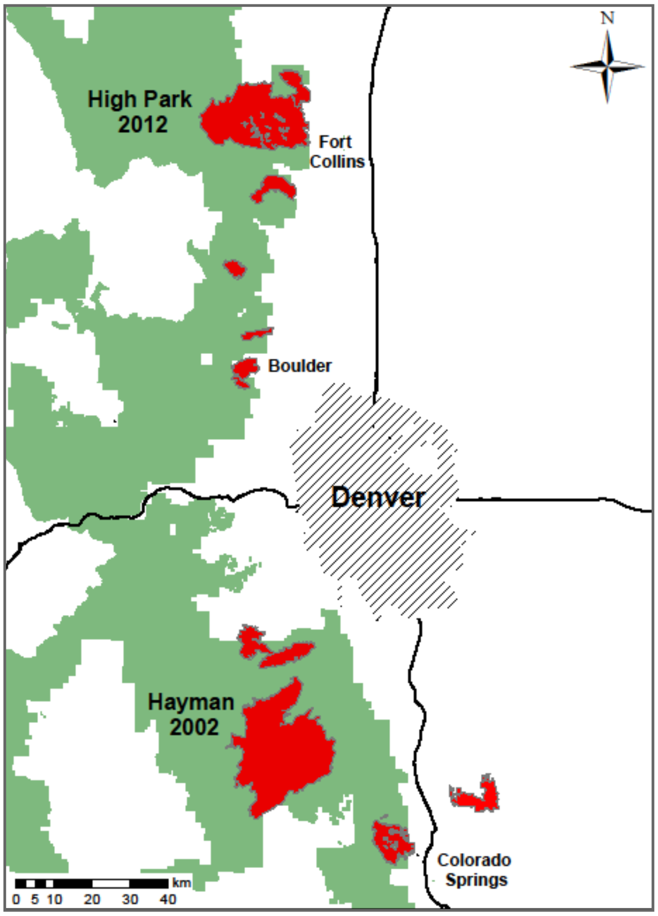


Figure 1. The perimeter of wildfires larger than 6,000 acres that have burned since 1996 and their proximity to Colorado Front Range population centers.

T. Fegel

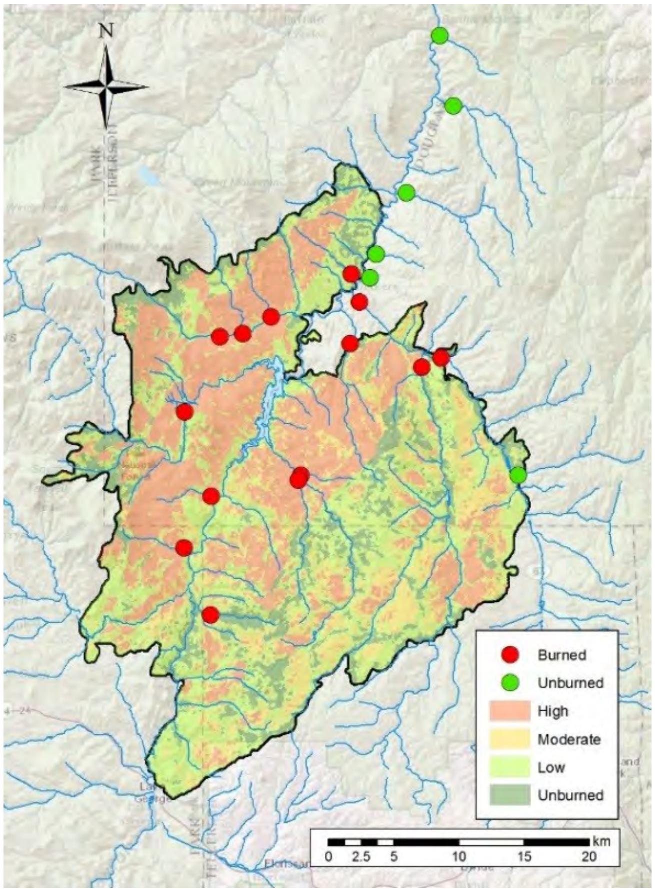


Figure 2. Sampling locations (red and green dots) and the Hayman Fire perimeter in the South Platte River watershed, southwest of Denver. The Fire burned (June 2002) largely on the Pike National Forest and private land surrounding Cheesman Reservoir.

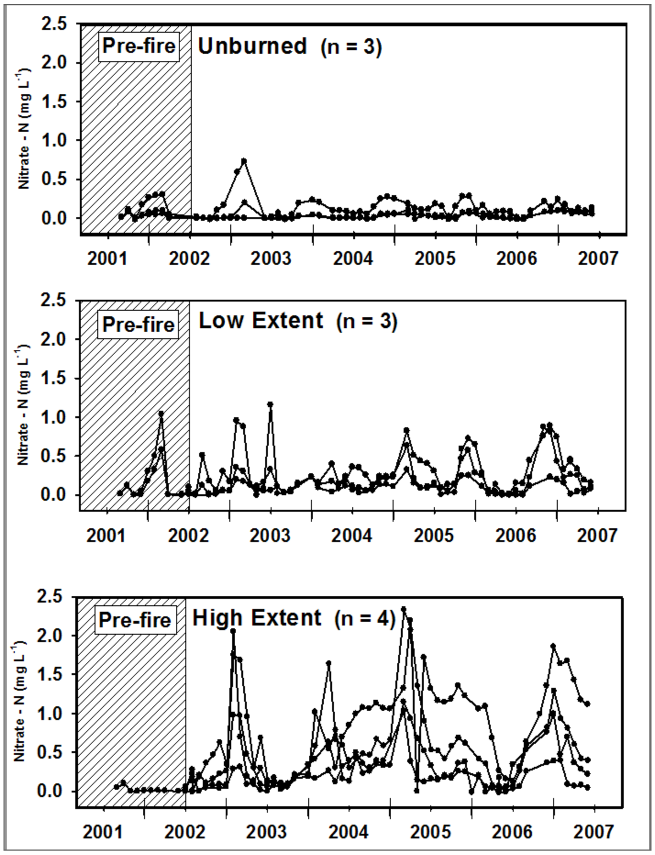


Figure 3. Stream nitrate sampled monthly in tributaries of the South Platte River within and near the 2002 Hayman Fire. Seasonal peak concentrations typically correspond to the spring runoff period.

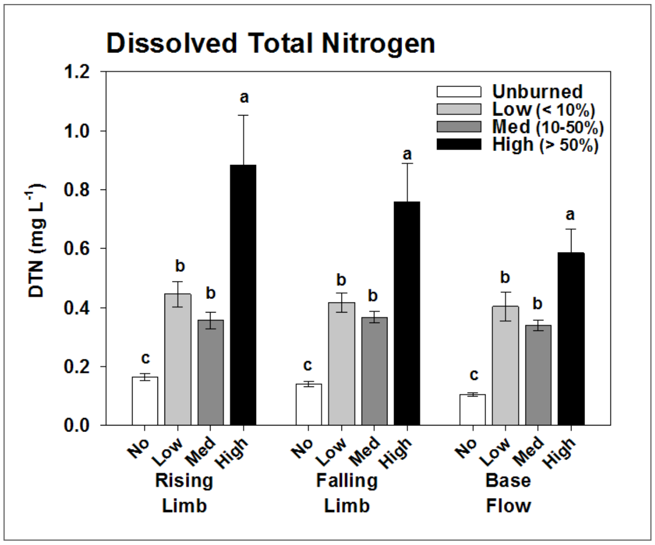


Figure 4. Persistent effect of the Hayman Fire on stream nitrogen concentrations. Bars are seasonal averages from monthly samples collected 13- and 14-years after the fire. Seasonal divisions track the streamflow hydrograph as follows: Rising Limb = March, April, May; Falling Limb = June, July, August; 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

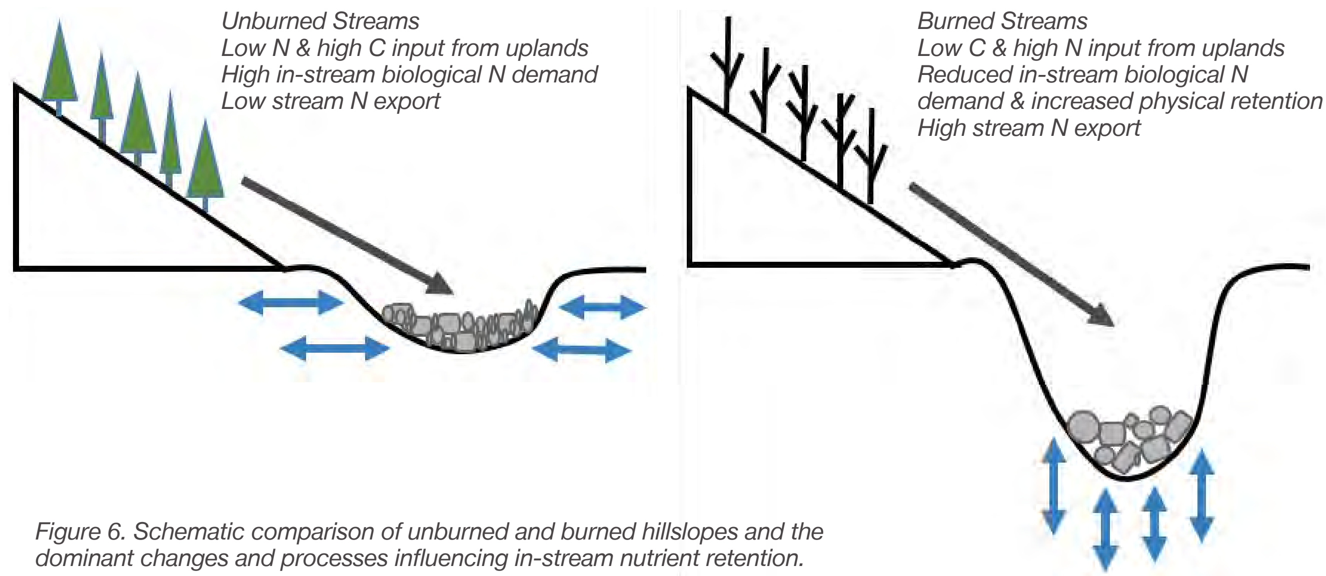


Figure 6. Schematic comparison of unburned and burned hillslopes and the dominant changes and processes influencing in-stream nutrient retention.

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.

Brad Piehl, JW Associates Inc.

Protecting Watersheds and Water Supplies from Forest Fires

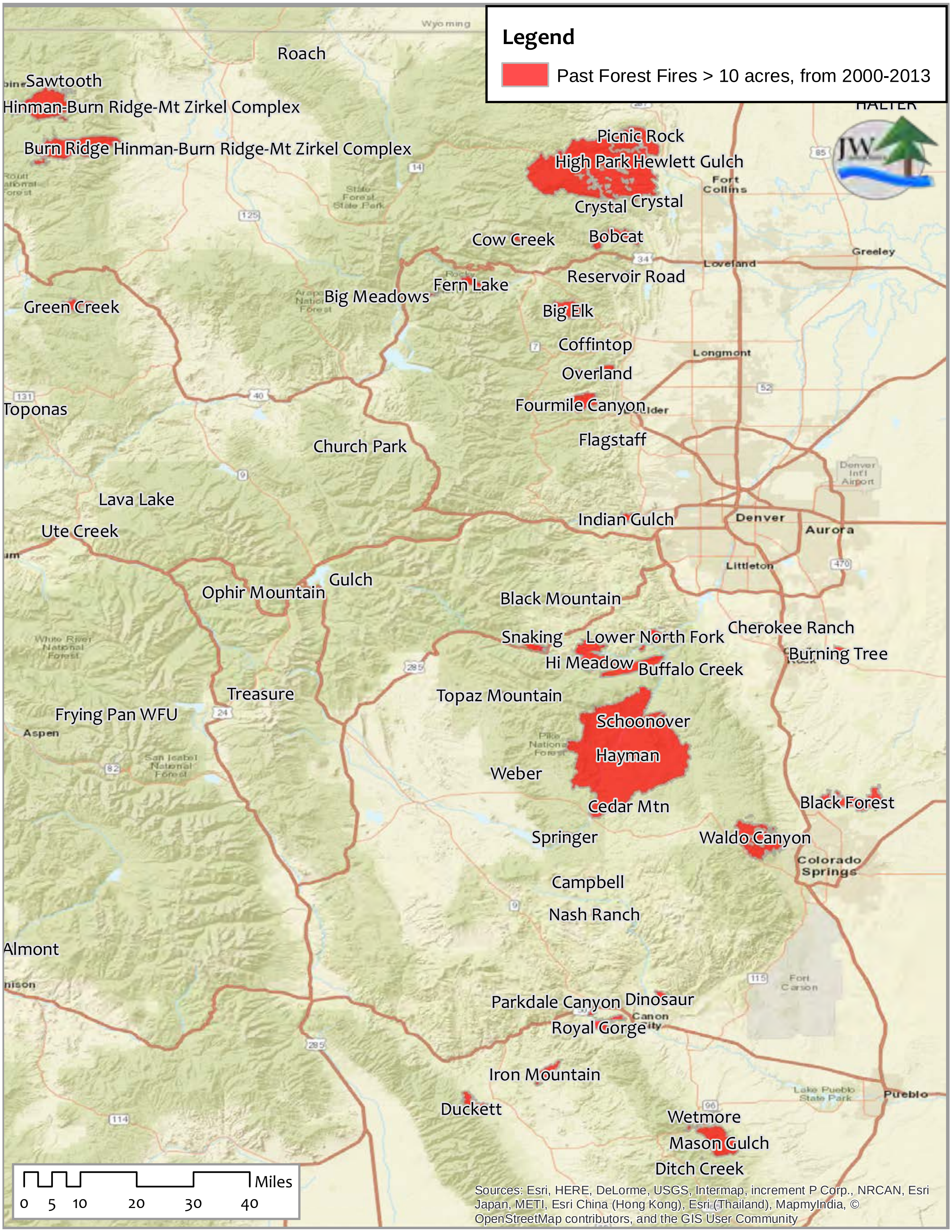
Brad Piehl, Watershed Planner, JW Associates Inc.

The state of Colorado is fortunate to have high-quality water from forested watersheds for municipal and irrigation uses. More specifically, these forested watersheds provide drinking water to a majority of the cities throughout Colorado including portions of the Northern and Southern Front Range, the Denver metropolitan area, and communities on the western slope. However, it is important to note that while this precious natural resource is available to so many individuals, there are threats to the state's water resources, such as forest fires, which places a stain on such an important resource.

(Above) Debris flow into the Cache la Poudre River caused by runoff from the High Park Fire burned area.

Forest fire represents one of the most significant and dramatic watershed risks to the water supply for many communities. Wildfires can have a host of impacts on watersheds including: degrading water quality, changing the characteristics of surface soils and runoff, and increasing sediment production and deposition in downstream waterbodies. These impacts may be experienced in the first rainstorm after a fire but can also extend for decades afterwards. Furthermore, even more dramatic impacts include debris flows, which sometimes occur in recently burned watersheds after heavy rain.

Over 1 million forested acres have burned in Colorado since 2000. Although the majority of these forest fires have been relatively small, generally covering less than 20 acres,



Brad Piehl, JW Associates Inc.

Map of the Colorado Central Mountains and Front Range forest fires from 2000-2013 greater than 10 acres.

some of the larger fires have had significant impacts on water supplies. The Buffalo Creek Fire of 1996 was notable for its dramatic post-fire affects in the watershed. A rainstorm occurred soon after the fire, triggering a debris flow that transported and deposited large quantities of sediment and debris into Strontia Springs Reservoir. In the years that followed, the cities of Denver and Aurora spent significant amounts of money to mitigate those impacts. Other more recent fires have also had major impacts on water supplies, including the Hayman Fire (2002), High Park Fire (2012), and the Waldo Canyon Fire (2012). Water providers are still working today to mitigate the impacts of those fires.

Why Are We Seeing These Destructive Fires Now?

Forests in Colorado, and throughout the western U.S. look much different than from previous centuries. The density of trees is much greater than what existed prior to European settlement in the 19th century, particularly in lower elevation forests that experience frequent fires. Although high elevation forests are typically denser than those found at lower elevations, they also show an increase in tree density since human settlement starting in the 1800s. Activities such as timber harvesting, historic mining, grazing, combined with large forest fires in the early 1900s and subsequent fire suppression policies, served to alter the composition and density of the forests. On a landscape scale, diversity in high elevation forests has been reduced as meadows and openings are slowly filled by trees as forests move towards climax conditions, and as successional aspen stands are converted to conifers.

The changes in Colorado's forests have numerous repercussions for wildfire, forest health, watersheds, and supply protection. Below are just a few examples:

- From a water supply perspective, changes in the forest structure are just as important as the areas of lower density forest filled with snow during winter and water during the spring and early summer.
- Areas of aspen, meadows, and lower density forest do not burn as intensely in wildfires as densely forested areas, serving as buffers to the effects of wildfire.
- Fire suppression has led to an increase in both ground and ladder fuels such that surface fires can easily move into the tree canopy, fueling more intense crown fires. In many forests, the presence of higher-density and continuous fuels allow fires to spread quickly over large distances, making control difficult and dangerous.
- Forests that are dense or have closed canopies usually contain trees that compete for limited resources such as water, nutrients, and sunlight. Trees within these dense stands may be less vigorous and therefore more susceptible to insects and disease, and have a higher wildfire hazard due to connected crowns and high fuel loading.

Climate change has also impacted Colorado's watersheds in the past and will continue to influence the magni-

Tim Engleman

Buffalo Creek, Jefferson County, CO.

tude of disturbances affecting watersheds into the future. In Colorado, statewide annual average temperatures have increased by 2 degrees (F) over the past 30-years (Colorado Water Conservation Board, 2014). Further increases in temperature are predicted (Walsh et al., 2014). Although there is not a consensus on changes in precipitation (Colorado Water Conservation Board, 2014), changes in climate are expected to lead to increases in the frequency of droughts, insect epidemics, and large wildfires in Colorado (Funk and Saunders, 2014). Large forest fires have already increased in size, frequency, and duration in the western U.S. (Westerling et al., 2006 and Jolly et al., 2015). Changes to Colorado's forests from climate change are difficult to predict, but it appears that scientists are expecting more drought, earlier and warmer springs, more wildfires, and more large-scale insect outbreaks. Furthermore, natural disturbances are expected to become more significant to the forests that supply our water.

Resilient Forested Watersheds

One ecological concept that is being increasingly used is that of "resilience." Watershed resilience can be defined as the ability of forests to experience a disturbance and return to previous function within a reasonable period of time. Forested watersheds that are highly resilient are more likely to experience fewer impacts from disturbances that could affect the quantity, quality, or reliability of water supply provided by those watersheds.

Forested watersheds have higher integrity or resiliency when they have diverse vegetation. Forest diversity can be associated with a mix of species, amount of openings, or a variety of aged trees. Many forested watersheds in Colorado have become vulnerable to disturbance events because they have low diversity. In some cases, low diversity is caused by fire suppression or past human activities. It may also be their natural condition without human-caused influences. For example, many of the watersheds that contain ponderosa pine and douglas-fir forests have lower diversity because of the lack of natural disturbances, especially wildfire.

What Can Be Done to Reduce Impacts to Watersheds and Water Supply?

Public and private entities have invested millions of dollars to implement emergency measures to protect people, communities, and critical resources from post-fire events such as flooding, erosion, mudslides, and related degradation of water supplies, and storage facilities. In the wake of the 2002 wildfire season, federal agencies invested more than $26 million in emergency rehabilitation, while at least $16 million was invested for non-federal lands. Denver Water and the Colorado State Forest Service (CSFS) undertook a massive post-fire rehabilitation effort at Cheesman Reservoir that was impacted by the Hayman Fire.

One of the most direct techniques to reduce the impacts from forest fire on watersheds is to reduce the tree density, thereby reducing the intensity and wildfire severity. Targeted thinning can also reduce the threat of crown fire, which often leads to higher intensity wildfires. In forested stands that have developed without regular disturbance, combinations of mechanical harvest/thinning and prescribed fire are the most effective technique for altering the fuels matrix (Graham et al., 2004).

There are millions of acres of overly dense forest in Colorado's watersheds. It is not practical, economically feasible, or desirable to manage all of these areas to reduce forest density because there would be negative impacts on other values including wildlife, recreation, and scenery. Water providers have used watershed assessment analytical tools to prioritize watersheds that have a combination of hazards from fire, soil erosion, and debris flows, as well as important values to the water supply systems. The Colorado Watershed Wildfire Protection Group (csfs.colostate.edu/forest-management/watershed-management) has created an assessment template that has been used in 15 watersheds in Colorado. Areas (zones of concern) are identified within these watersheds that have the highest hazards and importance to water supply.

Some water providers have taken additional steps because they understand the value of minimizing risks to their water supply systems. Some of the additional steps include:

1. Completing a small-scale watershed analysis and planning to identify specific areas that will be the priority for vegetation or other treatments before fire, or targeted mitigation efforts after fire. Small-scale targeting of high-hazard areas also allows water supply agencies to justify investments in hazard reduction or watershed protection projects.
2. Forming collaborative groups with federal, state, and local agencies, as well as private landowners, to facilitate projects that can be implemented and to leverage funding.
3. Identify roads that could be problematic following forest fires and survey them to see if some actions could be taken before a fire to reduce their post-fire impacts.
4. Completing post-fire planning that identifies actions and responsible staff for post-fire mitigation actions. Post-fire actions are an emergency and happen quickly following the fire being put out. Water agencies that are prepared for quick action will perform better in that emergency situation.
5. Identify potential locations of post-fire sediment basins. These temporary structures can catch some or most of the post-fire erosion if they are located strategically and designed properly. Identifying locations and designs before the fire allows quick installation which maximizes the effectiveness of these basins.

Sediment deposition in the Seaman Reservoir following the Hewlett Gulch fire of 2012. The deposition area has expanded since this photograph was taken.

Brad Piehl, JW Associates Inc.

WATER RESOURCES ARCHIVE

The Papers of Evan Vlachos

Patricia J. Rettig, Head Archivist, Water Resources Archive, Colorado State University Libraries

Dr. Vlachos leads a lively table discussion at Water Tables 2007.

The University Digital Photograph Collection, University Archive, CSU Libraries.

Such a dynamic person as Evan Vlachos can hardly be captured just on paper, yet the 21 boxes donated to the Water Resources Archive at Colorado State University (CSU) last fall make that attempt. With subjects ranging from irrigation systems to Greek migrants, from urbanism to futurism, the Papers of Evan Vlachos document his work in both sociology and civil engineering as a professor at CSU and as a consultant around the world.

Career

Born in Greece in 1935, Evan Vlachos began his CSU career as a professor and administrator in 1967. He had accumulated a number of degrees by then, including an LL.B. from the School of Law, Athens (1959) and an M.A. (1962) and Ph.D. (1964) in sociology from Indiana University. Dr. Vlachos briefly returned to Greece following his Ph.D. but made his way to CSU in 1967 as an assistant professor of sociology. In 1973, he secured a joint appointment in both sociology and civil engineering. Added to that, for a time he was also the director of CSU's Environmental Resources Center and then the associate director of the International School for Water Resources at CSU.

Dr. Vlachos pursued numerous research projects and related activities over the years. His first foray into water came in 1969 as the principal investigator for a three-year project, "Consolidation of Irrigation Systems: Engineering, Legal and Sociological Constraints and Facilitators." Other projects soon to follow included "Technology Assessment for New Water Supplies," "Socio-economic and Institutional Factors in Irrigation Return Flow Quality Control," and "Drought Control and Water Management in Humid Regions." More eclectic projects included "Comparative Urbanization in

Southeastern Europe," "Secondary Impacts and Consequences of Highway Projects," and "Cumulative Impacts of Energy Development on Fish and Wildlife."

Dr. Vlachos' consulting on a diverse array of topics spanned the country, from Utah to Mississippi, and the globe, from Brazil to Portugal to Saudi Arabia. He served as a policy analyst and lecturer in Washington, D.C., and as a member of many local, national, and international committees. He published and presented his research widely and was active in a number of professional organizations. The American Water Resources Association presented Dr. Vlachos with its Iko Iben Award in 1993 in recognition of interdisciplinary excellence in water resources.

Collection

During this 40-plus year career, Dr. Vlachos carefully filed the paperwork resulting from his voluminous publications, presentations, and projects. Along with the final products, letters, notes, drafts, and data comprise his collection now at the Water Resources Archive in Morgan Library.

Donated last fall, the 21 boxes document the research and consulting aspects of Dr. Vlachos' career more thoroughly than the teaching or administrative side. Beyond the subjects of water resources planning and management, the collection also documents Dr. Vlachos' interests in urban planning, technology assessment, demography, migration, and futurism.

Due to health issues, Dr. Vlachos could not join the Archive staff who visited his home office with his son Dean, but quick work was made of filling archival boxes with folders from orderly file cabinets. A modest selection of books from Dr. Vlachos' extensive library was packed up to add to the Libraries' Special Collections as well.

It will take Archive staff some time to get everything organized and inventoried, but researchers will have access to information not only on the particular subjects Dr. Vlachos studied, but on the man himself. Though there are few personal items in the collection, many of the notes, drafts, and letters he saved reveal the passion with which he worked.

Collections that have some documentation about Dr. Vlachos already available through the Water Resources Archive include the Records of the Colorado Water Resources Research Institute and the Papers of Maurice L. Albertson. Uniquely, Dr. Albertson, a colleague in civil engineering, had an affinity for making and saving recordings of meetings and seminars. Dr. Vlachos, easily identified by his strong Greek accent, can be heard on several of those reel-to-reel tapes, which now supplement and extend Dr. Vlachos' paper legacy.

For more information about the Water Resources Archive, see the website (http://lib.colostate.edu/water/) or contact the author at any time. (970-491-1939; Patricia.Rettig@ColoState.edu)

Jennifer Gimbel

Jennifer Gimbel, Senior Water Policy Scholar, Colorado Water Institute, Colorado State University

Working at Colorado State University (CSU) and being a part of the academic atmosphere is an exciting prospect at this point in my career. I have been fortunate to work with Reagan Waskom and the Colorado Water Institute (CWI) for many years in various capacities for both state and federal government agencies and am proud to be associated with them. Working for the CWI is a privilege and pleasure. It seems fitting for me to be back in a teaching environment and it has been an adventure.

My first career as a teacher of mathematics allowed me to work with all levels of students, from junior high through college. One of my favorite times was in Douglas, Wyoming, where I taught Algebra to high school students during the day and their parents in the evening. Circumstances led me apply to law school, where I became interested in water issues. My time spent with the Attorney General Offices in Wyoming and Colorado provided many opportunities to learn and apply the law. However, my interests focused more on policy side of the equation. My first plunge into policy was working for the Department of the Interior (DOI) and the U.S. Bureau of Reclamation (USBR) on western water issues. From there, my path led back to the state of Colorado as Director of the Colorado Water Conservation Board. I worked to further policy discussions and solutions related to the Colorado River, instream flows, interstate and intrastate relationships, construction of worthwhile projects, and climate change, including projects with the CWI. After this experience, my career path changed again, this time to Washington D.C., to work for President Obama and Secretary Sally Jewell. During my time in Washington D.C., I was in charge of water and science issues for the DOI. Here, I expanded my knowledge base, learning about the U.S. Geological Survey (USGS) and trained by some of the best scientists in the country. In that capacity, I had the opportunity to work with all the water institutes throughout the country and learned of all the profound work they do.

Throughout my career, I had growing concerns about the future of water policy and those participating in the discussion. Who in the next generation or two will thoroughly understand the issues and work to continue progress? My initial meetings on water issues early on in my career were with several seasoned professionals, mostly men and indicating a lack of diversity. Whereas today, I notice that individuals participating in the meetings include more young professionals and women, although it will take more time to diversify those participating in the conversation. CSU and the CWI are helping to foster new professionals. This gives me great solace to know that is happening and a thrill that I can be a part of it.

My focus at the CWI is on water policy, asking questions such as: What can we do? Whom should we bring together? My research focuses on the Colorado River, with an emphasis on the Upper Colorado River. Climate change and drought have negatively affected the river, which so many individuals rely on. Compacts have divided the river among the states, but less water stretches those compacts and interstate relationships to the limit. Fortunately, the seven states and federal government came together with an agreement to get through these tough years. However, we are finding that even more research is required. I will be exploring Upper Basin solutions among the four Upper Basin States, Colorado, Wyoming, Utah and New Mexico while I work at the CWI.

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Water Calendar

April

7 — 2017 Annual Water Seminar: Southwestern Water Conservation District; Durango, CO
A broad range of topics will be covered in the 35th Annual Water Seminar, including the various local projects that have been funded by the district's grant program.
swwcd.org/programs/annual-water-seminar

20-22 — 2017 Federal Water Issues Conference; Washington, D.C.
National Water Resources Association presents federal water Issues.
www.nwra.org/2017-fwic.html

24-25 — Environmental Justice and Sustainability in the Anthropocene; Fort Collins, CO
Symposium highlighting transdisciplinary and international research in the study of the environment, public health, and sustainability.
sustainability.colostate.edu/research/gcrt environmental-justice-and-sustainability-anthropocene

25-26 — Groundwater Quality and Unconventional Oil and Gas Development: Current Understanding and Science Needs Workshop
Share your knowledge and discuss with interested parties the latest findings regarding groundwater quality and unconventional oil and gas development during this two-day NGWA event
www.ngwa.org/Events-Education conferences/Pages/224apr17.aspx

30-3 — 2017 Spring AWRA Conference; Snowbird, UT
Connecting the Dots: The Emerging Science of Aquatic System Connectivity.
www.awra.org/meetings/Snowbird2017/

May

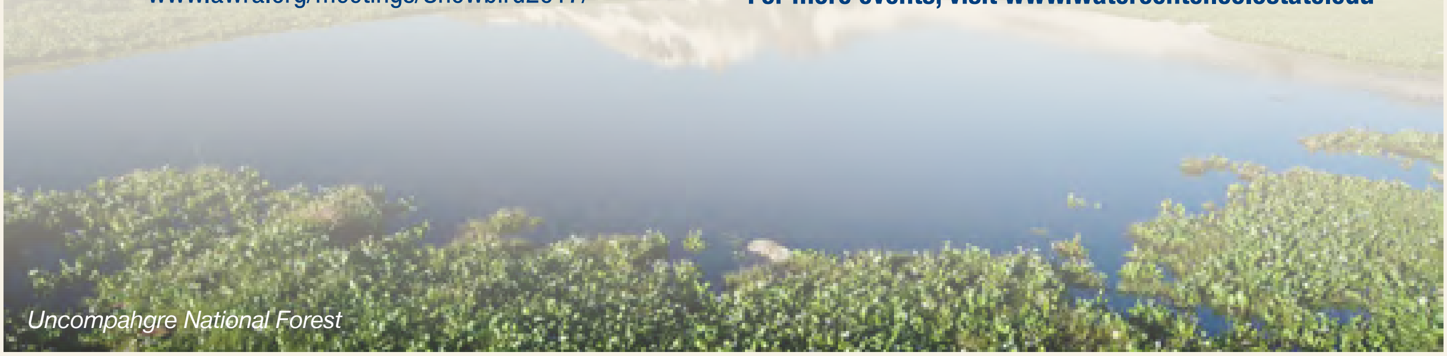
7-13 — American Water Works Association – Drinking Water Week
A week devoted to educating the public about the positives of water utilities organizations.
www.awwa.org/resources-tools/public affairs/public-affairs-events/drinking-water-week aspx#15548459-celebration-ideas

11-13 — 2017 FGWA Annual Convention and Trade Show; Orlando, FL
An event for contractors and those in the well water industry. This event offers a wide variety of sponsorship opportunities.
www.fgwa.org/convention.php

17 — Denver Metro Water Festival; Denver, CO
An opportunity to volunteer or present water-related information to 6th grade students in the Denver metro area.
www.denvermetrowaterfest.org/

21-24 — Modflow and More 2017: Modeling for Sustainability and Adaptation; Golden, CO
An event focused on the challenges imposed by changing climate and urban population growth. The event also focuses on adapting modeling tools accordingly.
igwmc.mines.edu/MODFLOW2017.html

For more events, visit www.watercenter.colostate.edu



Uncompahgre National Forest

Bureau of Land Management

Water Research Awards 12/13/16—2/10/17

Evangelista, Paul H., Walton Family Foundation, Mapping and Monitoring Invasive Species in Riparian Habitats of the Colorado River Basin, $230,120.50

Heuberger, Adam L., U.S. Brewers Association, Metabolite Profiling of Heirloom Barley to Facilitate Breeding for Flavor and Sustainability, $11,871

Ippolito, Jim, City of Littleton, Biosolids Land Application Research Program–Bennett Study (2017), $ 54,059

Ippolito, Jim, City of Littleton, Biosolids Land Application Research Program-Byers Study (2017), $60,716

Jacobson, Peter A., Department of Defense-Army Corps of Engineers Alaska, Municipal Separator Storm Sewer System (MS4) Minimum Control Measures (MCM), $199,871

Jones, David S., Department of Defense-Army Corps of Engineers Kansas City, Clean Water Act Program Support, Fort Leonard Wood, Missouri, $594,457

Jones, Kelly W., National Science Foundation, Role of Citizen Science in Watershed Hydrology Research: Relationships between Volunteer Motivation, Data Quantity and Quality, and Decision-Making, $47,170

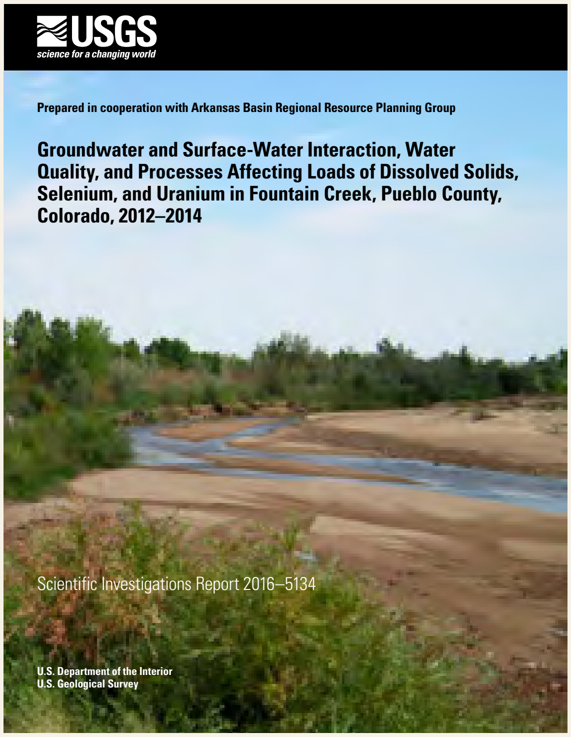
Lemly, Joanna, Environmental Protection Agency, Colorado Wetland Program Plan and Reference Network, $111,473

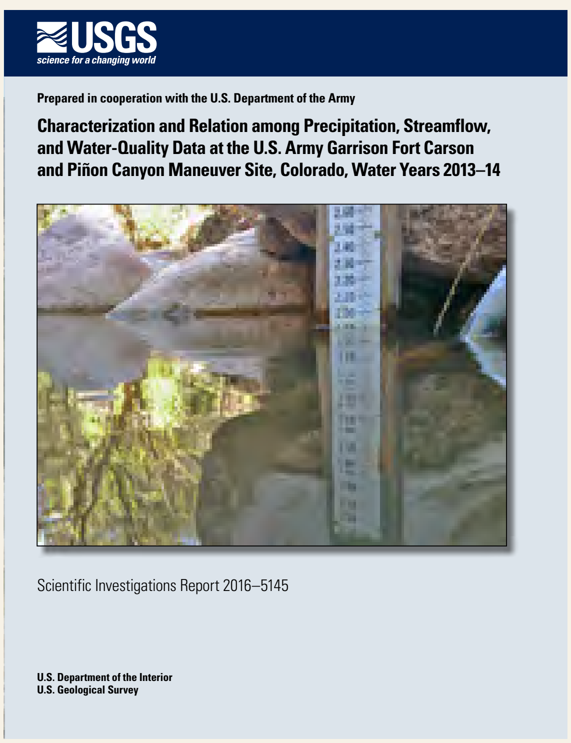
Wohl, Ellen, E., Department of Defense Army Corps of Engineers Omaha, A Review of Scientific Knowledge of Channel Heads, $20,000

Elaine Moore

New Aspen Growth in the Hayman Fire recovery land.

USGS Recent Publications





Groundwater and surface-water interaction, water quality, and processes affecting loads of dissolved solids, selenium, and uranium in Fountain Creek, Pueblo County, Colorado, 2012–2014; 2016, U.S. Geological Survey Scientific Investigation Report 2016–5134, L.R. Arnold, R.F. Ortiz, C.R. Brown, K.R. Watts

Characterization and relation of precipitation, streamflow, and water-quality data at the U.S. Army Garrison Fort Carson and Piñon Canyon Maneuver Site, Colorado, water years 2013–2014; 2016, U.S. Geological Survey Scientific Investigations Report 2016–5145, M.J. Holmberg, R.W. Stogner Sr.,J.F. Bruce

Effects of flow regime on metal concentrations and the attainment of water quality standards in a remediated stream reach, Butte, Montana; 2016, Environmental Science & Technology 1264112649, R.L. Runkel, B.A. Kimball, D.A. Nimick, K. Walton-Day

The precipitation of indium at elevated pH in a stream influenced by acid mine drainage; 2016, Science of The Total Environment 574, 1484-1491,S.O. White, F.A. Hussain, H.F. Hemond, S.A. Sacco, J.P. Shine, R.L. Runkel, K. Walton-Day, B.A. Kimball

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Colorado State Forrest Service

Vail, Colorado