WILDFIRE PLANNING AND RISK MITIGATION

Increasing the Resilience of Public Drinking Water Systems

ABSTRACT

Worsening wildfire hazards pose growing risks to drinking water providers because they may negatively impact water quality and water infrastructure. Little is known about how water providers are planning for these risks and mitigating them. Through an analysis of available water resource protection planning frameworks and three case studies of drinking water utilities in Colorado, we identify learning mechanisms and current industry practices available to water utilities to increase their resilience to wildfire.

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EXECUTIVE SUMMARY

Drinking water utilities that rely on surface water supplies from forested watersheds are increasingly confronted with the threat of wildfires. Wildfires are increasing in intensity, size, and frequency due to a combination of historical fire suppression practices, development, and climate change impacts (Calkin et. al 2014; Calkin et al. 2015; Martin 2016). In Colorado, for example, ten of the fifteen largest wildfires in Colorado history have occurred in the last decade (9News 2019). Water providers experience severe consequences from burns in their source watersheds, including immediate and long-term water quality degradation and destructive post-fire storm runoff (Martin 2016, Sham et al. 2013). However, water utilities are limited in their ability to address wildfire hazards due to resource limitations, land ownership constraints, and the complexities of working at the watershed scale. These coupled challenges for water providers – growing wildfire risks and constraints to mitigating these risks – prompted this study. Through an analysis wildfire planning practices and case studies of three Colorado water utilities impacted by wildfires (City of Fort Collins, City of Durango, and Pagosa Area Water and Sanitation District), we identify learning patterns and mechanisms that allow for water utilities to implement on-the-ground wildfire mitigation projects and increase overall system resilience.

Through an analysis of publicly available planning documents, we identified six planning frameworks utilities can use to address wildfire risk and evaluated them based on five criteria: (1) what role water utilities played in the planning process, (2) how central wildfire was to the framework, (3) the accessibility of the planning process for utilities in terms of resource requirements, (4) how plans helped utilities gather funding to implement projects, and finally, (5) how the planning frameworks engaged stakeholders beyond the water utility (see Table 1). Wildfire-specific plans we analyzed included community wildfire protection plans (CWPPs), critical community watershed wildfire protection plans ($(CWP)^2s$), and watershed wildfire hazard assessments. Broader resource plans evaluated were source water protection plans (SWPPs), drought plans, and stream management plans (SMPs). We found CWPPs to be the most prevalent wildfire planning framework for communities, but that these plans rarely include water utilities. In terms of wildfire-specific planning being conducted by water utilities, we found that wildfire watershed hazard assessments and corresponding risk maps of critical water infrastructure to be most popular. Wildfire watershed hazard assessments and risk mapping are technically advanced but are costly and lack guidance for stakeholder engagement; they can, however, act as an engagement mechanism. All three utilities interviewed had some kind of drought management plan and remarked on the overlap between drought planning and planning for wildfire.

After analyzing these formal ways water providers were addressing wildfire risk, we considered the more informal ways utilities were learning about wildfire impacts and planning for mitigation. The three trends we found in informal learning mechanisms that helped utilities adapt to changing wildfire risk were (1) learning through experience of wildfire events, (2) learning through scientific research and partnerships with local academic institutions, and (3) learning through regional watershed or forest health partnerships. Local networks were central to robust inter-watershed wildfire learning, but intra-watershed learning was less apparent.

Once we investigated the various wildfire planning pathways available to utilities and formal and informal learning processes at play, we turned our focus towards how planning translates into project implementation. We defined wildfire mitigation projects to include modifications or development of water utility infrastructure, forest health treatments such as thinning or prescribed burns, or projects that help prevent damaging debris flows or flooding such

as creation of debris flow catchment structures or stream channel stability treatments. Fort Collins, Durango, and PAWSD all addressed wildfire mitigation through internal measures that made their utilities more resilient through the redundancy and flexibility of utility infrastructure. The saving grace for all three utilities when they had wildfires in their source watersheds was the availability of a second source from a different diversion in an un-impacted watershed.

In addition to making internal modifications to infrastructure, all three utilities participated in watershed scale wildfire mitigation through their respective watershed or forest health partnerships, which helped them address the challenges of working at the watershed scale. None of the water providers interviewed had individually implemented wildfire risk mitigation projects in their watersheds for three major reasons: the scale of watershed management is beyond any of the utilities' available resource capacity, utilities do not usually employ experts on forest health or wildfire mitigation actions, and they do not own all of the relevant land in their source watersheds. We found that strong regional networks in the forms of watershed and forest health nonprofits or partnerships allow water utilities to leverage the resources they have for source water protection to make a bigger impact, connect them with people who have expertise in forest health management, and build strong networks with relevant land management agencies and private landowners to overcome jurisdictional barriers that can prevent the implementation of projects. When we looked at how much time the individual utilities could engage with wildfire mitigation or watershed health projects day to day, we saw the amount of resources each utility could dedicate correlated with utility size. City of Fort Collins being the largest utility had the most robust source water protection program with two full time employees dedicated to watershed monitoring and management. PAWSD, being the smallest of the three utilities, dedicated time and resources towards building a robust and flexible treatment and distribution system and relied heavily on their involvement with the San Juan Headwaters Forest Health Partnership to address watershed scale concerns. A clear pattern for all three utilities was that through watershed and forest health organizations, the utilities participated in collaborations to which they provide funding and input, but do not have to implement wildfire mitigation projects on their own.

Watershed and forest health nonprofits also play a pivotal role in funding development for project implementation, leveraging the funds water utilities are able to contribute by having the expertise to apply for and manage relevant private, state, or federal grants or loans. Because of the multi-jurisdictional nature of forest health management at the watershed scale, many types of grants or loans available for forest management require a collaborative approach to project development and implementation. Watershed and forest health organizations also allow small- to medium- size utilities to pool resources together, which also allows for watershed management activities to have a larger and more meaningful impact. Through our case study of Durango, we also found that regional partnerships are starting to develop novel funding mechanisms to address resource and funding limitations to increase the pace and scale of forest health treatments.

In summary, we found several overarching trends consisting of the increasing prevalence of wildfire watershed hazard assessments, variation in wildfire risk mitigation planning and implementation activities based on utility size, an emergence of novel partnerships and funding mechanisms to increase the pace and scale of forest health treatments, and finally that networking and collaboration play a vital role in allowing utilities to meaningfully address wildfire risk. Reiterated throughout our results was the theme of utilities engaging in collaborative partnerships and networks to address wildfire risk to improve their resilience. Local watershed and forest health organizations bridge resource, knowledge, and jurisdictional gaps, which allow water utilities to more effectively engage with the complex nature of wildfire risk.

PROBLEM DEFINITION & RESEARCH QUESTIONS

In Colorado and elsewhere, drinking water utilities that depend on surface water supplies from forested watersheds are facing increasing wildfire risk. Historical fire suppression policies, development in the wildland-urban interface, and climate change have combined to elongate the wildfire season and to make contemporary wildfires hotter and larger (Calkin et. al 2014; Calkin et al. 2015; Martin 2016). When wildfires burn in source watersheds, they generate serious consequences for water providers. Post-fire storm runoff may contain damaging levels of ash, sediment, and debris (Calkin et. al 2015), and may also be contaminated with heavy metals, hydrocarbons, increased nutrients, and dissolved organic carbon (Martin 2016). These source water disturbances can compromise critical water supply infrastructure and water treatment systems. For example, after the 1996 Buffalo Creek Fire and the 2002 Hayman Fire, Denver Water spent over $27 million to repair their water conveyance and storage system and to address water treatment problems (Martin 2016).

These risk conditions are further complicated by the fact that water utilities are constrained in their ability to mitigate wildfire-related risks in source watersheds. The constraints they face are due to three major reasons: water rights and infrastructure, land ownership, and the challenges of working at the watershed scale. Surface water is a limited resource in the arid western U.S. that is allocated via a complex system of water rights and expensive water conveyance infrastructure. As a result, some water providers depend on a narrow set of sources for their water supply, sometimes within a single watershed. On top of these challenges, most water utilities do not own or control the land where their water sources originate. Rather, land ownership in most watersheds is characterized by a multi-jurisdictional patchwork of state and federal lands managed by a variety of agencies and interspersed with private lands held by individual landowners. Finally, affecting change at the watershed scale to restore forest health, prevent high severity burns, and protect critical drinking water infrastructure is an enormous task. No single drinking water utility has the resources to operate at this scale.

These paired issues – water utilities' growing wildfire risks, plus the challenges involved in addressing those risks – motivate this study, where we endeavor to understand how water utilities can reduce their exposure to wildfire hazards and make themselves more resilient to wildfire. Water resilience is defined as the capacity of the physical and socio-economic systems related to water resources to withstand disturbances and adapt to changes through assessment, response, and effective recovery strategies (Chi-hsiang Wang et al. 2009). More specifically, in this study we explore how water utilities are planning for wildfire and how they are implementing on-the-ground risk mitigation projects (modifications/development of water utility infrastructure, forest health treatments, etc.) via the following five research questions:

Research Questions: Wildfire Planning and Implementation

1. *What formal wildfire planning pathways are currently available to water utilities? What are their strengths and limitations for water utilities, specifically?*
2. *Aside from formal wildfire planning processes, what relatively more informal learning processes are drinking water utilities engaged in for the purpose of mitigating wildfire risk?*
3. *Are there effective ways for water utilities to learn from each other's wildfire experiences?*

4. *What actions are utilities taking to implement wildfire risk mitigation projects and increase their overall system resilience?*
5. *What resources do utilities have available for mitigating wildfire risk? How does resource availability impact project implementation?*

RESEARCH DESIGN

The initial stage of the study entailed a thorough literature review on the impacts water utilities have experienced from wildfires, what types of planning processes are available to combat these impacts, and how utilities can effectively implement risk mitigation projects. Because the academic literature is limited in these areas, we supplemented the literature review with an effort to identify existing wildfire planning pathways available to, and in use by, water utilities in Colorado via an Internet search for water utilities' planning reports and related documents. The search included the websites of Colorado drinking water utilities and agencies such as the Colorado Department of Public Health and Environment, the Colorado Water Conservation Board, and the Colorado State Forest Service. Once identified, the planning pathways were analyzed for strengths and limitations.

After identifying how utilities are impacted by, and are coping with, wildfire risk via the literature review and planning document analysis, the research shifted into a case study phase designed to gather wildfire adaptation insights from three Colorado water utilities that have experienced wildfires in recent years. The case studies included a small, a medium, and a large water utility in order to capture variation in wildfire adaptation by size. We also chose to explicitly incorporate small and medium water utilities in the analysis because they have thus far been understudied in wildfire research. The three case studies, from large to small, focused on the City of Fort Collins, the City of Durango, and the Pagosa Area Water and Sanitation District.

The Fort Collins water utility serves a population of over 120,000 people and has experienced multiple wildfires in their watershed, the most destructive being the High Park Fire in 2012 that burned a little over 87,000 acres in the Cache la Poudre watershed. The City of Durango has also experienced multiple fires, with its most impactful fire occurring in 2018: the 416 Fire, which burned 54,129 acres 10 miles north of the city. Durango's water utility serves a population of around 31,000. The Pagosa Area Water and Sanitation District (PAWSD) provides drinking water to over 10,000 people in and around Pagosa Springs. Pagosa Springs dealt with the consequences of the West Fork Complex Fire in 2013, wherein three fires ignited by lightning strikes combined to burn a total of 109,000 acres.

The case study design incorporated in-depth interviews with officials at the water utilities. The study design was approved by the Colorado School of Mines Humans Subjects Research Board. Interviews were conducted using a semi-structured format, which included 13 questions and allowed for deviations in the conversation as necessary. We crafted interview questions to elicit how utilities had been impacted by past wildfires and how they were engaging with the continual risks they face. The semi-structured format allowed interviewees to guide the conversation through their utilities' experiences and knowledge. The interviews ranged from 30 to 70 minutes in length.

RESULTS AND DISCUSSION

Wildfire Planning Pathways and Learning

What formal wildfire planning pathways are currently available to water utilities? What are their strengths and limitations for water utilities, specifically?

No studies in the academic literature directly address how water providers are planning for wildfire impacts. The first step in answering this question was cataloguing what utilities are currently doing to address hazards to their surface water sources, with an emphasis on what sorts of formal planning frameworks are available to water utilities that want to mitigate wildfire risk. A review of publicly available planning documents revealed several different planning frameworks that directly or indirectly may help utilities tackle the enormous task of protecting water resources from wildfire. The main planning frameworks identified and analyzed were source water protection plans (SWPPs), community wildfire protection plans (CWPPs), critical community watershed wildfire protection plans $(\mathrm{CWP})^2$s, watershed wildfire hazard assessments/risk mapping, drought plans, and stream management plans (SMPs). All are described in more detail in Table 1.

The wide array of options available to utilities demanded a closer inspection of the strengths and limitations of each planning framework for water utilities. The assessment focused on five criteria, derived from a review of the literature on wildfire resilience and knowledge of water utility operations. First, we considered whether the planning pathway typically includes water utilities as an active or leading participant in the planning process. Second, we looked at whether the planning pathway includes wildfire risk as a specific focus. Once these two threshold criteria had been considered, the analysis shifted to bigger questions of whether the planning framework is accessible to water utilities of all sizes in terms of resource requirements, how planning efforts work towards funding opportunities for utilities to implement risk mitigation projects, and finally, to the important question of if (and how) the planning framework engages stakeholders beyond the water utility. There is no one-size-fits-all approach to downgrading wildfire threats, and different landscapes require different combinations of management options (Calkin et al. 2015), but these five criteria stood out as important to effective wildfire planning. Table 1 provides background information on each planning framework, as well a snapshot of our assessment of its strengths and limitations in terms of wildfire planning for water utilities, which we discuss in more detail below.

Water utility involvement and wildfire specificity

Five of the six planning frameworks assessed include drinking water utilities as active participants in the planning process: watershed wildfire hazard assessments, $(\mathrm{CWP})^2$s, SWPPs, drought plans and stream management plans. SWPPs and drought plans are created by, and are specific to, individual public water systems or municipalities. Both SWPPs and drought plans are planning frameworks with developed methodologies and guidance from regulatory or governmental agencies. They are also both prevalent among water utilities in Colorado. Stream management plans are less common, but are growing in popularity. These plans can be spearheaded by local municipalities or water providers, as well as by non-profit watershed groups or local water conservation districts. Watershed wildfire hazard assessments are a scalable planning process and can be specific to one utility or to multiple utilities that depend on the same

watershed. $(CWP)^2$s are an expanded version of a CWPP and are meant to be spearheaded by major local water providers, water rights holders, and water transport and storage entities. One planning framework – the CWPP, or community wildfire protection plan – does not emphasize water resources and does not often include water providers. Because these plans focus on protection of life and property in the wildland urban interface (WUI), they are typically spearheaded by local fire authorities, homeowner associations, county commissioners, or sheriff and emergency service personnel with water providers not occupying a lead role the process.

Three of the available planning frameworks are focused centrally on wildfire: CWPPs, $(CWP)^2$s, and wildfire watershed hazard assessments. However, only the latter is actively being undertaken by water utilities. As previously mentioned, CWPPs focus on people and property in the WUI. They can be written by communities of any size, from an HOA to an entire county. A critical component of CWPPs is the identification and prioritization of forest health and fuel treatment projects that reduce wildfire risk to communities and landowners. As a result, the geographic focus of these plans is the WUI. While the WUI itself can be quite extensive, the WUI is typically a smaller piece of a much larger watershed. CWPPs usually recognize the importance watersheds have in producing water resources, but managing an entire watershed in order to mitigate hazards such as post-fire debris flows and considering water resources and conveyance infrastructure outside community boundaries are beyond the scope of this planning tool. The previously mentioned critical community watershed wildfire protection plans ($(CWP)^2$s) represent a broadening of CWPPs with the express goal of integrating water resource and critical infrastructure protection into community wildfire planning. $(CWP)^2$s aim to protect water resources that serve WUI residents and the majority of Colorado's population living in Front Range communities. Expanding the protection focus from the WUI to the entire watershed increases the scale and complexity of this planning framework, which is perhaps why $(CWP)^2$s have not gained traction as a planning framework with utilities.

The most common wildfire-specific planning pathway being used by utilities, as suggested by interviews and Internet searches, are watershed wildfire hazard assessments. These types of assessments are usually instigated and led by water providers concerned about wildfire threats to their critical infrastructure and are carried out by consultants. Watershed wildfire hazard assessments are geared toward evaluating specific wildfire risks, such as destructive post-fire runoff, sedimentation, and debris flows. A key aspect of these hazard assessments is that they are spatially explicit. In other words, a crucial output of the assessment is a risk *map* that pinpoints areas of concern, such as locations where burns may be most likely, where sedimentation could be the most severe, and where water infrastructure may be the most susceptible to post-fire sediment and debris flows. These are technically heavy assessments that generate detailed hazard geographies, which can then be used to prioritize on-the-ground risk mitigation interventions. The high cost associated with these assessments may make them out of reach for small- to medium-sized utilities, unless they conduct them in partnership with other utilities or watershed/forest health organizations.

Table 1: Comparison of Planning Pathways for Drinking Water Utilities to Address Wildfire Risk

Planning Framework	Goals, Origins, and Authors	Strengths for Drinking Water Utilities	Limitations for Drinking Water Utilities
Wildfire-Specific Planning Processes			
Community Wildfire Protection Plans (CWPPs)	• Goal is to mitigate wildfire risk for WUI communities • Prompted by the federal 2003 Healthy Forest Restoration Act • Contributors include local government, fire authority, federal land management agencies, Colorado State Forest Service (which offers CWPP templates)	• A wildfire-specific plan • Identifies forest health and fuels treatment projects • Prioritizes areas where mitigation projects are most needed • Community and cross-jurisdictional engagement builds social capital for project implementation, fire response • Enables state/federal funding access	• Utilities not typically included • Water resources are not a main focus; emphasis is on WUI property/residents • Geographic focus is the WUI rather than the watershed • Individual plans are not useful for landscape-scale goals • Plans are rarely updated, more so in communities with wildfire experience
Critical Community Watershed Wildfire Protections Plans (CWP^2)	• Goals are same as CWPPs, plus water resource protection is integrated • Framework developed by Front Range Fuels Treatment Partnership • Contributors are same as for CWPPs, plus local and regional water providers	• A wildfire-specific plan • Geographic focus is the landscape scale, which allows water providers to engage with risk mitigation on lands outside their jurisdiction • Expands stakeholder engagement to include local water providers, researchers, and non-profit groups	• These plans are not prevalent, possibly because their expanded scale and stakeholder involvement make them more involved, there is less guidance available for them, or the emphasis on protecting watersheds is less compelling than CWPP's emphasis on protecting life and property
Watershed Wildfire Hazard Assessments/Risk Mapping	• Goal is to map and rank wildfire-related risks to water resources to protect drinking water quality and quantity • Methodology developed by Front Range Watershed Wildfire Protection Group • Typically written by consultants for water providers and USFS/CSFS	• Spatially overlays water infrastructure with wildfire hazards to generate risk rankings, identifying where mitigation projects are most needed • Generates evidence-based support for projects and funding opportunities • Methodology is scalable • Products include a mapping tool, which can be updated • Utilizes the same tools as USFS and CSFS, which allows for data sharing	• Technical analysis usually conducted by consultants; may not be financially doable for small/medium utilities • Water utilities must still decide how to act upon the risk rankings • Does not necessarily include a stakeholder engagement process, which could become problematic for later decision-making and implementation of risk mitigation projects

Broad Water Resources Planning Processes			
Source Water Protection Plans (SWPPs)	• Goal is to assess susceptibility of public water sources to contamination • 1996 Amendments to the Safe Drinking Water Act require that states assess public water supplies • Colorado Department of Public Health and Environment offers guidance materials; plans often written by the Colorado Rural Water Association or a consultant	• Plans are specific to individual public water systems • Potential contamination sources are identified and ranked from highest to lowest concern • Water infrastructure identified • Includes methods for prioritizing interventions • Collaborative design that includes stakeholder engagement meetings	• Wildfire mentioned as a potential source of contamination, but may or may not be a main focus of source water protection efforts • Can be biased toward point sources of contamination; not focused on forest health • Implementation can be piecemeal; plans are rarely updated and often can be shelved for smaller utilities
Drought Plans	• Goal is to be prepared for water shortages caused by drought • Voluntary plans encouraged by the Colorado Water Conservation Board (CWCB) and the Colorado Water Plan • Crafted by water providers or municipal governments	• Communities may experience water shortages after a wildfire and/or may experience wildfire during a drought, so these preparedness efforts overlap • Emphasizes water supply redundancy, including collaboration among water rights holders in an emergency • Emphasizes public education • Aims to support multiple water values • Includes evaluation/updating process	• Focuses on demand management, while wildfire risk mitigation is more water supply-oriented • Focused on long-term changes rather than acute emergencies such as wildfire • May not address wildfire-induced supply challenges, such as water quality, debris flow, flooding, etc. • Does not focus on watershed or forest health management
Stream Management Plans (SMPs)	• Goal is to protect river health and flows for ecological and recreational uses • The Colorado Water Plan sets the goal of 80% of locally prioritized rivers being having SMPs by 2030 • SMPs include large stakeholder coalitions by design, but are typically led by local entities such as municipalities, non-profit watershed groups, and water conservancy districts	• Restoration actions could overlap with wildfire risk mitigation goals (e.g., methods to reduce stream temperatures or stabilize flows could connect to forest health efforts, bank stabilization and channel restoration objectives could help with post-fire debris flow and sedimentation) • Requires a strong and diverse stakeholder engagement process • State funding available • Monitoring and updating are inherent to the planning process	• SMPs are focused on recreational and environmental assets (e.g., maintaining critical flows and temperature), not wildfire risk • Plans are focused on the stream or river corridor and may not emphasize broader watershed or forest health

Priorities around stakeholder engagement and partnerships

Dynamics of stakeholder engagement are important to examine across the planning pathways for several reasons. Fire planning efforts that facilitate the development of relationships within communities, and between community members and fire personnel, have been shown to improve preparedness at the individual and community scales by facilitating learning, exchange of information, and helping to build a sense of community (McCaffery et al. 2015). Furthermore, community fire resilience is an inherently complex and multi-scalar issue (Schusler et al. 2003), so building diverse coalitions and partnerships geared towards addressing wildfire risks is vital to the success of risk mitigation and preparedness actions. Diversity in stakeholder inclusion and designing solutions in terms of mutual benefits for stakeholders has also been shown to develop the support necessary for project implementation (Sharma-Wallace et al. 2018). In particular, partnerships built out of resource limitations can spur collaborative processes needed to implement change to current wildfire risk regimes as well build relationships that become vital in post-fire scenarios. Given the importance of stakeholder engagement and wildfire partnerships, we wanted to clearly identify if and how these dynamics are embodied in each of the planning frameworks.

Of the wildfire-specific planning pathways available, CWPPs and $(\mathrm{CWP})^2$s do the most to encourage stakeholder engagement and partnership development. Of the two frameworks, $(\mathrm{CWP})^2$s include a broader set of stakeholders because, in addition to including local fire authorities, emergency services personnel, and WUI residents, they fold in water providers, scientific institutions (local universities, USGS, NRCS, etc.), and interested environmental nonprofit groups. Watershed wildfire hazard assessments and risk mapping, the most common planning pathway being pursued by water utilities, do not as a rule engage watershed stakeholders more broadly but they have the potential to do so. Available guidance states that these technical hazard assessments can be integrated into existing CWPPs or be used as a basis for the development of $(\mathrm{CWP})^2$s, though it is not clear that this is happening in practice. Because these assessments spatially identify risk in the watershed landscape and demarcate land ownership patterns, they could also be used to identify partners for collaboration, bringing together groups that may not have been connected through the other planning frameworks, including downstream water utilities.

Of the three non-wildfire-specific planning pathways available to water utilities – source water protection plans (SWPPs), stream management plans (SMPs), and drought plans – SMPs encourage more robust stakeholder engagement and invite diverse participants into the planning process. While SMPs' focus on increasing stream flows for ecological and recreational purposes does not squarely address wildfire risk, their emphasis on stakeholder engagement is notable. Linking different stakeholder groups in networks creates opportunities for new interactions that are important for dealing with environmental change and uncertainty (Folke et al. 2005). New interactions from participants with different knowledge systems supports the production of holistic and multi-objective wildfire management plans with greater communal support because of the way they are developed. SWPP guidance recommends initiating stakeholder engagement as the first step in the planning process, but it is possible that SWPPs' scope and audience may inherently limit stakeholder engagement. Because SWPPs are intended for individual public water systems, they are both specific to a single water provider and are written for a utility-specific audience. This can limit the diversity of participants in the process. Drought plans are more limited in their stakeholder involvement due to their specific focus on a single water provider's water supply and demand in their service area. Drought planning does require an in-depth analysis into the water

rights portfolio of drinking water utilities, and this process can help identify partners for wildfire contingency planning. Importantly, SMPs, SWPPs, and drought plans also integrate public education efforts, which is another key type of stakeholder engagement. Having local community members understand the ecosystem services their watersheds provide them is fundamental in building the social capital necessary to implement source water protection measures.

Navigating planning pathways and options

Given the range of planning pathways available to water utilities, and their various strengths and weaknesses, it was important to understand how our three case study utilities were navigating the options. All three practiced water resources planning by utilizing some of the mentioned frameworks, but due to utility size and resources, engaged with these formal planning processes in different ways. All of the utilities interviewed were located in communities with CWPPs, but none of the three identified CWPPs as something they were actively engaged in. City of Fort Collins described how different planning frameworks have different goals and stakeholder concerns and as a utility, they take advantage of many different planning methods to create a multi-pronged approach to source water protection. Fort Collins engaged in utility specific plans including a Water Supply Shortage Response Plan (drought planning), a Water Supply and Demand Management Plan (drought planning), a Raw Water Vulnerability Assessment with significant modeling, a SWPP, and a watershed wildfire hazard assessment for the Upper Cache la Poudre River watershed. They also participated in a more collaborative watershed planning effort (guided by the Coalition for the Poudre River Watershed) known as the Poudre River Watershed Resiliency Plan. City of Durango has developed a Drought Management Plan and will in the next two years conduct a wildfire watershed hazard assessment with critical infrastructure risk mapping in the Florida watershed. Durango is also involved in a novel program and funding mechanism, the Southwest Colorado Wildfire Mitigation Environmental Impact Fund, which they described as a planning and implementation effort that ties economic benefits in the community to forest health treatments. Pagosa Area Water and Sanitation District (PAWSD) had completed a SWPP in 2008, but the planning effort was not a driving force behind the utility's current source water protection actions. PAWSD also had their own Drought Management Plan. Fort Collins, Durango, and PAWSD all highlighted the connection between drought planning and wildfire risk as both droughts and wildfires pose supply limitations and pressure on their water resources, and droughts and wildfires are often linked. PAWSD also participated in a wildfire watershed hazard assessment with critical infrastructure risk mapping and was able to have this assessment done through its participation in the San Juan Headwaters Forest Health Partnership.

In sum, all three utilities interviewed had engaged in, or were planning to conduct, watershed wildfire assessments with risk mapping and all three had developed drought plans and were aware of drought-wildfire links. All three of the interviewed utilities also recognized the financial and operational importance to their utility of proactively addressing source water risks, including wildfire. In addition to these relatively more individual planning pathways, all three were involved in various watershed-oriented networks that were engaged in collaborative planning at a larger scale. These larger-scale collaborations seemed to be the most active sites of stakeholder engagement, partnership development, and on the ground implementation of wildfire mitigation projects. Fort Collins being the largest utility interviewed had the most resources available to put towards source water protection and participated in many types of water resource protection planning efforts. The wildfire risk assessments were more of a financial stretch for the smaller

utilities – Durango and Pagosa Springs – which either had not yet conducted the studies or had done so as part of a larger partnership. Finally, CWPPs, $(CWP)^2$s, and SMPs, did not serve as significant wildfire planning pathways for the three water utilities we interviewed.

Aside from formal wildfire planning processes, what relatively more informal learning processes are drinking water utilities engaged in for the purpose of mitigating wildfire risk?

Opportunities for improved socio-ecological resilience emerge from processes of learning through collaboration, management, feedback, and adjustment (Abrams et al. 2015). Processes of wildfire adaptation can occur outside of formal planning frameworks, which makes it important to examine other – relatively more "informal" – ways that water utilities are learning about and preparing for wildfire. We looked at our interview data for indications of what informal learning our utilities engaged in. Acknowledging that our dataset is small, we found the following three examples of informal learning processes at play: experiences from past wildfire events and their impacts; independent review of scientific literature, particularly via connections to local academic institutions; and networks developed through regional partnerships and forest health or watershed health organizations.

Informal learning through experiences of wildfire events

City of Fort Collins, City of Durango, and PAWSD were selected as utility interview candidates because of their experiences with wildfires that impacted their operations. The informal learning that takes place during wildfire response and post-fire recovery can increase community capacity to respond to changing wildfire risks and improving future planning efforts, both of which bolster a system's capacity to adapt, and therefore its resilience (Jakes et al. 2013). All three utilities reported having learned important lessons from recent burns. City of Fort Collins experienced heavy sediment loads, high total organic carbon levels, and taste and odor issues from storm events after the 2012 High Park Fire. Fort Collins could not use their most senior water rights on the Cache la Poudre River for over 100 days because of these severe water quality impacts. This spurred the design and build of a pre-sedimentation basin, which is a basin that slows the flow of diverted water so that sediment and debris can be removed prior to entering utility infrastructure. The Fort Collins sedimentation basin was constructed in an unprecedented six-month timeframe and is now a fixture in their normal water operations and overall wildfire preparedness. The Tri-Districts Water Treatment Plant utilized the same raw water pipeline and also contributed funds to build the pre-sedimentation basin. To combat post-fire runoff water quality issues, Fort Collins also uses an on-line raw water monitoring station located at their diversion to provide advanced warning to plant operators of poor water quality coming down the Cache la Poudre River. The High Park Fire also created slope stabilization problems because it burned at a high intensity that left some slopes scarred. Figuring out the best material to use to stabilize slopes and the logistics (physical *and* jurisdictional) of applying straw or mulch to slopes was a massive learning experience for the utility and highlighted for them a knowledge gap in existing science and practice. Although Fort Collins worked closely with the NRCS, the geology of each watershed in Colorado is unique and presents its own unique challenges. Another major theme for Fort Collins through their High Park Fire experiences was the instrumentality of collaborative partners during the response and for future planning efforts. Being off the Cache la Poudre water supply for over 100 days forced the city to rely on their more junior water rights in

Horsetooth Reservoir via the Colorado Big Thompson system, which was only possible due to relationships and working agreements they had with other water rights owners. Having a secondary water source and diversion point was essential for Fort Collins to continue operations. The mulching and slope stability effort was also only possible because of the relationship between City of Fort Collins and the City of Greeley, another municipal water provider impacted by the High Park Fire.

In a similar fashion, Pagosa Area Water and Sanitation District was unable to treat their source water after the West Fork Complex Fire in 2012. PAWSD relied on the Snowball Plant, a direct filtration treatment system, to provide water to the majority of their service area. When they diverted water from Snowball Creek post-fire, it was inundated with ash and suspended solids. When the dirty water was introduced, the plant's filters clogged so quickly that plant staff were unable to produce enough treated water to backflush and clean the filters, completely killing the plant's operability. Faced with this emergency situation, operators at PAWSD had to try something they had not done before: use the district's other two treatment plants to backfill the distribution system so they could continue to provide water to the residents of Pagosa Springs. The interconnections between the three plants were already there, but they had yet to try opening up valves and pumping water into the entire system from these nodes. PAWSD is extremely fortunate and forward thinking to have three treatment plants that divert water from three separate diversions and two watersheds. One thing that was clear with this experience with the West Fork Complex Fire was the need for them to have redundancy and flexibility within their system. The inability to treat post-fire storm runoff also prompted PAWSD to partner with the U.S. Forest Service to install a telemetry based advanced monitoring system so they could have ample warning when high turbidity water was coming down the creek in the future.

For the City of Durango, the 416 Fire in 2018 impacted Hermosa Creek, a tributary to the Animas River, which runs through the heart of the city. Durango's water operations were not severely crippled from this fire and the post-fire runoff for two reasons: (1) they had advanced monitoring stations on the river alerting them to poor-quality water coming down the Animas, which allowed them to proactively shut off their Animas River diversion, and (2), water from the Animas is their secondary source, enabling them to shut off this diversion for hours or days at a time with minimal impact. Durango relies mainly on the Florida River, which originates in a neighboring watershed, as their main daily supply. The city draws from the Animas only during peak demand in the summer. Their experience with the 416 Fire highlighted the importance of the Florida River supply and infrastructure, prompting the utility to plan to complete wildfire hazard assessment and risk mapping in the Florida watershed in the next two years. Experiences from the 416 Fire – as well as the Gold King Mine spill, which impacted the Animas as well – also prompted the utility to become more engaged in how its citizens understand their own drinking water supply. The Durango utility acknowledged that their citizens are generally well informed, care about environmental issues and are supportive of efforts that promote ecology, forest health, and water quality. At the same time, they also wondered how many citizens are aware that most of their water comes from the more distant Florida River and not the nearby Animas River. Durango is also concerned about how well the connection between water quality and forest health is understood in the community, and wants to convey the message to their citizens that having and using funds upfront to improve forest health conditions is less costly than having to recover from the impacts of catastrophic wildfire.

Informal learning through scientific research and partnerships with academic institutions

The second trend we found in informal learning pathways for utilities is their own independent research and the research they are exposed to through partnerships with local scientific research and academic institutions. For example, the need to stabilize the slopes burned by the High Park Fire to reduce the impact from post-fire erosion and debris flows and increase the quality of post-fire runoff was evident to the City of Fort Collins water utility. Unfortunately, the best methods for *how* to stabilize slopes were not very clear, and because of this utility staff spent time doing their own research to learn about how other regions in the state or other areas in the country stabilize slopes after large and severe wildfires. Through their own research, the Fort Collins utility discovered how complex and idiosyncratic slope stability is, and that stabilizing soils after severe burns is highly dependent on soil chemistry and the geological and mechanical characteristics of the region where the burn occurred. Picking out the right materials to stabilize the slopes became not only a question of geologic engineering, but also one of ecology and determining where mulch or straw came from and if it was contaminated with invasive weed species. When interviewed, Fort Collins lamented the complexity of slope stability and logistics, as well as large gap in actionable information in this area for utilities. Another way Fort Collins engages in their own utility research is through their source water monitoring program. The utility staffs two fulltime employees devoted to their watershed program to conduct watershed health and water quality studies in conjunction with partners from the City of Greeley and the Tri-Districts. Fort Collins also stays on top of the relevant scientific publications and studies on wildfire and its impacts on drinking water utility operations through its strong relationships with several academic and reserach institutions. They have and continue to work with Colorado State University, University of Colorado, Colorado School of Mines, American Water Works Association, Association of Metropolitan Water Agencies, and the Water Research Foundation. With the concerns City of Durango has for their critical water supply infrastructure in the Florida watershed, they looked into studies of the Waldo Canyon Fire and how debris flows impacted Colorado Springs Utilities' water supply infrastructure. Review of articles and studies from the Waldo Canyon Fire was one of many elements that influenced Durango's decision to invest and plan for a watershed wildfire hazard assessment and risk mapping in the Florida watershed. Both Durango and PAWSD have strong relationships with the local Mountain Studies Institute, whose mission is "to empower communities, managers and scientists to innovate solutions through mountain research, education, and practice," (http://www.mountainstudies.org/). Working with this local research entity helps both utilities stay connected to the most up-to-date scientific information on a range of regional issues including forest health. The Mountain Studies Institute is a nonprofit organization that in addition to providing access to scientific studies, also provides both water providers access to a greater regional network, which leads us to the third trend in informal learning we found.

Informal learning through regional forest health and watershed health networks

The regional networks utilities participate in can connect them to new knowledge sources as well as increase their exposure to diverse knowledge systems they may not come across in industry-specific groups. Informal learning through social networks is important because it can counter conditions that limit learning and adaptability by promoting communication between

diverse stakeholders, fostering trust, and enabling coordination across social and political boundaries to address resilience on a meaningful ecological scale (Spies et al. 2014). All three utilities are active participants in at least one collaborative and regionally specific watershed or forest health organization. City of Fort Collins has extensive watershed networks built through their partnerships with the Coalition for the Poudre River Watershed, Big Thompson Watershed Coalition, and the Poudre Runs Through It Study/Action Workgroup (in addition to their partnerships with local academic institutions). Fort Collins also participates in a larger, statewide stakeholder organization known as the Watershed Wildfire Protection Group (WWPG). PAWSD, in addition to their association with the Mountain Studies Institute, is a member of the Water Information Program as well as an active partner with the San Juan Headwaters Forest Health Partnership, which is in turn part of an even larger regional organization called the 2-3-2 Cohesive Strategy Partnership. The 2-3-2 (two watersheds, three rivers, and two states) is a collaborative comprised of multiple federal, state, and tribal agencies as well as multiple nonprofit organizations that work to protect and preserve the forest health, water quality, wildlife habitat and communities within the San Juan, Chama, and Rio Grande Watershed landscapes. PAWSD relies heavily on the San Juan Headwaters Forest Health Partnership to advocate for them with the USFS and to promote projects that protect their water resources and critical infrastructure from wildfire. City of Durango stressed in their interview the importance of having a strong network of people the utility was tied into that had institutional knowledge of fire risk and post-fire concerns. Similar to PAWSD, Durango also works closely with the Mountain Studies Institute and is a member of the Water Information Program (WIP), which is a public information program sponsored by the water districts, organizations and agencies in the San Juan and Dolores watersheds of Southwestern Colorado. The purpose of the WIP is to provide information to the public and community on water topics and water related issues. Durango participates in additional regional partnerships as well including the Southwest Basin Roundtable, Southwest Water Conservation District, Community Action Group – post Gold King Mine spill, Animas Watershed Partnership, Water Information Steering Committee, and the novel network and funding mechanism called the Southwest Wildfire Mitigation Environmental Impact Fund (EIF). The Southwest Wildfire Mitigation EIF was prompted by regional leaders realizing the need to work on a local level with private landowners, local governments and the USFS in order to increase coordination to implement larger scale forest health treatments. The conceptualization and creation of the EIF is a collaboration among the San Juan National Forest, the Mountain Studies Institute, the finance consulting firm Quantified Ventures, and local attorney and former state legislator Ellen Roberts.

Stakeholder engagement that brings in local, private community members in the planning structures allows for informal learning processes to occur by bringing together key players in the watershed social-ecological system and building out these networks within the community. This type of informal learning allows for non-traditional information, like local knowledge and experiences from community members, to be more integrated into wildfire planning which can be influential when implementing wildfire mitigation. Community wildfire preparedness programs that take into account local context and knowledge are more effective in building community capacity because interpersonal networks are better at communicating information, engaging residents, ensuring local values are considered, and addressing specific local barriers (McCaffery 2015). All three utilities engaged in public education measures to help them convey to their communities the importance of watershed health and its connection to water quality, but many of these measures lean towards one-way communication instead of the dynamic, two-way communication highlighted academic literature as an effective means of developing and

implementing wildfire mitigation with grassroots, local community support. By contrast, the City of Fort Collins in their interview specifically highlighted how the nonprofit organizations they are a part of help them by facilitating outreach and communication efforts with private landowners, which help them develop the relationships, social capital and trust in their source water basins to perform wildfire mitigation. Being a part of and utilizing watershed and forest health organizations helps water providers build their regional social networks, incorporate local knowledge systems and work towards addressing the jurisdictional barriers that prevent wildfire mitigation from being implemented on a larger scale.

Do any of the wildfire-related learning dynamics that are currently underway (formally or informally) promote learning among water utilities and across watersheds? In other words, are there effective ways for water utilities to learn from each other's wildfire experiences?

The case study interviews made it clear that there were strong wildfire-related networks and learning occurring within watersheds as discussed above, but cross-watershed learning was much less apparent. Fort Collins did mention multiple workshops and seminars were held right after the High Park Fire along with the fires near Colorado Springs by the Water Research Foundation. Fort Collins also discussed their participation in the Watershed Wildfire Protection Group, an organization with a mission that promotes intra-watershed learning. The water providers in Colorado that participate the most actively in the WWPG are Colorado Springs Utilities, Aurora Water, and Denver Water. They are among the largest water providers in the state and divert water from multiple fire-prone watersheds. This participation trend may indicate that small-to-medium utilities might not have the time or the resources to participate in stakeholder groups that are focused on issues with a broader scope that fall outside of their own utility's watersheds. Durango and Fort Collins both also mentioned after they had gone through their fire experiences, finding studies published about the recovery efforts of other utilities in Colorado, but there was not a lot of direct utility communication or discussion of a larger arena where multiple utilities could share important wildfire lessons. It is important to note that not all natural resources management strategies or experiences are transferrable. Learning can be time- and place-specific, especially in complex social-ecological systems (Armitage et al. 2008). Still, the absence of intra-watershed learning is notable, given the prevalence of wildfire in Colorado and extensive community reliance on fire-prone watersheds for water resources. In addition to the Water Research Foundation, another organization of note that seems to be working to address this issue is Coalitions and Collaboratives (COCO). In 2019, COCO hosted the first ever After the Flames conference whose goal was to bring together researchers, practitioners, and community members responding to post-fire impacts. COCO continues to develop resources to help communities and agencies access research and best management practices related to post-fire recovery (https://aftertheflames.com/).

Implementation

What actions are utilities taking individually or collaboratively to implement wildfire mitigation projects and increase their overall system resilience?

Case study interviews suggested that water providers' first priority for reducing wildfire risk and increasing wildfire resilience was to bolster redundancy and flexibility within their individual water systems from an infrastructure and operations standpoint. All of the water

providers worked from the baseline assumption that they will have to deal with wildfires and post-fire impacts, and the first thing water providers can do and what they can control is the mechanisms within their system. All three systems were able to get through recent wildfires and post-fire impacts because they had multiple water sources originating in, and being delivered via, more than one watershed system. The water supply redundancy exhibited by the three utilities is most likely an artifact of concerns about water scarcity and Colorado's water rights regime rather than wildfire planning per se, but this is an example of how drought planning and wildfire planning can overlap. Pagosa Area Water and Sanitation District, in addition to their water supply redundancy, has the infrastructure redundancy of three drinking water treatment plants supplied by different water diversions. PAWSD's experience with the West Fork Complex Fire demonstrated to them the importance of having these plants and the distribution system networks they serviced interconnected so that the water district could have operational redundancy and flexibility. PAWSD sees this as their main defense against post-fire water supply disturbances. Durango also has increased infrastructure redundancy on the horizon, mentioning in their interview water storage rights secured in Lake Nighthorse and plans for a second water treatment plant that would be able to backfill all of their existing infrastructure. Durango, as mentioned earlier, is also planning on conducting their own watershed wildfire hazard assessment and risk mapping of the critical infrastructure for their main water supply in the Florida watershed. It is important to consider that some smaller utilities may not enjoy the level of infrastructural and operational redundancy that our small- and medium-sized case study water utilities had achieved. Some water utilities rely on one water supply source or only have one diversion point. For these utilities, taking steps to address wildfire risk to prevent catastrophic wildfires from occurring and developing debris flow and sediment catchment structures may be some of the only options available to them to increase their individual system resiliency.

Another mechanism all three water providers utilized to improve their operational flexibility was monitoring stations installed above their source water diversions. These monitoring stations detect poor water quality from post-fire storm events and give advanced warning to treatment plant operators prior to the water getting to plant diversion points. Having an advanced warning system in combination with water holding ponds at treatment plants allows operators to shut their head gates when post-fire storm events occur so difficult-to-treat water can pass by and plants can continue to operate using cleaner water stored in the holding ponds. Holding pond capacity and water demands in these scenarios have a big influence on how long operators can hold head gates shut and not divert water.

Once the individual systems took steps internally to increase their resilience to post-fire disturbances, they turned to addressing wildfire risk at the watershed scale. How involved each utility was in watershed efforts depended on the time and resources they had, which usually correlated with the size of the utility. None of the water providers interviewed had individually implemented wildfire risk mitigation projects in their watersheds for three major reasons: the scale of watershed management is beyond any of the utilities' available resource capacity, utilities do not usually employ experts on forest health or wildfire mitigation actions, and they do not own all of the relevant land in their source watersheds. Because of these reasons, all of the interviewed utilities tackled watershed scale wildfire mitigation through their regional networks and partners, which were mostly nonprofit watershed and/or forest health organizations. After the High Park Fire, both Fort Collins and the City of Greeley helped in the sponsorship and start up the Coalition for the Poudre River Watershed realizing the need for a watershed organization in the post-fire recovery effort. Today, both the Coalition for the Poudre River Watershed and the Big Thompson

Watershed Coalition proactively work on watershed resiliency and fire mitigation measures that improve and protect water resources for the City of Fort Collins. The San Juan Headwaters Forest Health Partnership helped PAWSD with their infrastructure mapping and watershed wildfire hazard assessment and they actively lobby on PAWSD's behalf with the USFS to advocate for forest treatments in areas that are critical for PAWSD infrastructure. City of Durango works with the Mountain Studies Institute and is in preliminary stages of a partnership with the Southwest Fire Mitigation Environmental Impact Fund whose goal is to set up a mechanism to implement transformative forest health treatments on a larger scale. Fort Collins, Durango, and PAWSD all partnered with organizations that could help them build relationships and coordinate across jurisdictional land boundaries and with private landowners in the WUI, connect with people with the expertise on forest health and mitigation, and network with organizations that could dedicate staff to coordinating and pursuing the funding resources necessary fully implement projects. Through their relationships with watershed and forest health organizations, each of the utilities have set up collaborations to which they provide funding and input, but do not have to implement wildfire mitigation projects on their own.

What resources do utilities have available for water resource protection? How does resource availability impact project implementation?

The drinking water utilities interviewed are funded by the rate payers they serve, and this money goes into water funds that are earmarked to finance the operation and maintenance of the utility. There can also be capital improvement funds to finance special projects that occur outside of planned annual operations or maintenance. PAWSD has a capital improvement plan in place to increase the flexibility and redundancy of their three water plants and distribution system. The portion of the water funds each utility was able to dedicate to water resource protection were proportional to their size, with Fort Collins being able to spend the most and PAWSD spending the least. All three utilities commented on not having as much funding as they would like to devote to source water protection and how financial limitations forced the need to prioritize risks and risk mitigation projects. These resource limitations were another reason for building watershed and forest health partnerships in their source water protection practices. Banding together with other utilities or agencies in the region allows for utilities' investments in source water protection to go further. Additionally, Fort Collins and PAWSD both mentioned that providing funds to the Coalition for the Poudre River Watershed and the San Juan Headwaters Forest Health Partnership, respectively, allowed those organizations to leverage funds as matches and apply for grants to further increase the finances available for fire mitigation projects.

A preliminary analysis of grants or other funding available for watershed/forest health projects that mitigate wildfire risk revealed a range of choices. Grants are available from state, federal, and private entities, each with their own application, match, jurisdictional and reporting requirements. Applying for and managing grants can be a complex process. The Fort Collins and PAWSD utilities shared that applying for grants is typically not a major focus for water providers, and that they would rather defer to watershed organization partners to tackle grant funding efforts. Because many risk mitigation projects would be conducted on lands that fall under multiple land management agencies, it is common for grant programs to require some type of collaborative sponsorship in order to qualify for the funds. Obtaining grant funding for implementing projects promotes collaboration with the USFS in particular. The USFS has limited funds for wildfire mitigation efforts as well. Being able to partner with local entities can help to earn them the

grassroots support to successfully implement projects such as forest thinning or prescribed fire, while also helping them leverage their funding to have a bigger impact.

Because of the complexity of finding financial resources to support large-scale forest health and fire mitigation projects, water utilities and other watershed stakeholders are also developing novel funding mechanisms. Durango pointed in particular to the Southwest Colorado Wildfire Mitigation Environmental Impact Fund (EIF), which is being developed by Ellen Roberts, Quantified Ventures, the Mountain Studies Institute and the San Juan National Forest. The idea of the wildfire mitigation EIF is to use a revolving loan fund model to increase the scale and pace of forest health projects in the region by finding local industrial uses for the wooded material that would be produced by forest health treatments. The industrial uses would include electricity, thermal energy, and biochar which would spur economic incentives for transformative management practices for forests in southwest Colorado.

CONCLUSION

Wildfires and post-fire impacts like sediment transport and debris flows can impair source water quality and damage or destroy the infrastructure needed to divert water supplies to public drinking water systems. Water providers are being confronted with wildfire threats and disturbances on an increasing scale, with ten of the fifteen largest wildfires in Colorado occurring in the last decade (9News 2019). Building the capacity to withstand disturbances and adapt to changing ecological conditions increases water providers' resilience to wildfire and improves their ability to manage wildfire risks. Through this study, we worked to identify what planning efforts and mechanisms water utilities are using to implement on-the-ground projects that bolster their capacity to cope with wildfire threats. We found several trends including the increasing prevalence of wildfire watershed hazard assessments, variation in wildfire risk mitigation planning and implementation activities based on utility size, an emergence of novel partnerships and funding mechanisms to increase the pace and scale of forest health treatments, and finally that networking and collaboration play a vital role in allowing utilities to meaningfully address wildfire risk.

There are a considerable number of planning frameworks available for water utilities to plan for and formally address wildfire risk. More broad water resource planning frameworks include source water protection plans (SWPPs), drought plans, and stream management plans (SMPs). Many utilities have SWPPs and drought plans, and all three of our utility case studies remarked on the overlap of drought planning and wildfire planning. It will be interesting to see if wildfire starts to play a larger role within these planning frameworks, as water providers begin to engage with wildfire disturbances on an increased frequency. Wildfire-specific plans include community wildfire protection plans (CWPPs), critical community watershed wildfire protection plans ($(CWP)^2$s), and wildfire watershed hazard assessments. CWPPs are the most prevalent type of wildfire planning framework, but water providers do not typically play a substantial role in the process. Also, CWPPs focus on protection of life and property in the wildland urban interface and do not focus on the entire geographic area of a watershed with the intention of minimizing or preventing debris flows or other post-fire impacts to water sources. $(CWP)^2$s could be an ideal planning framework for water utilities because they are a broadened version of CWPPs that aim explicitly to incorporate water providers and their concerns surrounding wildfire and post-fire impacts, but $(CWP)^2$s do not appear to be widely in use. Through our water utility case studies and an Internet search, we found that wildfire watershed hazard assessments have been the most popular approach drinking water utilities are taking to understand and prepare for wildfire risk.

Wildfire watershed hazard assessments are technically rich and intellectually very useful, but are lacking in terms of guidance on stakeholder engagement. The spatial analysis of wildfire risk on the watershed scale and the cost for performing these assessments set wildfire watershed hazard assessments up as potential engagement mechanisms, so how these assessments are integrated into the social and political aspects of wildfire planning will be important to keep track of.

City of Fort Collins, City of Durango, and Pagosa Area Water and Sanitation District had similarities and differences on how their organizations handled wildfire risk. In terms of their similarities, all three utilities were able to handle fires that impacted their source waters because they all had secondary sources and diversions in un-impacted watersheds. All three utilities had also implemented or were planning to implement infrastructure changes within their utility to improve operational flexibility and resilience. Fort Collins after the High Park Fire built a pre-sedimentation basin off the Cache la Poudre River and they continue to use it to this day. Durango plans to eventually build a second water treatment plant, and PAWSD has three water treatment plants with three separate diversions and continues to improve their distribution system flexibility between the three plants. All three water utilities also employed advanced warning monitoring stations to alert water treatment plant staff of poor water quality headed their way during post-fire storm events.

The utilities differed somewhat in their approaches to wildfire risk planning. The volume of staff time that each utility could devote to wildfire planning seemed to correlate with utility size, which had implications for both in-house efforts and collaborations. Fort Collins being the largest of the three utilities, spoke of participating in many of the source water planning frameworks and reiterated the need to have a multipronged approach to watershed protection and monitoring. Fort Collins also had the most robust source water protection budget, as well as two fulltime employees dedicated to watershed monitoring and management. Durango had not yet conducted a watershed wildfire hazard assessment, but had set aside funds to complete one within the next two years. PASWD had completed a watershed wildfire hazard assessment, and had developed a critical infrastructure risk map in the process, but PASWD was only able to complete this through their participation with the larger San Juan Headwaters Forest Health Partnership. Fort Collins engaged in watershed management activities the most, per its dedicated watershed division, while PAWSD largely relies upon the San Juan Headwaters Forest Health Partnership for wildfire planning and resources. None of the utilities implemented wildfire mitigation projects such as forest thinning or prescribed burns themselves. Instead, all the utilities relied on their regional networks, which usually took form in watershed or forest health organizations, to conduct wildfire mitigation projects for them and others.

One of the most consistent themes we found echoed throughout this study was water utility participation in regional partnerships and collaborative watershed or forest health organizations. Collaborative organizations play a pivotal role for utilities in their efforts to address the complex and increasing risk of catastrophic wildfires. Water utilities are unable to address wildfire risk on their own due to resource limitations, land ownership constraints, and the related logistical and jurisdictional challenges that go along with implementing wildfire mitigation on the watershed scale. Participating in regional networks allows water utilities to connect with private landowners as well as state and federal land management agencies and build the relationships necessary to implement mitigation projects across jurisdictional boundaries. Being a part of collaborative watershed or forest health organizations also enables utilities to pool funding with other partners, leveraging the funds to go further. Collaborative approaches to wildfire risk management and forest health treatments also open up doors to new funding sources through private, state, and

federal grants and loans, which can be capitalized on by watershed nonprofits who have the expertise and knowledge on applying for an managing these types of funds. Building out these regional networks connects water utilities with partners that have the skills and capacity to implement forest health treatments or other wildfire mitigation projects so that water utilities can focus doing what they do best, treating and distributing drinking water. The community communication that takes place during collaborative wildfire planning has also been shown to foster quicker recovery and response (Jakes et al. 2013), which additionally boost utilities resiliency in face of wildfire disturbances. Through these partnerships we are also seeing the development of novel funding mechanisms and management paradigms like the Southwest Colorado Wildfire Mitigation Environmental Impact Fund that work to increase the pace and scale of forest health treatments in the hopes to make transformative change in how forests are managed. Regional networks and collaborative partnerships address multiple challenges and allow water utilities to engage with the complex nature of wildfire risk in a meaningful and impactful way.

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