BRIEFING PAPER • DECEMBER 2021

WILDFIRE & WATER SUPPLY IN CALIFORNIA

ADVANCING A RESEARCH & POLICY AGENDA

Gregory Pierce, Peter Roquemore, and Faith Kearns

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources | California Institute for Water Resources

UCLA Luskin Center for Innovation

AUTHORSHIP

This report was produced by University of California Agriculture and Natural Resources (UC ANR), California Institute for Water Resources and the Luskin Center for Innovation (LCI) at the University of California, Los Angeles (UCLA). It was authored by the following researchers:

- Dr. Gregory Pierce, co-director, LCI
- Peter Roquemore, project manager, LCI
- Dr. Faith Kearns, academic coordinator, California Institute for Water Resources

The report is based on input from 23 workshop participants as listed on page 15.

ACKNOWLEDGEMENTS

Funding for this research was provided by the U.S. Geological Survey through the California Institute for Water Resources. We also thank Lauren Dunlap for editing and designing this report.

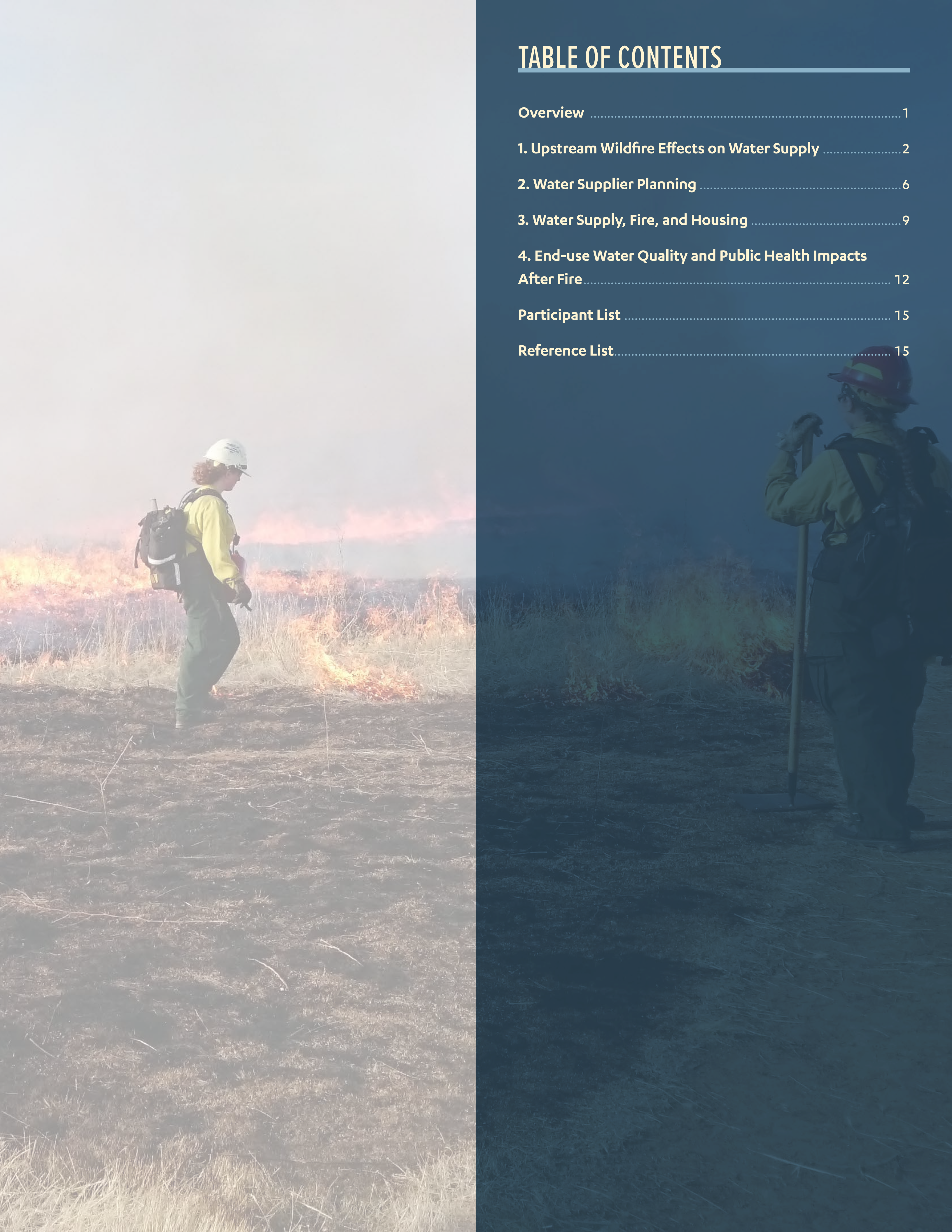
We acknowledge the Gabrielino/Tongva peoples as the traditional land caretakers of Tovaangar (the Los Angeles basin and So. Channel Islands). As a land grant institution, we pay our respects to the Honuukvetam (Ancestors), 'Ahiihirom (Elders) and 'eyoohiinkem (our relatives/relations) past, present and emerging.

FOR MORE INFORMATION

Contact: **gspierce@ucla.edu** or **faith.kearns@ucop.edu**

Cover photo: VladTeodor / iStock.
Inside cover photo: Bureau of Land Management Oregon and Washington / Flickr.

TABLE OF CONTENTS



OVERVIEW

The linkages between wildfire and water are numerous, and many of them are relatively well researched, such as the effects of wildfire on riparian areas. However, in recent years, a newer issue has emerged: the relationship between wildfire and water supply. Some aspects of this topic are relatively well understood, such as how higher elevation wildfires might impact water storage reservoirs through siltation. Other aspects are less understood, such as how wildfires lead to drinking water contamination.

During the Tubbs (2017), Camp and Woolsey (2018), and CZU Complex (2020) Fires, in particular, community water systems were affected in various ways, presenting a new set of issues. The Tubbs and Camp fires "are the first known wildfires where widespread drinking water chemical contamination was discovered in the water distribution network and not in the source water after the fire" (Proctor et al. 2020).

To address the recent emergence of wildfire-caused drinking water contamination, we asked a group of interdisciplinary and cross-sector participants to provide input and review on a research and policy agenda for how California can more proactively address the ways in which wildfire is increasingly putting water supply systems at risk. Workshop sessions were focused on four different research and policy issues and related questions at the intersection of wildfire events and water supply provision:

1. Upstream Wildfire Effects on Water Supply

- How can forest and other ecosystem management help mitigate fire's effect on downstream water flows?
- Should we expect upstream post-fire water quality impacts to evolve qualitatively or just quantitatively?
- How can disaster management efforts in the state better address post-fire water supply impacts upstream?
- How can research efforts better support Indigenous leadership, knowledge, and practice to help manage healthy ecosystems?
- What are the most effective methods to support long-term forest and other ecosystem management to adapt to upstream effects?

2. Water Supplier Planning

- What can be done to proactively mitigate and reactively address damage to water reservoirs?
- How can water systems be supported to maintain power and continuous supply during a fire?
- How should water systems be expected to finance fire-fighting efforts?

3. Water Supply, Fire, and Housing

- What are the impacts of new fire-sensitive building codes and regulations on long-term residents?
- How can displaced communities (re)gain access to affordable housing and essential services?
- How do we rebuild damaged plumbing infrastructure that is resilient to fire/reduces the contamination impacts experienced in communities?

4. End-use Water Quality and Public Health Impacts After Fire

- Are new or enhanced drinking water regulations for testing and treatment needed to better address near or at point-of-use drinking water quality impacts from wildfire?

- Who should provide emergency water supply, and what scale is feasible given the cost?
- How can we improve post-fire response guidance and testing support to improve communities' trust in water quality?

This document contains a high-level summary of initial research and policy gaps, as well as key questions to be answered, identified by UC ANR and UCLA and refined by workshop participants. The organization of and dividing lines between topics as presented here are necessarily overlapping. This report serves as an agenda for conversation, but does not contain final answers.

1. UPSTREAM WILDFIRE EFFECTS ON WATER SUPPLY

California's drinking water supply has relied on the health of upstream alpine forests, chaparral, and grasslands to collect, filter, and deliver rainfall and snowmelt to groundwater, rivers, streams, and reservoirs. However, the unprecedented frequency, scale, and intensity of wildfires in recent years—as well as a return to extreme drought conditions—can damage the health of these critical environments, with high associated economic costs (Headwater Economics 2018).

Headwater ecosystems in particular play a critical, initial role in the water supply which is ultimately delivered to communities through piped infrastructure. In California, 60 percent of potable water is sourced from forested watersheds, the majority of which flows from the forests of the Sierra Nevada mountain range (Uzun et al. 2020; McCann et al. 2020). These flows are also variable, leaving aside the altering effects of fire and the increasing variability that comes with climate change, so it is important to incorporate variability in the models to show where we will likely see change due to fire (Maina and Siirila-Woodburn 2019).

The rapid onset of climate change impacts such as drought, severe heat, and wildfire are disrupting the health and stability of upstream ecosystems. These landscape-scale disturbances can cause downstream impacts (including changes in water quantity and quality as well as hazardous debris flows) that can be costly for water suppliers to manage and recover from. The slow and costly implementation processes for CEQA and NEPA can potentially complicate quick and proactive land management projects to mitigate the occurrence or severity of wildfire events. Mitigating future impacts of wildfires on downstream community water supplies thus invites new strategies which can be supported by answering research and policy questions in the following key areas.

▸ How can forest and other ecosystem management help mitigate fire's effect on downstream water flows?

The quantity and predictability of water flow delivered downstream is affected by changes in upstream environments. High intensity fires, like those California has experienced in recent years, can create long-term ecosystem changes, such as a decrease in transpiration from removing vegetation. They may also create a hydrophobic pyrogenic organic matter (POM) layer that increases runoff volume. Additionally, Maina & Siirila-Woodburn (2019) found that burned landscapes in the Sierra Nevada may accumulate more snowpack, increasing the runoff during a summer melt and altering timing of runoff due to the amount of water stored in snowpack. The timing of a return to "normal" flow regimes varies. Flint et al. (2019) found a return to pre-fire stream flows in two to four years in burned landscapes studied.

Large burn areas from intense fires also produce high risk conditions for erosion, debris flows, and landslides, imperiling local communities and downstream water infrastructure. A recent study suggests that water supply improvements of up to 14 percent can be found through prescribed burns, cultural burns, and mechanical thinning (McCann et al. 2020). However, more evidence is needed on this front, both in terms of predictability of estimates of interventions and to restore flow at more meaningful levels as we see increased fire activity.

▸ Should we expect upstream post-fire water quality impacts to evolve qualitatively or just quantitatively?

Hotter, faster, and bigger fires have altered upstream ecological processes and affect downstream water supply operations, motivating new ways of thinking about managing and remediating upstream environments. Historical research on burned areas in California provides insight into predicting and planning for post-fire water quality impacts downstream (Hohner et al. 2019).

High intensity fires turn biomass into pyrogenic organic matter (POM) on the surface of the forest floor. During post-fire rains, severely burned areas deliver higher levels of precursors to disinfectant byproducts, dissolved organic nitrogen, and dissolved organic matter with higher turbidity, color, and suspended particles downstream.

These constituents all require intensive treatment to meet potable water standards and thus higher cost. High concentrations of contaminants can be detectable for up to two years, depending on the scale of the fire and precipitation patterns the following years (Uzun et al. 2020).

▸ How can disaster management efforts in the state better address post-fire water supply impacts upstream?

Natural disasters occurring in California can cascade like a set of dominos, passing the effect of each disaster to the next, compounding impacts on frontline communities. Drought increases risk of fire in forests and wild lands leading to larger, faster, and hotter fires that burn at higher elevations, destabilizing snowpack and snowmelt cycles, and leave large burn scars with damaged soils that leads to increased and unpredictable runoff (AghaKouchak et al. 2018).

The increase in runoff from burned landscapes increases the risk of erosion, debris flows, and flooding in steep, mountainous watersheds during California's heavy rainy season. A study of Southern California burned slopes indicates landslide risk remains up to three years after a fire (Rengers et al. 2020).

Debris flows threaten infrastructure near and far. Communities in the wildland urban interface face immediate risk, while water supply infrastructure further downstream may be damaged by debris carried over long distances if upstream debris catchment solutions are not adequately deployed.

Research on catchment basins in Los Angeles County in areas burned by the Colby and Fish fires suggests that as vegetation returns to burned landscapes, sediment flows reduce. Continued research into the relationship between burned landscapes and catchment basins can aid policymakers in preparing for future impacts (Gray 2019).

A number of state and federal agencies respond to natural disasters in California today including the California Office of Environmental Services (Cal OES), local OES offices, the Federal Emergency Management Agency, California Department of Forestry and Fire Protection (CAL FIRE), California Highway Patrol, and nonprofit volunteer organizations like the Red Cross respond to disasters in California (UCANR 2020). It is also critical to support local organizations, including Fire Safe Councils, to do this work and create jobs locally. Currently, the patchwork system of grant-funded opportunities for local efforts means that organizations are applying for and managing funding, which takes away from the on-the-ground work.

The deadly mudslides in Montecito in 2018 after the Thomas fire are a grim call for researchers and policymakers to conduct further research to understand the impacts of, and how best to prepare and respond to, the cascading natural disasters in California today. A *Los Angeles Times* investigation details decades of tensions between the U.S. Forest Service, Army Corps of Engineers, Santa Barbara County officials, and the public over the appropriate deployment and maintenance of debris catchment basins and disaster preparedness interventions, none of these groups had thought the devastation Montecito experienced was possible (Mozingo 2018).

▶ How can research efforts better support Indigenous leadership, knowledge, and practice to help manage healthy ecosystems?

Indigenous nations and communities have long practiced ecosystem management strategies that include diverse applications of low-intensity fire. The use of fire created landscapes of widely spaced trees and low levels of forest floor flora. With successive waves of Spanish, Mexican, and American colonialism in California, Indigenous cultural fire practices were outlawed and replaced with a forest management strategy of fire suppression, which in turn resulted in forest densification and left forests vulnerable to fire, diseases, and pests (Hankins 2015; Goode et al. 2018).

Today, many tribal communities retain little autonomy over the stewardship of their ancestral lands. This lack of practical management authority severely limits their ability to apply traditional land stewardship mechanisms, including cultural burning. The inability to apply fire in turn decreases the health and resilience of culturally important plants. The overall lack of Indigenous stewardship creates conditions of increased vulnerability for both people and ecosystems faced with catastrophic fire.

There is also a need to incorporate the effects of cultural burning into fire modeling efforts. It is currently difficult to understand the full benefit of cultural burning in larger landscape management efforts. Much of the current research on cultural burns focuses on single burns in a specific context. There is a need for further study into how contemporary forest management and cultural burning can produce mutually beneficial outcomes over larger geographic areas and long periods of time (Long et al 2021).

Progress has been made to engage cultural practitioners in ecosystem restoration in some contexts. For instance, the Karuk Tribe has developed a framework for a return to traditional management (Norgaard 2014). The Karuk Tribe now co-leads the Western Klamath Restoration Partnership, restoring a 1.2 million acre area, in partnership with the U.S. Forest Service (Durglo 2018). Moreover, the Yurok tribes are leading the Cultural Fire Management Council, which is a nonprofit with a mission to increase cultural burning on the Yurok Reservation and ancestral lands.

These efforts offer examples of how the State might be able to expand work with tribal leaders dramatically to achieve its aggressive forest sustainability goals (Buono 2020). There is great opportunity to expand partnerships with Indigenous peoples and Tribal communities, and potential collaborators should approach these partnerships with inclusivity and openness as knowledge and practice of various types of cultural burning are held across different Tribal community members (Lake 2021). The recently passed bills AB 642 and SB 332 will help to further support prescribed and cultural burning in the state (Larson 2021).

▶ What are the most effective methods to support long-term forest and other ecosystem management to adapt to upstream effects?

To limit the growth of large wildfires, an estimated 20–30 percent of California's 33 million acres of forested wildland must be managed and actively maintained through a mix of prescribed fire, managed wildfire, and mechanical thinning (McCann et al. 2020). Achieving the state's goals for managed forest requires intergovernmental and cross-sector cooperation. State and local governments only own three percent of forested lands in California with the majority owned by the federal government and private landowners. Forest management tactics like controlled burns must also align with regional air quality regulations, and policymakers must consider the equity implications for small landowners and tribal communities.

In 2020, California and the federal government signed a stewardship agreement that set a goal of treating one million acres of wildland in California each year. However, the state burned only 32,000 acres of wildland in 2020—well below that goal. An obstacle moving forward is matching funding and resources. California's final 2021 budget includes a recently-approved $1.5 billion for fire prevention (Beam 2021). Increasing wildland management means a long-term investment in personnel, training, and knowledge. However, the total amount of funding needed to implement long-term mitigation strategies is unknown (Feo et al. 2020).

To overcome the high cost of forest and other ecosystem management, agencies, nonprofit organizations, and private companies are coming together to pool resources. More of these kinds of new, inclusive, collaborative efforts are needed, including incentivizing private landowners to participate. There are examples of promising local and regional capacity building, such as the involvement of the Yurok Tribe with the Cultural Fire Management Council, and the formation of the Sierra Nevada Conservancy Watershed Improvement Program. Collaborative projects like the French Meadows Partnership managed by the Sierra Nevada Conservancy and the Forest Resilience Bond by Blue Forest are additional creative mechanisms for potentially scaling up the raising and targeted spending of forest management funds (Olick 2021).

To scale upstream management and restoration efforts, there is a need to increase engagement of downstream users to raise their buy-in as stakeholders and emphasize the multiple benefits of fire hazard reductions and landscape management. As downstream impacts of wildfire are far reaching, downstream communities and leaders across sectors are potentially under-utilized and supported as financial, political, and logistical actors to effect upstream solutions.

Finally, in some cases, local community groups, both upstream (including fire safe councils) and downstream, will need financial support to participate robustly in decisionmaking processes. Supporting local participation, however, is essential to ensure sustainable management as well as equitable decisionmaking.

▶ **Recommendations**

- Invest in local capacity and expertise, and communicate the multiple benefits of landscape management efforts in reducing fire risk and increasing water security.
- Invest in debris management basins, particularly in rocky and mountainous areas close to highly urbanized areas, like those found in many Southern California communities.
- Support Indigenous leadership, knowledge, and practice to help manage healthy ecosystems.
- Develop sustainable funding streams to support local organizations, landowners, and stakeholders in inclusive and equitable headwater land management and restoration.
- Conduct more research to determine with more precision how headwater forest and other ecosystem management, including cultural burning, affects the quantity and quality of downstream water supplies.

2. WATER SUPPLIER PLANNING

Wildfires bring new challenges to water system planners. The challenges include protecting infrastructure, treating increased contamination loads post-fire, cleaning water reservoirs, rebuilding destroyed infrastructure, and maintaining power and water access during a fire to, among other things, provide critical support to fire fighters. Water systems may also need to support their customers with interim drinking water during fire recovery and must ensure that the community can trust that tap water is safe as families and businesses return home. We need to identify policy and funding solutions to mitigate the impact of future fires on water systems and their ability to recover water quality quickly, provide water to displaced families, and restore trust in the tap.

California's current and expected intensity in future fire regimes presents new challenges for community water supply planners in many parts of the state. Wildfire is one of several climate threats that water utility planners are expected to account for, and the approximately 2,800 community water systems in the state have vastly different planning and operational capacities. Wildfire may threaten the processes to secure, store, treat, and deliver reliable water supplies to first responders and communities. The scale of the problem is evident in a recent Department of Water Resources estimate that "over half of the top at-risk [water] suppliers are in high or very high-risk zones for wildfire, as defined by CalFire" (2020 Water Resilience Portfolio). This is a water equity issue that leaves (often already vulnerable) communities to deal with compounding disasters.

The ability of water systems to maintain power during wildfires is critical for supporting firefighting efforts and minimizing damage to infrastructure. As systems divert water supply to help fight wildfire, and as fires contaminate water sources, water suppliers face impairments to both water quantity and quality in their mandate to maintain reliable water delivery to communities. As noted above, the runoff and debris flows after a fire also deliver sediment and contaminant loads downstream that can critically impair water reservoirs.

Moreover, policy does not support water suppliers' direct and indirect financing of fire fighting activities, although it often represents an outsized portion of water supplier budgets which fireflow sometimes represents. The Governor's Office of Planning and Research, the Department of Water Resources, and the State Water Board have begun working on monitoring and support for this issue, but more attention and resources may be needed.

▶ What can be done to proactively mitigate and reactively address damage to water reservoirs?

Large water suppliers often rely on reservoirs to store surface water for delivery to end-users. Rainfall on expansive wildfire burn scars washes excess contaminants and sediment downstream into reservoirs, which can clog water system filters or fuel algal blooms in reservoirs (Chow 2021). Erosion and debris flows can also carry sediment into reservoirs, thus accelerating the decline of reservoir capacity. This is an especially troubling trend considering California's reliance on stored water during droughts (Sankey et al. 2017). Research by Becker et al. (2018) provides recommendations to water systems for treatment technologies and techniques needed for varied wildfire impact and contamination scenarios, a useful resource for water systems in wildfire prone areas.

Moreover, reactively cleaning impaired reservoirs is costly, with a common price tag of $5–10 million per reservoir cleaning (SNC 2021). Proactive investments can help to avoid accumulation of reservoir cleanup costs. For instance, the French Meadows Project—a $10.6 million collaborative effort between The Sierra Nevada Conservancy, Placer County Water Authority (PWCA), The Nature Conservancy, the American River Conservancy, and the Tahoe National Forest to restore 28,000 acres of headwater forest—is cost effective and proves that proactive management and investment can prevent future wildfire damage to PCWA reservoirs (USFS).

▶ How can water systems be supported to maintain power and continuous supply during a fire?

Water supply failures have several negative impacts during a wildfire. Emergency firefighting teams rely in part on operable water pumps, and have to take more ad hoc measures to secure water supply if pumps fail, as occurred in the Woolsey Fire of 2018 (Griffith 2018). Loss of water service to local hospitals and other vital facilities can compound the impacts of wildfire on a community. Additionally, loss of pressure in water service lines can allow soil and contaminants to enter the distribution system. Keeping water systems operable during a wildfire emergency can be difficult, as fire may damage water system infrastructure, spreading fire can leave key parts of water system infrastructure inaccessible, and backup power generators may fail.

Water systems need to invest in backup power supply to maintain operation of treatment facilities and pump stations during an emergency. Yet publicly-regulated water systems have expressed concern with complying with California Air Resources Control Board Rule 1470, which, due to emissions concerns, limits the allowable hours of testing the diesel-powered backup generators many systems rely on during fires. Water managers are advocating for the ability to test backup systems regularly to ensure they operate effectively while under stress during a wildfire emergency (Carlson 2019). Compliant, lower-emission generators can cost $100,000 each (and are often ineligible for public subsidy funds from the State Board), take time to deliver and install, and require additional costs for regular maintenance, which water systems say constrains their ability to upgrade.

Additionally, asking water supplier staff to access water infrastructure as wildfires encroach place their health and safety of staff at risk from the fire and associated air quality. Innovations in remote operation of water system infrastructure and backup power systems like solar and battery technology, paired with building and site design to reduce fire damage, allow for some degree of offsite operation of water systems located in active fires that reduces risk to water system employees and maintains water operations for emergency use (Heaney et al. 2020). However, access to technology, the cost of these upgrades, and the managerial knowledge for implementation may be a limiting factor in water systems deploying these tactics, as these factors are more broadly constraining especially for small water system operation (Water Boards 2021). To protect the health and safety of their workforce, investments in air filtration and PPE are also recommended but may need centralized support.

More broadly, Tran recommends that, as part of their required emergency response plans (ERPs), water systems develop specific wildfire mitigation plans that include local or regional partnerships with surrounding water systems or water wholesalers with intertying supply connections (Tran et al. 2021). Developing these mutual aid relationships can lead to sharing of resource and critical staff and expertise support during an emergency. While ERPs are now required for systems serving 1,000 connections or more under SB 552, smaller systems may still lack the same ability to respond to and recover from disasters. A targeted toolkit that supports small water systems to address wildfire events, create and act on ERPs may be necessary. Finding ways to extend emergency planning support and expectations. to small water systems in wildfire prone areas is critical to ensuring water supply to the communities they serve.

▶ How should water systems be expected to finance fire-fighting efforts?

A large part of the way in which water systems are designed engineering-wise is to meet day-to-day fire-flow requirements. This compliance is necessary, but the associated cost can represent a large percentage of a water system's budgets and is not always called out as a specific expense in utility budgets (Tiger 2012). To the extent that water utilities face differential costs, they are usually obligated to pass on these costs to customers (see AWWA M1 Manual, 2017), especially among publicly-owned utilities in California due to Proposition 218.

The idea that the price of a good or service should reflect the cost of delivering that service to the user is referred to as cost causation or the benefit principle. This principle has been enshrined in internal drinking water utility practice to determine how to charge different users with different impacts on water supply production within a utility pricing structure (García-Valiñas et al. 2010-b). However, the connection between the cost of providing water supply for firefighting and specific charges on customers is lacking (Beecher 2020) and may undermine awareness of the need for additional revenue for water systems, especially in light of increased expectations that they serve on the front lines of supporting wildfire fighting efforts. Supporting small systems' ability to finance firefighting and broader emergency response efforts may require designated funding or regulatory guidance.

▶ Recommendations

- » Provide recommendations to water systems for current and expected treatment technologies and techniques needed to treat runoff contamination.
- » Better understand the challenges for big vs. small and private vs. public water systems, and consider the effects of water system consolidations on water system equity and security.
- » Further invest in targeted support for water systems' continuous service in wildfire events. What kinds of funds are available for emergency drinking water provision?
- » Clarify at the state level the financing authorities and constraints of fire-fighting efforts by water systems.
- » Develop further support for small water systems to aid in their response to and recovery from wildfire, including a small water system toolkit and supporting and further developing existing mutual aid systems like CalWarn.

3. WATER SUPPLY, FIRE, AND HOUSING

With a year-long fire "season" and increasing fire frequency, size, and intensity, communities are facing challenging planning decisions required to keep people safe. They must consider the risk to housing from fire, as well as potential for development to contribute to fire ignition. They must also prepare for the risks of flooding and debris flows after the flames have been extinguished. Questions remain around the strategies and costs of providing adequate temporary housing for displaced families and rebuilding equitability.

Addressing the housing affordability crisis while actively planning for housing supply that takes sufficient account of water availability and wildfire risk is a tall order in California. In the past several decades, housing has grown dramatically in the "wildland urban interface," where fire risk is high. This is in part due to housing affordability in these areas and has also been facilitated by local decisions regarding the designation of fire severity zones (Miller et al. 2020). These zones parallel local variation in implementation of "show me the water" laws (Hanak 2010) in California. Additionally, there are strategies including buffers and other land use and urban design features to protect communities in high-risk zones (Moritz and Bustic 2020).

More specifically, post-fire housing recovery efforts in California have revealed major gaps in comprehensive short-term and long-term support for affected households, especially those that are socioeconomically vulnerable and mobility-constrained (Gabbe et al. 2020). People who have lost homes and have been displaced by wildfire struggle to access immediate housing and livelihood relief programs, including bottled water, and secure affordable housing options that include access to clean drinking water infrastructure. Moreover, as communities rebuild new and more expensive housing to meet new fire safe housing codes, long-term residents face the impacts either of gentrification or experience long-term homelessness as interim assistance funds run low and housing is unattainable.

Communities who want to rebuild in fire-prone areas face feasibility challenges when trying to satisfy updated building codes which take account of both drought and fire risks. Agencies from the federal (FEMA), state (Housing and Community Development Department/HCD), and local levels (Local Agency Formation Commission/LAFCO, county and city housing authorities and planning departments, water systems) all have a role to play in this process. The HCD has developed a number of new, relevant programs but reports that many of them are under-utilized.

▶ What are the impacts of new fire-sensitive building codes and regulations on long-term residents?

During and after fires that displace entire communities and destroy or damage large numbers of housing units, many people face challenges in searching for or rebuilding new, long-term affordable housing. Burned homes leave behind toxic materials that pose a threat to the environment and local drinking water. Before homeowners are allowed to rebuild or reside on their property, the federal Environmental Protection Agency must complete a survey and removal of hazardous materials. Some types of housing, such as mobile home parks, must also show that in a rebuild they have come up to current state Housing and Community Development code to be officially habitable.

Additional local mandates, such as those imposed by the Santa Cruz County Board of Supervisors following the CZU Complex fire, require property owners to either hire a contractor or enroll in a government sponsored program to clean their property following the EPA inspection. However, owners who enrolled in the government program were subject to long wait times and had to find temporary housing in the meantime (Hagemann 2020a).

Other, broader regulations that are intended to make communities safer during a fire also make it harder for long-term residents to rebuild. For instance, in Santa Cruz County, proposed State Minimum Fire Safe Regulations impose new standards for road width for rebuilding to ensure emergency vehicle access, water supply, and defensible space. Property owners wishing to return to remote parcels to rebuild would be faced with the additional costs of funding road widening (Hagemann 2021).

▶ How can displaced communities (re) gain access to affordable housing and essential services?

Temporary housing is a direct lifeline to water access for many displaced by fire. In Santa Cruz County, Federal Emergency Management Agency funds provided hotel stays for 300 survivors of the CZU complex fire, with roughly one third of the enrollees extending their stay because they otherwise lacked access to clean water (Hagemann 2020b).

There is also increased concern around how wildfire-displaced populations affect surrounding communities and their infrastructure, including drinking water systems (Spearing and Faust 2020). An associated, open question is who should bear the cost of this impact on infrastructure, especially if displaced populations are served via temporary connections.

Some households that are uninsured and unable to afford rebuilding or relocating to new housing have turned to camping or living in mobile homes with no running water or electricity connection as they wait for relief from state or federal agencies—options that are technically illegal in some counties. Those with fire insurance still struggle to find housing as displaced families across the region compete for housing and haggle with insurance providers over housing options and payments (Mozingo 2021). Others are legally or functionally left without access to assistance options due to their immigration status or language barriers (Mendez et al 2020; Mendez et al 2021).

The state legislature and Governor's office have taken steps to boost insurance relief for affected families; however, a study in 2017 found two thirds of fire victims were underinsured, leaving them without sufficient resources to rebuild or rehome (Swindell 2020). Mobile home park residents are particularly hard hit and can see housing costs more than triple when having to relocate or find temporary housing (Rode 2019).

▶ How do we rebuild damaged plumbing infrastructure that is resilient to fire/ reduces the contamination impacts experienced in communities?

One of the major obstacles to displaced populations returning to their property long-term is the cost of repairing water infrastructure. Following the Camp Fire of 2018, the town of Paradise faced a $300 million bill to repair its drinking water system alone, for a pre-fire population of 27,000 (Associated Press 2019). A cost of $10 million was estimated to replace all utility infrastructure damaged by the Woolsey Fire, which also occured in 2018, burning through Seminole Springs Mobile Home Park in the Santa Monica Mountains (Sharp 2019).

As noted above, the costs of repairing water and broader utility infrastructure are high, and so are the costs of repairing or replacing private water infrastructure up to code. Homes with damaged or destroyed septic systems face high costs of permits and construction and inspections. For households not attached to sewer lines, the cost of restoring a septic system can reach $8,000 (Hanson 2020).

▶ Recommendations

- Continue to refine (re)building and infrastructure regulations to allow for three-fold objectives of fire protection, affordability and flexibility in compliance.
- Ensure that efforts to support displaced households to find emergency and temporary housing are coordinated with efforts to provide sufficient water supply.
- Consider ways to make existing funding mechanisms more accessible to displaced households, including specificity of targeting of different types of housing assistance to different displaced populations.
- Conduct more research on reducing infrastructure costs of buildback.
- Ensure water safety communications and alerts are proactively translated into locally accessible languages beyond English and Spanish.
- Develop a suite of "Code+" housing code recommendations to support housing density while ensuring future fire safety for communities.

4. END-USE WATER QUALITY AND PUBLIC HEALTH IMPACTS AFTER FIRE

Restoring the quality of and public trust in tap water after a fire is a critical step in community recovery. Wildfire can damage water quality at the source and within the water system (Solomon et al. 2021). Burned areas deliver higher levels of sediment and contaminant loads to water sources and reservoirs. Fires can damage or destroy water system, private well, and household plumbing infrastructure, introduce contaminants or aesthetic impairments to the water supply, and each has differently responsible parties. Moreover, displaced families need interim water and attention must be paid to ensuring they can trust the water in their homes when they are able to return.

As noted above, water quality impacts from wildfire occur at multiple points along the water delivery system. A wildfire can damage water quality at the source. Burned areas deliver higher levels of sediment and contaminant loads to water sources and reservoirs, which then require extensive treatment to meet potability standards. Of increasing concern is the damage or destruction of near or at point-of-use, publicly-regulated water system infrastructure, as well as private well and household plumbing infrastructure. In non-emergency situations, the maintenance of private well and household plumbing infrastructure is the responsibility of property owners, not water systems or regulators (for instance, see Pierce et al. 2019), but that model has proved wholly inadequate in emergency situations such as fire damage to plumbing systems. These point-of-use impacts range from emerging, volatile contaminants of immediate health concern to aesthetic impairments. Moreover, households displaced by fires or who have contaminated in-home supplies need high quality interim water and attention to ensuring they can trust and use the water in their homes when they are able to return or have their contamination issue remediated.

- **Are new or enhanced drinking water regulations for testing and treatment needed to better address near or at point-of-use drinking water quality impacts from wildfire?**

Water runoff from areas burned by wildfires carries elevated levels of contaminants, precursors to disinfectant byproducts, and sediments into drinking water systems and private well supplies. These upstream contaminants may require additional treatment technologies to meet federal and state safe drinking water standards (Uzun et al. 2020). Wildfires can also introduce dangerous levels of contaminants throughout the water distribution system or from impacts to premise plumbing.

Burned or melted water infrastructure—particularly those components made from cross-linked polyethylene (PEX) or polyvinyl chloride (PVC), including some storage tanks, distribution pipes, meters, and domestic well infrastructure—can release dangerous levels of volatile organic compounds, like benzene, into drinking water supplies. Moreover, this damaged infrastructure can cause water pipes to depressurize and introduce bacteria or spread volatile organic compounds (VOCs) from damaged parts of the network to undamaged areas. These VOCs may linger in the distribution and premise infrastructure for extended periods of time (Proctor et al. 2020). The question of where water suppliers and households can effectively use point-of-use treatment technologies in post-fire contexts, among other emergency situations requires extensive clarification from regulators (Hacker and Binz 2021).

▶ Who should provide emergency water supply, and what scale is feasible given the cost?

After a wildfire, residents may need emergency drinking water supplies for a period of days to months following displacement from their homes in an evacuation, if fire damage has contaminated the water supply or the distribution system, or if a water system is damaged and inoperable. The primary interim emergency water provided by state and federal agencies to families in need in California is bottled water.

State and Federal emergency planning guidelines list bottled water as an emergency water source when traditional supplies are unsafe (US EPA 2011). The California Office of Emergency Services Emergency Drinking Water Procurement & Distribution Planning Guidance contains a standing contract that local governments may use to purchase emergency bottled water supplies (Cal OES 2014). Further, authorized by water code section 13442, the California State Water Resources Control Board may use the California Cleanup and Abatement (CAA) account to address drinking water needs in emergency situations. During the 2012–2016 drought, the majority of funding distributed by the CAA for emergency interim water supplies was spent on providing bottled water to county and local governments or water systems for distribution to households (UDWN).

Despite the widespread use of bottled water as an emergency drinking water source, the State government has not been able to take advantage of any economies of scale to reduce the cost of bottled water, purchasing bottled water at market rates from local retail establishments. Bottled water retail costs are up to 156 times the cost of tap water and leave local governments and residents vulnerable to local retail supply. The State Water System Needs Assessment found the cost of providing only 60 gallons per month per connection (far below the State goal of 55 gallons per person per day) in systems on the State's Human Right to Water List would reach $1 billion annually (Water Boards 2021).

An alternative emergency water supply delivery mechanism for communities and water systems affected by wildfire is hauled water to communal supply points. Based on internal UCLA Luskin Center for Innovation research of projects authorized by CAA funds, hauled water might be less expensive to provide than bottled water, with a cost of $0.10–$0.25 per gallon at the allocation of 60 gallons per month. Further cost reductions are possible if a community filling station model, that reduces the cost and frequency of deliveries, is used. However, there has been no analysis of the water hauling industry's timing, capacity and reach in the context of emergencies.

Even more promisingly in terms of sustainable or diversified on-call water supply, water systems with sources that are reliable and safe from fire could be designated regionally as emergency water providers on call to disperse water to be hauled outside of their boundaries in emergency situations. This would require further coordination between LAFCOs, some of which believe they have jurisdiction to grant access for water to move across place of use boundaries in emergency situations, and the State Water Board.

▶ How can we improve post-fire response guidance and testing support to improve communities' trust in water quality?

As households in California recover from wildfire events, return home, and come together to rebuild communities, their trust in the safety of their drinking water often wanes (Odimayoni et al. 2021). As the presence of benzene and other VOCs in drinking water becomes apparent, and as water systems work to determine how widespread the contamination was, residents have at times received changing warnings and boil advisories and shifting recommendations on point-of-use or point-of-entry filtration from local officials.

Unclear communication from state and local officials on what type of at-home filter is appropriate in each circumstance have been made worse by insurance policies that reportedly cover the costs of filters that may not adequately address VOCs found in drinking water (Olsen 2020). Mixed messaging from local or state officials can decrease trust in the safety of drinking water and increased reliance on more expensive bottled water for drinking, cooking, bathing, and brushing teeth, which in turn greatly impairs the quantity of water consumed and imposes its own environmental impact (Wang et al. 2019). One resident, frustrated after the CZU Complex Fire, was quoted saying, "If the water is messed up, we understand. We had a catastrophic fire up here, we understand that. But just let us know why" (Becker 2020). There is also a question of whether employing better public communication or science outreach can solve the issue (Roy and Edwards 2019), or if broader distrust must be addressed. In response to VOC post-fire contamination, the US EPA has released guidance for water systems to use when identifying and treating VOC in water supply, including guidance on communication with the public (US EPA 2021).

Some residents interviewed turned to private testing labs after purchasing at-home water quality test kits out of pocket. It is unclear whether the state or counties can muster sufficient responses to resident concerns and information gaps in these contexts, or whether new resources need to be made available to public agencies. Given widespread distrust in the government, especially in rural areas often affected by wildfire, a more effective alternative may be supporting the expansion of the capacity of researchers, non-profit organizations and community-based organizations to provide information, technical assistance with testing, and an appropriate return to trust in a disaster recovery context. Resources and sustained assistance efforts to fire-affected communities, such as those carried out by the Purdue Center for Plumbing Safety, can serve as a model for future non-governmental efforts (PCPS 2021). For instance, in some other emergency contexts, public officials have only admitted water safety concerns related to tap water once external experts were engaged (Lambrinidou 2018).

▶ Recommendations

- Bring regulations and technology for point-of-use treatment more pointedly to be informative and deployable in post-wildfire contexts.
- Proactively fund and deploy emergency water supplies pre-wildfire event.
- Determine which stakeholders are best suited to communicate and what communication style and content helps different communities appropriately trust their water supply post-fire.
- Ensure water safety communications and alerts are translated into locally accessible languages.

PARTICIPANT LIST

(Alphabetical order, by first name)

Andrew Whelton, Purdue Environmental and Ecological Engineering

Annabelle Rosser, Public Policy Institute of California

Beth Rose Middleton Manning, University of California, Davis

Cathy Kungu, California Department of Housing and Community Development

Fadji Maina, NASA Goddard Space Flight Center

Faith Kearns, University of California, Ag and Natural Resources, California Institute for Water Resources

Grace Woodmansee, University of California Cooperative Extension

Greg Pierce, UCLA Luskin Center for Innovation

Hannah Haggemann, The Santa Cruz Sentinel

Jennifer Clary, Clean Water Fund

Jess Goddard, University of California, Berkeley Simple Lab

Julie Ekstrom, California Department of Water Resources

Max Moritz, University of California, Santa Barbara, Bren School

Michael Mendez, University of California, Irvine

Nic Enstice, Sierra Nevada Conservancy

Peter Roquemore, UCLA Luskin Center for Innovation

Richard Sykes, Upper Mokelumne River Watershed Authority

Safeeq Khan, University of California, Merced, Civil and Environmental Engineering

Skye Greenler, Oregon State University, College of Forestry

Steve Lucas, California Association of and Local Agency Formation Commissions

Steve Quarles, University of California Cooperative Extension

Tony Safford, Habitat for Humanity

Yvonne Heaney, State Water Resources Control Board

REFERENCE LIST

AghaKouchak, A., Huning, L. S., Chiang, F., Sadegh, M., Vahedifard, F., Mazdiyasni, O., Moftakhari, H., & Mallakpour, I. (2018). How do natural hazards cascade to cause disasters? *Nature*, 561(7724), 458–460. https://doi.org/10.1038/d41586-018-06783-6

Associated Press. (2019, April). Cancer-causing chemical taints water after California wildfire. NBCNews.com. Retrieved from https://www.nbcnews.com/news/us-news/cancer-causing-chemical-taints-water-after-california-wildfire-n1000136.

Beam, A. (2021, September 9). California OKs new spending on drought, wildfire prevention. *AP NEWS*. Retrieved September 20, 2021, from https://apnews.com/article/business-health-fires-climate-california-eec48e6279099449851b3c7f150cda33.

Beecher, J. A. (2020). Policy note: A universal equity–efficiency model for pricing water. *Water Economics and Policy*, 06(03), 2071001. https://doi.org/10.1142/s2382624x20710010

Becker, R. (2020, October 6). Unsafe to drink: Wildfires threaten rural California towns with tainted water. *The Press Democrat*. https://www.pressdemocrat.com/article/news/unsafe-to-drink-wildfires-threaten-rural-towns-with-tainted-water/.

Becker, W.C., Hohner, A., Rosario-Ortiz, F., & DeWolfe, J. (2018). Preparing for wildfires and extreme weather: Plant design and operation recommendations. *Journal - American Water Works Association*, 110(7), 32–40. https://doi.org/10.1002/awwa.1113

Benjemaa, F., Benin, N., Campagna, J., Ekstrom, J., Alarcon, J., Lichti, B., Frederick, M., Crisologo, J., Frevert, K., & Balazs, C. (2021). (rep.). Small Water Systems and Rural Communities Drought and Water Shortage Contingency Planning and Risk Assessment. California Department of Water Resources Water Use Efficiency Branch. Retrieved from https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency/CDAG/PART-2-CDAG-Report-Final.pdf.

Buono, P. (2020, November). *Quiet Fire Indigenous tribes in California and other parts of the U.S. have been rekindling the ancient art of controlled burning*. The Nature Conservancy.

Cal OES. (2014, May). *Emergency drinking water procurement & distribution planning guidance.* https://www.caloes.ca.gov/ICESite/Documents/Emergency%20Drinking%20H2O.pdf

California Water Resilience Portfolio (2020). In response to the Executive Order N-10-19. https://waterresilience.ca.gov/wp-content/uploads/2020/07/Final_California-Water-Resilience-Portfolio-2020_ADA3_v2_ay11-opt.pdf

Carlson, C. (2019, May 16). Water agencies: Air quality rules need changing to keep water flowing to fight wildfires. *VC Star*. https://www.vcstar.com/story/news/local/2019/05/16/water-agencies-say-air-pollution-rule-change-needed-keep-water-fight-wildfires/1193297001/.

Chow, A. T.-S. (2021, August 12). Wildfires are threatening municipal water supplies. *Eos*. https://eos.org/science-updates/wildfires-are-threatening-municipal-water-supplies.

Durglo, J. (2018). *Cross boundary collaboration between tribes and the United States Forest Service: Success stories from forest systems using the Tribal Forest Protection Act*. Intertribal Tinder Council.

Feo, T., Mace, A., Brady, S., & Lindsey, B. (2020). (rep.). *The costs of wildfire in California: An independent review of scientific and technical information*. California Council on Science and Technology.

Flint, L. E., Underwood, E. C., Flint, A. L., & Hollander, A. D. (2019). Characterizing the influence of fire on hydrology in Southern California. *Natural Areas Journal*, 39(1), 108-121.

Gabbe, C J., Pierce, G., & Oxlaj, E. (2020). Subsidized households and wildfire hazards in California. *Environmental Management*, 66(5), 873-883.

García-Valiñas, M. A., Martínez-Espiñeira, R., & González-Gómez, F. (2010). Affordability of residential water tariffs: Alternative measurement and explanatory factors in southern Spain. *Journal of Environmental Management*, *91*(12), 2696–2706. https://doi.org/10.1016/j.jenvman.2010.07.029

Goode, R., Gaughen, S., Fierro, M., Hankins, D., Johnson-Reyes, K., Middleton, B.R., Red Owl, T., and Yonemura, R. (2018) "Summary report from tribal and Indigenous communities." *California 4th Climate Change Assessment.* https://www.climateassessment.ca.gov

Gray, A. (2019). (rep.). *Debris flow and debris basin management impacts on water quality.* University of California Agriculture and Natural Resources. http://ciwr.ucanr.edu/files/298040.pdf

Griffith, K. (2018, November). Video: Firefighter fills helicopter water bucket from Malibu swimming pool. Daily Mail Online. Retrieved from https://www.dailymail.co.uk/video/

news/video-1800800/Video-Firefighter-fills-helicopter-water-bucket-Malibu-swimming-pool.html.

Hacker, M. E., & Binz, C. (2021). Institutional barriers to on-site alternative water systems: A conceptual framework and systematic analysis of the literature. *Environmental Science & Technology*.

Hagemann, H. (2020a, October 20). Santa Cruz County property owners must clean up fire damaged properties. *Santa Cruz Sentinel*. https://www.santacruzsentinel.com/2020/10/20/santa-cruz-county-property-owners-must-clean-up-fire-damaged-properties/.

Hagemann, H. (2020b, October 24). As hotel funds dry for fire survivors, a new housing crisis emerges. *Santa Cruz Sentinel*. https://www.santacruzsentinel.com/2020/10/24/as-hotel-funds-dry-for-fire-survivors-a-new-housing-crisis-emerges/.

Hagemann, H. (2021, February 23). Proposed fire safe regulations could impact Santa Cruz County landowners. *Santa Cruz Sentinel*. https://www.santacruzsentinel.com/2021/02/23/proposed-fire-safe-regulations-could-impact-santa-cruz-county-landowners/.

Hanak, E. (2010). Show me the water plan: Urban water management plans and California's water supply adequacy laws. *Golden Gate University Environmental Law Journal*, *4*(1), 5.

Hankins, D.L., 2015. Restoring Indigenous prescribed fires to California oak woodlands. In Standiford, Richard B.; Purcell, Kathryn L., tech. cords. 2015. *Proceedings of the seventh California oak symposium: managing oak woodlands in a dynamic world*. Gen. Tech. Rep. PSW-GTR-251. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 579 p.

Hanson, N. (2020, October 17). Grant for septic system repairs coming to aid Camp Fire rebuild. *Enterprise Record*. https://www.chicoer.com/2020/10/17/grant-for-septic-system-repairs-coming-to-aid-camp-fire-rebuild/.

Headwater Economics (2018). Rim Fire - California, 2013. See https://headwaterseconomics.org/wp-content/uploads/full-wildfire-costs-rim-casestudy.pdf

Heaney, Y., Wollbrinck, J., & Macler, B.A. (2020). What can a water system do to prepare for a power outage? *Opflow*, *46*(12), 10–15. https://doi.org/10.1002/opfl.1469

Hohner, A.K., Rhoades, C.C., Wilkerson, P., & Rosario-Ortiz, F.L. (2019). Wildfires alter forest watersheds and threaten drinking water quality. *Accounts of Chemical Research*, 52(5), 1234-1244.

Lake, F. K. (2021). Indigenous fire stewardship: Federal/Tribal partnerships for wildland fire research and management. *Fire Management Today* , *79*(1), 30–39. Retrieved from https://www.fs.usda.gov/treesearch/pubs/62060

Lambrinidou, Y., 2018. When technical experts set out to "do good": Deficit-based constructions of "the public" and the moral imperative for new visions of engagement. Mich. J. Sustain. 6. http://dx.doi.org/10.3998/mjs.12333712.0006.102

Larson, E. (2021). Governor signs bill to create prescribed fire training center; bill on control burn liability awaits signature. *Lake County News*. https://www.lakeconews.com/news/70553-governor-signs-bill-to-create-prescribed-fire-training-center-bill-on-control-burn-liability-awaits-signature

Long, J. W., Lake, F. K., & Goode, R. W. (2021). The importance of indigenous cultural burning in forested regions of the Pacific West, USA. *Forest Ecology and Management*, *500*, 119597. https://doi.org/10.1016/j.foreco.2021.119597

Maina, F.Z., & Siirila-Woodburn, E.R. (2019).

Watersheds dynamics following wildfires: Nonlinear feedbacks and implications on hydrologic responses. *Hydrological Processes*, 34(1), 33–50. https://doi.org/10.1002/hyp.13568

McCann, H., Bustic , V., Battles , J., Cisneros, R., Jim, Y., Kocher, S., Potts, M., & Stephens, S. (2020). (rep.). *The benefits of headwater forest management*. Public Policy Institute of California. Retrieved from https://www.ppic.org/wp-content/uploads/the-benefits-of-headwater-forest-management-april-2020.pdf.

Méndez M, Flores-Haro G, Zucker L. (2020). The (in)visible victims of disaster: understanding the vulnerability of undocumented Latino/a and indigenous immigrants. *Geoforum.* 2020;116:50–62. doi: 10.1016/j.geoforum.2020.07.007.

Méndez M, Paz O, Salinas M.(2021) Disparate impacts of wildfire on undocumented migrants: Lessons from Sonoma County. UC Irvine Policy Brief June 2, 2021.

Miller, R.K., Field, C.B., & Mach, K.J. (2020). Factors influencing adoption and rejection of fire hazard severity zone maps in California. *International Journal of Disaster Risk Reduction*, 50, 101686.

Moritz, M., & Butsic, V. (2020). Building to coexist with fire: Community risk reduction measures for new development in California. https://doi.org/10.3733/ucanr.8680

Mozingo, J. (2018). Santa Barbara County knew mudslides were a risk. It did little to stop them. *Los Angeles Times*. Retrieved from https://www.latimes.com/local/california/la-me-montecito-debris-basins-20181220-htmlstory.html

Mozingo, J. (2021, August 4). California's climate nomads: The 2018 Camp Fire left them homeless, struggling to survive. *Los Angeles Times*. https://www.latimes.com/california/story/2021-08-04/displaced-by-camp-fire-california-nomads-fear-eviction.

Norgaard, K.M. (2014). (rep.). *Karuk traditional ecological knowledge and the need for knowledge sovereignty: Social, cultural and economic impacts of denied access to traditional management*.

Odimayomi, T.O., Proctor, C.R., Wang, Q.E., Sabbaghi, A., Peterson, K.S., David, J Y., ... & Whelton, A.J. (2021). Water safety attitudes, risk perception, experiences, and education for households impacted by the 2018 Camp Fire, California. *Natural Hazards*, 1-29. https://link.springer.com/article/10.1007/s11069-021-04714-9

Olick, D. (2021, September 2). Wildfires are putting water supplies at risk, and corporate America is scared. CNBC. https://www.cnbc.com/2021/09/02/companies-investing-in-forest-protection-to-secure-water-supplies.html?utm_term=Autofeed&utm_medium=Social&utm_content=Main&utm_source=Twitter#Echobox=1630585830.

Olsen, S. (2020). *Implications of the California wildfires for health, communities, and preparedness: Proceedings of a workshop*. National Academies Press.

PCPS. (2021). *Response and recovery to wildfire caused drinking water contamination*. Center for Plumbing Safety - Purdue University. Retrieved from https://engineering.purdue.edu/PlumbingSafety/resources/wildfire-response

Proctor, C.R., Lee, J., Yu, D., Shah, A.D., & Whelton, A.J. (2020). Wildfire caused widespread drinking water distribution network contamination. AWWA Water Science, 2(4). https://doi.org/10.1002/aws2.1183

Rengers, F.K., McGuire, L.A., Oakley, N.S., Kean, J.W., Staley, D.M., & Tang, H. (2020). Landslides after wildfire: Initiation, magnitude, and mobility. *Landslides*, 17(11), 2631–2641. https://doi.org/10.1007/s10346-020-01506-3

Rode, E. (2019, November 5). The Woolsey Fire destroyed 110 homes in this mobile home park. No one has moved back yet. *VC Star*. https://www.vcstar.com/story/news/2019/11/05/woolsey-fire-seminole-springs-mobile-home-park-california-wildfire/3909997002/

Roy, S., Edwards, M.A., 2019. Citizen science during the Flint, Michigan federal water emergency: Ethical dilemmas and lessons learned. *Citizen Science: Theory and Practice*, 4(1), 12. https://doi.org/10.5334/cstp.154

Sankey, J.B., Kreitler, J., Hawbaker, T.J., McVay, J.L., Miller, M.E., Mueller, E.R., Vaillant, N.M., Lowe, S.E., & Sankey, T.T. (2017). Climate, wildfire, and erosion ensemble foretells more sediment in western USA watersheds. *Geophysical Research Letters*, *44*(17), 8884–8892. https://doi.org/10.1002/2017gl073979

Sharp, S. (2019, November 7). Half their community burned in the Woolsey fire. Recovery is wreaking its own misery. *Los Angeles Times*. Retrieved from https://www.latimes.com/california/story/2019-11-07/woolsey-fire-anniversary-seminole-springs-mobile-home

SNC. (2021, March 8). *Megafires create risks for water supply*. Sierra Nevada Conservancy. https://sierranevada.ca.gov/2020-megafires-create-risks-for-californias-water-supply/.

Solomon, G. M., Hurley, S., Carpenter, C., Young, T. M., English, P., & Reynolds, P. (2021). Fire and water: Assessing drinking water contamination after a major wildfire. *ACS ES&T Water*, *1*(8), 1878–1886. https://doi.org/10.1021/acsestwater.1c00129

Spearing, L. A., Faust, K. M. (2020). Cascading system impacts of the 2018 Camp Fire in California: The interdependent provision of infrastructure services to displaced populations. *International Journal of Disaster Risk Reduction*, 50, 101822. https://doi.org/10.1016/j.ijdrr.2020.101822

Swindell, B. (2020, October 11). Santa Rosa firm helps wildfire victims navigate battles with insurance companies. *Press Democrat*. https://www.pressdemocrat.com/article/business/santa-rosa-firm-helps-wildfire-victims-navigate-battles-with-insurance-comp/.

Tiger, M. (2012, August). Public fire service water charges – on the water bill or on the tax roll? Environmental Finance Blog. Retrieved from https://efc.web.unc.edu/2012/08/16/public-fire-service-water-charges-on-the-water-bill-or-on-the-tax-roll/.

Tran, T., Baribeau, H., & Sullivan, L. (2021). Mitigate wildfire impacts on drinking water quality and operations. *Opflow*, 47(5), 10–15. https://doi.org/10.1002/opfl.1543

USFS. (n.d.). *American river headwaters and French meadows*. Region 5 - land & resource management. https://www.fs.usda.gov/detail/r5/landmanagement/?cid=fseprd568828.

UCANR. (2020). (rep.). Disasters happen. We can and will be prepared. Davis, CA: University of California Division of Agriculture and Natural Resources.

UDWN (n.d.) Urgent drinking water needs project data. https://www.waterboards.ca.gov/water_issues/programs/grants_loans/caa/docs/UDWN_DATA_10_29_19.pdf

US EPA. (2011). (rep.). Planning for an emergency drinking water supply. United States Environmental Protection Agency. Retrieved from https://www.epa.gov/sites/default/files/2015-03/documents/planning_for_an_emergency_drinking_water_supply.pdf

US EPA. (2021) Addressing contamination of drinking water distribution systems from volatile organic compounds (VOCs) after wildfires. Retrieved from https://engineering.purdue.edu/PlumbingSafety/resources/EPA-Wildfire-VOC-Drinking-Water-Contamination-Guidance-Sep-2021.pdf

Uzun, H., Dahlgren, R.A., Olivares, C., Erdem, C.U., Karanfil, T., & Chow, A.T. (2020). Two years of post-wildfire impacts on dissolved organic matter, nitrogen, and precursors of disinfection By-products in California stream waters. *Water Research*, 181, 115891. https://doi.org/10.1016/j.watres.2020.115891

Wang, T., Kim, J., & Whelton, A.J. (2019). Management of plastic bottle and filter waste during the large-scale Flint Michigan lead contaminated drinking water incident. *Resources, Conservation, and Recycling*, 140, 115-124. https://www.sciencedirect.com/science/article/abs/pii/S0921344918303136

Water Boards. (2021). (rep.). 2021 drinking water needs assessment. California State Water Resources Control Board. Retrieved from https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/needs/2021_needs_assessment.pdf.

University of California Agriculture and Natural Resources
California Institute for Water Resources
ciwr.ucanr.edu

UCLA Luskin Center for Innovation
innovation.luskin.ucla.edu