WATER RESOURCES

IMPACT

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FIRE AND WATER

AMERICAN WATER RESOURCES ASSOCIATION

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Fire and Water
Guest Editors: Michael E. Campana and Lisa Beutler

It's September and in the Western US, that means wildfires. So we've got six articles, five of which deal with the US West: California (2), Arizona (2), New Mexico (1); and the true outlier, Australia (1). Let's start with the Golden State! Nekesha B. Williams and Diana Garcia-Colmenarez provide an overview of water resources management in fire-prone landscapes and then focus on some of the fire-water issues facing Contra Costa County in the San Francisco Bay area. Lisa Ellsworth, Erica Fischer, Laura Linderman, Jenna Tilt and Brad Wham introduce us to the wildland-urban interface (WUI) and water quality, infrastructure and related problems that arise when WUI fires occur. They describe a novel experiment to examine water contamination. Heading east to Arizona we encounter Rebecca Davidson who focuses on work in the Bill Williams Mountain (BWM) area west of Flagstaff. Here, a partnership among organizations is leading to brighter future vis-à-vis wildfires in the BWM area. From here we head south to the Greater Phoenix area, where the major water purveyor, the Salt River Project (SRP) is aggressively managing its watershed to protect water resources and lessen fire hazard. The SRP's Elvy Barton, Bruce Hallin and Tiffany Bolton weave an optimistic picture. Farther east, a team from the University of Arizona and the USGS - Ann Youberg, Luke McGuire and Francis Rengers – instrument a watershed in the Gila National Forest in New Mexico to ascertain how intense rainfall must be before debris flows are generated. Like the Ellsworth et al. experiment, it's a work in progress. Finally, it's off to Down Under where Andy Baker addresses the effects of fire on groundwater quality, especially in cavernous limestone. Fascinating!

FEATURE ARTICLES

About the Cover - Wildfire source: sippakorn-yamkasikorn, unsplash.com

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PRESIDENT'S MESSAGE

Lisa Beutler, Past-President

GREETINGS FROM SMOKE FILLED CALIFORNIA. I am filling in for President Betsy Cody this issue as she has been in Oregon working through evacuations and other fire related issues far more extreme than the bad-air days Sacramento is suffering through. Needless to say, this issue on Fire and Water could not be more timely as the West is literally on fire and the East Coast is being battered by hurricanes with the most storms making landfall since 1916. More than ever, the AWRA stance on the urgency in addressing climate change is affirmed.

Even in the midst of these unsettling times, and thanks to our extraordinary members, AWRA continues to be the preeminent water sector multidisciplinary professional association. Since our Summer 2020 Special IMPACT magazine issue on COVID-19, a number of exciting things have happened. Foremost, was the outstanding **2020 Virtual Geospatial Water Technology Conference** held August 4-13, 2020. The 237 attendees enjoyed 191 outstanding presentations that garnered 16,878 views. Poster presenters received an additional 1742 views and the Exhibitors were able to share their offerings over 1460 views.

If any group of members could successfully execute AWRA's first Virtual Conference, it was this tech savvy planning committee. We can't thank this team (listed below) enough for their remarkable transition to the virtual format. If you happen to interact with any of them, please give them a socially distanced high-five on our behalf.

2020 Virtual Geospatial Water Technology Conference Planning Committee

- Conference General Chair: **Lilit Yeghiazarian**, University of Cincinnati
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- Finance Chair: **Stephen Bourne**, Atkins North America Inc
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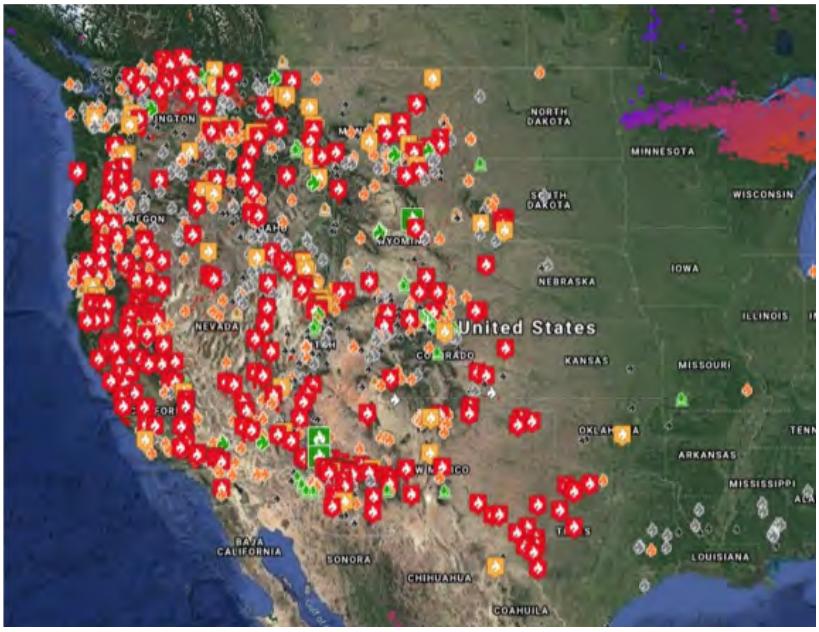

September 25, 2020 Fire Map: https://www.fireweatheravalanche.org/fire/

- NHD Workshops Chair: **Alan Rea**, USGS
- General Workshops Chair: **Amr Safwat**, APTIM
- Student Activities Chair: **Siddharth Saksena**, Virginia Tech University
- Field Trips Chair: **Timothy Whiteaker**, University of Texas at Austin

Diversity, Equity, and Inclusion

Over the last few years, the AWRA Board of Directors has sought to increase diversity, equity, and inclusion (DEI) in both our membership and the larger water sector. Recently, often shocking, events accentuated the urgency of this initiative and redoubled the Board's commitment. In late July, AWRA hosted a **Diversity, Equity, and Inclusion Workshop Series**. The goal was to offer water sector focused training suitable for our members and their organizations. These well attended, engaging trainings, led by organizational expert Joe Gerstandt, received high marks from all participants. Key to his delivery of the sometimes difficult material is the ability to seamlessly interweave art and science and use stories and research to illustrate how next generation cultures can flourish both inside and outside the workplace.

Stay tuned for additional DEI offerings and Board initiated efforts in the coming months. We would also love to hear if you have any ideas or would like to be involved as the DEI initiative moves forward.

(continued)

Students and Early Career Professionals

On the student front, there is a new student chapter at the University of the District of Columbia that is being sponsored by the Washington, D.C. Capitol Section. We are very excited about the creation of this student chapter and welcome them to AWRA.

AWRA is also planning a **Workshop Series for Early Career Professionals. Jillian Young**, a former University of Delaware student chapter president and current Stantec employee is leading the planning committee for this effort. We have had a sneak preview of the workshop agendas and it promises to be great.

Webinar Series

We hope you are taking advantage of another one of your free membership benefits. Every month, AWRA Past President and water steward extraordinaire **Michael Campana**, hosts best in class speakers, from literally throughout the world, to share interesting work and ideas in a webinar format. If for some reason you are not able to make a session, AWRA maintains a **webinar archive** where members can download the session video for free.

In addition to our regular Wednesday Webinar Series we are very excited to partner with the ***American Institute of Hydrology (AIH)*** on a special **Forecast-Informed Reservoir Operations (FIRO) Webinar Series** that launches October 14. This series will also be free to AWRA and AIH members. More information on the series and the registration link is **here**.

First Virtual Annual Water Resources Conference – November 9-11, 2020. With one virtual conference under our belt and an annual conference planning committee dream team, this year's annual conference will be a can't miss event. You can expect one of the most diverse and inclusive conferences in water resources management. Presenters will provide you with innovative, practical, and applied water resource management solutions, management techniques, and current research. Plus, there is still time to take advantage of the **Super Saver registration rate**.

Led by L. Donald Duke of Florida Gulf Coast University and Roger Copp of Water Science Associates, the planning committee is setting a standard for all other conferences to emulate. With AWRA's commitment to Community, Conversation, and Connection in mind, attendees can expect:

- Lessons learned from the implementation of multidisciplinary projects
- Best practices discovered in the design and application of water resource management
- Implications of water policy decisions
- Research into current and emerging issues

Plus, as a virtual attendee, you will participate in the comfort of your own home, office, or wherever you are. Wear flip-flops, enjoy your cup of coffee, eat snacks, and control your own AC - no more freezing conference rooms!

One additional benefit of this virtual conference is that you will have access to all tracks, there is no need to pick just one. This means there are more professional development hours available, no travel requirements, and the time and financial commitments to attend are greatly reduced.

You can also live-chat during the presentations and it's encouraged!! And, you will still receive the same quality content, information, and insights from conference speakers that you've come to expect from AWRA.

The last day to register at this rate is October 30, 2020.

Save the Dates –
2021 Summer Specialty Conference - Connecting Land and Water for Healthy Communities Conference, July 19 - 21, 2021 | Denver, CO

We are thrilled to be co-hosting this 2021 Summer Specialty Conference with the Babbitt Center for Land and Water Policy. It is hard to know what travel will look like next summer but there are tentative plans for an in-person conference. This will be another must attend event. You will receive a special preview of some of the conference topics in your March 2021 IMPACT issue.

Take Care in 2020

We deeply appreciate all our AWRA members and your continued engagement through 2020. As we head into the Fall, we send our best wishes to you and yours to stay healthy. We also encourage you to take advantage of all that your membership has to offer. ■

FOREWORD

Michael E Campana & Lisa Beutler

"I've seen fire and I've seen rain
I've seen sunny days that I thought would never end"
– 'Fire and Rain' by James Taylor (1969)

Fire...and More Fire

FOR SOME REASON JAMES TAYLOR'S SONG strikes a chord these days – except that right now we are missing the rain. We do have a surfeit of fire - at least in the western USA, where the two of us live – western Oregon for MEC and northern California for LB. The sky above the former's home is now bathed in an eerie orange-yellow glow and ash falls from the fires to the east. So the sunny days have ended in western Oregon, but no rain is on tap for two weeks.

When we decided upon this topic for *Water Resources IMPACT* in mid-2019 it was a no-brainer. We knew that fire was going to be around a while and there would be no problem developing an issue on the topic. We also suspected that there would be much interest because the fires were not likely to abate so practitioners and researchers would need to understand how fire and water would intersect. Fires abating? Did we ever underestimate that!

As this is being written (8 September 2020) much of the American West is ablaze. *The Washington Post* ran a story today with that very thought: *Much of the American West is on fire, illustrating the dangers of a climate of extremes* (see https://wapo.st/3hflmns). The article reported that over 70 large wildfires are now burning. California alone has 23, being fought by almost 15,000 firefighters. CAL FIRE, the state fire agency, circulated this graphic:

The contrast between 2019 and 2020 is quite stunning. The acreage burned so far this year is almost 3,600 square miles – over triple the land area of Rhode Island. Last year it was about 184 square miles – about the land area of San José.

We now have another essential worker that we'd be wise to thank and protect from COVID-19: the wildfire fighter.

Fire...and Water

Now we arrive at this month's *Water Resources IMPACT* topic. We have assembled an excellent suite of articles covering a variety of issues. The geographic distribution is limited: Arizona (2 stories); California (2); New Mexico (1); Australia (1). The latter article by Andy Baker deals with groundwater and fire. In Arizona, the roles of partnerships and a highly-engaged utility are examined. In California, we examine the effects of fire on water resources management, water quality, infrastructure and address an oft-forgotten theme - that of the slow recovery of communities that are low-income, minority, and other vulnerable populations. In New Mexico, we look at a hazard exacerbated by wildland fires: debris flows. How much rainfall intensity is needed to generate them? James Taylor would be pleased.

Last Words

Stay aware in fire-prone regions. Be cognizant of fire hazards and ready to evacuate at a moment's notice. Prepare a 'go-bag' for your family and pets that has all the necessities to survive away from home. Fire or no fire - please wear a mask. The *Bangor Daily News* (23 June 2020) said it best: "It is not a statement about politics, it's about science and compassion." ■

Imagine A Day Without Water - Sixth Annual Day of Action

Lisa Beutler and The Value of Water Campaign

JOIN US

ON OCT. 21, 2020 AWRA WILL JOIN 100s of sister organizations, agencies, utilities, private firms and non-government entities in raising awareness about the need for investment in the water sector. The vast majority of Americans do not understand the deteriorating status of much of the country's water infrastructure and the degree of risk they face in losing access to water. The annual day of action takes this discussion to the simplest terms and asks that we all imagine a day without water.

The Value of Water Campaign has made participation unbelievably easy by offering five easy options with instructions and samples for each.

1. Engage on social media
2. Host an event for your community, in person, or online
3. Get water in the news. Communicate the message that water, and the systems that deliver it, is an environmental, economic, and public health imperative
4. Partner with a local mayor or public official. Work to issue a proclamation supporting Imagine a Day Without Water
5. Bring Imagine a Day into the classroom. A sustainable water future will depend on the success of our next generation of water leaders

The events of 2020 have accelerated the need for this public conversation. As the world faced an enormous public health crisis from the coronavirus pandemic, a completely new understanding of the critical role that water and wastewater systems play in protecting public health, safeguarding the environment, and making a healthy economy possible, began to emerge. Climate change has also put a spotlight on the fragility of our water sector (including governance) systems.

It may seem that this type of outreach activity really belongs to someone else, not the water managers! In fact, many water managers spend their whole career trying to avoid too much attention. In their perfect world, consumers turn on the tap and clean water flows out. They flush the toilet and dirty water goes away. Those informed consumers understand the need for a rate increase or to vote for a bond. In this world, the people we serve don't think twice about the infrastructure that brings water to their home or business and then safely returns water to the environment – but they should.

Imagine a Day Without Water is a day to pause and notice the way that water systems impact our lives and communities. We need to commit to ensuring a sustainable water future for generations to come.

AWRA's 2017 policy on Ensuring Sustainable Funding for Water-Resource Infrastructure recommends that policy makers at national, tribal, state, and local levels develop sustainable investment strategies for the construction, maintenance, and long-term resilience of water resources infrastructure to protect public health and safety, community, quality of life, diverse economies, and the environment. The policy also includes recommendations for fiscal stewardship and due diligence.

We all know that a day without water is a public health and safety crisis and living without water is an economic crisis too; a single nationwide day without water service would put our entire economy at risk. Conversely, investing in water creates cascading economic benefits, strengthening American competitiveness, raising GDP, creating jobs, and increasing wages. Even if we just covered one-half of our capital investment needs, we would create over 700,000 jobs, raise wages by $2 trillion, and increase GDP by $3.5 trillion above baseline projections. As we faced the largest economic depression in a generation, investing in water provides a path to economic recovery.

Strong leadership on water is key to securing our future.

- Imagine a Day Without Water is an opportunity to share why water is important to you, your business, your community.
- We can speak out together, with one voice, and

ask public officials at every level of government to invest in water as a way to protect public health and recover from the economic recession.

- Investing in water now will help us out of the economic crisis we're in and make us more resilient for the next crises to come.
- Investing in our water is investing in a future where no American will have to imagine a day without water.

A number of resources are available to support participants including a Message Framework, Graphics and Logo, Op-Ed & Press Release Template, Resolution Template and sample Social Media Posts.

Join Us

You may find from a quick scan of the participating organizations that your employer is already participating. If so, this is a great time to reach out and let them know of your interest. If you are not participating yet, join AWRA and sign-up here.

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FEATURE

Sustainable Water Resources Management in Fire-Prone Landscapes: Taking a Closer Look at Contra Costa County, California

Nekesha B. Williams and Diana Garcia-Colmenarez

Introduction

IN A MATURE ECOSYSTEM, THERE ARE PROCESSES at work that replenish and renew natural communities. Wildfires are natural ecological perturbations that are essential for maintaining ecosystem health and function by contributing to increased biodiversity and enhanced biogeochemical cycling. However, increased frequency of destructive wildfires, often a result of poor land management, is of growing concern, especially in the wake of global climate change. Besides the obvious loss to critical infrastructure and personal property, the changes within the landscape are also devastating. Scorched landscapes are susceptible to accelerated soil loss, and the threat of geohazards such as landslides also increases. Debris flows are considered one of the most devastating and destructive impacts from wildfires. The mass movement of sediment from the landscape has the potential to impair vital water resources. Such an effect can produce additional hardship for areas that are water stressed, and may degrade sensitive aquatic ecosystems (see Youberg et al., this issue).

Wildfires and Debris Flows

Hydrologic processes such as runoff and infiltration can trigger debris flows in recently burned areas. Runoff can be enhanced by post-fire hydrophobic surfaces, and can lead to accelerated and enhanced soil erosion. Because of this, a supply of sediments is available on hillslopes for transport. This process can be initiated immediately after a fire in response to a storm event. Infiltration can trigger landslides if a small space has oversaturated conditions, resulting in slumping. The magnitude and frequency of debris flows from burned landscapes depends on intensity of rainfall events as well as duration. Watershed geology and geomorphic characteristics play a major role in landslide occurrence, hence the importance of evaluating these factors in devising strategies for water resources protection in wildfire prone landscapes. See Youberg et al, in this issue for more information on debris flows after wildfires.

Sustainable Wildfire Management

When discussing fire management, it is important to distinguish between planned and unplanned fires. Planned fires are necessary to achieve land management goals, protect properties and support forest health. There are many methods to prevent unplanned fires. Prescribed controlled burns have many ecological benefits without geohazards or property damage. Alternatively, the fuel load can be removed instead of burned away. In areas like Moraga, California, the fuel load is eaten by herds of sheep used for fire abatement (Figure 1). However, the question and challenge remain, how do we protect and treat water resources in the event of unplanned fires? What would sustainable water resource management look like in a fire-prone landscape?

Figure 1. A herd of sheep, a strategy for fire abatement, Saint Mary's College. Photo Credit: Haley Nelson

California: Fire-Prone and Water-Stressed

The state of California has experienced a series of

devastating wildfires. In 2019, California had the highest number of wildfires (8,194) compared to any other state, resulting in over hundreds of thousands burnt acreage. The Camp Fire of 2018 is the costliest fire in the past 17 years, with an estimated loss in the order of billions of dollars. This fire was also one of the deadliest, with a reported 85 lives lost. For the state of California, the increasing frequency of larger fires is worrying. Climate scientists predict that this trend will continue as global temperatures increase.

California is a water-stressed state. While the state receives greater than normal precipitation some years, there is a persistent water shortage. Adequate water is needed for maintaining communities and farms, all while sustaining environmental flows to support fish populations and riparian ecosystems. Wildfires and their cumulative impacts can produce an additional strain on the State's water resources that can be magnified in drought years. Therefore, current and future water resource planning for the state must provide guidance on rehabilitation of burned watersheds and post-fire water treatment.

Contra Costa County: Fire-Prone and Landslide-Susceptible

Contra Costa County is located in the East Bay region of the San Francisco Bay Area. The county covers 804 square miles of land and water, and is home to 1,049,025 people according to the 2010 census. It is primarily suburban, with many parks that support ecologically significant species and has over 1,200 miles of hiking trails. The trails traverse rangelands that are primarily managed by the East Bay Regional Park District (EBRPD), East Bay Municipal Utility District (EBMUD), Contra Costa County Water District (CCWD) and/or the State. Therefore, management of these wilder lands requires cooperation between local communities, state agencies and water districts.

The area is crisscrossed by the Hayward Fault, the Calaveras Fault, the Concord Fault, the Clayton-Marsh Creek-Greenville Fault, and other smaller fault systems. There are also several foothill areas, which lead up to the lone Mount Diablo. The extensive fault system in combination with the sloping landscape are prominent landslide risk factors. The county has a Mediterranean climate, characterized by very distinct wet and dry seasons. In wet years, the landscape is susceptible to landslides due to excessive rainfall amounts. For example, trails leading to Wildcat Regional Park as well as Del Valle Regional Park (managed by the EBRPD) were closed due to debris flows initiated by heavy rains. On the other hand, during the dry season, this county is at a high risk for wildfires - a result of low/no rainfall and intense temperatures. This risk is magnified by the presence of invasive grass species brought over by Spanish colonization and eucalyptus trees heightens fire risk, as they are non-natives that are not adapted for this landscape. When the impacts of wildfires and storm events interact, there is an increased potential for fire-initiated landslides.

Sustainable Water and Wildfire Management Framework: Contra Costa County

Within Contra Costa/Alameda county juncture, there are four major reservoirs: San Pablo Reservoir, Briones Reservoir, Upper San Leandro Reservoir and the Los Vaqueros Reservoir. The first three are managed by EBMUD and the last by the CCWD. These reservoirs are surrounded by rangelands. Therefore, fires in these areas can jeopardize public water supply, industry and agricultural activities in the area. The CCWD serves 13 cities within Contra Costa County; approximately 500,000 residents. Roughly half of these residents are provided with treated water directly from the CCWD. The other 250,000 residents live in cities where the CCWD provides raw, untreated water that is processed in the individual city's treatment plants. The primary source of water is the Sacramento - San Joaquin Delta, which is diverted to reservoirs and treatment plants in the county. San Los Vaqueros is the largest reservoir in the county (160,000 acre-ft), and a fire within its associated watershed that compromises water quality may cause additional water stress in an already dry landscape (Figure 2).

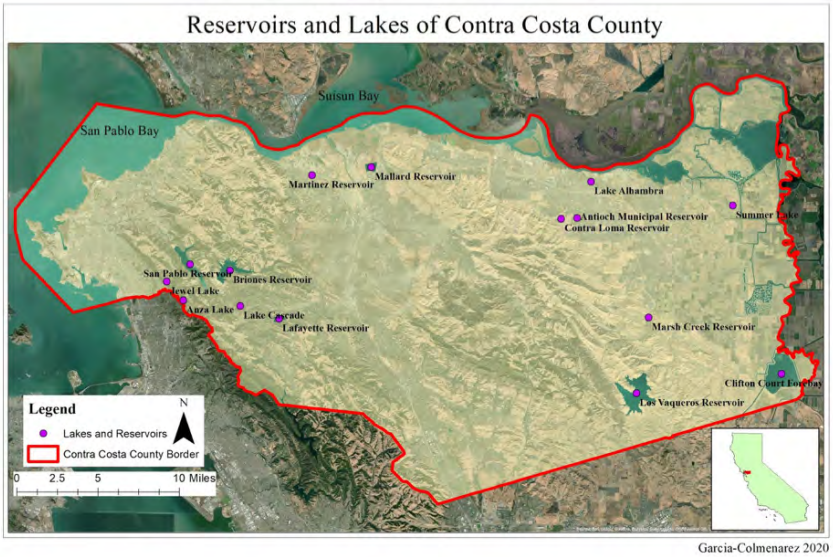

Figure 2. Key water sources within Contra Costa County, San Francisco Bay, California.

So, what should sustainable water resource management look like for Contra Costa County, a locale that is fire prone with soils and geology susceptible to mass movement? Integrated water management

plans for this county must include protocols for water treatment and water flows during and after unplanned fires. It will require a framework that integrates sustainable fire and landscape management strategies into local water management plans and policies.

A key component to developing a sustainable water and wildfire management framework for Contra Costa County will be restoration of landscapes. This will be key in mitigating the impacts of wildfires and landslides. Restoration and maintenance processes can only begin after these risk zones have been identified, and geospatial technologies such as a geographic information system and remote sensing can assist with this effort. Additionally, existing decision support tools may produce management scenarios that can provide guidance on managing water resources in fire prone landscapes. Regardless of what technology is used, what is most important is fostering collaborative decision-making and planning that involves hydrologists, wildfire managers, restoration ecologists and the community.

In an ever changing environment, collaborative decision making is necessary for sustainable development of natural resources. ■

Nekesha B. Williams is an Assistant Professor at Saint Mary's College of California in the Environmental and Earth Science Department. She teaches introductory and advance courses such as environmental science, hydrology and wetland sciences. She is passionate about preparing the next generation of environmental, coastal and watershed professionals and often partner with students on research projects. **Contact:** Saint Mary's College of California, 1928 St. Mary's Road, Moraga, CA 94575; (925) 631-8202; Email: nbw1@stmarys-ca.edu

Diana Garcia-Colmenarez is a student at St. Mary's College Email: dvg2@stmarys-ca.edu

AWRA NEEDS YOUR HELP

SHARE YOUR WORK

In response to the COVID-19 pandemic, AWRA would like to invite members to highlight their work or research addressing the impact of COVID-19 on the field of water resources. Your work will be highlighted in our COVID-19 Online Repository.

Please upload information regarding your work here. You can include a paper, a write up of your work, or a presentation.

Questions? Contact info@awra.org.

Upload your paper at bit.ly/3hDHTfV

FEATURE

Water in Paradise: Research on Water Network and Community Vulnerabilities

Lisa Ellsworth, Erica Fischer, Laura Linderman, Jenna Tilt, and Brad Wham

WILDFIRES HAVE INCREASED IN INTENSITY and frequency over the last decade. In addition, the wildland urban interface (WUI) land use is the fastest growing land use in the US, with almost one-third of the US population living in a WUI. As such, recent wildfires have caused catastrophic damage to civil infrastructure, and engineers and fire scientists must develop solutions for WUI communities to be resilient. In particular, recent fires in California have caused significant damage to water distribution systems. Both the 2017 Tubbs Fire and the 2018 Camp Fire (see Figure 1) caused damage to the water distribution systems in Santa Rosa and Paradise, respectively, which resulted in contaminated water within the system. The fires heated the service pipeline materials thereby causing contaminates - benzene and other volatile organic compounds (VOCs) - to migrate from the pipe materials into the water and negative pressure due to homes burning-caused backflow of soot and ash into the water distribution system. However, there are no current solutions to this problem, and at the time of this article, many communities in California are being evacuated due to wildfires.

With funding from the Alfred P. Sloan Foundation, a research team from Oregon State University has shown that the density of damaged residential homes is a pseudo-indicator for contaminated water samples after a WUI wildfire. This research will be expanded in the coming years to determine if certain service line pipe materials are vulnerable to elevated temperatures, develop a field-deployable sensor network that indicates a critical temperature for vulnerable pipe materials, and investigate how communities can synthesize layers of data (including the data from the sensors) together to inform communities of the extent of damage after a WUI wildfire.

The experimental investigation will consist of component-level testing of service pipe materials (e.g., copper, HDPE, PVC) to correlate pipe material with exposure temperature, heating duration, post-fire stagnant water duration, and levels of potable water contamination per EPA 524.2. A specially-designed environmental chamber will be constructed with precision-controlled heaters and water extraction capability for periodic sampling under controlled conditions representing in-service water distribution pipelines. The information from these tests will inform the durability and temperature indicator needs for the development of temperature sensors for pipeline networks. The sensors will be tested on buried pipes in varying soil conditions using scaled experimental setups. Multiple components of the water distribution system will be included in the large-scale fire test at Oregon State University's O.H. Hinsdale Laboratory. As depicted in Figure 2, an array of real-time

Figure 1. (a)

Figure 1. (b)

Figure 1. (c)

Figure 1. (d)

Figure 1. Photos of the region impacted by the Camp Fire (taken by E. Fischer) (a) wildfire safety zone for public assembly in Concow, CA, photo was taken in February 2019, (b) remaining home foundation from a destroyed house in Concow, CA, photo was taken in February 2019, (c) remaining chimney from a destroyed house in Paradise, CA, photo was taken in February 2019, and (d) new house under construction in Paradise with Paradise Irrigation District (PID) sign, photo was taken in October 2019.

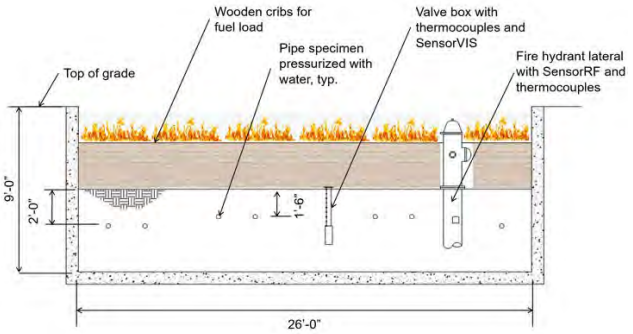

Figure 2. Large-scale test design. A full water pipeline network with new sensors to detect heat damage will be buried and tested under live-fire conditions at Oregon State University.

instruments will be deployed throughout the test basin to verify measurements of the newly developed sensors and, or the first time, monitor wildfire impact on critical, buried infrastructure.

The cascading impacts of large wildfires such as the Tubbs fire in Santa Rosa and the Camp fire in Paradise, CA are still strongly felt in these communities today. Because the water distribution system has been damaged, access to clean water impedes individuals and households from fully recovering. Unfortunately, past disaster events have shown there is a strong likelihood that a community will recover unequally, with low-income, minority, and other vulnerable populations recovering at a slower rate, or leaving the community altogether. In an effort to understand and close the inequality gap in community recovery, we are investigating how different populations have been impacted by fire, the subsequent water contamination, and the on-going recovery of the water system in Santa Rosa and Paradise. By using a combination of demographic data, property and housing permit data, remotely sensed data (e.g. satellite sensor data that can detect temperature, burn areas, topographic features, etc.), as well as social media data, we will create predictive models that illustrate both pipeline and household vulnerability to water contamination, as well as a household's ability to recover and access clean water. This model will then be transferred to a user-friendly web-based platform where other communities exposed to wildfire risks can utilize the information to visualize and understand where their water system may be vulnerable to contamination and which community members may suffer disproportionately from lack of access to clean water. ■

Dr. Lisa Ellsworth works at the intersection of fire ecology, fire behavior modeling, and community resilience. Her research is focused on finding strategies to improve ecosystem resilience to wildfire for both human and non-human inhabitants. She was a wildland firefighter prior to moving into fire research. She currently works as a Research Professor in the Fisheries and Wildlife Department at Oregon State University. **Contact: Dr. Lisa Ellsworth**, Assistant Professor, Department of Fisheries and Wildlife, College of Agricultural Sciences, Oregon State University, Corvallis, OR 97331; Email: lisa.ellsworth@oregonstate.edu

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Arizona's Most Burning Question: The Future of Our Forests and Water

Rebecca Davidson

HIGH SEVERITY FIRES (Figure 1) in forested headwaters dramatically alter watershed hydrologic conditions, increasing the potential for post-fire floods and debris flows, and pose a significant risk to many communities across the West; from small mountain towns situated in the forested Wildland Urban Interface (WUI) to bustling cities that are connected to and depend upon upstream forests for municipal water supplies. Wildfire season often ends at the onset of monsoon rainfall, which can help extinguish wildfires, but then often produces large floods and debris flows in the immediate aftermath. These scenarios allow for very little time to address post-wildfire damage and hydrologic impacts, and to implement appropriate restoration or mitigation measures.

Figure 1. Rodeo-Chediski Fire Backdrop, Flagstaff Arizona (USDA Forest Service)

In response, communities, businesses, cities and governments, and nonprofits are coming together in new ways to protect our National Forest's 'green infrastructure,' that in large part produces the nation's clean air, its water supplies, and that also propels local and regional tourism and recreation-based economies. Partners are well-aware that proactive forest restoration treatments can minimize unnatural wildfire threats, protecting environmental, social and financial interests. And while restoration treatments can be expensive, the cost of inaction, and the cost of response and recovery post-wildlife is many times more expensive and impactful.

In the past decade in Arizona, we have experienced the costly and painful 'one-two punch' of high-severity fires and the floods that follow, expensive to recover from, devastating to landowners, difficult for management agencies, and harmful to local and downstream water users. Motivated by these impacts, partners are working together to find innovative ways to fund the extensive efforts that are needed to protect and restore our forests and watersheds.

Case Study

The Bill Williams Mountain Restoration Project in northern Arizona is one such project that aims to reduce the risk of high-severity fire and post-fire flooding that pose an imminent threat to the local and downstream communities. Situated adjacent to the City of Williams (about 35 miles west of Flagstaff on Interstate 40), the majority of Bill Williams Mountain (Figure 2) faces an extreme risk of high-severity fire, and restoration treatments have been prioritized based on results of a 2017 Federal Emergency Management Agency (FEMA) funded study. The FEMA Post-Wildfire Debris-Flow & Flooding Assessment models suggest that even a moderate monsoon rain event following a wildfire on Bill Williams Mountain would lead to flooding that would inundate the City of Williams in up to six feet of floodwater and debris. Such an event would also shut down Interstate 40 and the BNSF Railroad, close the Grand Canyon Railway indefinitely, destroy communication and power line infrastructure located at the mountain's peak, and cause irreparable damage to much of downtown Williams. The regional economic impact of such an event has been estimated by the

W.A. Franke College of Business at Northern Arizona University to be between $350 million and $700 million, encumbered largely by the local community.

Figure 2. Bill Williams Mountain Backdrop, Williams Arizona (USDA Forest Service)

Shared Stewardship

The Kaibab National Forest, Coconino County, the National Forest Foundation, the Arizona Department of Forestry and Fire Management, and other partners (Figure 3) have galvanized resources, bringing together funding and operational capacity to begin the hardest to access, steepest-slope forest restoration and hazardous fuels reduction work. Jointly, partners are working together to reduce unnaturally dense forest stands and heavy accumulations of dead and down woody fuels on the steepest portion of the mountain's north face, particularly in areas most difficult to access and treat.

Complexity in Action

Steep slope material removal requires specialty equipment that is not commonly used nor is easily accessible in the Southwest, and cost-per-acre is far greater than traditional timber operations. We considered a number of alternative treatment options, considering the need to implement cutting and removal techniques on steep, rocky terrain; including tethered machinery known as Ponsse, helicopter logging, and/or hand-thinning and piling. With this type of technical treatment work requiring expensive mobilization costs, we were concerned that operators would have little incentive to bid on the opportunity unless it was combined with other nearby work. Another complication was the requirement by the Forest Service to remove and process all material, including the large volume of dead and downed hazardous fuels and small diameter trees, which have little to no market value in Arizona, and therefore are difficult to manage post-cut.

Figure 3. Forest Service Partners Working on Bill Williams Mountain (USDA Forest Service)

The Cost of Doing Business

In addition to managing on-the-ground treatments, partners are also working together to creatively finance the first 1,000 high priority acres at the top of Bill Williams Mountain where the risk of wildfire and subsequent post-fire flooding is the greatest. The estimated funding needed to complete the entire 1,000 acres is $10 million; approximately $10,000/acre. Recognizing the upfront cost is significant and we cannot depend upon sales of residual material as an offset, we must instead consider an 'all-in' funding approach, where beneficiaries of the work, large and small are identified as potential partners to the effort. And although expensive, we know that this upfront investment in the work will result in savings more than 30 times greater in avoided costs for fire suppression, community and infrastructure recovery, and flood disaster relief.

Implementing Acres

A contract for the first 300 acres of treatment was awarded in 2019 with activities including hand-thinning, skidding, bundling thinned trees and dead and down materials, and removing fuels from forest floor via helicopter operations. The work on the project started in late September 2019. A majority of the 300 acres of hand-thinning in the project area was completed by the end of October. After trees were cut and bundled, a forestry helicopter crew began hauling trees to a landing zone where the trees were processed into wood chips (Figure 4).

Early November of 2019 brought unexpected heavy winter storms to northern Arizona, and with more than 4 feet of snow on the Bill Williams Mountain, the helicopter crew had to halt work. Before being grounded, the contractor finished removing, hauling and processing approximately 85 acres of logs, shipping nearly 200 truckloads of chips – approximately 5,000 tons of chips –

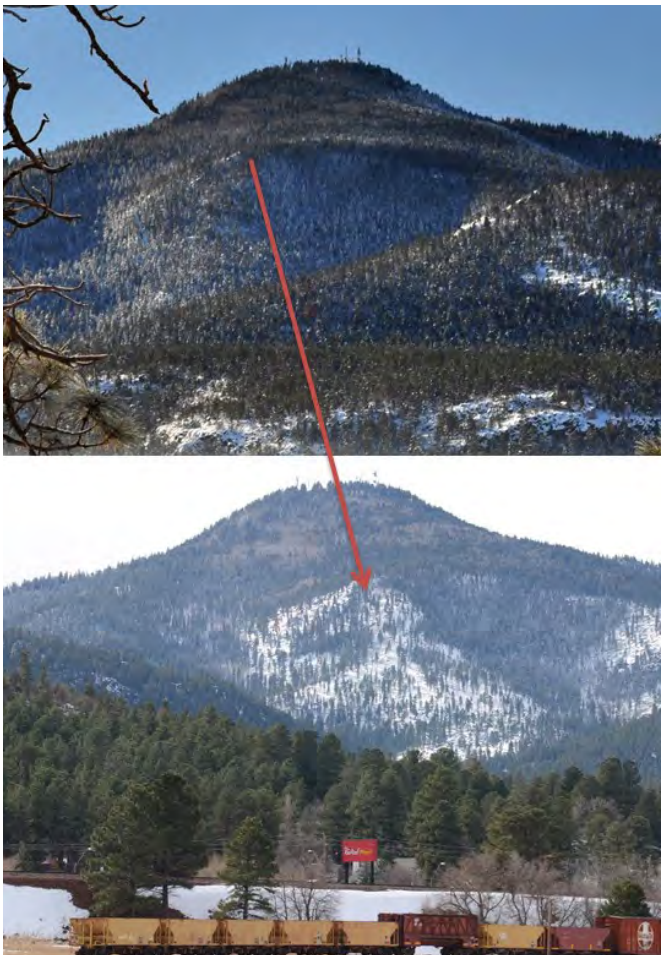

Figure 4. Bill Williams Mountain, Before and After Treatment (USDA Forest Service)

to Novo Power and Gro-Well Industries; the chips are to be used as fuel for a biomass plant and wood chips for landscaping, respectively.

Partners are gearing up now and remobilizing in September 2020, with an expectation that all thinning, helicopter removal, and processing will be finished before Christmas this year.

The Kaibab National Forest has also been implementing other forest restoration and fuels reduction efforts in the area to include preparing 3,500 acres that are currently offered in timber sales; treating more than 700 acres using hand thinning operations on the steep slopes of the mountain's south side; and, treating 200 acres using mechanical thinning south of the mountain in an area critical to the success of any future wildfire suppression efforts. The steep slope fuels reduction work will be ongoing, and implemented in phases over the next several years.

Lessons Learned

The FEMA study shows us that forest health initiatives, like the Bill Williams Mountain project, can effectively reduce fire risk and mitigate post-fire flood and debris flow risk, and further, the modeling indicates that forest thinning treatments must include entire watersheds to enhance downstream benefits. Other recommendations we can draw from this project include the importance of developing guidelines to better protect landowners in the Wildland Urban Interface, creation of emergency action plans to streamline post-fire recovery efforts, and building community awareness and public education to build support for ongoing treatment actions.

We still have a long way to go to achieve resiliency on Bill Williams Mountain. We also know the path to proactively treat, finance, and implement projects to protect forests and water supplies is not always straightforward. But with creativity and diligence we can find a path forward to protect communities, improve water supply resiliency, and ensure that present and future generations can depend upon our National Forests for the many benefits and opportunities that they provide. ■

To learn more about the story of Bill Williams Mountain and meet the partners, check out this video: https://tinyurl.com/y3erqhst More photos and videos of the project area: https://tinyurl.com/y4q5mrbh

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FEATURE

The Salt River Project's Leadership to Protect Sustainable Water Supplies

Elvy Barton, Bruce Hallin and Tiffany Bolton

Introduction

FOR THE SALT RIVER PROJECT (SRP), delivering water throughout the Greater Phoenix area, including the nation's fifth-largest city, is a core mission. To do that, we must look beyond the physical infrastructure that stores and delivers water. We must also consider the 8.3 million acres of green infrastructure where the water first collects. Three watersheds – the Salt River, Verde River and East Clear Creek watersheds – feed water into SRP's seven reservoirs that serve over 2.0 million people with sustainable and reliable water (Figure 1). One of the greatest threats to these watersheds, and the Greater Phoenix area's water supply is unhealthy and overgrown forests. SRP is tackling this threat by acting today.

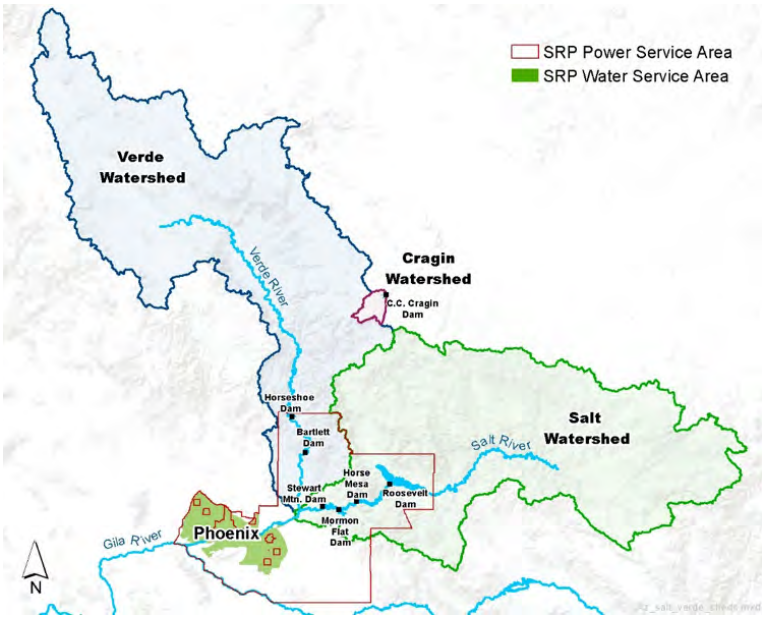

Figure 1. Three watersheds – the Salt River, Verde River and East Clear Creek watersheds – feed water into SRP's seven reservoirs that serve over 2.0 million people with sustainable and reliable water

The Problem with Overgrown Forests

The Salt River, Verde River and East Clear Creek watersheds are overstocked with trees and brush. On average these forested lands have about 100 trees per acre, but in many areas there are thousands of trees per acre. When so many trees grow near one another, they compete for resources. This stress makes them more susceptible to pests and disease, less tolerant to drought conditions and the effects of climate change. What's worse, overcrowded forests can fuel large, hot wildfires that are uncontrollable with catastrophic impacts (Figure 2).

Figure 2. Overcrowded forests can fuel large, hot wildfires that are uncontrollable with catastrophic impacts.

Over the past two decades, Arizona has experienced seven mega-fires (wildfires that burn more than 100,000 acres), six of which were on the Salt and Verde River watersheds (Figure 3). These wildfires not only devastate natural ecosystems, they also degrade water quality and impact the resiliency of the water supply. After a wildfire, rainfall washes sediment, ash and debris into rivers and reservoirs. The large amounts of sediment that washes into SRP's reservoirs prematurely reduces our water storage capacity and damages our water infrastructure. This is a huge concern considering that we live in a desert environment where long-term storage capacity and resiliency to drought are crucial.

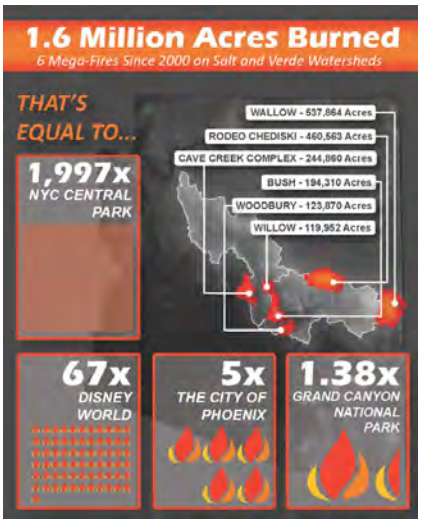

Figure 3. Over the past two decades, Arizona has experienced seven mega-fires (wildfires that burn more than 100,000 acres), six of which were on the Salt and Verde River watersheds.

The Value of Healthy Forests

SRP has historically delivered water mostly for agricultural purposes, but today, because Greater Phoenix is growing quickly, much of the raw water we deliver goes to city water treatment plants and irrigation customers. When a wildfire sends sediment, ash and debris into our water storage delivery system, everyone must deal with the consequences. In some cases, water may be so heavily contaminated that cities can't treat it. The water must then be diverted from our canal system and released into a dry riverbed, which is not a good outcome when we are trying to sustainably manage our water supplies during droughts.

Figure 4. A healthy forest

In a healthy forest (Figure 4), the very opposite happens. The forest floor will soak up rain and snow. The soil then acts as a natural filter, creating healthier streams and ecosystems, and sending cleaner water into SRP's reservoirs.

SRP Leads Forest Restoration Efforts

SRP has put an unprecedented goal in place to protect the watersheds and preserve the Greater Phoenix area's water supply. In June 2019, SRP's Board and Council approved a forest health goal — the first of its kind in the nation — to support the strategic thinning of 50,000 acres of forest a year or 500,000 acres by 2035.

Our goal is big, but crucial. According to an Electric Power Research Institute study from 2019 titled *Watershed Management and Economic Considerations: Case Studies*, a catastrophic wildfire could cause hundreds of millions of dollars of damage to infrastructure and restoration costs for a single watershed. The cost of strategic forest thinning is far less than the consequences of waiting for a catastrophic wildfire, so to accomplish our goal, SRP will use every tool possible.

Engaging Partners at Every Level

To help restore forests in northern and eastern Arizona, were partnering with:

- SRP residential and commercial customers
- SRP municipal customers
- The U.S. Forest Service
- The U.S. Bureau of Reclamation
- The Arizona Commerce Authority
- The Arizona Department of Forestry and Fire Management
- The Nature Conservancy
- The National Forest Foundation
- Local governments
- Academic institutions

SRP is committed to growing this list. We're bringing everyone to the table to ensure we succeed in protecting the watersheds that are critical to the ensuring a sustainable and reliable water supply.

Sustainable Industry for the Future

We know that having a sustainable and thriving forest product industry will be important to our success. This means that existing industry needs to expand, and more forest product companies need to relocate to Arizona. SRP has partnered with the U.S. Forest Service, the U.S. Bureau of Reclamation and the State of Arizona to develop a request for proposals (RFP) for forest thinning work on 605,000–818,000 acres across northern and central Arizona for the next 20 years.

Figure 5. To be successful, more forest product companies need to relocate to Arizona.

This collaborative effort was an unprecedented way to issue an RFP. In 2021, we anticipate an award for one or more contracts that will make large-scale, strategic forest

thinning possible over the next 20 years. We look forward to bringing more forest industry jobs, as well as products, into rural Arizona.

Innovative Forest Research

SRP is committed to data- and science-based forest restoration efforts. We've invested in numerous research projects, together with academic institutions, nonprofits and private industry organizations, to understand the short-term and long-term effects of forest restoration. We've also invested in innovative and proprietary LiDAR and field instrumentation, known as Flowtography (Figure 6), that provides real-time visual watershed condition and forest data.

Investments in research and development provide

Figure 6. SRP has invested in innovative and proprietary LiDAR and field instrumentation, known as Flowtography, that provides real-time visual forest data.

SRP with invaluable insights that both inform our water management decisions and quantify the ecological benefits associated with forest restoration. According to McCauley et al. in a 2019 Ecological Applications article titled *Large-Scale Forest Restoration Stabilizes Carbon Under Climate Change in Southwest United States*, strategic forest thinning will sequester more carbon emissions over time. Forest thinning may also improve the water balance and resilience of forests, according to Marco Robles et al. in a 2014 PLOS ONE article titled *Effects of Climate Variability and Accelerated Forest Thinning of Watershed-Scale Runoff in Southwestern USA Ponderosa Pine Forests*. Most importantly, strategic thinning (Figure 7) will help prevent catastrophic wildfires, which can devastate communities, forest ecosystems, and the water supply.

Figure 7. Strategic thinning will help prevent catastrophic wildfires, which can devastate communities, forest ecosystems, and the water supply.

Final Thoughts

SRP may not have all the answers just yet, but we do have a strong vision on how to tackle the challenges that lie ahead. With support from SRP's leadership, partners, forest product industry, our customers and researchers, we have the tools to succeed in reaching our 2035 Forest Health goal. ■

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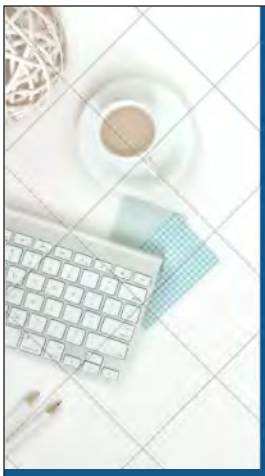

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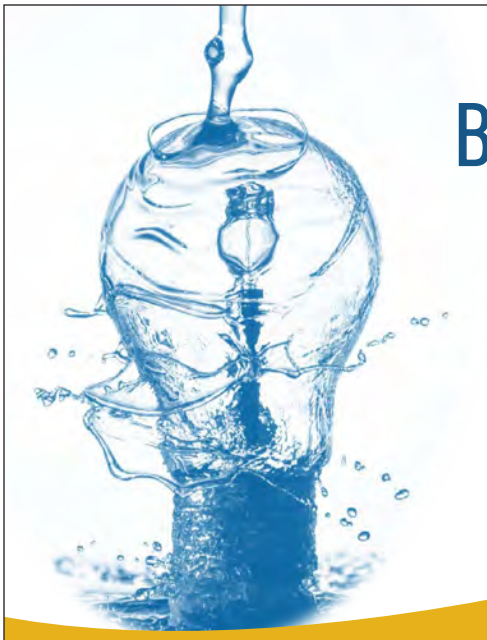

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FEATURE

After a Wildfire, How Intense Must Rainfall Be to Cause a Debris Flow?

Ann Youberg, Luke McGuire, and Francis Rengers

Note: *This article originally appeared as a post in the Arizona Geological Survey's blog. We obtained the AGS's and the authors' permission to reprint it in Water Resources IMPACT. The editors are grateful to all involved and convey their thanks. This is a work in progress; for more information, consult the AZGS blog (https://bit.ly/3fMf5jE) or contact the senior author.*

EVEN IN THE MIDST OF A PANDEMIC, Ann Youberg (UArizona Arizona Geological Survey) and Luke McGuire (UArizona Dept of Geosciences), along with their partner Francis Rengers (US Geological Survey), study how wildfires throughout the Southwest, such as the Bighorn Fire in the Santa Catalina Mountains, Tucson, Arizona, impacts geologic hazards, specifically post-wildfire debris flows.

Debris flows are mixtures of water, soil, and rock (think flowing concrete) that behave differently from floods. Because debris flows are a thick slurry and can carry large boulders and trees, they can generate high impact forces which may damage buildings and infrastructure and, more importantly, pose significant threat to human life and safety. In recently burned landscapes, there is frequently a rapid switch from floods to debris flows once a critical rainfall intensity is exceeded. One of the of questions our research addresses is how intense does rainfall need to be to cause a debris flow in the Southwest?

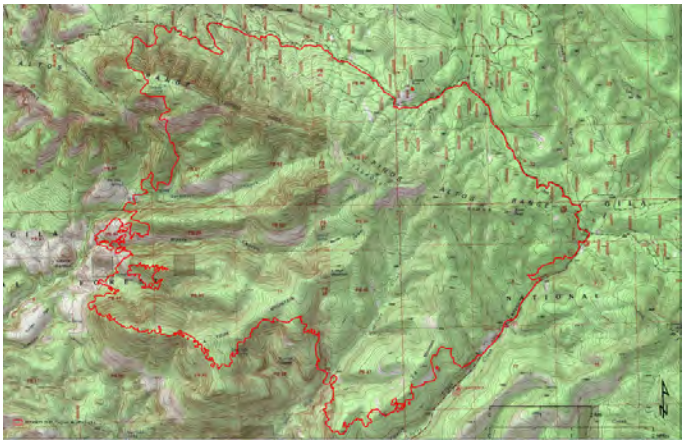

Figure 1. Perimeter of Tadpole Fire as of 29 June 2020 from infrared data (red line).

To answer that question, we monitor rainfall rates and debris flow activity within recent burn scars throughout the Southwest. Most recently, we set up a monitoring site at the Tadpole Fire burn scar (Figure 1) in the Gila National Forest north of Silver City, NM.

During the second week of July, we installed equipment in four watersheds on the north side of Tadpole ridge (Figure 1) with in the Tadpole Fire burn scar. We installed non-vented pressure transducers in four bedrock channels (Figure 2A); these allow us to capture the timing and type of flow (flood/debris flow). In a different watershed, we installed a USGS geophone (Figure 2B) that allows us to not only capture timing and type of flow, but also allows us to calculate flow velocity.

Figure 2. Panel A: installing a pressure transducer in a study channel. Luke McGuire is programming the pressure transducer (blue circle) before placing in the drilled hole. Inset photo shows a pressure transducer installed in the bedrock. Panel B: The USGS geophone setup. The inset photo shows the solar panel, rain gauge and battery and datalogger box. Two geophones (blue arrows) are attached to the datalogger via wiring through conduit. The datalogger starts recording when rainfall is above a programmed threshold.

Above the pressure transducer in one of the watersheds, we also installed a rain-triggered camera (Figure 3) to capture the flows on video. Finally, in addition to the rain gauge on the geophone and on the camera, we installed a third rain gauge much higher in the watershed to capture rainfall information in areas where debris flows are likely to start. Throughout the monsoon, we will return to the study site after significant rain events to download our data and to assess deposits to field verify if a flood or a debris flow occurred.

Figure 3. Installing the rain-triggered video camera in the age of COVID-19. View in the background is looking up the study channel. In photo, Luke McGuire (left), Francis Rengers (middle) and University of Arizona Geosciences grad student, Olivia Hoch (right).

We also have active debris flow monitoring sites in the Superstition Mountains, the Pinal Mountains, and the Tularosa Mountains. Findings from these studies will help us understand how fires like the Bighorn Fire in the Santa Catalina Mountains will respond to monsoon rainstorms. Results will inform USGS post-fire debris-flow models (https://landslides.usgs.gov/hazards/postfire_debrisflow/ or https://on.doi.gov/35fbfxM), and provide information for warning thresholds to the National Weather Service (NWS) and partner state and local agencies such as county flood control districts.

Support for this work is provided by the Federal Emergency Management Agency (FEMA) and the Arizona Department of Emergency and Military Affairs (DEMA) through the Hazard Mitigation Grant Program (HMGP), and by the National Oceanic and Atmospheric Association (NOAA) National Integrated Drought Information System (NIDIS) program. We thank the Gila National Forest and the Silver City Ranger District for their assistance in setting up the Tadpole Fire monitoring site. ■

Ann Youberg is a Senior Research Scientist at the Arizona Geological Survey in the University of Arizona. Ann has over 30 years of experience in geological, geotechnical and geomorphic investigations and has been with the Environmental Division of the AZGS for over 20 years. Ann's work at the AZGS includes surficial geologic, geomorphic and geologic hazards mapping, but her main focus is on post-wildfire hazard assessments and research.
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Wildfire and Groundwater

Andy Baker

VERY LITTLE IS KNOWN ABOUT THE EFFECTS of fire on groundwater. We need to know more. Recently, a group of us have been collecting evidence of the effect of fire on the subsurface environment. Not by sampling water from wells, but by analyzing water percolating into caves. Our research shows that fire does influence subsurface water quality, with soluble ash products are transported underground. But we don't yet know whether they can reach the aquifer.

The impacts of wildfire on river catchments are well known. But what about the water that moves to the subsurface? As this water filters through surface ash deposits, it can transport the soluble elements found in the ash. Particulate matter is likely to be filtered by the soil and bedrock, and not reach the subsurface. But soluble matter can.

Figure 1. Using caves as observatories of water movement from the surface to the groundwater. Here, close to the Blue Mountains region of New South Wales, we are monitoring hydrology and water quality before and after an experimental burn in this shallow cave system. (photo by Andy Baker)

Working with the state government here in New South Wales, Australia, we designed a set of experiments to provide an evidence base for the effects of fire on the subsurface environment. The focus was limestone caves, and the possible effects of prescribed or hazard reduction burns. During this project, we were able to also investigate the impacts of intense fires and wildfire on water percolating underground. What did we find?

After an intense fire, in shallow caves that were fewer than ten meters below the surface, we observed changes in hydrology and water chemistry after the fire. Hydrographs of the discharge of water percolating into the cave became 'peakier' – that is, they had a shorter duration and higher maximum flow. That is similar to what is observed in rivers. Our evidence suggested this was caused by fire damage to the soil amount and its properties, which meant the soil could hold less water after the fire.

We also observe physical damage to the surface geology after an intense fire. We see the cracking and fracturing of the limestone. Where vertical fracturing is enhanced by a fire, we expect this to increase the rate at which water can be infiltrated to the subsurface.

The chemical response in these shallow caves included an increase in nutrients. Again, this is like what is observed in river catchments, and the process is the same. Ash can contain some nutrients that were present in the original vegetation. In very severe fires, these nutrients will volatilize rather than form ash. But in most fires, these nutrients will remain in the ash. Then they can become soluble in water flowing through the ash. Finally, if infiltration to the subsurface occurs, these nutrients will be transported towards the groundwater.

We also observed changes in the chemistry of the water itself after a fire. We measured the stable isotopes of water and found that these vary with the intensity of the fire. Why? If there is water in the soil at the time of fire, then some of that water can evaporate. When this evaporation occurs, the isotope with the lowest mass is more likely to evaporate compared to the isotope with the heaviest mass. What this means is that, after a fire, any residual soil water has a changed isotope signature,

with slightly more of the heavier stable isotopes. We can detect this when this soil water eventually infiltrates into the cave.

Those examples were all from the shallow caves. We also monitored the hydrology and chemistry of water reaching a deeper cave, before and after a hazard reduction burn. In this case, at 30 m below land surface, we saw no impact of the fire on the subsurface water quality. Maybe this was because the fire was a low intensity fire, late in our season for hazard reduction burns and during cold and damp weather? Or maybe it was due to the dilution of the soluble ash products, with mixing of water of different recharge zones and different time periods? Maybe, the soluble ash products are not be stable, or 'conservative' as they are transported towards the water table. This would be expected to be the case for the nutrients, which would be utilized by the subsurface microbial ecosystem. Probably, it was all three.

Our research project was to provide evidence for the impact, or otherwise, of hazard reduction burns on the subsurface environment. And our evidence base allowed us to report that hazard reduction burns would have negligible impact compared to that of wildfires. Wildfires, on the other hand, could change how water infiltrates to the subsurface, and the chemistry of that infiltration water. The exact effects of wildfire on subsurface water quality would depend on the surface vegetation and the amount of ash generated, the fire intensity and the soluble elements remaining in the ash, the character and timing of post-fire rainfall, and the extent to which the soluble ash-derived elements are transported to the water table.

And where has our research gone next? Maybe surprisingly, back in time, to use cave stalagmites to obtain records of past fires. We know that the stalagmite calcite preserves the chemistry of the water dripping on to them. And we now know where to go in caves to find stalagmites which are fire sensitive. That is, shallow caves, just a few meters below ground surface, where the soluble ash elements are likely to be present.

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Rejecting the Prophets, Seers and Scientists and its Consequences

Eric J. Fitch

"A person is smart, people are stupid" - **Agent K (Tommy Lee Jones) Men in Black**

E pur si muove ("And yet it moves") or Eppur si muove ("Albeit it does move") phrase attributed to Galileo after the Church made him recant his observation that the Earth moves around the Sun, not the other way around.

GLOBAL MEAN ATMOSPHERIC TEMPERATURE is rising due to increasing levels of CO2, CH4 and other greenhouse gases (GHGs). Sea levels are rising due in large part to the melting of icecaps and glaciers and thermal expansion of sea water. The oceans are both becoming warmer and acidifying due in large part to increased CO2 levels. Drought and desertification are not only increasing globally, but they appear to be moving into long term climatic conditions. Has this has been a major, unpredicted surprise? Of course not! Is it something we could do nothing about, which we were entirely at the mercy of natural forces? No, the evidence and scientific consensus are that the driving factor in climate change is human-made or anthropogenic and which we could have changed the outcome is we had acted. We needed to greatly reduce the additional levels of CO2 and other GHGs into the atmosphere by reducing the burning of fossil fuels.

These cause and effect relationships were predicted by science going back more than 50+ years. Concerted economic and political interests in society fought back against acceptance of the science much less the implementation of policies to address the problems/threats. In the 2006 documentary, former Vice President Al Gore called it what it is for these groups, "An Inconvenient Truth". Through disclosures in court actions in the United States and other countries, it has come to light that leadership in the fossil fuel industry knew and understood the science decades ago. They chose to act against the knowledge and foresight created by these experts because acceptance of it by the powers that be would compel action. The fossil fuel industry and their allies feared action to reduce greenhouse gas emissions would cost them profits and perhaps even put them out of business. They engaged in a concerted disinformation/debunking campaign. It was very successful, especially in the court of public opinion and in the halls of the U.S. government.

This climate change denial campaign was greatly aided by a long-term social phenomena of deep seated rejection of science, indeed of expertise in general. This phenomenon has been studied more intensively in recent years especially by those in the social sciences. A good recent work in this field is Tom Nichols' "The Death of Expertise: The Campaign against Established Knowledge and Why It Matters:" It is my contention is that this phenomenon is not just recent and of growing import, but it his historic and cyclical and a great threat to the preservation of the biosphere and its ancillary systems including the hydrosphere.

In the 1st Book of Kings in the Hebrew Scriptures, the young King Solomon went to the heights of Gibeon and made burnt offerings to God. That night when he was asleep, God came to Solomon in a dream. God said to Solomon, "Ask something of me and I will give it to you." Solomon asked Him for something so astonishing that it remains through today as a quintessential right answer. Solomon was selected to be King succeeding his father David when he was but a callow youth. Solomon recognized that he was unprepared to be King of "the people whom you have chosen, a people so vast that it cannot be numbered or counted". So Solomon asked for "an understanding heart to judge your people and to distinguish between right and wrong:" God was pleased with Solomon's request and granted it so that Solomon would be the wisest of all time. Solomon went on to have from a reign which, from an economic, societal and diplomatic standpoint, was a great success. He finished the great work started by his father, the completion of the construction of the First Temple. So powerful was his leadership, that a unified Israel did not survive his death.

What makes Solomon such an anomaly amongst leaders is that he was his own best counsel. He combined Earthly wisdom with prophetic vision. All of the Abrahamic faiths recognize Solomon as a prophet

as well as a king. It is rare in history that the leader of a people, a group or nation were also the wisest, most intelligent, most knowledgeable or informed person in their society. Cultures over time have variously labeled this people as shaman, mage, kahuna, wise person, scholar, philosopher, scientist and thousands of more names. Experts, those holding expertise, are those who acquire/create, learn and share knowledge and wisdom. Under the right conditions, societies choose to benefit from the expertise. This does not mean that all expertise provides positive outcomes, but there are tendencies for better outcomes. This has become even more evident since the beginning of the 17th century through the 19th century, otherwise known as the Age of Enlightenment or the Age of Reason. In the 20th century, science became a dominant force in shaping society and civilization.

In parallel with the rise of expertise in all its forms, and especially through the rise of Intellectualism, there has almost always been pushback/backlash from interests in societies. This has been such a common phenomenon, that we have cautionary stories and terms for it throughout history. A story/legend that comes to us from ancient Greece mythology is the Legend of Cassandra. She was a princess of Ancient Troy in the time of the Trojan War, daughter of King Priam and Queen Hecuba. The god Apollo is said to have fallen for her and gifted her with true vision of the future (clairvoyance, precognition, prescience). She was able to convey these visions of the future clearly. When she spurned Apollo, he cursed her: all those who heard her considered her to be mad and her visions wrong.

Many of the Jewish prophets had their words and warnings rejected; the knowledge and foresight given to them by God rejected. In modern language, we have a term: Jeremiad. It is defined as a prolonged lamentation or complaint. Jeremiah was a great prophet whose words of repentance for the sins of his day fell on deaf ears though at least some recognized that he was speaking to them from God.

In the modern world, and in particular in the United States, we have simultaneously greatly benefited from the fruits of science while simultaneously developing a strong strain of anti-science, anti-intellectualism in our society/cultures. Our embrace of knowledge, reason, and the fruits of science and other intellectual discourse are critical to protection of the only home humanity knows and of its ability to protect and maintain itself as the abode of life including our own. Examples from our myths, legends and faiths show us what happens when the knowledge gifted to us by gods or God is rejected. Disregarding the knowledge and rejecting the prophets often led to downfall and destruction. Let us not repeat those errors in our modern world lest we suffer the same fate. ■

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