# Wildfire in Washington State

A Summary of the Proceedings of the 12th Annual Symposium
Held as part of the 2019 Annual Meeting of the
Washington State Academy of Sciences
September 12, 2019, Museum of Flight, Seattle, WA

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# About WSAS

## Who We Are

The Washington State Academy of Sciences (WSAS) is a not-for-profit organization of more than 300 elected members who are nationally recognized for their scientific and technical expertise. All members of the National Academies of Sciences, Engineering and Medicine who reside in Washington State are invited to join; others are elected in recognition of their scientific and technical contributions to our nation and their desire to contribute their expertise to inform issues in Washington State.

## Our Mission

WSAS provides expert scientific and engineering assessments to inform public policy making and works to increase the impact of research in Washington State.

## Our Value to Washington

WSAS mobilizes the expertise of our members, plus our network of partners, to provide independent, non-advocate scientific and engineering assessments of issues that impact the citizens, government and businesses of Washington State.

## Our Approach

We accomplish our mission by drawing on our statewide pool of distinguished members, state government officials, and other key stakeholders and experts to address critical issues facing Washington State. We organize and conduct multi-disciplinary roundtable discussions, workshops, and symposia to assess risks, identify technological opportunities, and define critical research gaps. Our use of peer review ensures the studies we conduct, programs and projects we evaluate, and reports we provide are scientifically and technically sound and unbiased resources for informing the development of Washington State policy.

Learn more about WSAS on our website: **www.washacad.org**

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# Preface

Washington's status as the Evergreen State is at risk. Large portions of our majestic forests are overcrowded, diseased, and at risk from wildfires. Local, state, and federal efforts to improve forest health are yielding progress, but the hotter and drier conditions expected in many places as the planet warms will increase stresses on our forestlands. The long-term future of our state's greatest natural asset cannot be taken for granted.

After an unprecedented string of wildfires in recent years, which burned millions of acres in our state and shrouded many Washington communities in smoke for days at a time, the Washington State Academy of Sciences decided to devote its 12th Annual Symposium to the topic of wildfires in Washington State. On September 12, 2019, many of the Academy's 300 members, along with a wide range of policy makers, foresters, firefighters, and other experts, gathered at the Museum of Flight in Seattle to explore such topics as wildfires across space and time, the effects of smoke on health, and the intersection between wildfire research and policy. It was an eye-opening, sometimes alarming, and yet optimistic and encouraging meeting.

The complexity and scope of the issues posed by wildfires in Washington State are daunting. Preparing for, responding to, and recovering from wildfires involve topics ranging from land use to emergency preparedness to climate change to health care. One of the greatest needs is for the creation of a coordinating entity that can connect these issues and provide policy guidance, particularly as climatic and forest conditions continue to change. The Washington State Academy of Sciences intends to continue monitoring this issue and providing advice and guidance wherever needed.

As chair of the Symposium, I want to thank the distinguished presenters (biographies in Appendix B) who shared with us their expertise and insights. I also want to thank Donna Gerardi Riordan, the executive director of the Academy; program operations manager Devon Emily Thorsell, who helped organize and run the meeting; and Steve Olson, who wrote the following summary of the meeting. Providing expert scientific and engineering assessments to inform state policy making is the principal goal of the Washington State Academy of Sciences. Few topics are as important to our state as the future of our forests.

Ron Mittelhammer
Regents Professor, Washington State University
Board Member, Washington State Academy of Sciences

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# 1. Wildland Fire Protection in Washington State

In 2018 Washington State had more than 1,800 wildfires, the most in the state's history. Of those fires, 40 percent were west of the Cascades Mountains. Parts of the state had the worst air quality in the world at times, and fires burned more than 400,000 acres — an area about the size of Thurston County, where Olympia is located.

"People often asked me, 'Is this the new normal?'" said Hilary Franz, Washington State Commissioner of Public Lands, in her keynote address at the 12th Annual Symposium of the Washington State Academy of Sciences. "Are the gray skies that we're used to seeing in January, February, and March — and that we're now seeing throughout the summer, but in a context of smoke rather than clouds — our new reality?" The goal of the Department of Natural Resources, which Franz administers, is to make sure that years like 2018 do not become routine, she said.

"People often asked me, 'Is this the new normal?"

-Hilary Franz

The resources the state has to fight fires are limited. The entire state has eight helicopters for firefighting, all dating back to the Vietnam War. "We are putting our pilots and firefighters in dangerous and arduous conditions with very old machines," said Franz. Furthermore, on any given day, the state could have dozens of fires breaking out. "It literally becomes whack-a-mole at times."

To counter these fires, the state has just 43 full-time state firefighters. It supplements these personnel with seasonal firefighters, people doing other jobs in government agencies, and firefighters from other local, state, and federal agencies. However, the changing nature of wildfires makes it harder to staff up at certain times of the year. For example, many seasonal firefighters are college students, but with the fire season starting earlier in the spring, many of seasonal workers are still in school and cannot help.

The Washington State Department of Natural Resources works on communication, coordination, and collaboration among the various groups responsible for firefighting. It also works to ensure that firefighters have the training and equipment necessary to do their jobs and be safe. To put fires out more quickly, the state has begun prepositioning fire equipment in locations where fires are more likely. But these steps will not be enough to meet the challenge in the years ahead, said Franz. With fires threatening every part of the state, no wildlands or communities are safe from wildfires.

## DETERIORATING FORESTLANDS

A major reason for the larger and more catastrophic fires that have occurred in recent years is the deteriorating state of Washington's forests. A hundred years ago the forests were much less dense, so individual trees did not have to compete with so many other trees for water and nutrients. Forests had clumps of trees and gaps devoid of trees, and stands of trees were stronger and healthier. "We have to get back to that, and part of that starts with education," said Franz.


FIGURE 1-1 Firefighters conducting burnout operation, Cougar Creek Fire, Okanogan-Wenatchee NF, WA, 2018. Source: U.S. Forest Service. Photo by Kari Greer.

Since forest managers began suppressing wildfires more than a century ago, the forests have become more crowded and overgrown, which has made them more susceptible to insect infestation, disease, and drought. Furthermore, when wildfires do occur, they are more intense and destructive. Returning to the spatial densities that existed before fire suppression requires removing dead, dying, and diseased trees, cutting down dead limbs, and bringing back prescribed fire, "which is one of the toughest issues we have," according to Franz. "Prescribed fire is an area where we have a long way to go, and we're going to need everybody's help, including the science community, the regulatory community, and the political community" to overcome regulatory and political hurdles.

Franz used the community of Roslyn in central Washington as an example of the threat. The community has recognized that it is at risk because of the condition of the surrounding forests and the lack of evacuation routes — so much so that Franz compared Roslyn to the community of Paradise, California, which was destroyed in a 2018 fire that killed 86 people and burned more than 18,000 structures. To lower its risk, residents have sought to create defensible spaces around the community and to make properties more resilient to wildfire. Neighbors are talking to neighbors to encourage change, creating a "a true social marketing campaign," said Franz. "It's not government telling them what to do, which usually goes only so far. It's neighbors saying, 'Hey, I just did this on my property, you should do it on yours.'"

## THE TEN-YEAR PLAN

To respond to the growing threat posed by wildfires, the state, in cooperation with local and federal agencies, has recently developed its first ten-year wildfire strategic plan.[1] The plan inventories all the resources available to fight fires and highlights obstacles to success. It describes the training being provided to responders and those living in fire-prone areas. With new funds from the state, the plan has led to the addition of new full-time firefighters. It provides clear direction to the legislature regarding the kinds of investments needed to avoid the catastrophic fires of recent years. "We call it the all-lands all-hands policy," Franz said.


FIGURE 1-2 The Washington National Guard continues to provide support to the people of North Central Washington who have been affected by the Carlton Complex Fire. Source: Washington National Guard. Photo by SFC Jason Kriess.

An essential complement to the plan is a 20-year strategic plan for forests in Eastern Washington that was released in 2016.[2] The plan calls for treating 1.25 million acres of forests in central and eastern Washington by 2037 to increase forest and watershed resilience. This land includes not only federal land but state, tribal, and private land, including land owned by individual landowners. "Just as fire and disease are agnostic to property lines, we are as well," Franz said. As an example of collaboration, she cited a Good Neighbor Authority signed with the U.S. Forest Service in 2017 to expedite the federal-state partnership.

In the first year of the forest health plan, 35,000 acres were treated, with an expansion to 50,000 acres in 2019 and further expansions to 70,000 acres per year slated for future years. The plan also seeks to educate the public about what a healthy forest looks like, why catastrophic fires are more common, and how people can help address the problem.

In addition, the plan looks to new uses of forests as one component of a solution. For example, cross-laminated timber, which can be manufactured from small-diameter trees harvested during thinning operations, is now being used to build high rises and new housing that is desperately needed in the Northwest. "This is the future of our built environment that is more sustainable and affordable," said Franz. The first cross-laminated timber manufacturing plant in Washington State created more than a hundred jobs in economically depressed rural communities near Colville, with another plant about to come online in Vancouver and discussions under way about plants elsewhere. Such approaches produce wins on multiple fronts, said Franz. They address environmental, economic, and social problems all at the same time.

Over the past ten years, the state has spent an average of about $150 million per year fighting fires, Franz noted. If the state invested its money up front in forest health, it would need less funds to fight fires by preventing crises before they occur. Investing money in forest health would also reduce the impacts of wildfires on health, the economy, and individual lives.

## CONTINUING CHALLENGES

Western Washington is also seeing worsening forest health, in part because of hotter and dryer conditions,

1 Washington State Department of Natural Resources. 2019. Washington State Wildland Fire Protection 10-Year Strategic Plan: Solutions for a Prepared, Safe, Resilient Washington. Available at https://www.dnr.wa.gov/publications/rp_wildfire_strategic_plan.pdf.

2 Washington State Department of Natural Resources. 2016. 20-Year Forest Health Strategic Plan: Eastern Washington. Available at https://www.dnr.wa.gov/publications/rp_forest_health_20_year_strategic_plan.pdf.

and very large fires have historically affected the western side of the state. When such fires occur again, they could have catastrophic effects on built communities that normally think of themselves as safe from forest fires, which calls for a forest health plan for the west side, Franz said.

The bottom line is that wildfires affect everyone in Washington State, whether directly through the burning of forests and communities or indirectly through the health effects of smoke. People need to know what they can do to create defensible spaces around structures, contribute to fire-resilient communities, and prevent fires from starting.

The year 2019 was somewhat less troublesome than earlier years, Franz noted. As of the September 12 meeting, the state had experienced 1,100 fires, 35 percent of which were west of the Cascades. Firefighters had also been more successful in putting out fires in 2019, partly because of better partnerships but also because the summer of 2019 was wetter and cooler than previous years in much of the state. But the threat will persist because of the underlying problems of underinvestment in wildfire protection and prevention.

FIGURE 1-3 Cougar Creek Fire, Okanogan-Wenatchee NF, WA, 2018. Source: U.S. Forest Service. Photo by Kari Greer.

Washington needs more firefighters, more forest health experts, and more people who specialize in natural resources, said Franz. To address these needs, the Department of Natural Resources is seeking to get the next generation engaged and invested in this work. For example, it is partnering with Washington State University and with local school districts to heighten student interest in working with the state's natural resources.

Finally, Franz observed that the Department of Natural Resources is responsible for more than wildfires. The residents of Washington State are also at risk from the state's five live volcanoes, earthquakes, tsunamis, and landslides. "There's never a boring day at the office. We're literally on the front lines of a rapidly changing environment. . . watching and trying to be responsive to the needs of our communities."

# 2. Wildfires Across Space and Time

Wildfires and their effects extend across both space and time. On a very long time scale, Native Americans have been living with wildfires for more than 15,000 years and 500 generations. On the opposite end of that time scale, firefighting in the Pacific Northwest has changed significantly over the past 40 years as large and intensely burning wildfires have become more common and suppression costs have increased. Two speakers at the meeting explored these large-scale issues, with a focus on both traditional uses of wildfire and the application of western science.

## TRIBAL LAND STEWARDSHIP AND LIVING WITH WILDFIRE

The forests that European explorers and settlers saw when occupying the Americas were the product of natural fires and the tribal presence in the land, said Tony Harwood, a retired professional fire manager with over 35 years of experience with the Confederated Salish and Kootenai tribes. Native people, in particular, had a great respect for fire. They used fire as part of their food gathering, their medicine, their hunting and fishing, and their subsistence lifestyle. For Native Americans, fire was part of what Harwood called "the circle of life, shoulder to shoulder with the soil, the wind, the water, and life forms."

Over the past 400 years of European occupation, fire suppression has increased, though traditional tribal uses continued through that period. At the same time, settlers adopted traditional fire practices for their own purposes, such as clearing land. In his presentation at the meeting, Harwood drew from his work in the Flathead Indian Reservation north of Missoula, Montana, which is the homeland of the Confederated Salish and Kootenai tribes. Established in the 1855 Hellgate treaty, the reservation covers about 1.3 million acres, of which about 900,000 acres are tribal. It is characterized by high mountains and broad open valleys used for agriculture. The reservation has an abundance of wildlife, including big game and fisheries. Its human population is about 15,000, with many people in the wildland-urban interface and scattered small communities. Part of the reservation consists of commercial timber lands that have always been of great economic value for the tribes.

The tribes took over the management of the land from the Bureau of Indian Affairs in the 1990s. At that point, the tribes decided not to manage the land as a tree farm, said Harwood, but to develop a cultural forest through an ecosystem management plan. The tribes studied the historical condition of the land before pre-European settlement, compared that condition with existing conditions, and decided what was sustainable and desirable in developing management strategies. Before the arrival of settlers, the forest was much more open and marked by fire scars on the landscape, resulting in a patch-and-edge structure that has been largely lost due to nearly a century of fire-exclusion practices. With the onset of fire suppression, the growth of too many small trees and densification of stands has resulted in unhealthy landscapes. In developing the ecosystem management plan, planners talked with elders who said that they could no longer ride historical tribal trails through the forests to engage in traditional activities. Planners went on field trips with elders and recorded thousands of hours of interviews. In addition to gathering this traditional knowledge, planners used the processes of western science to model the spread of fire, map fire scars, and otherwise learn more about their forests.

> Fire is part of "the circle of life, shoulder to shoulder with the soil, the wind, the water, and life forms."
> -Tony Harwood

The resulting ecosystem management plan has protected tribal identity, provided opportunities for forest restoration, and supported traditional practices, Harwood said. The tribes have used prescribed burns for multiple purposes, including site preparation, wildfire protection, and wildlife benefits. They have sought to adopt what Harwood called Native light burning, even as they have continued to fight large and destructive fires.

The tribes continue to face challenges, including the need to fight fires at the wildland-urban interface. Meanwhile, climate change has extended the fire season, leading the tribes to develop a climate change strategic plan.[3] As part of that work, the tribes have begun a collaborative research project with the local tribal community college, Montana State University,

3 Confederated Salish and Kootenai Tribes of the Flathead Reservation. 2013. Climate Change Strategic Plan. Available at http://www.csktribes.org/CSKTClimatePlan.pdf.

and the University of Washington, part of which involves a sediment pond analysis that has revealed recurrent climate variability over periods of hundreds of years. The tribes also work closely with other groups on partnerships and cross-boundary collaborations, including the state government, nonprofit organizations, and federal agencies. For example, in a recent partnership with the U.S. Forest Service, the tribes treated more than 5,000 acres of forests that crossed a boundary into commercial timber.

## A FIREFIGHTER'S VIEW OF FIRE ON THE LANDSCAPE

John Giller, director of fire, fuels, and aviation management for the Pacific Northwest and Alaska region of the U.S. Forest Service and Bureau of Land Management, worked on many of the same issues as Harwood during his 27 years on incident management teams, but from a somewhat different perspective.

Giller began by citing the first two principles laid out in the 1995 report Federal Wildland Fire Management: Policy and Program Review, which established the basic policy that has guided the management of wildfires for the past quarter century:[4]

1. Firefighter and public safety is the first priority in every fire management activity.
2. The role of wildland fire as an essential ecological process and natural change agent will be incorporated into the planning process.

While the first priority may be obvious, the second often surprises people, Giller said. "We are not supposed to just put out fires. That's not our mandate." Rather, a fire can be concurrently managed for one or more objectives, and those objectives can change depending on fuels, weather, topography; varying social understanding and tolerance; and the involvement of other governmental jurisdictions with different missions and objectives.

Fires are as natural as thunderstorms, Giller observed. As a result, the suppression of fires has changed the landscape. If fires were no longer suppressed, they would again occur naturally. The complication, said Giller, is that "people are in the way."

4 U.S. Department of the Interior and U.S. Department of Agriculture. 1995. Federal Wildland Fire Management: Policy and Program Review. Available at https://www.forestsandrangelands.gov/documents/strategy/foundational/1995_fed_wildland_fire_policy_program_report.pdf.

The number of acres burned and the amount spent by the Forest Service fighting fires vary from year to year, but both have increased substantially over time. In 2018, 8.8 million acres burned and federal agencies spent $3.1 billion on fire suppression. Though an average of 5,000 structures are destroyed by wildfires each year, 20,000 were destroyed in 2018.

FIGURE 2-1 Tanker drop on Washington wildfire. A single-engine tanker makes a water drop on a wildfire in central Washington as firefighters from numerous agencies watch and fight the blaze, Aug. 9, 2018. Source: Bureau of Land Management. Photo by Nick Pieper, BLM.

During August of 2018, about 30,000 firefighters were in the field nationwide, about 10,000 of whom were from the Northwest. This represents the maximum workforce that can be deployed nationally to fight wildfires, said Giller. "We were tapped out." Firefighters are able to put out almost all the fires that start. But the ones that expand rapidly can be devastating. "When I started in 1981, a 10,000-acre fire was a humongous fire. Nowadays, 100,000 acres is not that unusual."

The U.S. Forest Service has the largest fire department in the world. The members of fire crews make 15 to 20 dollars an hour, work 16 hours a day, and typically are young, fit, and love to work outdoors. On average, about 17 wildland firefighters die in the line of duty per year, which makes the job one of the most dangerous in the United States.

"When I started in 1981, a 10,000-acre fire was a humongous fire. Nowadays, 100,000 acres is not that unusual."

-John Giller

Firefighters work to put out fires wherever they start. But when the fire season gets intense, they tend to be in and around private land structures that are in the wildland-urban interface, even if that means that not enough firefighters are trying to put out fires elsewhere. "It's a tradeoff," Giller said. "It's a decision that we make."

Added to the expense of personnel is the expense of the equipment needed to fight wildfires. A Boeing 747 can drop 20,000 gallons of fire retardant at a time. Helicopters, planes, and firetrucks are expensive but essential. Yet even with expenditures of this size, "we're not winning this battle," said Giller.

## THE NEED FOR TACTICAL FIREFIGHTING

Giller briefly surveyed some of the fires that have made headlines in recent years. The Gatlinburg, Tennessee, Chimney Tops 2 fire in November 2016 caused 14 fatalities and destroyed 1,600 structures. The October 2017 Tubbs fire in Santa Rosa, California, destroyed 5,000 structures and caused 22 fatalities. The Thomas fire in Ventura, California, later that year caused 23 fatalities, including one firefighter. "That fire was interesting because it burned from December into January. That's when we stopped using the terminology of fire season. It's now a fire year." The Carr fire in Redding, California, in July 2018 destroyed 1,500 structures and killed three firefighters and five civilians, which was followed by the tragic Camp fire that burned Paradise later that year. As was the case in this last fire, Giller pointed out, having a good evacuation route can be more important than how well a home is protected. "Can you get everybody out of your community before things get really bad?"

The wildland-urban interface is shaped by local planning. Local communities or the state determine where and how people are allowed to build. "That's the crux of the problem into the future," said Giller. "Do we protect somebody's home just because they decided to build their house in a very vulnerable place? I don't know the answer."

Firefighters engage in tactical firefighting. They look for a barrier like a road, a ridge line, or an old fire scar that will hold a fire and keep it from spreading. Such barriers also can be created in a landscape before a fire occurs. Prescribed burning, removing trees and other vegetation from next to roadways, and establishing cleared areas around vulnerable communities can all help firefighters do their jobs. "We don't want fires in and around homes, Giller said. "Those are the places where we're going to be really critical about fire prevention."

Giller is an operations chief who plans how to put a fire out. "But when I'm developing that plan, in the back of my mind is, 'Why didn't these folks prepare for this fire before it ever happened?'" Firefighters know in advance where fires are most likely to occur, and it usually is where fires have occurred before. "Isn't there something that we could have done before that fire ever got there? Rather than me coming in there with a lot of logging equipment and hundreds of firefighters."

The United States treats about 4 million of its approximately 750 million acres of forestland each year with prescribed burns. Furthermore, even when the U.S. Forest Service is able to do a prescribed burn, it typically does not have enough money to go back and do repeat treatments. But "that's how we are going to maintain the landscapes is to keep doing those treatments," Giller observed. "If you had a natural fire return interval of 10 years, then you probably should look at trying to get fire in there at least every 20 years or so." In other words, "we're not going to burn our way out of this problem," said Giller. "We need to manage wildfires."

The vision of the National Cohesive Wildland Fire Management Strategy is to safely and effectively extinguish fire when needed, use fire where allowable, and manage natural resources.[5] Such a vision needs to be supported by science, said Giller. That way, the nation can learn to live with wildland fire, develop resilient landscapes and fire-adapted communities, and mount strong wildfire responses.

FIGURE 2-2 Firefighters conducting burnout operation, Cougar Creek Fire, Okanogan-Wenatchee NF, WA, 2018. Source: U.S. Forest Service. Photo by Kari Greer.

5 U.S. Department of the Interior and U.S. Department of Agriculture. 2014. The National Strategy: The Final Phase of the Development of the National Cohesive Wildland Fire Management Strategy. Available at https://www.forestsandrangelands.gov/documents/strategy/strategy/CSPhaseIIINationalStrategyApr2014.pdf.

As an example of resilient landscapes and science-based management, Giller drew attention to the intensity of wildfires. In the Eagle Creek fire of 2017 in the Columbia River Gorge, 23 percent of the land burned at high severity, 30 percent burned at moderate severity, and 54 percent was unburned or burned at low severity. In the Chetco Bar fire that same year near Brookings, Oregon, more than 90 percent of the land burned at moderate or low intensity or did not burn. Such fires do "more good than harm," said Giller. For example, when another fire occurred the next year near Brookings, the only reason is did not reach the town is because the Chetco Bar fire was in the way.

Fire intensity is a consideration no matter where a fire occurs. Giller pointed out, for example, that major portions of Washington State's wilderness areas are at risk because fires have not been allowed to follow their natural course. As described earlier, the wilderness has historically had large openings caused by wildfires. Many fires put out in wildernesses today "probably are the ones we should be letting burn. They're the ones that are burning at the lower intensity on days when it's easy for a firefighters to work." Firefighters could manage rather than extinguish such fires and benefit from their good effects on the landscape.

The U.S. Forest Service does not have enough money to treat millions of acres across the landscape, but mapping has shown the most vulnerable areas where treatments should be focused. For example, treating the vegetation next to roads provides timber as well as a place for firefighters to work as a fire is approaching.

# 3. Wildfires and Health

Wildfires can have a wide variety of effects on human health and well-being, from direct physical injury and death to the consequences of smoke inhalation to the psychological disruption of evacuation from a nearby fire. Two speakers at the meeting focused on two specific aspects of these health effects: wildfire smoke impacts, and community and individual perceptions, interpretations, and responses to the risks associated with wildfire smoke.

## WILDFIRE SMOKE AND HUMAN HEALTH

Wildfires expose people in surrounding and sometimes distant regions to smoke. Sometimes the exposures are relatively brief — just a day or two. Sometimes they are much more extended. Sverre Vedal, professor emeritus of Environmental and Occupational Health Sciences at the University of Washington and a pulmonologist at University of Washington Medicine, began the session on wildfires and health by reviewing some of the recent results on the health impacts of exposure to wildfire smoke.

FIGURE 3-1 The Carlton Complex wildfire burning in north-central Washington state, USA. Source: Washington National Guard. Photo by Jason Kriess.

Many parts of the West have experienced days of intensive exposure to smoke. In both 2017 and 2018, for example, Seattle had periods with very high concentrations of particulate matter lasting from several days to, with occasional breaks, more than a week. During these periods, Vedal noted an increase in symptoms of respiratory irritation caused by smoke in his patients, his colleagues, and even himself, in particular after a long bike ride. This is not surprising, given that many components in wood smoke are toxic and can cause not only irritation but more serious effects. However, people have a wide range of sensitivity to inhaled pollutants, he noted, which means that no one person's experiences are necessarily representative.

Six reviews of the health effects of smoke have almost all found strong evidence of respiratory morbidity.[6] However, the reviews are more divided in their results on all-cause mortality, with the evidence ranging from suggestive to moderate to strong. For cardiovascular effects, the reviews find the evidence to be suggestive rather than moderate or strong. This result is "paradoxical," said Vedal, in that research on exposure to particulate matter from other forms of air pollution provide stronger evidence for cardiovascular effects than for respiratory effects. "But that's not what we're seeing here, at least with the current state of evidence for wildfires."

Individual studies have produced similar results. For example, a study of smoke exposure from wildfires in Canada showed an increase in physician visits for respiratory symptoms but not for cardiovascular or mental health conditions.[7]

6 Luke P. Naeher, Michael Brauer, Michael Lipsett, Judith T. Zellkoff, Christopher D. Simpson, Jane Q. Koenig, and Kirk R. Smith. 2007. Woodsmoke health effects: a review. Inhalation Toxicology 19(1)67-106.
Sarah Elise Finlay, Andy J. Moffat, Rob Gazzard, David Baker, and Virginia Murray. 2012. Health impacts of wildfires. PLoS Currents 4:e4f959951cce2c.
Hassani Youssouf, Catherine Liousse, Laurent Roblou, Eric-Michel Assamoi, Raimo O. Salonen, Cara Maesano, Soutrik Banerjee, and Isabella Annesi-Maesano. 2014. Non-accidental health impacts of wildfire smoke. International Journal of Environmental Research and Public Health 11(11):11772-11804.
Jia C. Liu, Gavin Pereira, Sarah A. Uhl, Mercedes A. Bravo, and Michelle L. Bell. 2015. A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. Environmental Research 136:120-132.
Colleen E. Reid, Michael Brauer, Fay H. Johnston, Michael Jerrett, John R. Balmes, and Catherine T. Elliott. 2016. Critical review of health impacts of wildfire smoke Exposure. Environmental Health Perspectives 124(9):1334-1343.
Olorunfemi Adetona, Timothy E. Reinhardt, Joe Domitrovich, George Broyles, Anna M. Adetona, Michael T. Kleinman, Roger D. Ottmar & Luke P. Naehe. 2016. Review of the health effects of wildland fire smoke on wildland firefighters and the public. Inhalation Toxicology 28(3):95-139.
7 David Moore, Ray Copes, Robert Fisk, Ruth Joy, Keith Chan, and Michael Brauer. 2006. Population health effects of air quality changes due to forest fires in British Columbia in 2003: estimates from physician-visit billing data. Canadian Journal of Public Health

The conventional wisdom is that the very young, the very old, and those with underlying heart or lung disease are most susceptible to health effects from wildfire smoke. But this wisdom may not be completely accurate, Vedal noted. For example, a study of smoke exposures from wildfires in Canada showed greater respiratory effects on young and middle-aged adults than on children or older adults.[8] This study, too, found little evidence for increases in cardiovascular problems. Similarly, a study in Seattle of respiratory hospitalizations from 2007 to 2017 found respiratory but not cardiovascular effects and not much effect among older patients.[9] Perhaps young and middle-aged adults receive more exposure than children or older adults, Vedal speculated, but the reason for these results remains an open question. Again, this result contrasts with other air pollution research, which shows a distinct increase in risk for the elderly.

Overall, Vedal summarized, the evidence for respiratory clinical outcomes from smoke exposure is strong, while the evidence for all-cause mortality and airway inflammation is moderate. Other evidence related to cardiovascular disease and birth outcomes is suggestive, and little or no evidence points to effects on lung function in healthy individuals or to systemic inflammation.

> "The evidence for respiratory clinical outcomes from smoke exposure is strong."
>
> -Sverre Vedal

Vedal briefly discussed the use of masks and indoor air cleaners to prevent or manage health effects from smoke exposures. Masks are effective sometimes, he said, though they have to fit and are generally not the proper size for children. But tests show that they block 95 percent of particles 3 microns in diameter or larger and that they reduce the levels of symptoms among people who have extended exposures to highly polluted air.[10] Indoor air cleaners also can significantly reduce indoor air pollution, and use of such air cleaners can reduce respiratory symptoms and inflammation from woodsmoke.[11]

Based on this overview of smoke's health effects, Vedal had several recommendations for policy makers. First, more needs to be known about population exposures, he said, though atmospheric models are beginning to produce useful exposure estimates from wildfires. Different levels of susceptibility also need to be studied, as do the different forms of interventions. The long-term health impacts of repeated exposures, including the possibility of cancers or neurological effects like Parkinson's disease or Alzheimer's disease, are still not known, though some evidence is suggestive. A better health surveillance infrastructure could provide much more data, Vedal said. Today, health care systems in other countries, such as Canada, are much better at providing such data, but better systems could be built in the United States — for example, through enhanced surveillance of schoolchildren.

## PERCEPTIONS OF RISK AND RISK REDUCTION ACTIONS

Populations are differentially exposed depending of the characteristics of their wildfire experience, observed Pat Butterfield, professor at the Elson S. Floyd College of Medicine at Washington State University. To address this heterogeneity, Butterfield presented a socio-ecological model with different sub-populations that are affected proximally or distally by wildfire. Across

97(2):105-108.

8 Sarah B. Henderson, Michael Brauer, Ying Macnab, and Susan M. Kennedy. 2011. Three measures of forest fire smoke exposure and their associations with respiratory and cardiovascular health outcomes in a population-based cohort. Environmental Health Perspectives 119(9):1266-1271.

9 Lesly Deloya Franco, Ernesto Alvarado (advisor), Cliff Mass (committee member), Brian Potter (committee member) and Sverre Vedal (committee member). 2018. The Association Between Wildfire Emitted PM2.5 and Hospital Admissions in the Greater Seattle Area. MS thesis, University of Washington School of Environmental and Forest Sciences.

10 Jeremy Langrish, Nicholas L. Mills, Julian Chan, Daan L. A. C. Leseman, Robert John Altken, Paul H. B. Fokkens, Flemming R. Cassee, Flemming R. Cassee, Jing Li, Ken Donaldson, David E. Newby, and Lixin Jiang. 2009. Beneficial cardiovascular effects of reducing exposure to particulate air pollution with a simple facemask. Particle and Fibre Toxicology 6(1):8.
Jeremy Langrish, Socrates Li, Shengfeng Wang, Matthew M. Y. Lee, Gareth D. Barnes, Mark R. Miller, Flemming R. Cassee, Nicholas A. Boon, Ken Donaldson, Jing Li, Liming Li, Nicholas L. Mills, David E. Newby, and Lixin Jiang. 2012. Reducing personal exposure to particulate air pollution improves cardiovascular health in patients with coronary heart disease. Environmental Health Perspective 120(3):367-372.

11 Prabjit Barn, Timothy Larson, Melanie Noullett, Susan Kennedy, Ray Copes, and Michael Brauer. 2008. Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. Journal of Exposure Science and Environmental Epidemiology 18(5):503-511.
Ryan W. Allen, Chris Carlsten, Barbara Karlen, Sara Leckie, Stephan van Eeden, Sverre Vedal, Imelda Wong, and Michael Brauer. 2011. An air filter intervention study of endothelial function among healthy adults in a woodsmoke-impacted community. American Journal of Respiratory and Critical Care Medicine 183:1222-1230.

these categories, social and behavioral responses vary dramatically. Some families have lost everything, while others have had their lives temporarily interrupted. Other families may be distally affected by wildfire smoke and respond exclusively by seeking information or social support online. Scientific guidance on responding to the needs of these different groups is frequently found in different subtopics in the scientific literature, Butterfield noted. For example, studies of wildfire refugees tend to appear in research on disaster mitigation and response, while studies of interrupted lives usually appear in the literature on adverse childhood experiences.

As an example of one area of research, Butterfield described a study of the ecosystem and health impacts of a record wildfire season in the Northwest Territories of Canada.[12] Based on interviews with 30 respondents who experienced the wildfires, the researchers found feelings of isolation, fear, stress, and uncertainty. Activities involving their livelihoods and the land like hunting, fishing, or simply being outside were disrupted. But the researchers also found narratives of resilience and adaptation. “There’s complexity here,” said Butterfield.

An overarching observation is the need for better communication and coordination of messages at the territorial and local levels. In particular, the authors of this study concluded that communities need to take steps to address community-based education, communication, and adaptation initiatives that are inclusive of local knowledge, values, and context. Even if messages are based on broad principles, they need to be “locally flavored,” Butterfield said.

FIGURE 3-2 A wildfire in 2015 destroyed 29 homes as well as fruit warehouses and a recycling center. Source: Wikimedia Commons. Photo by Thayne Tuason.

12 Warren Dodd, Patrick Scott, Courtney Howard, Craig Scott, Caren Rose, Ashlee Cunsolo, and James Orbinski. 2018. Lived experience of a record wildfire season in the Northwest Territories, Canada. Canadian Journal of Public Health 109(3):327-337.

Many kinds of losses can have health risks, Butterfield pointed out. Losses of friends, homes, pets or livestock, meaningful items, jobs, social networks, communities, and an imagined life course all can have pervasive impacts on subsequent physical and mental health outcomes. Refugees from wildfires may experience all these losses, and specific populations, such as school-aged children, may experience especially acute effects.

The effects of wildfires also can manifest in ways that may not be immediately apparent to health authorities. After the 2016 Fort McMurray wildfire in Canada, researchers sampled 103 caregivers of infants who were evacuated during the fire. Though 64 percent were exclusively breastfeeding before the fire, only 36 percent were doing so afterwards. “That not always what you think about in terms of public health impacts,” Butterfield said.

Butterfield also discussed research she has done on community-level responses to wildfire smoke as reflected in postings on social media.[13] After consulting with their clinician colleagues, Butterfield and her associated conducted searches in five categories:

- Air quality
- Respiratory symptoms
- Risk perception
- Self-efficacy/behavioral responses
- Quality of life and health care utilization

For each category, they developed lists of words that people might use in social media, eventually compiling 170 words altogether. Using these lists, they were able to track interest in search terms and compare that with concentrations of particulate matter. For example, in the category of air quality, searches turned up such tweets as “We peaked out this morning at more than 400. Scale tops out at 500, although I’ve read that some parts of China, etc., occasionally top that level.” In the categories of risk perception and self-efficacy, they found “Sick of the fires and looking to get out of town? Plan a road trip, and don’t forget to bring the #existential dread.”

One important conclusion from this study, said Butterfield, is that narrowly focused searches of social media — on issues of air quality, for example — can miss “how sad people are.” Also, broad-based searches can reveal the functional challenges that people face when

13 Abigail DeNike, Julie Postma, Marissa Grubbs, Yoni Rodriguez, Von Walden, and Patricia Butterfield. 2018. A conceptual approach to identifying search terms addressing public health responses to wildfire related air pollution. Journal of Medical Internet Research (preprint).

they are told to stay inside, such as walking their dogs or taking their children outside to play.

> Focused searches of social media can miss "how sad people are."
> -Pat Butterfield

A 2018 symposium in Washington State on risk communication about wildfire smoke identified research needs in five key areas:[14]

- Exposure research
- Health risk research
- Behavior change and intervention research
- Legal and policy research
- Risk communication research

In particular, Butterfield discussed two opportunities in the final category:

- Advancing real-time population-level communication between health authorities and the communities they serve
- Advancing an understanding of how to develop risk communication messages in an ideologically polarized social milieu

There is evidence that people will take action, said Butterfield, if risk messages are clear, direct, socially relevant, and actionable. In the California Station fire of 2009, for example, 88 percent of respondents took at least one action — mostly commonly, by staying inside.[15] These kinds of findings reveal opportunities for expanded research in the area of real-time local risk communication.

Butterfield also discussed the challenge of risk communication in politically charged environments. For example, when the President suggested, after visiting locations of wildfires in California, that forest fires are less severe in Europe because the people there rake the forests, this message inevitably was discussed and parodied on social media. "We need to recognize the complexity of today's social media environment and formulate clear and evidence-based in that context," she observed. Trust is gained when information addresses the felt needs of the public and focuses on practical answers that allow people to protect themselves.

Another consideration is that narratives addressing wildfires are often linked to those addressing climate change, which raises the issue of how to develop and disseminate maximally effective risk communication messages on charged ideological topics. "Risk communication science is occurring in real time in a polarized political environment," Butterfield said. "We need to situate our messages thoughtfully while acknowledging the realities of that dynamic."

14 Nicole A. Errett, Heidi A. Roop, Claire Pendergrast, C. Bradley Kramer, Annie Doubleday, Kim Anh Tran, and Tania M. Busch Isaksen. 2019. Building a practiced-based research agenda for wildfire smoke and health: a report of the 2018 Washington Wildfire Smoke Risk Communication Stakeholder Synthesis Symposium. International Journal of Environmental Research and Public Health 16(13):2398.

15 David E. Sugerman, Jane M. Keir, Deborah L. Dee, Harvey Lipman, Stephen H. Waterman, Michele Ginsberg, and Daniel Fishbein. 2012. Emergency health risk communication during the 2007 San Diego wildfires: comprehension, compliance, and recall. Journal of Health Communication 17(6):698-712.

# 4. Preparing for Wildfires

A wide variety of research can help government planners, communities, and individuals prepare for wildfires. In their presentations at the meeting, three speakers demonstrated this variety in their descriptions of three very different kinds of research. One looked at the collection and analysis of local social and wildfire risk assessment data to help create fire-adapted communities. Another described a decision support model that incorporates the interplay among wildfire intensity, snowpack, streamflow, temperature, and biomass production for energy across treatment scenarios. The third examined computer models of fire and smoke behavior that can be used to design optimal prescribed fire procedures and fuel treatments.

## A SCIENCE-BASED APPROACH TO CREATING FIRE-ADAPTED COMMUNITIES

Patty Champ, an economist with the U.S. Forest Service's Rocky Mountain Research Station, is part of an organization known as Wildfire Research, or WiRē (pronounced "wirey"), that does research on communities aimed at helping those communities prepare for fires. Creating fire-adapted communities generally means making homes more ignition resistant (for example, by creating defensible spaces around structures), reducing fuels, performing prescribed burns, and learning about risks in a fire-prone landscape. It also means acknowledging the fact that "fires don't respect boundaries," Champ said. "If we're going to get in front of a fire, we need to do that across jurisdictions."

The WiRē team unites research and practice, said Champ. It collects and uses community-specific data to tailor programs that support local solutions, allowing communities to get ahead of fire problems. It is an interagency team among the U.S. Forest Service, the Bureau of Land Management, the U.S. Geological Survey, the University of Colorado, and the West Region Wildfire Council, which is a Colorado-based nonprofit organization. Its goal is to co-produce science with users. It jointly develops research questions with communities, advances knowledge through research, communicates with audiences in a variety of ways, and then takes action. "That's really important to us — that practitioners can use the science on the ground."

Champ illustrated this process with an example involving wildfire risk mitigation in Washington State. A standard approach to wildfire risk mitigation is for a local agency like a fire department or fire council to do a rapid risk assessment of properties. These assessments rate every parcel on a dozen or so attributes such as the density of vegetation, how close it is to a home, and the flammability of the structure. WiRē has combined these assessments with social surveys sent to every homeowner in a community. These surveys gather a quite different set of information, including what a homeowner thinks about the fire risk on their property and how a homeowner engages with neighbors. "That allows us to understand why a parcel looks the way it does."

One of WiRē's partners is Chelan County Fire District 1 in north-central Washington. The partnership is part of a larger project called Co-Management of Fire Risk Transmission (CoMFRT), which seeks to understand key social dimensions related to cross-boundary wildfires, particularly where fire might move from national forestlands into communities. CoMFRT seeks to look at this issue across several social dimensions and scales, including the governance structure, the networks in place in a community, and the perspectives of residents.

FIGURE 4-1 The Mt. Dana fire, September 2019. Source: National Parks Service.

According to the Washington State Wildland Fire Protection 10-Year Strategic Plan, Chelan County has the highest levels of risk to highly valued resources and assets of any Washington county. In the Squilchuck Drainage in Chelan County a few miles south of Wenatchee, WiRē paired the risk assessments of about 700 parcels that have structures on them with social surveys, with the data being collected by the Chelan County Fire District. The results showed that people often rate their properties differently than wildfire risk professionals do. For example, homeowners tend to rate their risks from wildfires lower than do professionals, though this is not always true, Champ pointed out. "The homeowner is not necessarily wrong," she said, but "a goal of this kind of research is to get people on the same page" — for example, to motivate homeowners to thin vegetation that poses a risk to their homes.

The area studied by WiRē and the fire district consisted of four communities: a high-resource, high-amenity community, two rural areas, and a suburban neighborhood. The high-amenity, high-resource community is both a fire-wise community and at high risk because of surrounding Forest Service land. The rural areas have working landscapes like orchards and people who have maintained a rural lifestyle in the area for many years. The homes in the suburban neighborhood are fairly close together, "so that's a place where, if there's a fire, it's going to go from home to home."

FIGURE 4-2 Cox Valley Fire, Olympic NP, August 2016. Source: National Parks Service.

The surveys showed that most people — about 85 percent — in all the areas were aware of the wildfire risk when they purchased or rented their current residences. The surveys also showed that most had received wildfire risk information from Chelan County Fire Protection District 1, though the number was higher in the high-resource community (95 percent) than in the two rural areas (74 percent and 78 percent) and in the suburban neighborhood (72 percent). Similarly, the high-resource community found the information to be very or extremely useful at a higher rate (72 percent) than the two rural areas (52 percent and 36 percent) and the suburban neighborhood (38 percent).

When asked if they thought that there is a greater than 50 percent chance of a fire destroying their home if it reaches their property, 37 percent of the high-resource respondents said yes, as did 35 percent of the suburban neighborhood. But fewer people in the rural neighborhoods — just 20 percent and 22 percent — thought so. Partly this may be because the properties are larger in the rural areas, which means a fire could be farther from a structure. It could also be because more people in the rural areas than the high-resource area thought it was very or extremely likely that the fire department would save their home if a wildfire reached their property — 55 percent and 51 percent to 38 percent — and all the areas thought, by margins of 66 percent to 88 percent, that local firefighters have sufficient resources to protect threatened homes, even though the fire department views its resources as constrained in fighting wildfires.

The surveys showed that 85 percent of respondents in the high-resource area had talked about wildfire with a neighbor, compared with 61 percent and 59 percent in the rural areas and 45 percent in the suburban neighborhood. This is an important finding, said Champ, because talking with neighbors about wildfires has been associated with taking action. When asked about the most significant barriers to reducing wildfires, the main reason cited in the high-resource community was the expense, the main reason cited in the rural areas was the physical difficulty, and the main reason cited in the suburban neighborhood was a lack of specific information. This finding suggests that cost sharing may be more appropriate in some areas while provision of personnel and information may be more appropriate in others.

An overall finding from the surveys is that "communities are diverse," said Champ. "If you did this survey for the whole State of Washington or the whole county or the whole drainage and you didn't break it up into communities, you would miss the story and the actionable pieces." She also pointed out that fire protection districts are an effective way to educate people, and the more people understand the risks, the more fire protection districts will be able to achieve. In that respect, data like the information collected in the survey can help tell stories, Champ observed, which in turn can help change behavior.

She concluded by pointing out several areas that need additional research. One is to work on creative ways to encourage homeowners to mitigate risk, which often depends on having specific information. "Many people know about their home ignition zones, but they don't know the specifics of those branches over your deck or those leaves right there." One option, for example, might be to inform homeowners about their parcel risk assessment rating, perhaps even on a public-facing website. Such a website could also offer a link to make an appointment with a wildfire specialist. Another research need is for deeper thinking about wildfire as an integrated part of other locally relevant issues, including water, wildlife, and lifestyle. Finally, Champ mentioned the need for cross-boundary collaboration, shared stewardship, and local support.

"Science *can* empower the voice of practitioners."

-Patty Champ

Champ quoted the director of the Center for Collaborative Conservation at Colorado State University, Robin Reid, saying "Science *can* empower the voice of practitioners." Added Champ, "I want my science to empower practitioners. I want to produce science for people who are on the ground to make better decisions, to have more effective programs, and to encourage homeowners to mitigate risk."

## FIRE AND SMOKE MODELS IN THE WILDLAND-URBAN INTERFACE

William (Ruddy) Mell, combustion engineer with the U.S. Forest Service, spoke on the need for advancement in fire and smoke modeling and the potential for new approaches in the field. In particular, wildland-urban interface (WUI) fires that originate in wildland vegetation and spread into the built environment can cause respiratory problems, hamper people's evacuation abilities, and damage and destroy infrastructure, including homes, power lines, and cell towers, Mell said. However, modeling these fires is difficult for several reasons. First, the WUI problem does not fall under a single scientific discipline. Instead, "it spans a large range of physical processes that occur over a large range of scales," Mell said. These scales extend from firebrands that cause ignitions to the flame front that generates smoke to the interactions between fires and structures to long-range smoke transport. No one model can incorporate all these elements, Mell explained.

Issues involving the wildland-urban interface span "a large range of physical processes that occur over a large range of scales."

-Ruddy Mell

Research teams and models must therefore focus on different aspects of the WUI fire problem. For instance, smoke models on the scale of tens of kilometers tend not to focus on ignition, on the physical processes related to the burning of vegetation, or on the physics of large-scale weather patterns. Instead, simplifications must be made to include enough physics from the fire and atmosphere to produce the best model for that scale.

A second challenge in tackling the WUI problem is that because these fires cross boundaries of land ownership and government agencies, the problem has no clear owner. From a research funding point of view, this means that there is no single place or organization dedicated to conducting research and finding engineering-based solutions to this problem. As a result, projects tend to tackle narrow aspects of the WUI problem. For instance, current funding provided by the Department of Defense (DOD) is supporting research on prescribed burning and on the resulting smoke transport. On the other hand, the DOD is not funding projects specifically related to the WUI problem and structure ignition, Mell said.

FIGURE 4-3 A CH-47 Chinook helicopter crew delivers 2000 gallons of water to the Carlton Complex Fire in North Central Washington. Source: Washington National Guard. Photo by SPC Jordan Hill.

A number of efforts are currently under way to address the WUI fire problem, many of which are centered on fuel reduction.[16] FIREWISE is one such effort that provides community members with guidance on how to reduce vegetation according to structural zoning. The FIREWISE guidelines recommend reduced vegetation loads around structures, with less reduction needed as

16 William E. Mell, Samuel L. Manzello, Alexander Maranghides, David Butry, and Ronald G. Rehm. 2010. The wildland-urban interface fire problem — current approaches and research needs. International Journal of Wildland Fire 19(2):238-251.

the distance from a structure increases. These guidelines are intended to raise homeowner awareness and reduce ignition potential. However, when this blanket approach is applied to high-density communities, the guidelines often cannot be implemented — for example, because of the varied parcel sizes and shapes throughout a WUI community. In addition, the FIREWISE guidelines do not incorporate measures of expected heat flux exposure from either flames or from firebrands, despite their importance in the spread of fires.

Four major initiatives could improve the efforts being made to reduce the WUI problem, Mell said. First, approaches and solutions should be examined from a community perspective. Second, mitigation guidelines should be created that identify expected exposure to heat flux from firebrands and flames. Third, strategies should incorporate lessons learned from the successes of traditional structure fire research and engineering. Fourth, interdisciplinary, mutually supporting measurement and modeling approaches are needed to produce the greatest impact.

FIGURE 4-4 The Cougar Creek Fire located northwest of Glenwood, WA began on Aug. 10, 2015 and has consumed an estimated 54, 000 acres. The fire was caused by a lightning strike. Source: U.S. Forest Service.

Mell pointed out that several types of models have been developed to analyze the WUI problem. Physics-based models that use computational fluid dynamics, such as weather-based models, are the most advanced of these simulations. However, these models have yet to rise beyond the research level due to the high levels of input, training, and computational resources that they require. Other models attempt to measure ignition, as produced by sufficient quantities of exposure and response, though more widely applicable solutions to reducing ignitions will require a greater understanding of both these factors.

A useful WUI fire simulation tool that operates robustly over a range of fuel, terrain, and weather scenarios needs to accomplish three objectives, Mell said. First, it should be able to characterize exposure due to fire and firebrands, including the location and measure of firebrand accumulation as well as the magnitude and duration of heat fluxes from flames, hot gases, and firebrands. Second, it should be able to predict smoke transport for evacuation study and prescribed burn planning. Third, it should be able to assess how modifying the vegetation, structures, and landscape influences exposure conditions.

The Wildland-Urban Interface Fire Dynamics Simulator (WFDS) is one example of an advanced model designed to enable hazard mapping based on wildfire-generated firebrand exposure. Though it has limitations, it can account for different forms of heat flux, produce the smoke generated from simulated fires, and handle complex geometrics across the terrain, structures, and vegetation. This information, as well the properties of vegetation, such as moisture, density, and distribution, can feed into the model to produce continuous improvements.

Though much work remains to be done to increase their validity, models such as the WFDS demonstrate considerable capability, said Mell. Validating these models requires controlled, repeatable experiments in a laboratory setting as well as additional information from the field, such as weather conditions and vegetation characteristics. Models are partway there, but the challenge is amassing enough funding over a long enough period of time to complete this work.

Mell drew three major conclusions related to addressing the WUI fire problem. First, an engineering-based approach is needed that includes well-coordinated experiments, post-fire field study, and modeling, as well as results in test methods, codes, and standards based on expected exposure to fire and firebrands. Second, though physics-based models can currently provide predictions of exposure, caution should be taken in interpreting these predictions, as community-scale fire simulations remain a computational challenge that require more model evaluation through experiment and observation. Finally, establishing the technical and non-technical foundations for WUI building codes, standards, and implementation is just as important and just as challenging as working on measurements and model developments, Mell observed.

## EVALUATING TRADEOFFS FOR WATER, FIRE, BIOFUELS, AND FISH

Forest restoration scenarios for a fire-dominated landscape aim to restore the landscape to a pattern that is more consistent with a wildfire-dominated region, explained Mark Wigmosta, chief scientist for the Computational Watershed Hydrology Team at the U.S. Department of Energy's Pacific Northwest National Laboratory (PNNL). Such restoration efforts are meant to result in more frequent but less intense wildfires in more locations through such means as commercial thinning, prescribed burning, and fire management. Restoration efforts can also achieve hydrologic benefits, which could support more hospitable conditions for salmon and the collection of forest residues for bioenergy. Researchers at PNNL and the U.S. Forest Service Pacific Northwest Research Station (PNWRS) are currently examining the interplay among forest restoration, snowpack, streamflow, and biomass production across treatment scenarios using a decision support application designed for that purpose.

The impact on snowpack is a major consideration in deciding upon the appropriate forest restoration strategies for the mountainous areas of Washington State, Wigmosta observed, since snowmelt is the dominant driver of streamflow in the state. Canopy cover in snow-dominated areas affects snow accumulation and melt, thereby altering the volume and timing of streamflow. In addition, the extent of forest cover may increase or decrease snow duration depending on the local topography, climate, and canopy characteristics, which vary over relatively short distances in Washington's mountainous regions.

Studies done by University of Washington researchers and others have shown that snow tends to last longer in the open where the winter air temperature is greater than minus one degree Celsius and precipitation is more than about 300 millimeters.[17] Slope also factors into snowmelt, with snow typically melting earlier on south-facing slopes than north-facing slopes under the same conditions. Research done in the University of Idaho Experimental Forest has shown that the amount of water stored in the snowpack is twice as much beneath gaps in the canopy compared with the adjacent forest, and that snow cover remained three weeks longer. All these results factor into the decision support tools being developed by PNNL and the PNWRS to determine the most promising paths toward forest restoration.

These tools incorporate simulation models that explore the landscape to assess the type and intensity of restoration efforts needed to produce the maximal positive effects on snowpack and streamflow. One such model is the Distributed Hydrology Soil Vegetation Model (DHSVM), a well-vetted, extensively used tool in the scientific community that Wigmosta developed previously at the University of Washington. This model predicts snow accumulation, melt, and runoff under different canopy and weather conditions and represents spatial variation in topography, weather, vegetation, and soils. It can accurately predict real-life observations made at the University of Idaho Experimental Forest, though the model's effectiveness is related to the comprehensiveness of the collected data. The DHSVM also has been validated in open areas using data from snow telemetry stations across the western United States, though additional observational data sets are needed to characterize the snow canopy interactions and model performance in Washington State, Wigmosta said.

FIGURE 4-5 Firefighters conducting burnout operation. Cougar Creek Fire, Okanogan-Wenatchee NF, WA, 2018. Source: U.S. Forest Service. Photo by Kari Greer.

The decision support system being developed by the PNNL/PNWRS team aims to examine various restoration scenarios to consider tradeoffs among water, fire, and biomass. It also addresses hydrologic impacts, such as stream discharge and temperature by reach, and includes an ecosystem analysis to address habitat suitability. Together, these tools will enable forest restoration planners to fully consider the potential and consequences of forest restoration, biomass, severe fire risk, hydrologic improvement, and ecosystem services.

Though modeling the spread of wildfires is not a focus

17 Jessica D. Lundquist, Susan E. Dickerson-Lange, James A. Lutz, and Nicoleta C. Cristea. 2013. Lower forest density enhances snow retention in regions with warmer winters: A global framework developed from plot-scale observations and modeling. Water Resources Research 49(10):6356-6370.

of the decision support system being developed by the team, wildfires still factor into restoration scenarios and evaluations. The tool uses a simple metric for changes in wildfire intensity, which indicates whether direct fire suppression is an option. A more detailed analysis of the contagion of severe and less severe wildfires is under way, and these metrics will be used to inform tradeoffs.

In a research project that applied the model to the Wenatchee and Entiat watersheds, Wigmosta and his colleagues simulated the impacts of introducing gaps in the forest canopy consistent with a naturally fire-dominated landscape. Each scenario was then analyzed in relation to different restoration efforts. The resulting scenarios were mapped onto the DHSVM hydrologic model grid that simulates changes in stream discharge and stream temperature. The resulting predictions contributed to an assessment of habitat suitability, including an evaluation of the conditions for salmon, allowing decision makers to examine the tradeoffs among water, wildfire mitigation, and biomass over a range of restoration scenarios.

> "Models have great potential to help planners return to landscape patterns that are more consistent with a wildfire-dominated regime."
> -Mark Wigmosta

The PNNL/PNWRS team analyzed the ratio of seven-day summer low flows under restoration versus current conditions and found that forest restoration produces higher low flows. This suggests that in areas where snowpack supplies late season flows, forest restoration can help increase habitat suitability, particularly for salmon. This decision support tool can also estimate the delivered costs of biomass for bioenergy, which depend as well on markets, processing, and transport costs. In one application of this capability, Wigmosta and colleagues created a model to analyze the cost of collecting forest residue for wood chips in the Wenatchee region. The model accounted for the costs to harvest the residue, process it, and then transport it to selected locations, revealing in the process the major role that road networks play in the economics of the final delivered cost. The analysis revealed that delivering 90 percent of the wood chips to the Wenatchee location would result in the lowest cost, based primarily on road networks and surfaces.

The decision support system being developed by PNNL and the PNWRS is one of several forest restoration resources that have been and continue to be developed. Continued efforts to integrate snow conditions into the decision system, reduce wildfire risk, improve streamflow, and maintain biomass supply will make it possible to evaluate tradeoffs over a range of spatial and time scales, consider uncertainty, and search for "multi-win" scenarios, Wigmosta said. In addition, "right now our restoration scenarios are just a snapshot in time. We go in and do the restoration and then we don't consider what happens when the vegetation grows back." All models have limitations, he acknowledged, but they have great potential to help planners return to landscape patterns that are more consistent with a wildfire-dominated regime.

# 5. The Intersection of Research and Policy

The results of research can have direct and immediate effects on risk-based fire management. Research can improve the efficiency and effectiveness of wildfire management, reveal and examine tradeoffs among policy options, and quantify the economic returns to investments in wildfire suppression and management. Three speakers at the symposium explored the intersection of research and policy, with an emphasis on the practical ways in which research can be applied.

## FACTORS BEHIND THE RISING COST OF WILDFIRE MANAGEMENT

Three major factors have driven the increased cost of fighting wildfires, now approaching $3 billion per year, said Jude Bayham, assistant professor of economics at Colorado State University. The first is the historical management of fires. For much of the 20th century, federal policy was to put out wildfires by 10 a.m. the day after they started. The result was a steady build-up of fuels in wildlands that has resulted in exceptionally large and fierce fires.[18]

The second contributing factor has been climate change.[19] More moisture in the winter and spring, warmer and drier summers, more extreme fire weather, and longer fire seasons have all contributed to increased wildfires, which has increased the costs of fire suppression.[20] As an example of these costs, Bayham cited preliminary work he has done on how incident commanders respond to changing weather over the course of a fire incident. When the burning index and severe fire weather potential are high, commanders tend to be proactive. They request more resources, in terms of crews and equipment, than they would under other circumstances. Changes in these indicators over time would be expected to drive up costs, Bayham said.

The third factor behind increasing costs is the changing wildland-urban interface. The combination of more and larger fires and more homes in the wildland-urban interface is making the management of fires more complex and is putting more valued assets at risk.[21] Suppression expenditures are high for fires near residential development, and they are even higher in low-density housing.[22] More resources are dispatched to fires that threaten homes, which draws resources from management objectives on other fires. Meanwhile, suppression and home protection incentivize further growth in the wildland-urban interface, which further increases fire suppression costs.

These factors all relate to one of Bayham's research interests, which is the organizational challenges that arise with multiple fires. Better and more timely data can help meet these challenges, he pointed out. One approach, for example, would be to use geographic information systems combined with expert knowledge to classify geographic units and guide suppression efforts and fuel treatment efforts. This has the potential to reduce suppression costs, even as the drivers of wildfire losses intensify. Another approach would be to levy a premium on top of homeowner insurance, which was proposed in Washington State legislation but not passed, which would be "a move in the right direction from an economic efficiency standpoint," Bayham observed.

> "We're spending billions on suppression. What return are we getting?"
>
> -Jude Bayham

Many research and policy questions remain unanswered, he noted. One involves the return on investment of wildfire suppression. "We're spending billions on suppression," he noted. "What return are we getting? Are we getting home protection? Are we improving outcomes on the landscape? Are we getting better ecological outcomes? Some of these things we know a little bit about, but we don't know much in terms

18 Sean A. Parks, Carol Miller, Marc-André Parisien, Lisa M. Holsinger, Solomon Z. Dobrowski, and John Abatzoglou. 2015. Wildland fire deficit and surplus in the western United States, 1984-2012. Ecosphere 6(12):1-13.
19 John T. Abatzoglou and A. Park Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences 113(42):11770-11775.
20 Emily S. Hope, Daniel W. McKenney, John H. Pedlar, Brian J. Stocks, and Sylvie Gauthier. 2016. Wildfire suppression costs for Canada under a changing climate. PLoS One 11(8):e0157425.
21 Tania Schoennagel, Jennifer K. Balch, Hannah Brenkert-Smith, Philip E. Dennison, Brian J. Harvey, Meg A. Krawchuk, Nathan Mietkiewicz, Penelope Morgan, Max A. Moritz, Ray Rasker, Monica G. Turner, and Cathy Whitlock. 2017. Adapt to wildfire as climate changes. Proceedings of the National Academy of Sciences 114(18):4582-4590.
22 Anna M. Clark, Benjamin S. Rashford, Donald M. McLeod, Scott N. Lieske, Roger H. Coupal, and Shannon E. Albeke. 2016. The impact of residential development pattern on wildland fire suppression expenditures. Land Economics 92(4):656-678.

of the data." Better geospatial and temporal data could help answer these questions, he noted.

He also asked whether it is possible to move toward a better fire balance through a combination of treatments and selective suppression. "Some fires are good for the landscape," he observed. "We would like to use suppression techniques that might encourage more fire where we can see those benefits."

## WILDFIRE: WHO'S AT FAULT AND WHY WE SHOULD CARE

When fires cause loss of life, loss of property, and other forms of damage, who is liable for the cost, asked Jonathan Yoder, professor of economics at Washington State University and the director of the State of Washington Water Research Center. Does the burden fall on the owner of the property, the person or entity responsible for starting a fire, or the owner of the land or structures that propagated a fire?

Liability comes in distinct "flavors," said Yoder. With no liability, the injured bears the loss and the injurer is immune. With strict liability, the injurer has to compensate the injured for the loss. Under a negligence rule, the injurer has to compensate the injured only if the injurer was negligent. For example, if lightning ignited a fire on someone's property that spread and destroyed a neighbor's house, the neighbor might contend that the owner of the property where the fire started did not try hard enough to stop the fire from spreading. "Who should take the blame here?" asked Yoder.

FIGURE 5-1 McLeod Fire, Okanogan-Wenatchee NF, WA, 2018. Source: U.S. Forest Service. Photo by Kari Greer.

Under a no liability rule, the property owner has no incentive to invest in the containment of the fire. Under a strict liability rule, the property owner has a strong incentive to contain a fire, while a neighbor has a weak incentive to self-protect from a fire. Strict liability works well when the injured party cannot self-protect, while immunity works well if the injurers have limited or no control over the spread of a fire. However, both perform poorly when both parties can affect the outcome of a fire.

From an economic incentive perspective, Yoder observed, the best approach is to impose the liability on the party that has the most control over risk reduction. The negligence rule can help achieve this outcome in that it can strike a balance between precautions taken by a potential injurer and self-protection by someone who could potentially be injured.

"Of course, it's a lot more messy than that in real life," Yoder acknowledged. But empirical evidence suggests that liability rules do have important effects on risks and outcomes by changing people's behavior. "Liability law is not just about fairness," said Yoder. "It affects the way people make decisions."

For wildfires, liability generally applies to "all damage proximately caused," including damage to real estate, personal property, bodily harm, loss of life, loss of business income, suppression costs, evacuation costs, smoke impacts, natural resource damage, and ecosystem services. The negligence rule generally applies, but it has important exceptions, including ignition and escape, prior conditions, and suppression efforts.

> "Liability law is not just about fairness. It affects the way people make decisions."
>
> -Jonathan Yoder

Legal qualifications also limit property rights for fire threats. For example, legislation and police powers can impose regulations to prevent fires, and firefighters can enter privately owned land to control a wildland fire. Regulations also deny compensation for official destruction of property to stop the spread of fire, so firefighters cannot be sued for damage to people's property except if there are legislative exceptions. However, this does not necessarily apply to prescribed fires, and some states have strict liability rules for such fires. In other places, certification programs relax liability to gross negligence.

Yoder also briefly discussed inverse condemnation, which involves whether a party has an obligation to compensate for a fire attributed to that party. Such is the case, for example, with the fires caused by the infrastructure of utility companies when that infrastructure sparks a fire. In California in particular, inverse condemnation amounts to strict liability in which the government must compensate for losses due to its infrastructure regardless of negligence. This has led to important realignments in the actions of public utilities such as Pacific Gas and Electric, which recently filed bankruptcy over billions of dollars in wildfire losses due to their assets in 2017 and 2018 and led the utility to impose electrical "blackouts" on ratepayers during high fire risk periods. This liability regime strongly incentivizes public utilities to take precaution to reduce wildfire risk, but it weakens incentives for homeowners to protect their properties or not build in fire-prone areas. The result, said Yoder, is essentially a subsidy to build in the wildland-urban interface. More research on aligning private incentives with public welfare would help explain how incentives and organization in the wildland-urban interface affect wildfire outcomes.

## TOWARD A SHARED STEWARDSHIP MODEL OF WILDFIRE RESPONSE PLANNING

Science-based analytics and collaborative wildfire planning can transcend jurisdictional, cultural, and political boundaries, observed David Calkin, supervisory research forester with the U.S. Forest Service, in the final presentation at the symposium, and policy challenges are a prime driver of this work. The federal government has a clear objective of using fire on the landscape to achieve multiple purposes, whereas almost all western states have a clear directive to put out all fires while they are as small as possible. "This dichotomy creates a lot of challenges," said Calkin. States may blame the federal government when fire moves from federally managed land to state land. The federal government may blame the states for expansion of the wildland-urban interface. "There's a lot of finger pointing."

Land managers need to get past this finger pointing, said Calkin. Jurisdictional boundaries on the landscape are artificial. As U.S. Forest Service chief Vicki Christiansen has said, "Shared stewardship is about working together in an integrated way to make decisions and take actions on the land."

Four of the most devastating fires of the last decade — the Camp fire in 2018, the Tubbs fire in 2017, the Carlton Complex fire in 2014, and the Waldo Canyon fire in 2012 —were primarily state-managed fires rather than examples of federal forests transmitting fire into communities. In Washington and Oregon, some communities most at risk from wildfires are near national forests, while others are not.[23] "This is everybody's problem," Calkin said.

The Washington Wildland Fire Protection Strategic Plan established four goals:[24]

1. Washington's preparedness, response, and recovery systems are fully capable, integrated, and sustainable.
2. Landscapes are resilient — in the face of wildland fire, they resist damage and recover quickly.
3. Communities are prepared and adapted for current and future wildland fire regimes.
4. Response is safe and effective.

Calkin focused his remarks on the fourth of these goals, which has a number of subgoals, including:

- Conduct cross-boundary "pre-fire response" analysis and planning, including evacuation planning.
- Enhance communication during wildland fire response.
- Authorize the Chief of the Washington State Patrol to mobilize suppression resources prior to a wildland fire incident under predefined circumstances.
- Invest in robust infrastructure.
- Regularly monitor and evaluate the effectiveness of wildland fire protection in western Washington; identify and implement changes as needed.

"This is everybody's problem."
-David Calkin

The current fire decision management model is not necessarily designed to achieve these outcomes, said Calkin. In the existing model, when a fire gets out of control and becomes large, the local agency administrator looks to an incident team. Such teams have extensive expertise on the operational aspects of their job. They can bring thousands of people into hazardous environments and do large amounts of work with excellent safety records. However, such teams are not experts on such questions as: How can a fire be

23 Joe H. Scott, Julie Gilbertson-Day, and Richard D. Stratton. 2018. Exposure of human communities to wildfire in the Pacific Northwest. Briefing paper. 10 p. Available at http://pyrologix.com/ftp/Public/Reports/RiskToCommunities_OR-WA_BriefingPaper.pdf.

24 Washington State Department of Natural Resources. 2019. Washington State Wildland Fire Protection 10-Year Strategic Plan: Solutions for a Prepared, Safe, Resilient Washington. Available at https://www.dnr.wa.gov/publications/rp_wildfire_strategic_plan.pdf.

managed for extended periods? What are its implications for the land base? What are the implications for the future of the landscape and its uses? “We should expect poor performance not because they’re weak but because of the conditions of the problem they’re faced with.”

Calkin described a much more integrated shared stewardship model in which partners provide input on unit objectives, fire management objectives, and incident objectives. In this way, the incident teams have clear guidance on what they should be doing. Responses also can be monitored so that they are more flexible and agile when conditions change. Finally, performance measurement can provide for organizational learning and accountability.

FIGURE 5-2 Cougar Creek Fire, Okanogan-Wenatchee NF, WA, 2018. Source: U.S. Forest Service. Photo by Kari Greer.

As an example of one element of such a system, Calkin described a computer model developed by his colleagues that “looks at the landscape the way a fire responder would look at the landscape.” The model uses a variety of inputs, including such factors as steepness of slope, proximity to roads, and density of vegetation, to generate a “suppression difficulty index,” which indicates where fires are easiest to control.[25] The model also looks at the history of fire in a region to determine where fires are most likely to stop burning, such as roads, ridges, rivers, or fuel transitions. In this way, the model provides guidance about where fire crews should try to stop a fire and where such attempts are not going to work and could be dangerous. Furthermore, by overlaying the results of this model on maps of structures and other values at risk, planners can determine where an area would benefit from fire, including prescribed burns, and where fires would have significant negative consequences.

This model is now being applied to inform strategic response in a variety of western forests. It can support both the initial response and campaign fire decisions, Calkin noted. It also can lead to strategic responses that are commensurate with values. In some places, fires can be introduced back into the landscape with confidence that they can be held to specific locations. In other places, aggressive suppression of fires can protect assets. Model results are also combined with the local expertise of firefighters to increase validity and in some cases to modify the model results and to suggest places where firefighters might want to engage and stop a fire. Even in places where fires have been suppressed for decades, the model can provide confidence that fires can be controlled, thereby reducing risk from future conflagrations.

Results from this model and other modeling tools are available for most of the eastern side of the Cascades Mountains, said Calkin. Already, these tools have been used to identify operational delineations, or PODS, where fires are either controlled or extinguished. “We’re seeing a lot of interest in operational use of this,” Calkin said, with model results being supplied in 40 fires altogether in 2018.

A challenge for the future is gathering data on the effects of fire suppression actions. Information on the resources being used, the location of engagement, and the degree of engagement effectiveness for large fires would provide many opportunities to better understand fire suppression activities. Advances in geospatial tracking and legislative requirements to apply these technologies will help generate this information, he said.

Integrating landscape information with suppression actions on large fires will be very complex and will require ‘big data’ analytics, Calkin acknowledged. It also will require a cultural change in the firefighting world, where response planners and firefighters will have to be willing to “open their arms to a new analytical world.” But the opportunities are “immense,” he said. Such an approach provides the foundation for a more analytical approach to future wildfire management, including feedback, learning, and accountability. “We’re underinvesting in mitigation because we’re overinvesting in response. This is a way to get ahead of that.”

25 Christopher D. O’Connor, David E. Calkin, and Matthew P. Thompson. 2017. An empirical machine learning method for predicting potential fire control locations for pre-fire planning and operational fire management. International Journal of Wildland Fire 26:587-597.

# 6. Concluding Reflections

In the wrap-up session of the meeting, several of the presenters commented on a few of the prominent themes that had emerged over the course of the day.

One of these was the tension that exists between the federal government's mandate to manage fire for multiple objectives and the mandate at the state level to aggressively suppress all wildland fires. John Giller acknowledged that the states of Washington and Oregon are severely limited in their use of fire to produce benefits on the landscape, "especially on private land that they are protecting." But decisions at both the federal and state levels also depend on the availability of firefighting and management resources, he added. When private property is threatened, resources are devoted to suppression, but in other areas a fire may be actively managed rather than extinguished. Making such decisions can require "a hard and nuanced conversation with the public," he noted. Still, fire management is always done under a control strategy that dictates where a fire will be stopped or how management will change if weather conditions deteriorate.

On this point, David Calkin added that policies of fire suppression and fire management may not differ much in practice. The primary goal is to keep firefighters and the public safe, he said. "Just because we're aggressively suppressing something doesn't mean we head right into the fire. It means we go to the right place with the right resources that can be there safely, and that may be a mile away from private property." Patty Champ also noted that responses often cross agency lines, which requires coordination among goals and actions.

Tony Harwood pointed out that federal agencies, the states, and tribal agencies also work together on fire prevention, education, and mitigation programs. "These collaboratives and partnerships work very well," he said. As an example, he cited a program of education and enforcement to reduce the problem of unattended campfires. Talking with the community and applying local solutions to local problems produced a substantial reduction in the problem, reflecting the efforts of multiple fire protection agencies.

In response to a question about which of the three factors contributing to the increasing costs of fighting wildfires is largest, Jude Bayham observed that he is unaware of research on which factor has contributed the most. "My guess is that it would be the wildland-urban interface," he said, "but that would depend on how you are defining those contributions" to the overall cost. Giller pointed out that half the U.S. Forest Service's growing budget for fire suppression is spent on aircraft, and more than half the budget is spent in California. Thus, both the expense of firefighting resources and the increased exposure of valued assets to wildfires are driving up costs.

In response to a question about the different kinds of toxic substances in smoke, Sverre Vedal observed that different combustion products clearly have different carcinogenic potential. But for non-cancer outcomes, many questions still surround the negative health effects of wildfire smoke as opposed to, for example, smoke from coal combustion. Many researchers hold that smoke from coal combustion is more toxic in terms of cardiovascular and respiratory effects than wildfire smoke, but that conclusion is still uncertain, Vedal said.

Finally, Jonathan Yoder commented on the potential for the Washington State Academy of Sciences to provide guidance on which firefighting policies can be based. "WSAS could play an important role in influencing legislative outcomes based on evidence," he observed.

"WSAS could play an important role in influencing legislative outcomes based on evidence."
-Jonathan Yoder

# Appendix A

## Symposium Agenda — Wildfire in Washington State

### Agenda at-a-Glance

Skyline Room, Museum of Flight, Seattle

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|---|---|
| 8:00 AM | Registration |
| 8:00—9:00 AM | Continental Breakfast<br>Skyline Room |
| 9:00—9:40 AM | **Keynote Address**<br>"The Washington State Wildland Fire Protection 10-Year Strategic Plan—Vision and Implementation," *Hilary Franz* |
| 9:50—10:40 AM | **Wildfire: the Space-Time Continuum**<br>"Tribal Land Stewardship and Living with Wildfire," *Tony Harwood*<br>"A Firefighter's View of Fire on the Landscape," *John Giller* |
| 10:40—11:30 AM | **Wildfire: Health**<br>"Wildfire, air pollution, and health," *Sverre Vedal*<br>"#welcometohell: Perceived Health Risks and Risk Reduction Actions Taken by Washingtonians During the 2017 and 2018 Wildfire Seasons," *Pat Butterfield* |
| 11:30 AM—12:20 PM | **Wildfire: Fuel and Ecosystems**<br>"Wildland and Wildland-Urban Interface Fires: The need for advancing fire and smoke models," *Ruddy Mell*<br>"Forest Health, Distributed Hydrology, Wildfire Danger, Biomass, and Anadromous Fish: Exploring Practical Opportunities for Convergent Solutions," *Mark Wigmosta* |
| 12:20—1:00 PM | Lunch |
| 1:00—1:50 PM | **Economics of Wildfire**<br>"Homeowners and Wildfire: A Science Based Approach to Creating Fire Adapted Communities," *Patty Champ*<br>"The rising cost of wildfire management," *Jude Bayham* |
| 1:50—2:40 PM | **Wildfire: Government Regulations and Policy**<br>"Towards a Shared Stewardship Model of Wildfire Response Planning," *David Calkin*<br>"Wildfire: Who's at fault and why we should care," *Jonathan Yoder* |
| 2:40—3:00 PM | **Moderated Discussion; Closing Remarks**<br>*Ron Mittelhammer* |

# Appendix B



## SYMPOSIUM SPEAKERS

### Keynote: Hilary Franz

Elected in 2016, Commissioner of Public Lands Hilary Franz protects and manages nearly six million acres of public lands in Washington State – from coastal waters and aquatic reserves, to working forests and farms, to commercial developments and recreation areas. Commissioner Franz is committed to ensuring our public lands are healthy and productive, both today and for future generations. She is leading the push to make Washington's lands resilient in the face of climate change, investing in carbon sequestration and clean energy with wind, solar, and geothermal infrastructure. As the leader of our state's largest wildfire fighting force, she has pushed for new strategies, innovations, and resources to protect our communities. In order to restore wildfire resilience in our forests, Commissioner Franz developed a 20-year Forest Health Strategic Plan. This plan will make more than one million acres of forest healthier and more resistant to wildfires – a scale and pace that is unprecedented. She holds a bachelor's degree from Smith College and a J.D. from Northeastern University Law School.

### Tony Harwood

Tony Harwood began his fire management career in 1970 as an emergency fire fighter at the Blackfeet Indian Agency in north-central Montana. Mr. Harwood received a B.A. in Journalism from the University of Montana in 1975. In 1979, he was hired as a Bureau of Indian Affairs Timber Sales Officer, at Flathead Agency, Montana and later moved into the Salish & Kootenai Tribes Division of Fire as the Wildland Fuels Specialist from 1990 to 2000, the Fire Program Manager 2001-2007, and later worked as the Forest and Inventory Manager 2008-2016. In 2016, Mr. Harwood retired from a 37-year career in Forest and Fire Management with the Confederated Salish and Kootenai Tribes at Ronan, Montana. From experience as a Timber Sales Manager, Prescribed Fire Burn Boss, Fire Behavior Analyst, and Operations Section Chief, Mr. Harwood presently works as a Land Resource Consultant in Polson, Montana.

### John Giller

John Giller has lived and worked in the Pacific Northwest for most of his life, working in various fire management positions in the private and public sectors, including the U.S. Forest Service, Bureau of Land Management, Keno Fire Department and Klamath Fire, Inc. Over the last 38 years, Mr. Giller has gained extensive knowledge and experience in multiple aspects of Fire and Aviation Management and served in many leadership positions throughout his career. Mr. Giller is currently the Director of Fire, Fuels and Aviation Management, for the Pacific Northwest and Alaska Regions of the U.S. Forest Service and OR/WA Bureau of Land Management.

# Appendix B



## Sverre Vedal

Sverre Vedal is an epidemiologist who has served as a Professor in the Department of Environmental & Occupational Health Sciences at UW, a pulmonologist at the Occupational and Environmental Medicine Clinic (UW), and the head of the EPA Center for Clean Air Research (UW). Together, these roles provided the tools for investigating exposure-response relationships, reducing uncertainty about cause and effect and giving insight into how low-level air pollution exposures could be so harmful. Dr. Vedal also advised the EPA on clean air policy. He served on an air pollution panel that reviewed scientific assessments and provided policy recommendations for the EPA's Clean Air Scientific Advisory Committee. With an MD from the University of Colorado and an MSc in epidemiology from Harvard University, Dr. Vedal began his work at the University of British Columbia and National Jewish Health in Denver before moving to UW in 2004.

## Pat Butterfield

Pat Butterfield is a Professor at the Elson S. Floyd College of Medicine at Washington State University. Dr. Butterfield's experience includes: 8 years as WSU's statewide Dean of Nursing, inclusive of 5 campuses and 1,000 students; serving as the Director of the Occupational and Environmental Health Nursing Program at the University of Washington; and postdoctoral training at the Oregon Institute for Occupational Health Sciences. Dr. Butterfield served on the EPA Federal Advisory Committee for Children's Environmental Health, the Climate Change Roundtables for Health Science Deans convened in 2016 by the Obama administration, and as the Senator Norman Patterson Visiting Professor at the University of Saskatchewan's Centre for Agricultural Medicine. She is a Fellow of the American Academy of Nursing and an alumnus of the Robert Wood Johnson Executive Nurse Fellows Program. Dr. Butterfield's work addresses the impact of environmental determinants of health on low-income families, rural communities, and those differentially affected by occupational and household exposures.

## William (Ruddy) Mell

William (Ruddy) Mell is a combustion engineer with the U.S. Forest Service who has been involved with computer modeling of wildland fires and wildland-urban interface (WUI) fires for the past 15 years. Prior to entering the field of wildland fire, he worked in the areas of modeling turbulent combustion, microgravity combustion, and structure fires at the U.S. National Institute of Standards and Technology (NIST). His model development work collaborates closely with experimentalists and modelers at the U.S. Forest Service, NIST, and academia. His current focus is on the development and testing of the wildland-urban interface fire dynamics simulator suite (WFDS). The objective of these models, and results from field and laboratory work, is to provide better tools for wildland and WUI fire researchers and guidelines for WUI homeowners, communities, and fire officials for risk assessment and mitigation.

# Appendix B



## Mark Wigmosta

Mark Wigmosta is a Chief Scientist and Technical Lead for the Computational Watershed Hydrology Team at the U.S. Department of Energy Pacific Northwest National Laboratory. Dr. Wigmosta also has a Dual Appointment as a Distinguished Faculty Fellow in the University of Washington Department of Civil & Environmental Engineering. He has over 30 years of experience in distributed watershed hydrology, including the potential impacts of land-use and climate change on water resources and renewable energy. Dr. Wigmosta was the principal developer of the Distributed Hydrology-Soil-Vegetation Model (DHSVM), which has been widely used in forest management applications. He has authored more than 55 peer-reviewed research papers and book chapters, including the DHSVM publication that is currently the 22nd most citied paper from 1965–present in the American Geophysical Union Journal of Water Resources Research. His research on renewable energy received an American Geophysical Union 2012 Editor's Choice Award and was cited by President Obama during an energy policy speech in 2012. Prior to joining Pacific Northwest National Laboratory, Dr. Wigmosta was awarded a DOE Global Change Distinguished Postdoctoral Fellowship.

## Patty Champ

Patty Champ has been with the U.S. Forest Service Rocky Mountain Research Station in Fort Collins, CO for the past 25 years. She is an applied economist with expertise in nonmarket valuation and is lead editor on two editions of *A Primer on Nonmarket Valuation*. The Primer is an edited volume that has been widely used as an undergraduate and graduate text. What started with a nonmarket valuation study on wildfire over ten years ago has developed into a broad applied wildfire research program. Dr. Champ's wildfire research has focused on three aspects of wildfire: the economic costs of exposure to wildfire smoke, the effects of wildfire risk on home sales prices, and wildland-urban interface homeowners' perceptions of risk and risk mitigating behaviors. She is a member of the Wildfire Research Team (WiRē), a collaboration of researchers and practitioners that conducts innovative applied wildfire research to help communities adapt and become resilient to wildfires.

## Jude Bayham

Jude Bayham is an economist with research interests at the intersection of public policy, human health, and the natural environment. Dr. Bayham holds a Ph.D. from Washington State University, completed a postdoc at the Yale School of Forestry and Environmental Studies, and is currently an Assistant Professor in the Department of Agricultural and Resource Economics at Colorado State University. He researches the economics of wildfire management, infectious disease, and the valuation of natural capital. His work on wildfire management investigates the factors that influence how suppression resources are allocated across competing fires and the economic consequences of those decisions. This work reveals that fires that threaten property receive more resources which constrains the ability of management objectives on other concurrent fires. In related work, Dr. Bayham is investigating the effectiveness of suppression strategies with a goal of quantifying the economic returns to investments in suppression resources. He also studies the impacts of wildfire smoke on outdoor recreation and human health.

# Appendix B

SYMPOSIUM SPEAKERS — WILDFIRE IN WASHINGTON STATE

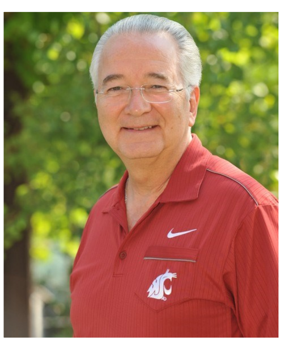
## Jonathan Yoder

Jonathan Yoder is a Professor in the School of Economic Sciences at Washington State University, Director of the State of Washington Water Research Center, and Affiliate Faculty in the Paul G. Allen School for Global Animal Health at Washington State University. He is an environmental and natural resource economist specializing in the economics foundations of environmental law, climate and energy policy, health and economic development in low-income communities, among other topics. Dr. Yoder is a member of the Washington State Academy of Sciences, president-elect and board member for the Universities Council on Water Resources (UCOWR). He is also on the Editorial Board of the journal *Fire*, the *Journal of Water Economics and Policy*, and the *Journal of Contemporary Water Research and Education*, among several past editorial positions. He has been the recipient of several quality of research awards. Dr. Yoder holds a B.A. in Biology and Journalism from Indiana University, a M.S. in Applied Economics from Montana State University, and a Ph.D. in Economics from North Carolina State University.

## David Calkin

David Calkin is a supervisory research forester at the Human Dimensions Program of the U.S. Forest Service Rocky Mountain Research Station in Missoula, Montana. Dr. Calkin leads the Wildfire Risk Management Science team working to improve risk-based fire management decision-making through improved science development, application, and delivery. His research incorporates economics with risk and decision sciences to explore ways to evaluate and improve the efficiency and effectiveness of wildfire management programs. He received a B.S. in applied math from the University of Virginia, and M.S. in natural resources conservation from the University of Montana, and his Ph.D. in Economics from Oregon State University.

## Ron Mittelhammer, Symposium Chair



Ron Mittelhammer was promoted to Regents Professor, Washington State University's highest academic rank, in 2004. He is a celebrated graduate-level teacher, having received national and university-wide awards for instruction, including the national Agricultural and Applied Economics Association award for Distinguished Graduate Teaching, the Washington State University Sahlin Faculty Excellence Award in Teaching, and the College of Agriculture and Home Economics Teaching Excellence Award. He was recognized as a *Journal of Econometrics* Fellow, a Fellow of the Agricultural and Applied Economics Association, a Fellow of the Western Agricultural Economics Association in 2004, served as President-elect, President, and Past President of the AAEA from 2008-2011, and is a member of the Washington State Academy of Sciences. He served as Dean of WSU's College of Agricultural, Human, and Natural Resource Sciences from 2013—2018, and served the University as Interim Co-Provost in 2015-2016. He received Washington State University's highest faculty honor, the Eminent Faculty Award, in 2014, and recently received the Lane Rawlins Distinguished Lifetime Service award from WSU in 2019.

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