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Wildland Fire Research Framework 2019-2022

U.S. ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF RESEARCH AND DEVELOPMENT

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> ***WILDLAND FIRE:*** *ANY NON-STRUCTURE FIRE THAT OCCURS IN VEGETATION OR NATURAL FUELS. WILDLAND FIRE INCLUDES PRESCRIBED FIRE AND WILDFIRE.*
>
> *—NATIONAL WILDLAND FIRE COORDINATING GROUP*

Purpose of ORD Wildland Fire Research Framework

The purpose of this document is to outline the U.S. Environmental Protection Agency's (EPA's) wildland fire priorities and coordinate the EPA Office of Research and Development's (ORD's) wildland-fire-related research across multiple National Research Programs (NRPs) to be implemented under their new 2019-2022 Strategic Research Action Plans (StRAPs). This document also provides background information on wildland fire research as it relates to EPA's mission; a narrative of the existing ORD research portfolio; and a landscape of future work that is within the purview, expertise, and capacity of ORD. Additionally, this research framework outlines an approach for collaborative research activities with other federal partners.

Vision for Wildland Fire Research in Support of EPA's Mission

The vision for ORD's wildland fire research is aligned with the Agency's broader mission to protect human health and the environment: *To understand and reduce the impacts of wildland fire on public and environmental health*.

Four primary goals support this vision:

(1) Identify effects of wildland fires on human and ecosystem health, including effects from burning of structures that occur in the urban-wildland interface resulting from fires that are initiated on wildlands;
(2) Determine the role of prescribed fire on reducing the severity of wildfires and the associated impacts on human health and the environment;
(3) Improve measurement and modeling methods to quantify and forecast wildland fire impacts to human health and the environment; and
(4) Communicate research-derived insights and strategies to reduce risks to public health and the environment from wildland fires, in close coordination with federal, state, and tribal organizations.

Introduction

Wildland fires, including wild and prescribed burns, occur every day around the world. Over the past 30 years, an average of more than 2 million hectares of wildlands in the United States have burned annually (*Figure 1*). Although the number of fires has not changed significantly over this period, the size and intensity of the fires have increased as a result of higher temperatures, drought, earlier snowmelt, and historically high fuel loading (e.g., undergrowth, tree density).[1] The average hectares burned has doubled over this time, and 9 of the 10 years of highest hectares burned have occurred since 2000, including the peak of 4.1 million hectares in 2015. This period also coincides with many of the warmest years on record in the United States.[2] Fire is important in fire-adapted ecosystems to maintain the health of native species, improve habitat and provide forage, control invasive species, and reduce the buildup of fuels to reduce the likelihood of highly destructive future wildfires.[3]

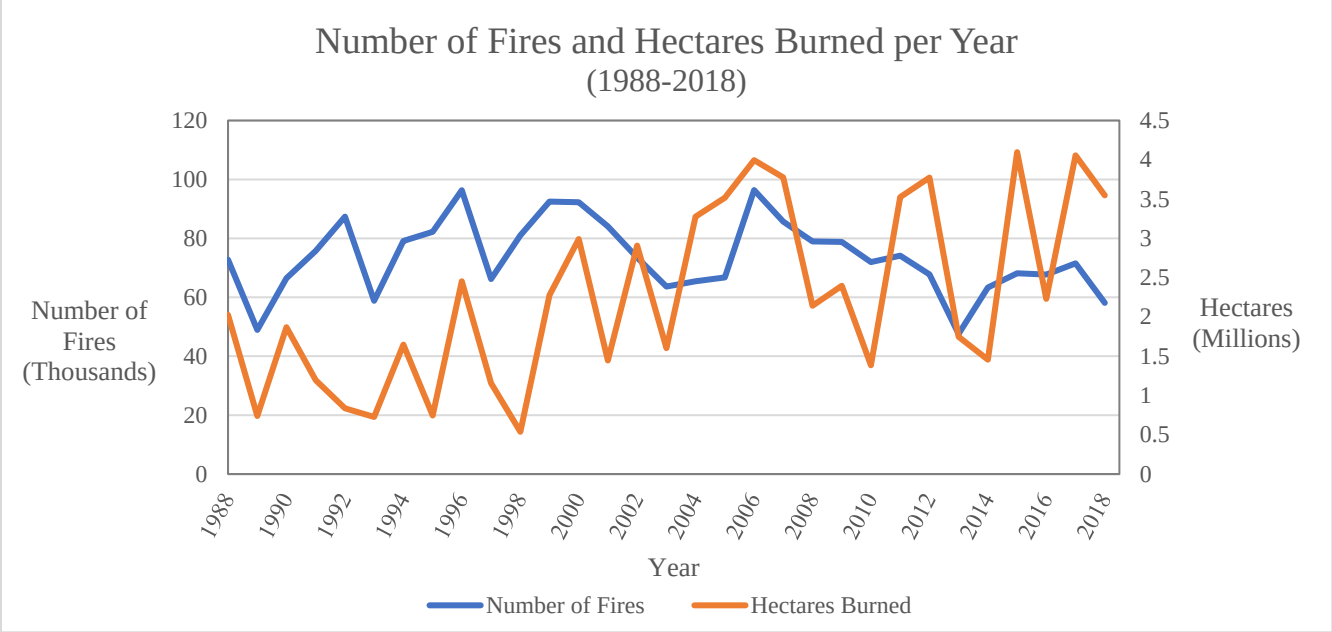

Figure 1. *Based on wildfire (not including prescribed fire) data provided by the National Interagency Coordination Center (NICC) as part of the National Interagency Fire Center (NIFC). The NICC at NIFC compiles annual wildland fire statistics for federal and state agencies. This information is provided through Situation Reports, which have been in use for several decades. [2004 fires and acres do not include state lands for North Carolina.][4]*

Uncontrolled wildfires and prescribed burns (fire used for land management to maintain fire-adapted ecosystems, agricultural lands, and grasslands and to manage fire risks in forests) increasingly are

[1] Landis, M.S., Edgerton, E.S., White, E.M., Wentworth, G.R., Sullivan, A.P., and Dillner, A.M. (2018). The impact of the 2016 Fort McMurray Horse River Wildfire on ambient air pollution levels in the Athabasca Oil Sands Region, Alberta, Canada. *Science of the Total Environment, 618*, 1665-1676.
[2] U.S. Environmental Protection Agency (2016). *Climate change indicators in the United States, 2016*. Fourth edition. EPA 430/R-16-004. www.epa.gov/climate-indicators.
[3] Neary, D.G., Ryan, K.C., and DeBano, L.F. (2005). Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42-vol. 4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250.
[4] National Interagency Fire Center (n.d.). Fire Information and Statistics: Wildland fires and acres (1926-2017). https://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html.

raising questions on the impacts of these activities on downwind ambient air quality, water quality, ecosystem services, and public health.[5] Wildland fire and the subsequent impacts are a complicated, systems-level issue. The *Fourth National Climate Assessment* indicates that "wildfire trends in the western United States are influenced by rising temperatures and changing precipitation patterns, pest populations, and land management practices. As humans have moved closer to forestlands, increased fire suppression practices have reduced natural fires and led to denser vegetation, resulting in fires that are larger and more damaging when they do occur."[6]

Many wildfires, as well as some agricultural fires, in National Forests, National and State Parks and Wilderness Areas can spread quickly to the wildland-urban interface (WUI). The WUI is defined as "the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels."[6] "Wildfires are increasingly encroaching on American communities, posing threats to lives, critical infrastructure, and property."[7] Recent wildfires have resulted in thousands of structures being destroyed.[8,9] When wildfires reach the WUI, the fuels burned shift from only natural ones to also include man-made structures and associated materials, such as plastics and other synthetic materials, whose combustion products may be more toxic than burned vegetation. More people are living in the WUI, which is considered a high-risk area for wildfire, resulting in higher risk to life and property.[10]

Impacts of wildland fires may occur near the location of the fire and, potentially, in areas further from the location of the burn. Smoke from wildfires can travel great distances, contributes to air pollution, and can harm human health.[6,11,12,13,14] According to the *2014 National Emissions Inventory*, wildland fires contributed approximately 30 percent of directly emitted fine particulate matter ($PM_{2.5}$).[15] Further, fire-prone ecosystems—forests in most cases—are critical sources of our national water supply, and

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[5] National Interagency Fire Center (n.d.). Fire Information and Statistics: Wildland fires and acres (1926-2017). https://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html.
[6] Wildland Fire Leadership Council (n.d.). Wildland Fire Leadership Council. Retrieved from Forests and Rangelands: https://www.forestsandrangelands.gov/resources/glossary/w.shtml.
[7] Lewis, K.L.M., Avery, C.W., and Reidmiller, D.R. (2018). Information in the Fourth National Climate Assessment. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, D.C., USA. https://www.globalchange.gov/browse/reports/overview-fourth-national-climate-assessment-volume-ii-impacts-risks-and-adaptation.
[8] Insurance Information Institute. https://www.iii.org/fact-statistic/facts-statistics-wildfires.
[9] Krishnakumar, P, Fox, J, and Keller, C. (2017) Here's where more than 7,500 buildings were destroyed and damaged in California's wine country fires. *Los Angeles Times*, October 23. http://www.latimes.com/projects/la-me-northern-california-fires-structures/.
[10] Martinuzzi, S., Stewart, S.I., Helmers, D.P., Mockrin, M.H., Hammer, R.B., and Radeloff, V.C. (2015). The 2010 wildland-urban interface of the conterminous United States. Research Map NRS-8. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 124 p. [includes pull-out map], *8*, 1-124.
[11] Liu, J.C., Pereira, G., Uhl, S.A., Bravo, M.A., and Bell, M.L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research*, *136*, 120-132.
[12] Cascio, W.E. (2018). Wildland fire smoke and human health. *Science of the Total Environment*, *624*, 586-595.
[13] Rappold, A.G., Stone, S.L., Cascio, W.E., Neas, L.M., Kilaru, V.J., Carraway, M.S., . . . , and Vaughan-Batten, H. (2011). Peat bog wildfire smoke exposure in rural North Carolina is associated with cardiopulmonary emergency department visits assessed through syndromic surveillance. *Environmental Health Perspectives*, *119*(10), 1415.
[14] Reid, C.E., Brauer, M., Johnston, F.H., Jerrett, M., Balmes, J.R., and Elliott, C.T. (2016). Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives*, *124*(9), 1334-1343.
[15] U.S. Environmental Protection Agency (2017). Profile of Version 1 of the *2014 National Emissions Inventory*. https://www.epa.gov/sites/production/files/2017-04/documents/2014neiv1_profile_final_april182017.pdf.

wildland fires can result in water quality degradation from elevated water temperature and sediment, nutrient, and contaminant transport.[16]

Wildland fire can impact air, water, and land and, thus, human health and the ecosystems across time and space. These impacts fall under the purview of EPA under the Clean Air Act (CAA), as well as various other federal agencies (indicated below in parentheses). During a wildland fire, fire, smoke, and ash can have impacts on ecosystems (U.S. Forest Service [USFS], Bureau of Land Management [BLM], U.S. Geological Survey [USGS], EPA, U.S. Fish and Wildlife Service [USFW], National Park Service [NPS], and National Oceanic and Atmospheric Administration [NOAA]) and human health (EPA, Centers for Disease Control and Prevention [CDC], Federal Emergency Management Agency [FEMA], National Institute of Environmental Health Sciences [NIEHS], and National Institute for Occupational Safety and Health [NIOSH]) that occur in and proximate to the area burned and distal downwind population centers on local, regional, and national/international spatial scales (EPA, BLM, NOAA, National Aeronautics and Space Administration [NASA], and the Bureau of Indian Affairs [BIA]). There can be other environmental impacts after fires, including landslides (USFS, USGS, and Army Corps of Engineers [USACE]) and increased dissolved organic matter that produces toxic by-products during drinking water treatment (EPA), for example.

The CAA requires EPA to set National Ambient Air Quality Standards (NAAQS) for six common air pollutants, also known as "criteria air pollutants." These pollutants are found all over the United States and can harm human health and the environment and cause property damage.[17] $PM_{2.5}$ and ozone are criteria pollutants of concern in relation to wildland fire. Thus, wildland fire is an important consideration in many aspects of air quality policy.

EPA's Office of Air and Radiation (OAR) developed the Air Quality Index (AQI) for reporting daily air quality.[18] It communicates how clean or polluted the air is in the indicated zip code and what associated health effects might be a concern. The AQI focuses on health effects that may be experienced within a few hours or days after breathing polluted air. EPA calculates the AQI for five major air pollutants regulated by the CAA: (1) ground-level ozone, (2) particulate matter ($PM_{2.5}$, PM_{10}), (3) carbon monoxide, (4) sulfur dioxide, and (5) nitrogen dioxide. For each of these pollutants, EPA has established NAAQS to protect public health and the environment. Ground-level ozone and airborne particles generally are regarded as the two air pollutants that pose the greatest threat to human health in this country.

EPA's mission requires the Agency's research efforts to focus on the fire impacts on the environment and public health, including the impacts on human health and ecosystems through worsening of ambient air quality from smoke, and on ecological impacts on soil and water. ORD has made and continues to make significant contributions to the body of knowledge on emissions characterization (emission factors), measuring and modeling smoke's impact on NAAQS, characterizing the components of smoke

[16] Neary, D.G., Ryan, K.C., and DeBano, L.F. (2005). Wildland fire in ecosystems: effects of fire on soils and water. Gen. Tech. Rep. RMRS-GTR-42-vol. 4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p.
[17] U.S. Environmental Protection Agency (n.d.). *Criteria Air Pollutants*. https://www.epa.gov/criteria-air-pollutants#self.
[18] U.S. Environmental Protection Agency (n.d.). *AirNow.* https://airnow.gov.

and their respective toxicities, physiological responses to smoke exposure, epidemiological studies for understanding population exposure to smoke and health outcomes, impacts of fire on water quality and quantity, and applying the social sciences to develop communications tools to help communities reduce exposure during smoke episodes.

ORD is well positioned to further engage with other Program and Regional Office partners within EPA, as well as organizations outside EPA, to further address knowledge gaps across the wildland fire topics, including:

- Development and evaluation of applicable ambient measurement technologies;
- Fate and transport of wildland fire smoke emissions;
- Elucidation of primary and secondary ambient air quality impacts;
- Effective interventions to reduce smoke exposure;
- Health risk communication and public education strategies to reduce the public's smoke exposure;
- Direct and indirect impacts of fire on watersheds and aquatic ecosystems;
- Indirect fire and smoke impacts on water quality and quantity, including drinking water infrastructure;
- Direct impact of fire and the remobilization of chemicals at contaminated sites;
- Air, water, and soil impacts of fires originating in the wildlands reaching and burning the WUI;
- Public health impacts resulting from smoke, including acute and repeated/chronic exposures over the course of a fire season; and
- Integration of social science approaches into public health research, including understanding the adverse impacts of these fires on vulnerable people and communities.

ORD will continue to engage and coordinate with EPA Program and Regional Offices (relevant EPA Program Office in parentheses below) through a Wildland Fire Coordinating Committee, described later in the document, as wildland fires and subsequent smoke can degrade air quality (OAR), affect hazardous waste sites (Office of Land and Emergency Management) and aquatic ecosystems and drinking water systems (Office of Water, Office of Homeland Security), impact tribal lands (Office of International and Tribal Affairs), lead to accidental releases of chemicals (Office of Environmental Compliance and Assurance), and trigger the use of fire retardants (Office of Chemical Safety and Pollution Prevention).

Wildland fire research coordination within EPA and externally with NOAA, NASA, Department of the Interior (DOI), USFS, FEMA, and other federal and nonfederal agencies continues to be essential.

Building a Solid Scientific Foundation in ORD

Through its National Laboratories, Centers, and NRPs and collaborations with other organizations, ORD has engaged in wildland-fire-related research for more than a decade. Additionally, ORD has convened and co-convened events to stimulate discussion on current research needs and areas of highest impact for future ORD research. These past activities have laid a strong basis for a well-coordinated and focused research program in the coming years.

Past and Future Activities

Several activities serve as stepping stones in the effort to scope and provide updates on ongoing work.

- *ACE Family Fire Summit*
  As a first step in a series of interactions to foster communication within EPA among ORD and Program and Regional Offices related to the Agency's work on fires, the Air, Climate, and Energy (now Air and Energy [A-E]) NRP sponsored the EPA-Family Wildland Fire Summit in May 2016. The workshop provided an internal forum to (1) develop a shared understanding of the nature of the problem, (2) establish a collective awareness of ongoing EPA research activities and current scientific uncertainties and policy challenges related to fire, and (3) explore opportunities for potential enhanced collaborations and leveraging of resources.

- *Wildfire Smoke Health Risk Communication Workshop*
  EPA convened the Wildfire Smoke and Health Risk Communication Workshop on September 22 and 23, 2016, with the goal of identifying opportunities for research and technological solutions that will improve health-risk communication strategies, increase health-protective behaviors, and reduce the public health burden during wildland fire smoke episodes.[19]

- *2nd International Smoke Symposium*
  EPA co-sponsored the International Association of Wildland Fire smoke symposium that brought together researchers from the atmospheric sciences, the ecological sciences, mathematics, and computer sciences and climatologists, social scientists, health professionals, smoke responders, and others to discuss the complex issues of wildland fire smoke and identify knowledge gaps and opportunities for innovation and development.[20]

- *Wildland Fire Prospectus*
  The *Wildland Fire Prospectus* organizes and summarizes the array of ongoing and planned fire-related activities across EPA Program Offices. The intent is to build on the ongoing work and thinking, not just within ORD but also across Program and Regional Offices. This prospectus identifies mechanisms to communicate EPA's wildland fire research and related work on protecting

[19] U.S. Environmental Protection Agency (n.d.). *Wildfire Smoke and Health Risk Communication Workshop and Report.* https://www.epa.gov/air-research/wildfire-smoke-and-health-risk-communication-workshop-and-report.
[20] International Association of Wildland Fire (n.d.). *2nd International Smoke Symposium.* https://www.iawfonline.org/event/2nd-international-smoke-symposium/.

public health, encouraging cross-EPA investment of effort to devise an integrated strategy built on systems-based science and policy.

- *Co-sponsorship of Workshop at the 2019 American Thoracic Society (ATS) International Conference*
  The ATS International Conference draws nearly 14,000 pulmonary, critical care, and sleep professionals to attend, present, and learn about the latest advances; meet with colleagues from around the world; and explore new collaborations. At the May 2019 annual meeting, EPA will co-sponsor the "Respiratory impacts of wildfire smoke: Future challenges and policy opportunities" workshop with expert panelists internal and external to EPA. The primary goal of the workshop is to identify impacts of wildfires on cardiopulmonary health in exposed individuals, communities, and heavily exposed occupational groups, as well as to determine how clinicians and the public health community should respond to protect respiratory and heart health.

Research Highlights

Flint Hills Air Measurement Campaigns

EPA researchers are supporting best smoke management practices for prescribed burns of prairies to reduce the impact of smoke in nearby communities and those much farther away. In November 2017, EPA and USFS researchers traveled to the prairies of Flint Hills, KS, to take air measurements during planned fires using novel air-sampling systems. Researchers also had visited the area in March 2017 during peak burn season to take air samples. They are using the two data sets to determine whether there are any differences in smoke plume emissions from spring to fall.[21]

Open Burn Test Facility (OBTF)

EPA's Research Triangle Park location has a 70 m^3 OBTF that has been used for laboratory simulation of burns for more than 20 years. The OBTF is an enclosed facility ventilated with a high-volume blower that pulls in ambient air and smaller, interior fans that, together, ensure complete mixing and oxygen concentration close to ambient conditions. Various studies have been performed in the OBTF to simulate fires that occurred naturally to hold constant various elements of burning (e.g., fuel type, moisture) and measure the characteristics of the smoke emitted (including amount and composition).

Sensors Field Testing and Wildfire Sensors Challenge

EPA and other federal agencies and states recognize the need for compact and field-deployable sensor technology to measure air pollutants emitted during wildfires. Data from these small sensors complement measurements obtained from more complex regulatory-grade monitors that are stationary or not easily transported. EPA, USFS, NPS, NOAA, NASA, and CDC partnered to

[21] U.S. Environmental Protection Agency (2017, December 5). *Science Matters: Novel Air Measurement Technology Supports Smoke Management Practices for Prescribed Burns*. https://www.epa.gov/sciencematters/novel-air-measurement-technology-supports-smoke-management-practices-prescribed-burns.

respond to the need for more monitoring capabilities during wildland fires through the Wildland Fire Sensors Challenge. The challenge aimed to stimulate innovation in the development of multipollutant sensors that can operate in wildfire conditions. A companion effort involving EPA ORD, Region 9, and Region 10 collaborating with USFS and other parties evaluates commercially available sensors during wildfire smoke events. These projects build on EPA's expertise in developing emissions and ambient monitoring systems that integrate sensor technologies, as well as field evaluation of commercially available sensors under smoke-impacted ambient conditions.[22]

Following the sensors challenge, EPA included a wildfire topic in the 2018-2019 Small Business Innovation Research (SBIR) program solicitation, requesting proposals on innovative measurement tools for ground-level air pollution levels from wildland fires.[23]

Modeling Smoke To Predict Air Quality Impacts

EPA applies its Community Multiscale Air Quality (CMAQ) model, developed to support air quality regulations and to study wildland fire smoke and evaluate its impact on air quality.[24] New approaches and methods developed for the model are making it possible to more accurately simulate and track emissions from smoke. As model sophistication improves, this tool could be used to help balance prescribed fire activity for land management with negative human health impacts resulting from smoke exposure.[25]

Wildfire Smoke Toxicity and Fuel Studies

In a laboratory in Research Triangle Park, NC, researchers are using an innovative tube furnace system to study the health effects of smoke in controlled conditions. They are investigating whether particles in smoke have different health effects depending on the type of wood burned and the stage of the fire, such as flaming or smoldering. Studies also are investigating aged smoke to understand how the properties and toxicity of smoke can change after traveling long distances.[26]

Smoke Sense Study and Mobile Application

EPA researchers are conducting a citizen science study called "Smoke Sense" to (1) determine the extent to which exposure to wildland fire smoke affects health and productivity and (2) develop health risk communication strategies that protect public health during smoke days. Individuals who

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[22] U.S. Environmental Protection Agency (2018, April 6). *Science Matters: Advancing Sensor Technology to Monitor Wildfires*. https://www.epa.gov/sciencematters/advancing-sensor-technology-monitor-wildfires.
[23] Small Business Innovation Research-Small Business Technology Transfer Program (n.d.). *Sensor Technology for the 21st Century*. https://www.sbir.gov/Sensor-technology-for-the-21st-century.
[24] U.S. Environmental Protection Agency (n.d.). *CMAQ: The Community Multiscale Air Quality Modeling System*. https://www.epa.gov/cmaq.
[25] U.S. Environmental Protection Agency (2018, April 23). *Science Matters: Tracking Smoke with Models to Protect Public Health.* www.epa.gov/sciencematters/tracking-smoke-models-protect-public-health.
[26] U.S. Environmental Protection Agency (2018, March 18). *Science Matters: The Science Behind Wildfire Smoke's Toxicity.* https://www.epa.gov/sciencematters/science-behind-wildfire-smokes-toxicity.

want to contribute to science can participate in the study by using the Smoke Sense app, a publicly available mobile application. Citizen scientists can use the app to learn about wildland fires and smoke health risks in their area.[27]

Community Health Vulnerability Index

EPA scientists developed a Community Health Vulnerability Index that can be used to help identify communities at higher health risk from wildfire smoke. Breathing smoke from a nearby wildfire is a health threat, especially for people with lung or heart disease, diabetes, and high blood pressure, as well as older adults and those living in communities with poverty, unemployment, and other indicators of social stress. Health officials can use the tool, in combination with air quality models, to focus public health strategies on vulnerable populations living in areas where air quality is impaired, either by wildfire smoke or other sources of pollution.[28]

Wildfire Smoke: A Guide for Public Health Officials

The guide is an easy-to-use resource that outlines whose health is most affected by wildfire smoke, how to reduce exposure to smoke, what public health actions are recommended, and how to communicate air quality to the public. The guide was developed through a collaboration among EPA, USFS, CDC, and the California Air Resources Board. The recommendations are based on science conducted by EPA and others.[29]

Smoke-Ready Toolbox for Wildfires

The Smoke-Ready Toolbox for Wildfires collects the various materials related to wildfires in one place. Public health officials can use the resources in the toolbox to help educate the public about the risks of smoke exposure and actions people can take to protect their health.[30]

Stream Water and Drinking Water Quality

Ongoing EPA research is focused on how wildfire affects both stream water quality and violations of drinking water standards at public water systems. Results have shown that large fire events often are associated with increases in extreme suspended sediment concentrations and stream temperatures in studied streams. The spatial and temporal variability of these postfire changes appear to be influenced by regional (e.g., vegetation type, fire regime, weather) and local (e.g., terrain, area)

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[27] U.S. Environmental Protection Agency (n.d.). *Smoke Sense Study: A Citizen Science Project Using a Mobile App.* https://www.epa.gov/air-research/smoke.

[28] Rappold, A.G., Reyes, J., Pouliot, G., Cascio, W.E., and Diaz-Sanchez, D. (2017). Community vulnerability to health impacts from wildland fire smoke exposure. *Environmental Science & Technology*, 6671-6682.

[29] U.S. Environmental Protection Agency, U.S. Forest Service, U.S. Centers for Disease Control and Prevention, California Air Resources Board (2016). *Wildfire Smoke: A Guide for Public Health Officials.* https://www3.epa.gov/airnow/wildfire_may2016.pdf.

[30] U.S. Environmental Protection Agency (n.d.). *Smoke-Ready Toolbox for Wildfires*. https://www.epa.gov/smoke-ready-toolbox-wildfires.

factors. For drinking water, the number of violations in standards for nitrate and two types of disinfectant by-products (potentially harmful by-products of water disinfection) show a significant increase postwildfire. Maximum violation concentrations also increase postwildfire for nitrate and disinfectant by-products, although mean violation concentrations increased only for nitrate. This work illustrates that wildfire can impact water quality in both streams and drinking water systems.

Extramural Science to Achieve Results (STAR) Grants

EPA's STAR program engages some of the nation's best scientists and engineers. Through grants, STAR researchers conduct targeted research across several scientific disciplines. STAR research is funded through a competitive solicitation process or request for applications (RFA). The RFAs are derived from the EPA ORD's Strategic Plan and research plans for specific topics in cooperation with other parts of the Agency.

Impact of Climate Change on Wildfire and Air Quality

Seminal studies resulting from the 2004 "Fire, Climate and Air Quality" solicitation showed that wildfires drive interannual variability of the organic carbon component of $PM_{2.5}$ in the western United States in summer, and that projected increases in wildfire area burned in the western United States could lead to more frequent or longer episodes of wildfire smoke across the region.[31,32] More recent studies investigated the contribution of wildfire to ozone.[33,34] Efforts are continuing through internal research activities and several "Particulate Matter and Related Pollutants in a Changing World" STAR grants.[35]

Health Impacts of Wildfire Smoke

EPA and STAR researchers have investigated the impacts of wildfire smokes on premature mortality and hospital admissions, as well as factors that affect people's susceptibility to smoke.[36,37,38,39]

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[31] Spracklen, D.V., Logan, J.A., Mickley, L.J., Park, R.J., Yevich, R., Westerling, A.L., and Jaffe, D.A. (2007). Wildfires drive interannual variability of organic carbon aerosol in the western US in summer. *Geophysical Research Letters*, *34*(16).

[32] Spracklen, D.V., Mickley, L.J., Logan, J.A., Hudman, R.C., Yevich, R., Flannigan, M.D., and Westerling, A.L. (2009). Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. *Journal of Geophysical Research: Atmospheres*, *114*(D20).

[33] Lin, M., Horowitz, L.W., Payton, R., Fiore, A M., and Tonnesen, G. (2017). US surface ozone trends and extremes from 1980 to 2014: quantifying the roles of rising Asian emissions, domestic controls, wildfires, and climate. *Atmospheric Chemistry and Physics*, *17*(4).

[34] Yue, X., Mickley, L.J., Logan, J.A., Hudman, R.C., Martin, M.V., and Yantosca, R.M. (2015). Impact of 2050 climate change on North American wildfire: consequences for ozone air quality. *Atmospheric Chemistry and Physics*, *15*(17), 10033-10055.

[35] U.S. Environmental Protection Agency (n.d.). *Particulate Matter and Related Pollutants in a Changing World*. Retrieved from National Center for Environmental Research: Science to Achieve Results (STAR) Program.

[36] Rappold, A.G., Cascio, W.E., Kilaru, V.J., Stone, S.L., Neas, L.M., Devlin, R.B., and Diaz-Sanchez, D. (2012). Cardio-respiratory outcomes associated with exposure to wildfire smoke are modified by measures of community health. *Environmental Health*, *11*(1), 71.

[37] Liu, J.C., Pereira, G., Uhl, S.A., Bravo, M.A., and Bell, M.L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research*, *136*, 120-132.

[38] Liu, J.C., Wilson, A., Mickley, L.J., Ebisu, K., Sulprizio, M.P., Wang, Y., . . . , and Bell, M.L. (2017). Who Among the Elderly Is Most Vulnerable to Exposure to and Health Risks of Fine Particulate Matter From Wildfire Smoke? *American Journal of Epidemiology*, *186*(6), 730-735.

[39] Liu, J.C., Wilson, A., Mickley, L.J., Dominici, F., Ebisu, K., Wang, Y., . . . , and Anderson, G.B. (2017). Wildfire-specific Fine Particulate Matter and Risk of Hospital Admissions in Urban and Rural Counties. *Epidemiology*, 28(1), 77-85.

Epidemiological studies are ongoing in "Particulate Matter and Related Pollutants in a Changing World" and "ACE Centers" STAR grants.

Characterization of Fire Emissions

Across multiple solicitations, STAR has funded research to characterize the properties of emissions from a wide range of fires. Highlights include laboratory measurements of photochemical properties of organic aerosol from fire emissions, field measurements of gaseous and particulate emissions from prescribed burns in Georgia, and ambient sampling to characterize physicochemical and toxicological profiles of PM from fires in southern California and chemical markers of PM from fires in Montana.[40,41,42,43]

Extramural National Priorities Grants

EPA's National Priorities grants are similar to the STAR program in that they engage leading experts in water quality and quantity and complement EPA's exceptional intramural water research program. Research grants awarded by ORD's Safe and Sustainable Water Resources (SSWR) NRP emphasize a "systems thinking" approach to understand wildland fire impacts, for example:

- Evaluation of fire reduction management techniques and resulting drinking water impacts from erosion, sediment, dissolved organic matter (DOM), and disinfection byproducts (DBPs) [This research is measuring fluxes and trends of DOM and exported nutrients, in-stream biogeochemical processes (e.g., photochemical and algal effects on DOM characterization), conventional treatment and DBP precursor treatability, and the change in geno- and cyto-toxicity indices of DBPs.];
- Modeling the mobilization and transport of DOM, sediments, and nutrients through the watershed and to the water treatment plant;
- Developing source water thresholds for turbidity and DBP precursors based on regulatory constraints in the finished water and using stream water quality data with extreme value theory to predict water quality threshold exceedances; and
- Evaluating a suite of adaptation and operation strategies (e.g., watershed management, wildland fire mitigation, water treatment plant modifications), along with their economic, societal, and policy implications using multiobjective optimization and multicriteria analysis tools.

[40] Hennigan, C.J., Miracolo, M.A., Engelhart, G.J., May, A.A., Presto, A.A., Lee, T., . . . , and Hao, W.M. (2011). Chemical and physical transformations of organic aerosol from the photo-oxidation of open biomass burning emissions in an environmental chamber. *Atmospheric Chemistry and Physics, 11*(15), 7669-7686.

[41] Lee, S., Baumann, K., Schauer, J.J., Sheesley, R.J., Naeher, L.P., Meinardi, S., . . . , and Clements, M. (2005). Gaseous and particulate emissions from prescribed burning in Georgia. *Environmental Science & Technology*, *39*(23), 9049-9056.

[42] Verma, V., Polidori, A., Schauer, J.J., Shafer, M.M., Cassee, F.R., and Sioutas, C. (2009). Physicochemical and toxicological profiles of particulate matter in Los Angeles during the October 2007 southern California wildfires. *Environmental Science & Technology*, *43*(3), 954-960.

[43] Ward, T.J., Hamilton Jr., R.F., Dixon, R.W., Paulsen, M., and Simpson, C.D. (2006). Characterization and evaluation of smoke tracers in PM: results from the 2003 Montana wildfire season. *Atmospheric Environment, 40*(36), 7005-7017.

Opportunities for Connection, Coordination, and Collaboration

To build on the planned research across the NRPs and move wildland fire research forward, both internal coordination at EPA and outreach to other organizations are crucial to design and produce research that informs solutions that protect communities and ecosystems from wildland fire impacts.

ORD Research 2019-2022

There are six NRPs in ORD: (1) Air and Energy (A-E), (2) Safe and Sustainable Water Resources (SSWR), (3) Chemical Safety for Sustainability (CSS), (4) Human Health Risk Assessment (HHRA), (5) Homeland Security (HS), and (6) Sustainable and Healthy Communities (SHC). Each NRP supports the needs of various EPA Program and Regional Offices, states, and tribes. Wildland fires have been identified in the 2019-2022 StRAPs as a cross-cutting issue that requires coordination across the NRPs, covered primarily by A-E, SSWR, and HS. Each program has provided valuable input to this forward-thinking planning as it pertains to its program.

Emissions from conventional sources of air pollution have been reduced, yet the changing environment increases the likelihood and severity of wildfires and the optimal window for the prescribed burning season. Research in A-E will focus on improving our understanding of wildland fire impacts on public and environmental health and informing approaches to reduce associated risks. This will include improving models and measurement methodologies to assess emissions and determine impacts, determining what ecosystems and human populations are susceptible and vulnerable to wildland fires, developing approaches to mitigate risks to human health and ecosystems, and developing health risk communication strategies.

Wildland fires also can affect drinking water quality through increased sedimentation; mobilization of nutrients, heavy metals, and other pollutants; and shifts in treatment processes and associated effects, such as higher concentrations of nitrate and DBPs posttreatment. For SSWR, this cross-cutting research will provide information needed by utilities, especially small drinking water systems, to anticipate and respond to wildfire impacts.

The HS research program is concerned with the fate and transport of pollutants from contaminated areas during wildland fires and the health and environmental effects of the release of contaminants from waste facilities and sites resulting from wildfires. Such a release can pose risks to communities and impact disaster preparedness and response and ecological restoration. Difficult to remediate areas can remain a source of exposure or spread contamination; wildland fires offer one potential method of spreading this contamination to uncontaminated or remediated areas.

Internal Coordination

To ensure cohesion for the cross-cutting topic of wildland fire research across the NRPs, A-E will chair the Wildland Fire Coordinating Committee (WFCC) to connect the research across ORD. The committee will consist of representatives within ORD NRPs, Laboratories, and Centers, as well as interested Regional and Program Offices. The WFCC will meet twice a year, possibly more as needed, to provide updates and foster opportunities for connections of research across ORD and convene an

annual wildland fire meeting for EPA researchers. This meeting is also an opportunity to provide updates on research activities and plans, revisit the research questions (see Problem Statements and Research Questions below), and assess the impact of ORD research every year. This coordinated ORD effort also may improve information sharing and connections with Program and Regional Offices, state and local agencies, and tribal organizations.

Examples of Projects with ORD Coordination

The WFCC will foster connection, communication, and collaboration across the Agency. Two ongoing projects that draw on expertise across ORD and coordinate across NRPs are highlighted below.

Cross-NRP Research on Wildfires and Drinking Water

Recognizing the increased risk to drinking water from wildland fire, SSWR has included in its 2019-2022 StRAP research an assessment of impacts from wildfires and drought on aquatic resources. Additionally, ORD received an initial investment of funds to respond to the Agency's needs for improved understanding, information, data, and tools to assist our stakeholders in managing wildfire-water quality risks. Scientists from various laboratories in ORD have formed an interdisciplinary collaboration, under the auspices of the A-E and SSWR NRPs, to begin coordinating relevant research activities and building an integrated knowledge base about wildfire impacts on watersheds, ambient water quality, and drinking water systems in the fire-prone areas of the United States. This emerging research activity is cross-laboratory and cross-program to focus on the water quality-related impacts of wildfires while, simultaneously, building the foundation for a longer-term effort to systematically explore the numerous ways that wildfires have multimedia impacts.

Solutions-Driven Research Pilot

ORD is committed to improving its approaches for translating research results to inform decision making by studying the ways in which Agency researchers design integrated research and engage with each other, Program and Regional Offices, state and local agencies, and tribal organizations to identify and deliver science that is used to address and solve complex environmental public health problems. This solutions-driven research approach, as outlined in the StRAPs, will provide ORD with critical information needed to continually improve and increase the value of ORD research products to our partners and external stakeholders.

ORD is adopting a three-pronged strategy for Solutions Driven Research:

(1) Apply principles of translational research broadly across research programs;
(2) Conduct two pilot solutions-driven research science projects that apply and evaluate methods of translational research to plan and conduct research that addresses a well-defined and unmet need of stakeholders, including application and evaluation of outputs with partners; and
(3) Conduct case studies of previous and current research activities that embody the principles of translational research to begin developing a list of good practices for translational research.

A-E will coordinate one of the above pilot projects that is focused on wildland fire. This project is under development and will focus on identifying effective intervention strategies to reduce wildland fire impacts on human health. This pilot provides another opportunity to expand communication and cross-pollination within ORD and across partners around both existing and future projects.

Federal Partnerships

Although commitment and capacity are strong in ORD, coordination with other organizations is crucial to ensure communities and ecosystems are protected and to avoid duplication of efforts. Beyond communication, the key to translational research is stakeholder involvement from research planning through implementation and evaluation. Providing opportunities to foster and expand workgroups at international, federal, state, and regional levels is critical to ensure that the data, tools, synthesis products, and resources produced in ORD continuously and consistently are addressing needs and are readily applicable to issues. EPA's Regional and Program Offices have ongoing collaborations with other federal agencies related to wildland fire, public health, and environmental impacts. This document is focused on ORD's partnerships.

Federal Partners

Table 1 is a compilation of other federal agencies involved in wildland fire research, their self-described role and summary of research (if noted on their external facing Web sites), and ORD's recent or ongoing collaborations with these agencies.

Table 1. Federal agencies' roles, research, and collaborations with ORD related to wildland fire.

Agency	Role of Agency in Wildland Fire Research	Summary of Research	Recent or Ongoing Collaboration with ORD
	"Recognizing the scale and complexity of wildland fires, which affects millions of acres each year, the [USFS] has a network of fire labs and research stations across the country. [USFS] fire scientists develop knowledge and tools that help reduce the negative impacts of fire while enhancing its beneficial effects for society and the environment. [USFS] experts work with the NASA, which provides satellite imagery and other resources to assist the [USFS] in fighting fires and preventing future ones."[44]	"The research focuses on understanding and modeling fundamental fire processes, interactions of fire with ecosystems and the environment, social and economic aspects of fire, evaluating integrated management strategies and disturbance interactions, and applying fire research to management problems."[45]	Wildland Fire Sensors Challenge Wildfire Guide for Public Health Officials The Interagency Agreement with the USFS for collaborative research on

[44] U.S. Forest Service (n.d.). *Fire Research*. www.fs.fed.us/science-technology/fire/fire-research.
[45] U.S. Forest Service (n.d.). *Wildland Fire & Fuel*. https://www.fs.fed.us/research/wildland-fire/.

			forested watersheds is a joint effort between EPA and USFS to examine the interactions of wild fire, pests, and disease on forest health. Results will inform both EPA and USFS on the risks to water resources from wildland fire.
	The Earth System Research Laboratory Chemical Sciences Division is leading the FIREX multiyear experiment, which will • include laboratory, field, and modeling research; • culminate in an extensive field study during the peak fire season of 2019 (July-August) using a chemically instrumented NOAA research aircraft to measure trace gases and particles.[46] "The objective of the [National Weather Service (NWS)] Fire Weather Program is to provide fire weather and other products and decision support services to the fire, land management and emergency response community for the protection of life and property, promotion of firefighter and emergency responder safety, and stewardship of America's public lands." NWS also produces daily air	Smoke plume modeling and hazard mapping; transport, transformation, and plume chemistry; sampling of emissions via aircraft; and fire influence on regional and global environments	Wildland Fire Sensors Challenge Hazard Mapping System integrated into tools, such as Smoke Sense

[46] National Oceanic and Atmospheric Administration (n.d.). *The Impact of Wildfires on Climate and Air Quality: An emerging focus of the NOAA ESRL Chemical Sciences Division.* Retrieved from FIREX 2016-2019 Science Overview: https://www.esrl.noaa.gov/csd/factsheets/csdWildfiresFIREX.pdf.

	quality forecasts that include smoke forecast.[47]		
	"The Wildland Fires Application area promotes the use of Earth observations and models focused on addressing issues related to wildland fire in support of management strategies, business practices, and policy analysis and decisions."[48]	"The Wildland Fire applications includes support of all aspects of pre, active and post-fire analysis tools that use Earth observations and models to enhance fuel load estimates, fuel treatment planning, risk assessment, air quality, insect infestations, burned area remediation and rehabilitation, and other topics that lead to improved land-management decisions."[50]	Wildland Fire Sensors Challenge
	The National Institute of Standards and Technology "Fire Research Division develops, verifies, and utilizes measurements and predictive methods to quantify the behavior of fire and means to reduce the impact of fire on people, property, and the environment. This work involves integration of laboratory measurements, verified methods of prediction, and large-scale fire experiments to demonstrate the use and value of the research products."[49]	"Through its programs in measurement, prediction, systems integration, and the dynamics of fire and its interactions with the built and natural environment, the division provides leadership for advancing the theory and practice of fire safety engineering, firefighting, fire investigation, fire testing, fire data management, and intentional burning."[51]	
	The CDC provides information on how to stay safe and healthy before, during, and after a wildfire, including avoiding health impacts from wildfire smoke and cleaning up safely.[50]	Development of consistent health risk communication Development of information and messages about impacts of smoke exposure, and community preparedness	Wildfire Guide for Public Health Officials Wildland Fire Sensors Challenge
	"Every year, hundreds of thousands of acres of land burn across the United States and Wildland Firefighters (WFFs) are asked to protect our lives, our homes and our forests. NIOSH provides up-to-date information about occupational health and safety research and investigations	Apply findings from occupational health respirator use for smoke to community-level recommendations	

[47] National Weather Service (2017, November 7). *National Weather Service Policy Directive: Products and Services to Support Fire and Other Incidents.* https://www.nws.noaa.gov/directives/sym/pd01004curr.pdf.
[48] National Aeronautics and Space Administration (n.d.). *Applied Sciences Program: Wildland Fires Program.* https://appliedsciences.nasa.gov/programs/wildfires-program.
[49] National Institute of Standards and Technology (n.d.). *Fire Research Division.* https://www.nist.gov/el/fire-research-division-73300.
[50] Centers for Disease Control and Prevention (n.d.). *Natural Disasters and Severe Weather: Wildfires.* https://www.cdc.gov/disasters/wildfires/index.html.

	conducted by NIOSH and our partners."[51]		
NIH NIEHS	NIEHS is funding grantee research "to better understand the impacts of wildfires on the health of vulnerable individuals and communities exposed to such events."[52]	"The NIEHS Worker Training Program serves communities after wildfires, hurricanes, and other natural and manmade disasters. WTP develops training tools for those who perform hazardous material removal, transportation, emergency response, and related activities. The program develops model courses, and its awardees deliver peer-led, hands-on instruction, as well as comprehensive train-the-trainer programs."[53]	
FEMA U.S. Fire Administration	"As an entity of the U.S. Department of Homeland Security's Federal Emergency Management Agency, the mission of the U.S. Fire Administration is to provide national leadership to foster a solid foundation for our fire and emergency services stakeholders in prevention, preparedness and response."[54]	Planning and response materials for communities	
NSF	National Science Foundation's Atmospheric Chemistry Program supports research to measure and model the concentration and distribution of gases and aerosols in the atmosphere, including research studying the contributions of fire to atmospheric ozone and PM.[55]	Funding of interdisciplinary wildland fire research activities	
SERDP DOD • EPA • DOE ESTCP	"To support DoD's continued use of fire as a management tool, Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) are working to address both characterizing emissions associated	"SERDP supports research to characterize fire emissions from southeastern and southwestern vegetation types managed by DoD and to advance the development of models for assessing the impact of fire on air quality."[68]	

[51] National Institute for Occupational Safety and Health (n.d.). *Workplace Safety and Health Topics: Fighting Wildfires.* https://www.cdc.gov/niosh/topics/firefighting/default.html.
[52] National Institute of Environmental Health Sciences (n.d.). *Global Environmental Health Newsletter.* https://www.niehs.nih.gov/research/programs/geh/geh_newsletter/2018/10/articles/research_explores_link_between_global_wildfires_climate_change_and_human_health.cfm.
[53] National Institute of Environmental Health Sciences (2018, October). *Wildfire cleanup crews benefit from worker training.* Retrieved from *Environmental Factor*: https://factor.niehs.nih.gov/2018/10/community-impact/wildfires/index.htm.
[54] U.S. Fire Administration (n.d.). *About the U.S. Fire Administration.* https://www.usfa.fema.gov/about/.
[55] National Science Foundation (n.d.). *Division of Atmospheric and Geospace Sciences: Atmospheric Chemistry.* https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=11692.

	with fire and understanding how fire acts as a disturbance process that resets ecological communities."[56]		
	"DOE's Atmospheric System Research (ASR) program supports science to advance understanding the interactions among aerosols, clouds, precipitation, radiation, dynamics, and thermodynamics, including the role of wildland fires as source of atmospheric aerosols."[57]	"The primary research objectives for the new ASR program are grouped according to the following themes: • aerosol life cycle • cloud life cycle, and • aerosol-cloud-precipitation interactions."[58]	
	"The Office of Wildland Fire (OWF) leads budget oversight and programmatic governance for the Department's wildland fire program. Representing the Secretary of the Interior, OWF bridges the individual fire programs of the four land management bureaus as well as supports the wildland fire needs of all the bureaus across the Department to create an integrated and cohesive Department-wide fire program."[59]	"The Department of the Interior's Wildland Fire Management seeks to use the best available science in planning and implementation of its programs, and conduct research when needed. The Joint Fire Science Program (JFSP) is the most prominent means of developing and sharing scientific information as it relates to wildland fire, although the Department bureaus perform the research (e.g., USGS) and in cooperation with USFS."[60]	
	"Our Mission is to execute our fiduciary trust responsibility by protecting lives, property, and resources while restoring and maintaining healthy ecosystems through cost-effective and creative fire-management programs, collaboration, and promoting Indian self-determination."[61]	"The Branch of Wildland Fire Management is responsible for the development of policies and standards for wildfire response, firefighting safety and training as well as preventing wildland fires. The Branch also provides guidance to BIA Regional Directors regarding the use of prescribed fire and fuels management to achieve integrated wildland fire management objectives based on management plans approved by the Indian land owner."[62]	

[56] SERDP-ESTCP: DoD's Environmental Research Programs (n.d.). *Wildland Fire and Prescribed Burning.* https://www.serdp-estcp.org/Featured-Initiatives/Range-Sustainment/Wildland-Fire-and-Prescribed-Burning/(language)/eng-US.
[57] U.S. Department of Energy (n.d.). *Climate and Environmental Sciences Division: Atmospheric System Research (ASR) Program.* https://science.energy.gov/ber/research/cesd/atmospheric-system-research-program/.
[58] U.S. Department of Energy (n.d.). *About Atmospheric System Research.* https://asr.science.energy.gov/about.
[59] U.S. Department of Interior (n.d.). *The Office of Wildland Fire.* https://www.doi.gov/wildlandfire.
[60] U.S. Department of the Interior (n.d.). *Office of Wildland Fire: Science.* https://www.doi.gov/wildlandfire/science.
[61] U.S. Department of the Interior: Indian Affairs (n.d.). *Division of Forestry and Wildland Fire Management: Branch of Wildland Fire Management.* https://www.bia.gov/bia/ots/dfwfm/bwfm.
[62] U.S. Department of the Interior: Indian Affairs (n.d.). *Division of Forestry and Wildland Fire Management.* https://www.bia.gov/bia/ots/dfwfm.

	"The NPS manages wildland fire to protect the public, communities and infrastructure, conserve natural and cultural resources, and restore and maintain ecological health."[63]	"Fire managers look to scientific research for guidance on how prescribed burns and lightning-started fires can be used to benefit ecological systems. They examine historic fire regimes and past cultural practices, and use predictive modeling to study future fire effects under different climates and communities. Fire research is also important for forecasting fire behavior and spread across the landscape for suppression tactics, planning fuels reduction treatments, and fire season preparedness."[64]	Wildland Fire Sensors Challenge
	"The BLM, a leader in the nation's management of wildland fire, carries out a broad range of actions to protect the public, natural landscapes, wildlife habitat, recreational areas, and other values and resources."[65]	"The agency's national Fire and Aviation Program, which focuses on public safety as its top priority, consists of fire suppression, preparedness, predictive services, vegetative fuels management, prescribed fire, community assistance and protection, and fire prevention through education." [64]	Forest management scenarios in a changing climate: Trade-offs between carbon, timber, and old forest
USGS science for a changing world	"[USGS carries out] a wide range of wildfire-related science activities that span multiple USGS mission areas, including landscape ecology studies, geospatial support for fire response, burned area hydrology, and post-fire debris flow warnings."[66]	"The U.S. Geological Survey produces wildland fire science, data, and tools that are essential to decision making before, during, and after wildfires, and are used by fire and land management agencies, states and tribes, landowners, and communities across the U.S. Areas of emphasis for fire science work at USGS include: • Effects of wildfire and prescribed fire on plants, wildlife and ecosystems • Wildland fire history and management, including post-fire restoration and recovery, especially on lands managed by the DOI • Characterize risk of post-fire flooding, sedimentation, debris flow, smoke, and toxic fire ash • Remote sensing and geospatial data, tools and products to support decision making by fire and land managers"[67]	Using unmanned aircraft systems, or drones, to acquire both fire intensity and emissions data during prescribed burns

[63] National Park Service (n.d.). *Wildland Fire Program: What We Do.* https://www.nps.gov/orgs/1965/whatwedo.htm.
[64] National Park Service (n.d.). *Fire Ecology and Research.* https://www.nps.gov/orgs/1965/fire-ecology-research.htm.
[65] Bureau of Land Management (n.d.). *Fire and Aviation Program.* https://www.blm.gov/programs/fire-and-aviation.
[66] U.S. Geological Survey (n.d.). *Wildfire Hazards.* https://www.usgs.gov/natural-hazards/wildfire-hazards?qt-programs_l2_landing_page=0#qt-programs_l2_landing_page.
[67] U.S. Geological Survey (n.d.). *Wildland Fire Science.* https://www2.usgs.gov/ecosystems/environments/fireecology.html.

	"The FWS manages land units in all of the 50 states, as well as all U.S. territories (in Puerto Rico, the Virgin Islands, and the Pacific Islands). The FWS fire program is responsible for protecting more land management units than any other federal agency, with more than 75 million burnable acres; many of these are small coastal and urban tracts with extensive WUI areas along the East, West, and Gulf Coasts and in the Midwest."[68]	"The FWS fire management program includes fuels management, wildfire management, and wildfire prevention. This involves technical expertise in firefighting and prescribed burning, an understanding of fire ecology, and interaction with the public. Arguably one of the most physically arduous and dangerous natural resource professions, wildland fire management involves multiple objectives and dynamic strategies, depending upon conditions and resource objectives outlined in the fire management plan for a specific unit."[67]	

Current and Planned Interagency Research Projects

ORD researchers are providing input on external interagency research activities, some highlighted below. The data and findings from these studies can inform ORD research.

WE-CAN

The Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption, and Nitrogen (WE-CAN) project team of federal and university partners notes that understanding the chemistry in western wildfire smoke has major ramifications for air quality, nutrient cycles, weather, and climate. This NSF funded project will systematically characterize emissions of western U.S. wildfire plumes from July 22 to September 14, 2018. The project will focus on three sets of scientific questions related to fixed nitrogen, absorbing aerosols, cloud activation, and chemistry in wildfire plumes. The data will be collected from the National Center for Atmospheric Research/NSF C-130 research aircraft.[69]

BB-FLUX

A related field campaign will take place in conjunction with WE-CAN to quantify gaseous emission fluxes from wildfires using a novel Solar Occultation Flux (SOF) instrument from July through September 2018. This project (BB-FLUX) will utilize the Wyoming King Air to quantify emission fluxes of carbon monoxide, carbon dioxide, and other gases and particle volume for different fuel types; characterize plume injection heights; and study radical sources and secondary plume chemistry that lead to secondary production of ozone and changes in the particle size distribution as plumes age.[70]

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[68] U.S. Fish and Wildlife Service (n.d.). *Fire Management: What We Do.* https://www.fws.gov/fire/what_we_do/.
[69] NCAR-UCAR: Earth Observing Laboratory (n.d.). *WE-CAN: Western Wildfire Experiment for Cloud Chemistry, Aerosol Absorption and Nitrogen.* https://www.eol.ucar.edu/field_projects/we-can.
[70] National Science Foundation (n.d.). *Awards: Biomass Burning Flux Measurements of Trace Gases and Aerosols (BB-FLUX) Using Solar Occultation Flux (SOF) on the Wyoming King Air.* https://www.nsf.gov/awardsearch/showAward?AWD_ID=1754019&HistoricalAwards=false.

FASMEE

"The primary objective of the multiagency Fire and Smoke Modeling Experiment (FASMEE) project is to gather observational data needed to evaluate and advance fire and smoke modeling systems. The project has two phases. The main deliverable of Phase 1 (2015-2018) is a comprehensive study plan that will include sampling methodology, safety, logistics, data management, and a detailed budget. Discipline leads for (1) fuels and consumption, (2) fire behavior and energy, (3) plume dynamics and meteorology, (4) emissions and chemistry, and (5) model simulation have been selected and are assisting in identifying observational data to be collected and in drafting the study plan. The planning phase is supported by the Joint Fire Science Program (JFSP) and the Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP). EPA participated in Phase 1. Phase 2 is a field data collection campaign that [began] in the fall of 2018 and extend[s] through 2021. During this phase, data is proposed to be collected on 4 to 8 large (>200 hectares) operational prescribed burns located on the Fishlake and Kaibab National Forests in the southwestern United States and on Fort Stewart and the Savannah River Site in the southeastern United States. The sites have heavy fuel loads and will be burned under prescriptions that will create a relatively high intensity fire."[71] Currently, there are no funding opportunities for the phase 2 field study component of this program.[72]

FIREX-AQ

A joint 2019 NOAA/NASA field program building off their 2016 laboratory experiment component, the Fire Influence on Regional and Global Environments Experiment-Air Quality (FIREX-AQ) campaign, combines the previously separate NASA FIREChem and NOAA FIREX programs to better study the atmospheric effects of wildland and agricultural fires in the United States. "The overarching objective of FIREX-AQ is to provide measurements of trace gas and aerosol emissions for wildfires and prescribed fires in great detail, relate them to fuel and fire conditions at the point of emission, characterize the conditions relating to plume rise, follow plumes downwind to understand chemical transformation and air quality impacts, and assess the efficacy of satellite detections for estimating the emissions from sampled fires."[73] "The overarching objective of FIREX-AQ is to provide measurements of trace gas and aerosol emissions for wildfires and prescribed fires in great detail, relate them to fuel and fire conditions at the point of emission, characterize the conditions relating to plume rise, follow plumes downwind to understand chemical transformation and air quality impacts, and assess the efficacy of satellite detections for estimating the emissions from

[71] Ottmar, R.D., and Larkin, N.K. (2017). Fire and Smoke Model Evaluation Experiment (FASMEE). The Nature Conservancy. Retrieved from https://www.frames.gov/catalog/22813.
[72] Fire and Smoke Model Evaluation Experiment (n.d.). *Fire and Smoke Model Evaluation Experiment (FASMEE).* https://www.fasmee.net/.
[73]National Oceanic and Atmospheric Administration (n.d.). *FIREX-AQ 2019: Science Overview.* https://esrl.noaa.gov/csd/projects/firex-aq/science.html.

sampled fires." [74] EPA served on the FIREX steering committee and will continue its participation on the FIREX-AQ committee. EPA's involvement with these leading fire field campaigns will ensure that the data collected is appropriate for model evaluation and development.

Monitoring Trends in Burn Severity (MTBS)

MTBS "is an interagency program whose goal is to consistently map the burn severity and extent of large fires across all lands of the United States from 1984 to present. This includes all fires 1000 acres or greater in the western United States and 500 acres or greater in the eastern United States. The extent of coverage includes the continental United States., Alaska, Hawaii, and Puerto Rico. The program is conducted by the USGS Center for Earth Resources Observation and Science (EROS) and the USDA Forest Service Geospatial Technology and Applications Center (GTAC). MTBS was first enacted in 2005, primarily to meet the information needs of the Wildland Fire Leadership Council (WFLC).

The primary objective at that time was to provide data to the WFLC for monitoring the effectiveness of the 10-year National Fire Plan. The scope of the program has grown since inception and provides data to a wide range of users. These include national policy makers, such as WFLC and others, who are focused on implementing and monitoring national fire management strategies; field management units, such as National Forests, National Parks, and other federal and tribal lands that benefit from the availability of GIS-ready maps and data; other federal land cover mapping programs, such as LANDFIRE, which utilizes burn severity data in their own efforts; and academic and agency research entities interested in fire severity data over significant geographic and temporal extents."[75]

Fire Research and Management Exchange System (FRAMES)

FRAMES "provides a method of exchanging information and transferring technology among wildland fire researchers, managers, and other stakeholders in an online environment. The FRAMES portal provides essential searchable information, a platform for data sharing and storage, development of new tools, and support to federal wildland fire management agencies in the United States throughout the various stages of wildland fire, including planning, operation, and postfire monitoring."[76] Partners include Alaska Fire Science Consortium, DOI/BLM, JSFS, NOAA, NPS, Montana State University, National Center for Landscape Fire Analysis, Southwest Fire Consortium, Tall Timbers Research Station and Land Conservancy, DOI/USFW, USFS, USFS Rocky Mountain Research Station, Oregon State University, USGS, University of Alaska Fairbanks, University of Idaho, University of Washington, University of Montana, Wildland Fire Lessons Learned Center,

[74] National Oceanic and Atmospheric Administration (n.d.). *FIREX-AQ 2019: Fire Influence on Regional to Global Environments and Air Quality*. https://www.esrl.noaa.gov/csd/projects/firex-aq/.
[75] Monitoring Trends in Burn Severity (n.d.). *Monitoring Trends in Burn Severity: Project Overview*. https://mtbs.gov/project-overview.
[76] Frames (n.d.). *About Frames.* https://www.frames.gov/about/about-frames.

and National Wildland Fire Coordinating Group-Wildland Fire Management Research, Development & Application Program.

Existing Interagency Coordinating Groups

There are existing interagency wildland fire research groups and committees in which ORD scientists have been involved.

- Air Resource Advisors (ARAs) are trained to be dispatched to an incident to assist with understanding and predicting smoke impacts on the public and fire personnel. They analyze, summarize, and communicate these impacts to incident management teams, air quality regulators, and the public. Smoke from wildfires can impact the public and fire personnel, affecting their health and safety, interfering with transportation and operational safety, and upsetting tourism and local economies. ARAs are technical specialists with expertise in air quality monitoring, smoke modeling, pollutant health effects, and communicating about smoke risks and mitigation. During wildfire incidents when smoke is a concern, their objective is to provide timely smoke impact and forecast information based on the best available science. They work within the National Incident Management System under the direction of an incident commander and engage with public information officers, fire behavior analysts, and incident meteorologists to understand and communicate smoke issues. In the course of their duties, ARAs coordinate with multiple agencies to address public health risks and concerns and risks to transportation safety and support the overall incident response. As of 2018, USFS has nine EPA ARAs, including one from ORD, who annually are deployed to support wildfire response.

- "The Wildland Fire Leadership Council (Council) is an intergovernmental committee of Federal, state, tribal, county, and municipal government officials convened by the Secretaries of the Interior, Agriculture, Defense, and Homeland Security dedicated to consistent implementation of wildland fire policies, goals, and management activities. The Council provides strategic recommendations to help ensure policy coordination, accountability and effective implementation of Federal wildland fire management policy and related long-term strategies through a collaborative environment to help ensure effective and efficient wildfire management, promote fire-adapted communities, and create resilient landscapes to achieve long-range benefits for society and nature."[77]

- The Joint Fire Science Program (JFSP) "provides leadership to the fire science community by identifying high-priority fire science research needs that will enhance the decision-making ability of fire and fuels managers, natural resource managers, and others to meet their management objectives. The program also meets the decision needs of those involved in developing and implementing fire-related policy. The Fire Science Exchange Network involves active knowledge exchange. The objective is to foster dialogue in which scientists and manger[s] help frame questions and research needs to address during both planning and execution of research. The JFSP, through its Governing Board, is chartered by the Fire Executive Council (FEC). The JFSP is jointly funded by the DOI and

[77] Forests and Rangelands (n.d.). *Wildland Fire Leadership Council.* https://www.forestsandrangelands.gov/leadership/index.shtm.

the USFS. It is governed by 12 members who represent the BIA, BLM, USFW, USFS, NPS, DOI office of Wildland Fire, and USGS."[78]

- The NIFC, "located in Boise, Idaho, is the nation's support center for wildland firefighting. Eight different agencies and organizations are part of NIFC [BLM, USFS, BIA, NPS, USFW, National Weather Service Boise, U.S. Fire Administration, and the National Association of State Foresters]. Decisions are made using the interagency cooperation concept because NIFC has no single director or manager. As partners, [they] work together on fire management issues covering the spectrum from safety and planning, to science, preparedness, operations, strategy development, logistics, intelligence, emergency response, and more. [They] also collaborate on interagency strategies to manage wildfires, not only for single incidents but as a matter of policy."[79]

- Air Quality Research Seminars and Discussion (AQRSD), an outgrowth of a subgroup of the former White House's National Science and Technology Committee on Environment, Natural Resources, and Sustainability (CENRS), meets informally to (1) enhance the effectiveness and productivity of U.S. air quality research and (2) improve information exchange between research and policy on air quality issues, including the scientific knowledge base for air quality standards, and assessing compliance.[80] AQRSD has identified the following as seminar and discussion focal areas:
  - Particulate Matter and Visibility;
  - Wildland Fires;
  - Ozone and Associated Air Pollutants
    - Hazardous Air Pollutants (Air Toxics), and
    - Indoor Air Quality.

  NOAA and EPA serve as the group co-leaders, and there are representatives from USDA, Department of Commerce, DOD, DOE, HHS, DOS, DOI, DOT, NASA, NSF, and the Tennessee Valley Authority.

Problem Statements and Research Questions

ORD is a significant contributor to wildland fire research and connected with various activities occurring across the federal government. Given the importance of this emerging issue for communities across the country, ORD reviewed past and ongoing research and developed five overarching, yet interwoven problem statements and related research questions. The problem statements set up the current state, desired state, and the gaps related to each topic area. These set up the context for the research questions.

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[78] Joint Fire Science Program (n.d.). *About Us: Joint Fire Science Program.* https://www.firescience.gov/JFSP_program_info.cfm.
[79] National Interagency Fire Center (n.d.). *Fire Information and Statistics: Wildland fires and acres (1926-2017).* https://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html.
[80] National Oceanic and Aeronautic Administration (n.d.). *Air Quality Research Seminars and Discussion.* https://www.esrl.noaa.gov/csd/aqrsd/.

The considerations when developing the research questions EPA will address with ORD research are that they (1) meet priority needs of state, regional, tribal, federal, and Program Office stakeholders; (2) match well with ORD's expertise and internal and external connections; (3) build on the existing body of knowledge, data, and tools, as well as ongoing research activities to focus future ORD wildland fire research; and (4) are in areas within the scope of the 2019-2022 StRAPs and consistent with EPA's overall mission.

These research questions outline the overall research, whereas the problem statements below offer context to the questions. The first four research questions feed into the final research question, which is the impetus for this work: preparing communities and ecosystems for the impacts of fire.

Air Quality: Problem Statement

Wildland fire smoke can negatively impact ambient air quality at local, regional, and national/international spatial scales relative to the fire origin. The emitted smoke is a complex mixture of thousands of particulate- and gaseous-phase compounds that are associated with multiple negative health effects. EPA is focused on understanding the factors that influence the public health impacts of wildland fire smoke to protect human health and the environment. State and local agencies need a clear understanding of the degree to which transported smoke from wildland fires contributes to an area's air pollution, as well as an understanding of how factors related to climate change and environmental factors (e.g., land use, land management) can influence the likelihood of exposure to smoke in the future.

More knowledge of smoke plume characteristics, chemical transformation, and transport is needed to improve air quality modeling representation of smoke events. Evaluation of Federal Reference Methods and Federal Equivalent Methods used to monitor NAAQS compliance in these smoky conditions is also necessary. Representing the short-term influence of fires on air quality is important for understanding the impacts and health protective strategies to reduce exposure during a fire. In the medium term (3 to 6 months) and long term, forecast and climate models, respectively, are necessary to understand how the risk of fire and, thus, smoke can impact ambient air quality over time. It is also important to understand how fire can be used as a tool to reduce the public health impacts of wild, uncontrolled burns. Further, existing models simulating different components of the earth system (e.g., air, land, water) can be connected to inform a more comprehensive understanding of the drivers and consequences of wildland fires.

Air Quality: Research Questions

- How can EPA, EPA Regional Offices, tribes, and states measure and forecast the impact wildland fires have on air quality across a range of spatial and temporal scales?
- To what degree do prescribed burns limit or reduce emissions and/or hazard to human health and ecological impacts of wildfires, and how do the emissions characteristics differ between prescribed burns and wildfires?
- How do factors related to climate, land use, and ecosystem health influence the likelihood and nature of exposure to smoke in the future?

Public Health: Problem Statement

Smoke from wildland fires can cause serious health effects, including premature death in people with heart or lung disease; nonfatal heart attacks; irregular heartbeat; aggravated asthma; decreased lung function; and increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing.[81] The increasing prevalence of wildfires near communities has emphasized the need for an improved understanding of the health effects of exposure to smoke, including acute (<24 hours), short-term (24 hours to 30 days), longer term (30 days to years), and chronic (many years) smoke exposure patterns (e.g., repeated exposure to low levels of smoke over several days, weeks, or months). Further, the concentration, frequency, and duration of smoke in the air and individual level parameters (e.g., indoor versus outdoor activities, tightness of building envelope, indoor air filtration or air conditioning) can vary. More information on the effectiveness and practicality of various intervention strategies (e.g., N95 masks, indoor air purifiers, dietary changes) to make recommendations that reduce exposure to smoke, given various smoke conditions.[82]

Various actions at the individual, interpersonal, organizational, community, and policy levels can work cohesively to protect public health from smoke exposure. Across these levels, it is critical that health risk communication messages are clear and consistent. Also, information regarding the effectiveness of various devices or behaviors that can reduce exposure to smoke is limited. These factors can influence a community's ability and willingness to take certain actions and make health risk communication and recommendations challenging.

Public Health: Research Questions

- How do health effects of short-term (a few weeks) exposure to smoke at high concentrations typically encountered near an active wildfire differ from long-term exposures (a few months) at lower concentrations?
- What are the effects of continuing exposure over days, weeks, and months?
- What is the effectiveness of recommending personal actions during smoke exposure, such as use of masks or filters, and how can they be improved?

Water Quality and Aquatic Resources: Problem Statement

Increased wildfire frequency and severity in the United States present an increased risk to water quality, potentially affecting both aquatic life and human health. For instance, wildfire can degrade water quality by postfire runoff of toxins, sediment, nutrients, heavy metals, and other pollutants. This can adversely affect both aquatic life and drinking water. Effects also can be indirect. Wildfire might affect exceedances of a state's temperature criteria indirectly, for instance, by the removal of riparian cover

[81] Pope III, C.A., and Dockery, D.W. (2006). Health effects of fine particulate air pollution: lines that connect. *Journal of the Air & Waste Management Association*, *56*(6), 709-742.
[82] U.S. Environmental Protection Agency (n.d.). Integrated Risk Information System (IRIS) Glossary. https://iaspub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do;jsessionid=ilszxLpichWbHSqETp1nKLKzlBrnVPaTC2GOvDOYSu5QfjNs4NV-!-1889.

and, thereby, prevent compliance under a temperature total maximum daily load. Water quality effects can occur in the immediate area of a fire, for example, changes in species habitats and stream temperatures, sedimentation, increased nutrient and contaminant loading, and the deposition of smoke and ash; whereas some of these alterations also may impact sensitive ecosystems in areas far from the fire location. It is important to understand these impacts to proactively protect ecosystems and drinking water quality, quantity, and distribution and, also, to plan the response should a wildfire disturb an aquatic environment.

More information is necessary to understand how these changes ultimately impact the quality of sources for and treatment of drinking water and recreational water. Impacts to ecological endpoints that are both proximal and distal to the immediate area of a fire are of interest and could be supported by EPA's National Aquatic Resource Surveys datasets. Additionally, a better understanding is needed of how watersheds and aquatic ecosystems respond to and recover from fire and the likelihood of subsequent fire in both the long- and short-term timeframes. Moving beyond the effects of wildfire, it is also imperative to understand management options for reducing potential vulnerabilities of water quality to wildfire. This includes both prewildfire (e.g., forest thinning) and postwildfire (e.g., soil erosion prevention, drinking water treatments). It also includes an understanding of potential trade-offs involved. For example, controlled burning might reduce the risk of catastrophic wildfire and larger impacts on air and water quality over the longer term, yet adversely affect air quality in the immediate term.

Water Quality and Aquatic Resources: Research Questions

- What are the watershed and ecosystem risks and benefits from wildland fire?
- What ecosystems are most vulnerable to wildfire?
- What are the wildland fire impacts on water quality and quantity for human use?
- What are the effective management options for reducing water quality vulnerability to wildfire? Are trade-offs associated with these options?

Chemicals: Problem Statement

The remobilization of contaminants or accidental release of chemicals at various contaminated, agricultural, or industrial sites, including Superfund sites, are a concern the Agency deals with on a regular basis. When wildland fires reach the WUI, the risk of mobilization of chemicals at these sites is increased. It is necessary to understand how these sites are impacted by fire. It is important to understand the wildfire risks and subsequent impacts of fires burning on these sites. Understanding these risks can inform preparedness and response activities to build resilience to wildfires and mitigation activities should a fire occur. Residential and industrial structures also can burn when fire reaches the WUI.

More information is needed to understand how fire affects methods used to contain or remediate contaminants at waste facilities and sites, how the chemicals at these sites and structures are mobilized and transported and how that influences the toxicity of smoke from these sites, as well as how the direct

releases of contaminants resulting from fire could occur and result in exposures to nearby communities. The human health and ecosystem risks related to all these potential mechanisms of exposure need to be understood. More research also is needed to reduce the fire vulnerability of these sites and the probability of these accidental releases occurring.

Chemicals: Research Questions

- What are the potential risks to sites and communities, and what measures could be taken to reduce vulnerability of contaminated sites and communities?
- What is the probability of release of toxics into the air, soil, and water from accidental releases of chemicals resulting from the burning of contaminated (brownfield, Superfund, etc.), agricultural, or industrial sites or treatment and transfer facilities?
- What is the consequent risk to communities from those releases and burning of structures, through the composition and toxicity of the subsequent smoke released or through direct contamination of water or air?

Preparing and Building Resilience: Problem Statement

Fires can impact ecosystems in the burned area and can compromise chemical remediation techniques and control technologies, whereas smoke and direct chemical releases from fire can impact ecosystems and human health, even at great distances from the burned area. Frequent large wildfires are a new reality because of the historic practice of fire suppression, combined with more people living in the WUI and climate change factors (i.e., rising temperature and increased drought). It is critical to prepare communities to build resilience for themselves and the ecosystems they depend on to smoke, fire, and potential direct exposure to chemical releases. Resilience is built by multilevel preparedness across individual, interpersonal, organizational, community, and political spheres for these events. More information is needed about long-term activities like land management practices and how they influence the ecological (including water) risk and severity of future fires, as well as short-term smoke and chemical release preparedness activities that can be taken at the regional, state, local, and individual level to reduce the negative effects these events can have, and effective messaging is needed to promote these actions.

Preparing and Building Resilience: Research Question

- How can communities mitigate and build resilience to the public health and ecosystem effects of wildland fire, smoke, and ash?

Next Steps

These research questions outline the direction and focus of ORD research and will help scope the narrative around the entire research portfolio, enhancing opportunities for collaboration and coordination to deliver solutions-driven research outputs. Implementation of this Wildland Fire Framework, including the research questions above, relies on ORD scientists and the ORD Wildland Fire Coordinating Committee (discussed in the "Internal Coordination" section). This committee can help foster internal and external connections, and the proposed annual meeting will serve as a status update. As ORD makes progress on addressing these research questions, and the end of the timeframe of this framework and StRAPs approaches, the coordinating committee can reevaluate the research questions and planning for future years. ORD also will consider the development of a research action network to enable dynamic interaction between researchers and stakeholders as they work together toward shared solutions.

ORD has made significant contributions to wildland fire research. With internal expertise and capacity, and an external network of collaborators and stakeholders to amplify the impact of this research, ORD is dedicated to fulfilling the Agency mission to protect human health from wildfire smoke. Looking forward to future wildland fire research across federal agencies, it is critical that federal and nonfederal agencies strengthen the connections between their work. ORD is committed to engaging with local, state, tribal, and federal organizations to share information, collaborate, and address the complex issues that arise.