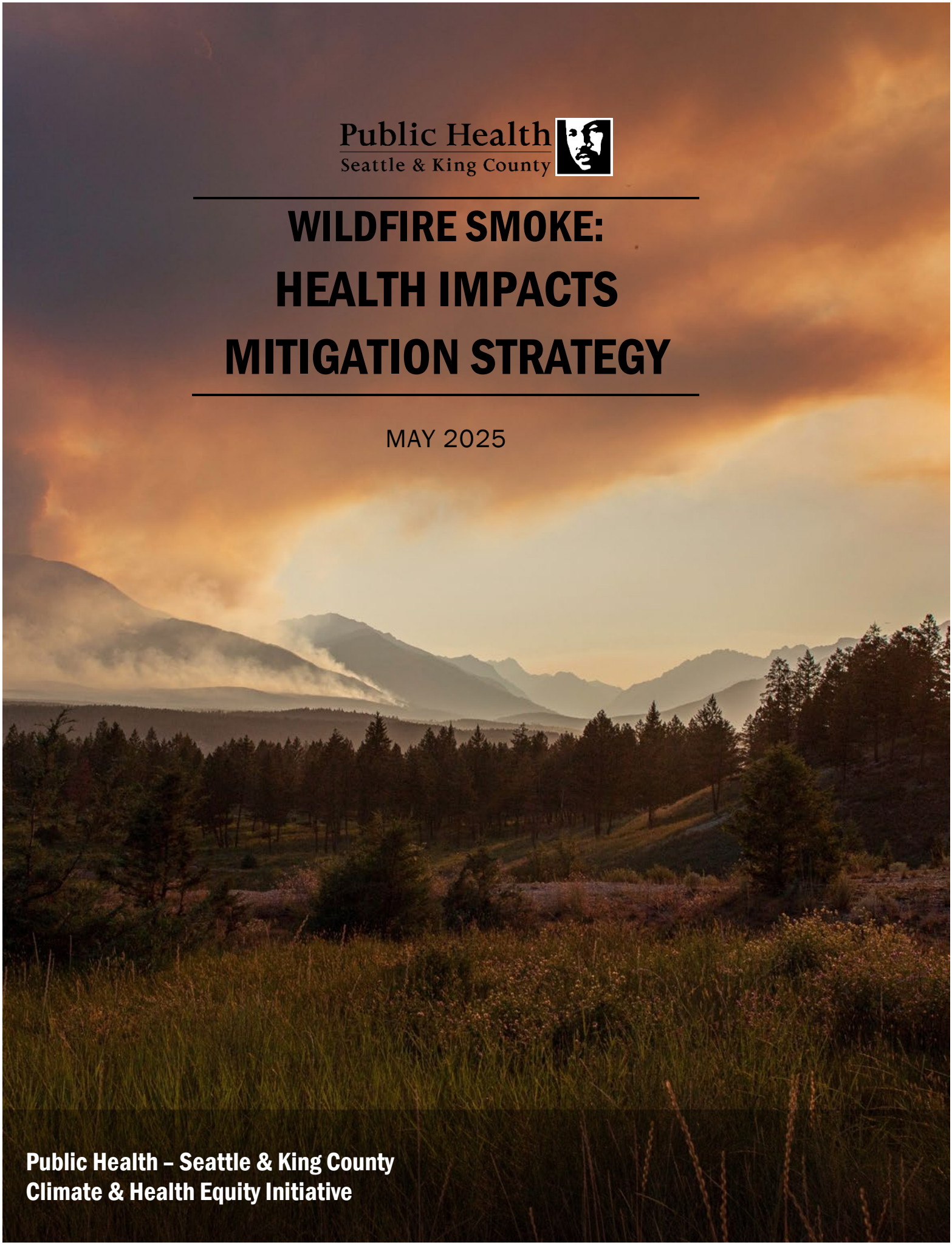

Public Health
Seattle & King County

# WILDFIRE SMOKE: HEALTH IMPACTS MITIGATION STRATEGY

MAY 2025

**Public Health – Seattle & King County**
**Climate & Health Equity Initiative**

# TABLE OF CONTENTS

# Executive Summary

In 2022, the Bolt Creek Fire caused areas of King County, for a period of time, to have the worst air quality in the world. Climate change is causing drier conditions and higher temperatures, resulting in an increase in the frequency and severity of wildfires across the western United States and Canada. As wildfires burn across the landscape, they can generate large plumes of wildfire smoke that can significantly impact the air we breathe and affect the air quality for communities far away from where fires may be occurring, and for extended periods of time. As we continue to experience the effects of climate change, driven by the release of greenhouse gases into the Earth's atmosphere, the occurrence of wildfires and presence of wildfire smoke is anticipated to become an increasing part of seasonal patterns in the Pacific Northwest. Planning and preparing for wildfire smoke requires recognition of the increasing role it will have in influencing our decision-making and how we navigate our day-to-day lives.

The health risks posed by wildfire smoke are significant. Exposure to wildfire smoke can range from mild symptoms – including irritation to people's eyes, noise, and throat – to more severe outcomes – including aggravation of asthma, cardiovascular complications, stoke, renal failure, and premature death. People most at risk to wildfire smoke include young children and older adults, pregnant individuals, people with pre-existing health conditions, outdoor workers, athletes, and people living unsheltered.

While wildfire smoke can impact air quality for entire populations, existing inequities related to income, housing status and quality, and proximity to industrial and transportation emission sources can contribute to disparities in the level of exposure and sensitivity individuals have to wildfire smoke. If left unaccounted for and unaddressed, the increasing occurrence of wildfire smoke will likely deepen existing community health disparities. Causing adverse health impacts likely to disproportionately affect communities of color and lower-income households and individuals. Without intervening action, the increasing occurrence of wildfire smoke could result in the additional loss of life of over 27,000 people each year, by the year 2050 in the U.S. alone[1].

[1] (Qui, et al., 2024)

The *King County Wildfire Smoke: Health Impacts Mitigation Strategy* identifies 14 actions to help mitigate the health impacts of wildfire smoke here in King County, and beyond. These actions focus on four strategic priorities:

- Increase the availability and accessibility of actionable public information and guidance.
- Increase accessibility to local air quality information to inform decision-making.
- Improve indoor air quality and the resilience of our built environment[2] to withstand air quality impacts.
- Increase capacity to prepare for and respond to emergent needs during wildfire smoke episodes.

The 14 actions outlined herein are aspirational and intended to reduce the harm to human health posed by wildfire smoke. Many of these actions will require exploration and identification of new funding opportunities to support implementation. To be successful, all of these actions will require multi-sector public-private partnerships and cross-jurisdictional collaboration across all levels of government.

The purpose of this strategy is to help guide decision makers, as funding and resources are available, through the identification of actions and measures that can be taken to increase the smoke readiness of King County communities and support the equitable adaptation to the increasing occurrence of wildfire smoke.

[2] The term built environment refers to human-made conditions and physical features that encompass buildings, public infrastructure, transportation, agricultural lands, parks, or any human created or modified spaces in which people live, work, and recreate on a day-to-day basis.

*Table 1. Wildfire Smoke: Health Impacts Mitigation Actions.*

| Priority Area | Mitigation Action |
|---|---|
| Public Guidance & Information | PGI-1. Co-create educational materials with trusted community messengers in multi-media formats. |
| | PGI-2. Increase language accessibility of risk communications. |
| | PGI-3. Provide educational outreach and equipment demonstrations at community events and resource fairs. |
| | PGI-4. Provide train-the-trainer opportunities for building community capacity and workforce opportunities in the mitigation of health impacts. |
| Air Quality Monitoring & Warnings | AQM-1. Deploy visual lighting installations at public parks and outdoor assembly areas to display current air quality conditions. |
| | AQM-2. Develop standard guidance on how to use available air quality data and forecast information to inform proactive decision-making during wildfire smoke episodes. |
| | AQM-3. Provide participatory youth STEAM engagement opportunities in air quality monitoring. |
| Indoor Air Quality & Built Environments | IAQ-1. Support distribution of portable air cleaners, indoor air quality sensors, and weatherization resources to frontline communities and low-income residents. |
| | IAQ-2. Increase equitable access to workforce development and vocational training opportunities related to indoor air quality assessment and HVAC system maintenance and operation. |
| | IAQ-3. Assess and identify publicly accessible buildings, including facilities operated by homeless service providers, capable of serving as cleaner air sites during wildfire smoke episodes through a certification and placarding process. |
| Wildfire Smoke Response | WSR-1. Establish inventory of deployable air filtration system to open cleaner air sites. |
| | WSR-2. Make N*95* respirators available to unsheltered individuals and people experiencing homelessness during wildfire smoke episodes. |
| | WSR-3. Increase the number of staff trained and certified as incident management team (IMT) air resource advisors (ARAs). |
| | WSR-4. Include severe wildfire smoke as a conditional measure in special and/or temporary event permitting that would require rescheduling or cancelation of outdoor events and activities during periods of severe wildfire smoke. |

# 1 Introduction

The *King County Wildfire Smoke: Health Impacts Mitigation Strategy* was developed for local decision-makers and the staff of agencies, departments, and organizations engaging in preparedness efforts to protect the health of people during periods of poor air quality caused by wildfire smoke. It provides a first-ever strategic decision support framework that identifies opportunities, referred to as mitigation actions, for cross-organizational and cross-jurisdictional work that can serve to reduce and prevent adverse health impacts from wildfire smoke. The strategy identifies 14 mitigation actions, that are organized around four strategic priorities:


*Figure 1. Risk management framework.*

- Increase the availability and accessibility of actionable public information and guidance.
- Increase accessibility to local air quality information to inform decision-making.
- Improve indoor air quality and the resilience of our built environment to withstand air quality impacts.
- Increase capacity to prepare for and respond to emergent needs during wildfire smoke episodes.

The purpose of the *King County Wildfire Smoke: Health Impact Mitigation Strategy* is to outline potential actions that can help residents and visitors cope and adapt to the increasing occurrence of wildfire smoke episodes in a manner that minimizes the risk to peoples' health, while addressing health inequities that place some communities and populations at greater risk. The goal of this strategy and the mitigation actions outlined herein is to increase the smoke readiness of communities as wildfire smoke becomes an increasingly frequent part of our lives, due to the effects of climate change. The actions in this strategy are not intended to be prescriptive; rather, they are intended to help direct local decision- makers and staff tasked with protecting the health, welfare, and well-being of residents and visitors towards relevant and regionally coordinated actions that can prepare our communities for a changing climate.

Wildfire smoke is an increasing threat to the health and the well-being of King County communities. As the frequency and severity of wildfire activity across the western United States and southwestern Canada have increased, periods of poor air quality across the region caused by wildfire smoke have become increasingly common. This impacts all King

*Figure 2. Satelite image of wildfires occuring across the western United States.*

County communities, including densely populated urban areas far removed from where active wildfires are occurring. Wildfire activity is also increasing close to urban areas, further contributing to intense and unpredictable air quality impacts. At the same time, there is a growing awareness of the projected increase in wildfire risk due to climate change, as well as a sense of urgency to prioritize mitigation efforts to better prepare communities for a future where wildfire smoke is increasingly a part of our lives.

In 2021, King County convened representatives from wildland-urban interface (WUI) communities, fire departments, local, state, and Tribal natural resource agencies, conservation agencies, utilities, and academic institutions to develop a strategy for coordinated work on wildfire risk reduction in King County. During these initial efforts, the group determined that the issues and actions necessary for mitigating the health impacts associated with wildfire smoke were unique, and, in many ways, different from actions necessary for reducing wildfire risk.

Wildfire risk reduction activities focus on reducing potential for wildfire ignition and increasing coordination for response and recovery efforts. Mitigating the health impacts of wildfire smoke, on the other hand, requires harm-reduction measures to help reduce the risk of exposure to wildfire smoke and poor air quality when wildfires are occurring. These mitigation measures to reduce the health impacts of wildfire smoke must also be undertaken by all impacted jurisdictions in King County, well beyond wildland-urban interface communities.

For this strategy to be successfully implemented, numerous organizations must participate in leading and supporting roles, across jurisdictions and levels of government. The local community must also be involved to center health equity, reduce health impacts, and increase community resilience to wildfire smoke. As no single agency or program is solely responsible for mitigating the health impacts of wildfire smoke in King County, this strategy is written for King County as a community of governments, organizations, and other public and private sector partners that have a role in implementing wildfire smoke health mitigation measures and shaping wildfire smoke resilience.

Planning for wildfire smoke is a shared priority among King County agencies, as well as federal, state, local, and community partners. King County will be the steward of the *King County Wildfire Smoke Health Impacts Mitigation Strategy*, tracking implementation and working with partners to evaluate the need for updates. Actions from this strategy and any future

updates should be integrated into county and local hazard mitigation plans, comprehensive plans, capital improvement plans, and other strategic planning documents such as King County's *Strategic Climate Action Plan (SCAP),* as appropriate. Plan integration can help to ensure the advancement and implementation of wildfire smoke mitigation actions, as well as support prioritization of fiscal and staff resources for this work.

## 2 STRATEGY DEVELOPMENT

Public Health – Seattle & King County (PHSKC) has been actively working to address the impacts of climate change on health since 2016. Since the 2018 release of its *Blueprint for Addressing Climate Change and Health*, it has engaged in and led community preparedness and mitigation efforts associated with preparing for and responding to the impacts of climate change on health. Since 2019, the department has collected input on wildfire smoke preparedness concerns, gaps, and needs through engagement with King County agencies and state and local partners, such as the Washington Department of Health, Washington Department of Ecology, and Puget Sound Clean Air Agency; participation in the state's Wildfire Smoke Impacts Advisory Group; and community outreach and engagement efforts by PHSKC in partnership with nearly 40 community-based and faith-based organizations.

The 2020 SCAP tasked PHSKC with leading development of the *King County Wildfire Smoke: Health Impacts Mitigation Strategy* under *SCAP* Preparedness Action 4.2.10 as a priority action that aims to strengthen collaborations and partnerships to increase community resilience in the face of climate impacts. Development of the *Wildfire Smoke: Health Impacts Mitigation Strategy* began in Spring 2023 with the establishment of a steering committee comprised of representatives from public agencies and organizations.

Steering committee members included staff from the following organizations:

- City of Seattle – Office of Sustainability and the Environment
- King County Department of Natural Resources and Parks
- King County Executive Climate Office
- King County Office of Emergency Management
- King County Regional Homelessness Authority
- Public Health – Seattle & King County
- Puget Sound Clean Air Agency
- University of Washington, Department of Environmental and Occupational Health Sciences
- Washington State Department of Ecology
- Washington State Department of Health

Additional community input was obtained during the development of this strategy by trusted community partners. In Fall 2023, PHSKC worked with five contracted community-based and faith-based organizations to host seven facilitated discussion and listening sessions with community members. The focus of these sessions was to identify additional community needs, barriers, and challenges towards taking action to reduce exposure to poor air quality during wildfire smoke events.

The most common themes raised by participants during these discussions included:

Concerns with not being able to find the information or resources necessary to stay informed and to cope with wildfire smoke's impact on air quality.

Language access limitations associated with accessing real-time air quality data, information, and guidance.

Concerns related to the recognition of deep inequities regarding exposure to air pollution and poor indoor air quality.

Challenges associated with access and affordability of devices that can be used to improve indoor air quality.

Challenges many residents face trying to deal with the combined risk of staying cool from the heat while also trying to reduce their exposure to wildfire smoke.

The need to clearly identify the places where people can go to seek shelter during wildfire smoke episodes and how people without access to transportation can get there.

The desire for increased distribution of air filtration equipment to frontline communities.[3]

In addition to input obtained from state and local partners and the community, the information and actions outlined in this strategy were further informed by a review of

[3] Frontline communities are those that are disproportionately impacted by climate change due to existing and historic racial, social, environmental, and economic inequities, and who have limited resources and/or capacity to adapt. These populations often experience the earliest and most acute impacts of climate change, but whose experiences afford unique strengths and insights into climate resilience strategies and practices. Frontline communities include Black, Indigenous, and People of Color (BIPOC) communities, immigrants, and refugees, people living with low incomes, communities experiencing disproportionate pollution exposure, women and gender non-conforming people, LGBTQIA people, people who live/work outside, those with existing health issues, people with limited English skills, and other climate vulnerable groups.

scholarly literature, case studies, federal guidance, and established best practices related to the reduction of health impacts resulting from wildfire smoke exposure.

Since the adoption of the *SCAP* in May 2021, and with it the call to action to develop this strategy, there have been several other significant developments and initiatives that have helped improve community preparedness for the risks posed by wildfire smoke. PHSKC has been working to find effective strategies to protect people from wildfire smoke in both home and congregate settings. These efforts have included developing a public health wildfire smoke response plan; developing and providing guidance for community shelters and cleaner air sites; deploying in-home strategies that have encouraged the use of air filtration equipment; and promoting low-barrier actions such as sheltering in place during wildfire smoke episodes, monitoring air quality, and using facial respirator masks (see Appendix A for a detailed description of countywide actions implemented to date). These strategies have evolved significantly during the COVID-19 pandemic as use of masks and indoor air filtration equipment have become more common. However, the science regarding the health impacts of exposure to wildfire smoke is still evolving and with it, so too is the information on the actions that can be taken to better prepare communities for the increasing frequency of wildfire smoke events.

Without committed action, wildfire smoke is likely to deepen existing health disparities and perpetuate inequities along lines of race and socioeconomic status. This strategy serves to help decision-makers identify additional actions that can reduce the health risks of wildfire smoke exposure and improve equitable access to cleaner air during wildfire smoke episodes. Several actions identified in this strategy will take multiple years to implement and see the tangible benefits to protecting the health of our communities, making it essential that we begin the important work now of preparing for our future in a changing climate.

# 3 MEETING THE CHALLENGE: WILDFIRE SMOKE HEALTH IMPACT MITIGATION ACTIONS

The following section details 14 recommended actions identified to address the increasing frequency of wildfire smoke episodes and reduce the health risks associated with wildfire smoke exposure in King County.

Actions are organized under four strategic priorities, including:

- Increase the availability and accessibility of actionable public information and guidance.
- Increase accessibility to local air quality information to inform decision-making.
- Improve indoor air quality and the resilience of our built environment to withstand air quality impacts.
- Increase capacity to prepare for and respond to emergent needs during wildfire smoke episodes.

Performance measures are provided for each strategic priority area, identifying potential indicators of success that could be used for monitoring implementation progress and effectiveness of actions under each strategic priority area over time.

Each action includes the following information:

- *Action description*: Briefly describes why the recommended action is needed, what the action involves, to whom the action is primarily directed, and what the action will accomplish.

- *Potential collaborators*: Identifies potentially relevant organizations or groups important to implementing the work and achieving the intended outcomes. Potential collaborators may include other organizations not listed in this field.

- *Implementation feasibility*: Provides a relative scale (easy, moderate, hard) indicating how quickly the action can be implemented. Factors that can influence feasibility include the cost of implementation, the degree to which organizations are already engaged in the work or similar activities, and the absence or presence of political, legal, technical, or organizational barriers.

**Easy**

Actions ranked as “Easy” are relatively low barrier actions able to be accomplished with existing resources and can be integrated into existing service areas. Actions ranked as “Easy” can be augmented by allocation or receipt of additional funding to support implementation.

**Moderate**

Actions ranked as “Moderate” can be integrated into existing service areas, however will require additional funding, staffing, or additional resources to support implementation. Actions ranked as “Moderate” also require broader coordination and collaboration across jurisdictional partners and may require additional planning and logistical considerations.

**Hard**

Actions ranked as “Hard” will require establishment of new programmatic service areas and may necessitate substantive financial investment to support implementation. Actions ranked as “Hard” also may face additional political and technical barriers, as well as additional legal considerations, and will require additional planning, coordination across jurisdictional partners, and collaboration across multiple sectors.

# PUBLIC GUIDANCE & INFORMATION

## PGI-1: Co-create educational materials with trusted community messengers in multiple media formats.

*Action Description:*

This action applies a community co-creation approach to the development of educational materials focused on wildfire smoke and other emergent climate-driven hazards. The goal of this action is to improve the reach and reception of public messaging and community educational materials while increasing availability of actionable information members of the public can use to proactively protect their health from the increasing frequency of wildfire smoke episodes and other climate-driven hazards.

Members of the public receive their information in a range of formats and through channels they view as trusted messengers. Trusted messengers are commonly community-based and faith-based organizations, service providers, or other community leaders who are already known and respected by the communities they serve. While it is the public sector's responsibility to provide credible information on hazards that pose a risk to public health and well-being, it is also essential to collaborate with trusted community messengers to develop public messaging and educational materials that will effectively reach diverse populations and communities they serve. By co-creating with community partners, health guidance and public information can be more tailored, culturally relevant, and provided in a variety of channels and platforms through which different communities predominately obtain their information.


*Figure 3. PHSKC's Breathe Better at Home infographic..*

Co-creation is an active, participatory approach which centers community in the development of strategies at the earliest possible opportunity. It assumes shared power, responsibility, accountability, and decision-making with community members and centers on the needs of those most harmed by inequality. Several King County departments and agencies have already begun adopting this

approach for their routine delivery of services and educational outreach efforts. *Breathe Better at Home* is one example of educational content developed in co-creation with community addressing the importance of indoor air quality and measures residents can take to improve it.

Implementation of this action necessitates meaningful engagement with community and recognition that King County itself is a community of diverse communities. Jurisdictions interested in this action should begin by identifying populations adversely impacted by existing inequality and assessing if there may be any populations or communities that may be particularly harder to reach, and then work to identify potential trusted messengers by putting out an open call for contributors from organizations, service-providers, and community leaders who may already serve those populations. In order for this action to be successful, it is important for all collaborating parties to be on the same page regarding the intended deliverables, available funding for projects, and the delineation of roles and responsibilities – including authorization for final approvals.

Recommended community educational content for co-creation includes topics on, but not limited to:

- Where to get information during a wildfire smoke event.
- Overview of the Air Quality Index (AQI) and how to access and interpret current air quality data and forecast information.
- Health risks of wildfire smoke exposure and factors that can increase an individual's sensitivity or level of exposure during wildfire smoke episodes.
- Effective use of indoor air filtration equipment and device maintenance.
- Proper method for putting on and removing N95 or other facial respirator masks.
- Other factors that can influence indoor air quality and increase risk of exposure to poor air quality during wildfire smoke episodes.

*Potential collaborators:*

Trusted community messengers, including community-based and faith-based organizations, community service providers, and other community leaders; local, state, and federal public health agencies; healthcare service providers; local clean air agencies; local, state, and federal weather forecasting and monitoring agencies; state and federal environmental protection agencies; state labor and industry agencies.

*Implementation Feasibility:*

**Easy**

## PGI-2: Increase language accessibility of risk communications.

*Action Description:*

Language access can be a significant barrier keeping residents from receiving key information on air quality and actions to reduce potential health impacts from wildfire smoke exposure. Agencies such as Public Health – Seattle & King County, Puget Sound Clean Air Agency, and the Washington State Department of Health have begun taking action to increase the availability of in-language guidance related to wildfire smoke. However, continued investments by these agencies and others are necessary to ensure King County residents with limited English proficiency and residents who do not speak English have access to this translated information.

There is an existing wealth of information on the health risks of wildfire smoke and guidance that has been developed by federal, state, and regional agencies and organizations. However, information developed at higher levels of government and by national organizations is often not translated into the range of languages commonly spoken by King County populations.

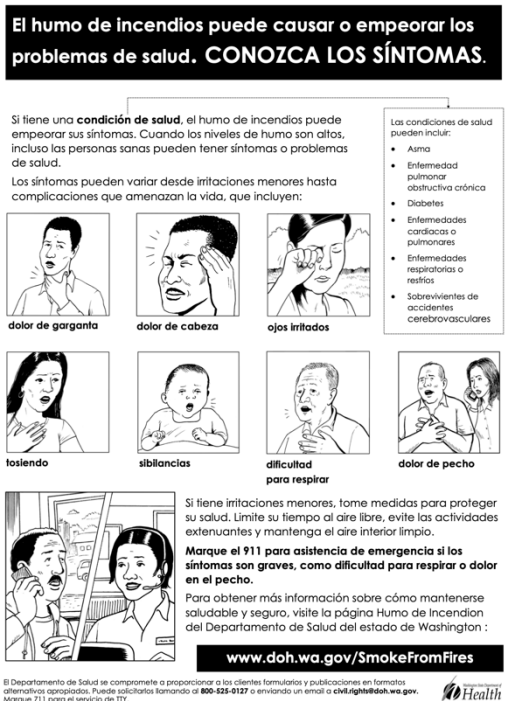


*Figure 4. Langauge accessible risk communications.*

This action encourages jurisdictions to work to ensure available information on air quality and actions residents can take to protect their health during wildfire smoke episodes is translated into languages spoken by residents. This action also encourages increasing the use of multi-media, multi-lingual and ethnic media outlets to help deliver in-language information to effectively reach these populations. Towards this end, PHSKC recently produced community educational videos in multiple languages to raise awareness of actions that can be taken to help residents reduce their exposure to poor air quality during wildfire smoke events. Leveraging video and in-language voice overs to further overcome barriers that can otherwise arise from limited language literacy.

Increasing the availability of in-language air quality information and guidance helps reduce the potential for public health disparities resulting from language access barriers during wildfire smoke episodes. However, to accomplish this

outcome, it is necessary to ensure messaging and guidance is translated and made available well in advance of the onset of wildfire smoke season.

In-language messaging campaigns must begin early enough in the season to ensure residents have ample time to make any necessary investments and acquire any needed resources to help them be prepared for when wildfire smoke arrives.

*Potential collaborators:*

Multi-lingual and ethnic media outlets; community-based and faith-based orgnaizations; local, state , and federal public health agencies; municipalities; local, state, and federal emergency management agencies; local clean air agencies; state and federal environmental protection agencies; state labor and industry agencies

*Implementation Feasibility:*

**Easy**

## PGI-3: Provide educational outreach and equipment demonstrations at community events and resource fairs.

*Action Description:*

This action encourages jurisdictions to engage in direct in-person outreach and engagement, and to provide demonstrations to community members on the use of technologies, equipment, and other resources that can be used to help protect people's health during periods of poor air quality due to wildfire smoke.

*Figure 5. Low-cost PurpleAir Outdoor Air Sensor.*

Several of the protective actions residents can take to reduce potential health impacts resulting from smoke exposure rely on the use of equipment, technologies, or other resources that they may be previously unfamiliar with, such as high efficiency particulate air (HEPA) portable air cleaners, air quality sensors, and proper use of facial respirator masks. There are many items that, when used correctly, can significantly protect an individual's health during a wildfire smoke episode. However, if used incorrectly, they may have a negligible benefit and may actually increase an individual's risk by providing a false sense of protection. While guidance and information can go a long way towards helping familiarize people with new equipment and technologies, one of the most effective ways to teach about its proper use is by conducting in-person outreach

and engagement, where residents can see and experience first-hand demonstrations of resources.

Tabling and participating at community events, resource fairs, and farmers markets can increase residents' familiarity with the various resources available to help protect their health and how to effectively use these resources. This enables them to navigate and select the right resources for their unique needs and circumstances with the confidence of knowing how to use these resources. Furthermore, by engaging in direct in-person outreach and engagement, community members can have the opportunity to speak directly to experts who may be able to help address their individual questions or concerns.

*Potential collaborators:*

Local businesses; community-based and faith-based orgnaizations; municipalities; local, state, and federal public health agencies; local and state community and human service agencies; local clean air agencies; local, state, and federal parks and recreation agencies; state and federal environmental protection agencies; state labor and industry agencies.

*Implementation Feasibility:*

**Easy**

## PGI-4: Provide train-the-trainer opportunities for building community capacity and workforce opportunities in the mitigation of health impacts.

*Action Description:*

This action calls for the expansion of services that provide communities opportunities for meaningful engagement and conversations with subject matter experts that build community capacity to be prepared for wildfire smoke episodes. This action can be accomplished by developing train-the-trainer courses and programs that can be periodically offered to interested members of the public and organizations on various topics related to air quality and wildfire smoke, including but not limited to:

- Ambient (outdoor) air quality monitoring.
- Indoor air quality (IAQ), IAQ monitoring techniques, and interventions for improving IAQ.
- Individual health factors that contribute to health risk of wildfire smoke.
- Administrative and occupational exposure mitigation.
- Respiratory protection and fit testing.
- Building ventilation and filtration systems and performance audits to aid in the identification and verification of facilities that may serve as cleaner air sites during wildfire smoke episodes.

Train-the-trainer learning opportunities can help develop the communications network necessary to bring awareness to the health risks associated with wildfire smoke exposure and actions individuals can take to reduce its potential health impacts. Providing in-depth learning opportunities for interested community members and organizations to engage with subject matter experts through two-way dialogue and discussion builds the capacity for those individuals and enables organizations to better support their communities. The goal of providing training opportunities for community members and organizations is to empower them with the knowledge and skills to support their communities while also adapting the delivery of that knowledge into culturally appropriate and relevant ways, or into existing services that are already being provided.

*Figure 6. Community members participate in a workshop.*

This model has already been employed with great success by Public Health – Seattle & King County (PHSKC) through its box fan filter kit distribution efforts from 2020 through 2023, and through the development of a pilot Clean Air Ambassador Program funded by the National Association of City and County Health Officials (NACCHO) and the U.S. Centers for Disease Control and Prevention (CDC) in 2022. During these efforts, PHSKC engaged with over 40 community-based and faith-based organizations to provide train-the-trainer learning opportunities on the basics of indoor air quality and the importance of using air filtration equipment during wildfire smoke episodes.

The National Oceanic and Atmospheric Administration (NOAA) Weather-Ready Nation (WRN) Ambassadors™ initiative also serves as an example of how train-the-trainer programs can work. The WRN Ambassador initiative partners with community organizations to train them on weather forecasting and severe weather preparedness. Through these efforts, NOAA builds communication networks to help promote the distribution of messaging and extend community reach, create opportunities for collaboration, share success stories of preparedness and resiliency, and educate member organizations and their staff on the delivery of severe weather preparedness information.

*Potential collaborators:*

Community-based and faith-based orgnaizations; local school districts and vocational schools; municipalities; local, state, and federal public health agencies; local and state community and human service agencies; local, state, and federal parks and recreation agencies; state and federal environmental protection agencies; state labor and industry agencies; local, state, and federal weather forecasting and monitoring agencies.

*Implementation Feasibility:*

**Moderate**

**Public Guidance & Information | Action Performance Measures**

- Number of co-created educational materials developed in partnership with communities.
- Media formats (e.g., print, digital text, audio, visual) in which educational materials are available.
- Number of educational materials, documents, and guidance translated into multiple languages.
- Number of community outreach and engagement events facilitated and/or attended to provide information on wildfire smoke.

# AIR QUALITY MONITORING & WARNINGS

## AQM-1: Deploy visual lighting installations at public parks and outdoor assembly areas to display current air quality conditions.

*Action Description:*

Access to real-time air quality information is essential to enable people to make informed decisions and take proactive measures to protect their health. Localized real-time air quality information is especially important when it comes to making decisions about participation and engagement in outdoor activities and events during periods of poor air quality due to wildfire smoke. Visual art installations at public parks and outdoor assembly areas that display current air quality conditions can provide access to vital information that can be used to help people understand their potential health risk, while helping to reduce disparities for those who many otherwise not have access to digital technologies necessary to access real-time air quality information.


*Figure 7. Air quality visual lighting display.*

There are a range of low-cost air quality sensors available that can provide real-time air quality data. When properly deployed and maintained, low-cost sensors can help provide access to locally accurate and reliable air quality information. By integrating RGB-LED lighting systems that correspond to the Air Quality Index (AQI) values into the deployment of sensors at public parks and outdoor assembly areas, real-time air quality information can be made publicly visible and be used to help enable the ability of individuals to make real-time decisions regarding their health based upon current air quality conditions.

Making air quality sensor AQI lighting displays into visual art installations can help to further increase public interest and awareness of these new features as they are deployed. Offering opportunities for local artists and community members to engage in placemaking through the development of community art. While helping to ensure the visual integration of air quality sensor AQI lighting displays into the visual aesthetics of existing areas.

This action highlights the deployment of public AQI lighting displays at parks and places of outdoor assembly. However, this action is not intended to be limited to those settings, and deployment of such visual AQI lighting displays should be encouraged in any outdoor setting where it may be feasible and appropriate to make such access to real-time air quality

information publicly visible and available. Additional considerations include public transit stations, outdoor sporting and concert venues, locations providing services to people experiencing homelessness, and outdoor common areas on private property accessible to the public.

*Potential collaborators:*

Municipalities; local, state, and federal parks and recreation agencies; outdoor sporting, event, and concert venues; local businesses; local school districts; local libraries; local, state, and federal public health agencies; local clean air agencies; local, state, and federal weather forecasting and monitoring agencies; state and federal environmental protection agencies; state labor and industry agencies.

*Implementation Feasibility:*

**Hard**

## AQM-2: Develop guidance on how to use air quality information from available forecasts and low-cost sensors to inform decision-making during wildfire smoke episodes.

*Action Description:*

This action recommends that state and local public health agencies work together to develop standardized guidance on how to access, navigate, and obtain credible and reliable localized data on air quality conditions to ensure data-informed and defensible decisions during wildfire smoke episodes. This strategy encourages regional coordination through the Washington Smoke Impacts Advisory Group (WSIAG) to help establish a consistent approach and best practices for accessing, navigating, and verifying the credibility of air quality data. Creating a regionally consistent process that can accommodate the use of data obtained from both regulatory air quality monitoring stations and low-cost sensors to support decision-making involving labor protections, outdoor recreation and commerce, and the mobilization and activation of emergency services such as the opening of cleaner air sites.

There are many sources of wildfire smoke information now available, from both trusted reliable government experts to potentially less vetted information, such as from weather sites, phone apps, and low-cost sensors (see section 4.7 for more information on wildfire smoke air quality monitoring and forecasting). With so many different sources of air quality information available during periods of wildfire smoke, decision makers can get confused and could benefit from additional guidance to help navigate the different sources.

Guidance could support informed decision making by emergency managers, as well as employers, event organizers, athletic organizations, youth camp directors, school districts, and others. These actions include, but are not limited to:

- outdoor labor protections,
- relocation or cancelation of outdoor activities and events,
- emergency management triggers for implementation proactive mitigation measures, such as opening cleaner air sites and expanding services for people living unsheltered.

*Figure 8. Outdoor worker at construction site.*

Decision makers need accessible, accurate, and defensible information. Regulatory grade air quality monitoring stations are the gold-standard for current air quality data. However, low-cost air quality sensors have played an important role to fill in gaps between existing regulatory air quality monitoring stations, particularly areas within the wildland-urban interface (see section 4.7.3 for additional information on low-cost air quality sensors). Guidance on which data is most recent, accurate, and representative can help decision makers make more informed decisions.

A few examples of the many sources of wildfire smoke information come from local and state health departments, federal, state, and local air agencies, including the Puget Sound Clean Air Agency Sensor Map, and EPA AirNow Fire and Smoke map, and the WA State Smoke Blog. Additionally, some low-cost sensors are more reliable or available than others and understanding the details on how accurate these sensors are could also benefit decision makers.

*Potential collaborators:*

Local, state, and federal public health agencies; local clean air agencies; state and federal environmental protection agencies; state and federal labor and industry agencies.

*Implementation Feasibility:*

**Moderate**

## AQM-3: Provide participatory youth STEAM engagement opportunities in air quality monitoring.

*Action Description:*

To help prepare youth to navigate a future in which decision-making regarding day-to-day activities is likely to be increasingly influenced by fluctuations in air quality conditions, this action promotes the development of opportunities for youth engagement in STEAM (science, technology, engineering, arts and mathematics) education opportunities to participate in air quality monitoring efforts across the region. As the frequency and severity of wildfires is anticipated to increase as a result of climate change, younger generations are likely going to experience more frequent impacts to their air quality due to wildfire smoke than older generations.

*Figure 9. Students engage in hands-on STEAM learning activities.*

STEAM is an educational approach to help guide inquiry, dialogue, critical thinking, and problem solving. By offering youth programs that facilitate STEAM learning opportunities, the aim is to help prompt lifelong interest in arts and sciences. Through development of youth STEAM engagement opportunities that focus on air quality and involving youth in opportunities to participate in air quality monitoring efforts, these programs can help increase the number of individuals trained and knowledgeable on issues related to air quality from a young age. By emphasizing a STEAM approach that incorporates the arts, it will be possible to engage a broader range of individuals than by just focusing on the technical aspects alone.

Additionally, this action encourages the exploration and identification of opportunities to place air quality monitoring stations in locations that are publicly owned and already provide youth educational programming, such as, but not limited to, schools, libraries, and community centers.

*Potential collaborators:*

Local school districts; local libraries; youth-based community service organizations; local, state, and federal public health agencies; local clean air agencies; state and federal environmental protection agencies; local, state, and federal parks and recreation agencies.

*Implementation Feasibility:*

**Moderate**

**Air Quality Monitoring & Warnings | Action Performance Measures**

- Development of public guidance on the use of air quality data sources to inform defensible decision making related to employee safety, and hosting of outdoor events and activities during wildfire smoke.
- Development of design and quality assurance project plan (QAPP) guidelines for voluntary development and deployment of public air quality displays.
- Number of STEAM educational opportunities to engage youth and communities in air quality monitoring efforts.

# INDOOR AIR QUALITY & BUILT ENVIRONMENTS

## IAQ-1: Support distribution of portable air cleaners, indoor air quality sensors, and weatherization resources to frontline communities and low-income residents leveraging community partnerships with community-based and faith-based organizations.

*Action Description:*

This action encourages the development of partnerships with community-based organizations (CBOs) and faith-based organizations (FBOs) to support the logistics of getting these resources to residents most in need. Many CBOs and FBOs are already engaged in providing support services within their respective communities. Through partnerships, these organizations are often capable of providing more meaningful engagement during the distribution of resources when integrated as part of their existing service models than what is achievable through bulk distribution by public sector agencies. Furthermore, by integrating distribution of resources with the delivery of existing community services, CBOs and FBOs may be able to help ensure that resources reach those most in need and can do so more rapidly than programs that rely upon strict recipient assessment and qualification processes.

*Figure 10. Woman changes filter in portable air cleaner.*

The most effective resources immediately available to King County residents to protect their health during wildfire smoke episodes are portable air cleaners (PACs) equipped with a (HEPA) filter. These units are capable of removing 99.97% of fine particulate matter from the air and come in multiple sizes that can be used individually or in conjunction with each other to provide a clean air delivery rate (CADR) that matches the volume of air in nearly any indoor space. The health benefits of using a PAC can be further increased when paired with other resources, such as an indoor air quality sensor that allows residents to observe changes in their indoor air quality and serves as a cue for taking certain actions, or weatherization resources that help seal gaps and drafts around doors and windows to prevent smoke from infiltrating into homes.

Together, PACs, indoor air quality sensors, and weatherization resources present a powerful toolkit that is readily available and can be applied in almost any space. However, the expense of these resources presents a disproportionate barrier to access among frontline

communities and low-income residents. This action encourages the purchasing, temporary storage, and distribution of these resources to frontline communities and low-income residents through partnerships with community-based and faith-based organizations.

Implementation of this action will require consideration of bulk procurement processes, temporary storage or warehousing, and distribution logistics in addition to coordination of community partnerships and communications. However, this action presents one of the most readily available and effective universally applicable strategies that can be used to reduce the risks of exposure during wildfire smoke episodes. It also provides numerous co-benefits through more generalized improvements in indoor air quality.

*Potential collaborators:*

Community-based and faith-based organizations; municipalities; local businesses; local and state public health agencies; local and state community and human service agencies; regional housing authorities; local libraries; state enviornmtnal protection agencies; healthcare service providers.

*Implementation Feasibility:*

**Hard**

## IAQ-2: Increase equitable access to workforce development and vocational training opportunities related to indoor air quality assessment and heating, ventilation, and air conditioning (HVAC) system maintenance and installation.

*Action Description:*

Improvements in how buildings and homes perform during wildfire smoke episodes are necessary to reduce the potential impacts of wildfire smoke on our health. However, because each building is often unique, the actions necessary to improve indoor air quality need to be uniquely tailored, installed, and maintained. Therefore, carrying out these actions is often very time intensive and typically requires the use of trained, certified, and sometimes licensed professionals to complete. The U.S. Bureau of Labor Statistics[4] generally defines this category of professionals as Heating, Air Conditioning, and Refrigeration Mechanics and Installers, and projects that demand in this industry will continue to grow over the decade.[5]

[4] Sector growth patterns
[5] (Bureau of Labor Statistics, n.d.)

To meet this need, the workforce of trained, certified, and licensed professionals in Heating, Air Condition, and Refrigeration Mechanics and Installers must either be locally increased or outsourced. This action aims to increase the workforce of trained, certified, and licensed professionals in this field and other allied professions related to the implementation of renewable energies and energy conservation measures, through the routine offering of workforce development and public sector vocational training opportunities. Furthermore, the goal of this action is to increase equitable access among frontline communities to technical trade programs by offsetting participation costs and helping pair participants with employment upon program completion.

This action requires the development of multiple public-private partnerships for the delivery of workforce development and vocational training opportunities. In addition, this action will likely require the utilization of public awareness campaigns to help raise awareness of emergent opportunities in technical trade professions, as well as focused advertisement of program offerings to frontline communities and low-income residents. Finally, this action calls for the establishment of a registry for any participants of workforce development and vocational training opportunities. This would support the ability to follow up with program participants to obtain feedback for continuous improvement and provide linkage and referral to professional openings and opportunities.

*Figure 11. HVAC technician completes installation of ductless heat pump.*

*Potential collaborators:*

Local school districts and vocational schools; trade unions; workforce development programs; local planning and community development agencies; local parks and recreation agencies.

*Implementation Feasibility:*

**Moderate**

## IAQ-3: Assess and identify publicly accessible buildings, including facilities operated by homeless service providers, capable of serving as cleaner air sites during wildfire smoke episodes through a certification and placarding process.

*Action Description:*

*Figure 12. Busy crowds navigate their way through city.*

During wildfire smoke episodes, people are often directed to reduce time spent outdoors and stay indoors. Unfortunately, not all residents have access to air filtration equipment or other means of improving their indoor air quality. They may need to seek refuge elsewhere during periods of poor air quality caused by wildfire smoke. To improve public wayfinding to locations that can offer cleaner air during wildfire smoke episodes, this action encourages the assessment and pre-identification of publicly accessible buildings and the use of placarding that can designate and help communicate which buildings are capable of serving as cleaner air sites.

Because not all buildings are properly equipped with systems that can reduce exposure to particulate matter, an assessment is necessary to determine if a building is capable of offering its occupants better air quality during wildfire smoke episodes. In recognition of this need, the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) developed ASHRAE Guideline 44, "Protecting Building Occupants from Smoke During Wildfire and Prescribed Burn Events." This guideline provides a planning framework to assist building managers take the steps necessary to ensure facilities are properly equipped to reduce health impacts among building occupants during periods of poor air quality. This action entails the use of ASHRAE Guideline 44, or similar guidance or standards related to indoor air quality filtration and performance, as a basis for conducting standardized assessments of publicly accessible buildings. The guidance includes the implementation of a third-party certification and a placarding system for buildings that have been verified as having the capability to provide cleaner air quality during wildfire smoke episodes.

The goal of this action is to increase the number of pre-identified publicly accessible buildings, including facilities operated by homeless service providers, that have necessary systems in place to serve as cleaner air sites. Cleaner air site designation placards will make it

easier for people to readily identify buildings that have been independently assessed and verified as being capable of offering better indoor air quality during wildfire smoke episodes.


*Figure 13. People exiting building.*

Efforts to make the necessary facility improvements and upgrades, along with maintenance and operational costs for maintaining and operating systems capable of providing cleaner air, can increase the expenses for building operators. Therefore, this action may need to be paired with other incentive or rebate programs to help offset additional costs associated with obtaining and maintaining a cleaner air site designation, to increase the feasibility and equitable distribution of cleaner air sites throughout the county. Placarding may aid as an incentive that can help to increase visitation rates of buildings that obtain cleaner air site designations. Other incentives may include seeking out partnerships with energy utility providers to help offset potential increased energy costs associated with the operation of cleaner air sites during wildfire smoke episodes, or using other local tax breaks for building managers who obtain and maintain cleaner air site designation status of their facilities.

*Potential collaborators:*

American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE); municipalities; local planning and community development agencies; local emergency management agencies; local community and human service agencies; homeless service providers; local, state, and federal parks and recreation agencies; local and state public health agencies; local businesses; building owners and property managers.

*Implementation Feasibility:*

**Hard**

**Indoor Air Quality & Built Environment | Action Performance Measures**

- Number of partnerships formed to support delivery of community indoor air quality assessments, and distribution and installation of air quality mitigation measures.
- Number of publicly identifiable buildings capable of protecting occupants from wildfire smoke, located in areas at high risk of environmental health disparities.

# WILDFIRE SMOKE RESPONSE

## WSR- 1: Establish inventory of deployable air filtration systems to open cleaner air sites.

*Action Description:*

Pre-identification and designation of locations that can serve as cleaner air sites can be a challenge because wildfire smoke sporadically impacts our air quality and can be hard to predict. Rapid repurposing of an existing facility can also disrupt access to other community services and activities a space is intended to provide. As a result, emergency managers must often make decisions in the moment based upon what spaces are available and accessible when wildfire smoke impacts occur.


*Figure 14. Commercial HEPA air cleaner located in reception lobby to improve IAQ.*

To increase the capacity to make cleaner air sites available during wildfire smoke episodes, this action encourages local emergency management agencies to establish an inventory of deployable air filtration units. There are a number of portable air cleaners and industrial commercial air scrubbers available that can be suitable for providing indoor air filtration in spaces ranging from a small room to entire gymnasium. By establishing an inventory of deployable air filtration systems, local emergency managers can ensure that they have the capacity to make cleaner air sites available regardless of whatever site or location may be used. Additionally, this action can serve as a way to enable emergency managers with the ability to augment the indoor air filtration capabilities of existing community and homeless service providers.

*Potential collaborators:*

Local emergency management agencies; local community and human service agencies; homeless service providers; local parks and recreation departments; local public health agencies; local libraries.

*Implementation Feasibility:*

**Moderate**

## WSR-2: Make N95 respirators available to unsheltered individuals and people experiencing homelessness during wildfire smoke episodes.

*Action Description:*

*Figure 15. People experiencing homelessness camped along city sidewalk.*

While other actions that reduce population exposure to poor air quality during wildfire smoke episodes are preferable, properly fitted N95 respirator masks can substantively reduce the levels of particulate matter that may be inhaled during wildfire smoke episodes. Even without proper fit-testing, the use of N95 respirator masks, when paired with proper guidance on how to properly wear and use a respirator, can result in moderate reductions in the amount of fine particulate matter that would otherwise be inhaled as a result of exposure. From a harm reduction standpoint, distribution of N95 respirators accompanied by guidance on how to properly wear and use them during wildfire smoke episodes should be considered for populations experiencing homelessness, with a focus on individuals living unsheltered or those who refuse to relocate to a shelter during wildfire smoke episodes.

*Figure 16. N95 respirator mask.*

Because it can be a challenge to rapidly distribute resources during a period of active wildfire smoke, this action encourages working with homeless service providers to help distribute N95 masks and usage guidance throughout the wildfire smoke season to help ensure people have access to these resources when necessary. In addition, due to potential complications that facial hair can pose to properly fitting an N95 mask, this action would be strengthened by pairing the distribution of these resources with shaving kits to help residents achieve a proper fit. However, it should be noted and clearly communicated during distribution efforts that use of a N95 mask should be a last resort measure, and that masks should only be used for a limited duration until individuals can relocate to an indoor location capable of providing cleaner air during wildfire smoke episodes.

*Potential collaborators:*

Homeless service providers and other services people experiencing homelessness access and use; public transit agencies; local parks and recreation departments; local and state public health agencies; local libraries; local emergency management agencies; local community and human service agencies;.

*Implementation Feasibility:*

**Moderate**

## WSR-3: Increase the number of staff trained and certified as incident management team (IMT) air resource advisors (ARAs).

*Action Description:*

Air Resource Advisors (ARAs) are a classification of technical specialists established under the Interagency Wildland Fire Air Quality Response Program of the U.S. Forest Service. They are trained to support incident management teams (IMTs) with understanding and predicting smoke impacts on the public and response personnel. ARAs are traditionally deployed to support IMTs engaged in wildfire containment and control efforts. However, as wildfire activity increases and wildfire smoke impacts regions far removed from areas with wildfire activity, there is an increasing need for personnel trained in understanding and predicting smoke impacts.

*Figure 17. Smoke plume from active wildfire.*

ARAs receive training to provide expertise in air quality science including air quality monitoring, smoke modeling, pollutant health thresholds, and communication about smoke risks and mitigation measures to decision-makers and the public. This action encourages increasing opportunities for local staff to receive training and certification to serve as ARAs to support local emergency response operations during wildfire smoke episodes. Air quality conditions can rapidly fluctuate during wildfire smoke episodes and vary significantly from location to location. By increasing the number of personnel trained to serve as ARAs that can support local response efforts, this action can help increase the availability at which spatially refined air quality data is available to support decision-making during wildfire smoke episodes.

The Interagency Wildland Fire Air Quality Response Program (IWFAQRP) typically offers annual training opportunities for Air Resource Advisors. Additional information on ARA training opportunities can be found online at https://wildlandfiresmoke.net/ara.

*Potential collaborators:*

U.S. Forest Serivce – Interagency Wildland Fire Air Quality Response Program; state and federal environmental protection agencies; local and state public health agencies; local emergency management agencies; local fire districts; state natural resource and wildfire protection agencies.

*Implementation Feasibility:*

**Moderate**

## WSR-4: Include severe wildfire smoke as a conditional measure in special and/or temporary event permitting that would require rescheduling or cancelation of outdoor events and activities during periods of severe wildfire smoke.

*Action Description:*

This action encourages the incorporation of conditional language into temporary and special event permits that would require rescheduling or cancellation of outdoor events that have the potential to draw large crowds of attendees during times of severe wildfire smoke as a force majeure clause.[6] The aim of this action is that by incorporating conditional language that would include severe wildfire smoke as a force majeure clause in the initial permitting processes of planning for outdoor events, event organizers will have more clarity on thresholds at which restrictions may be put into place that would limit large outdoor gatherings and provide ample time for identification of contingency plans if rescheduling or cancellations arise due to severe wildfire smoke.

Outdoor events and activities during the wildfire smoke season can draw large crowds, which can increase the risk of public exposure to poor air quality during wildfire smoke episodes. Because of this, PHSKC recommends that outdoor event organizers reschedule or cancel outdoor public events and activities when air quality conditions reach Air Quality Index (AQI) values of Very Unhealthy for All or worse. However, because organizers of outdoor events

[6] A "force majeure" clause is a contractual provision that relieves the parties from performing their contractual obligations when certain circumstances beyond their reasonable control arise, making performance inadvisable or commercially impractical.

are not always connected to emergency management channels of communication, these recommendations may not reach them.


*Figure 18. People gather at outdoor concert during Folklife at Seattle Center.*

By limiting the occurrence of outdoor events and activities during periods of severe wildfire smoke, this action would limit the potential number of people unnecessarily exposed to harmful environmental conditions. Including severe wildfire smoke as a force majeure clause serves to reduce the potential liability and hold outdoor event organizers harmless for rescheduling or canceling events and performances that otherwise have the potential to draw large crowds. Furthermore, including language on thresholds for cancellation and rescheduling in special and/or temporary event permits will presumably increase awareness of these thresholds to all parties involved in the organization, hosting, and attendance of outdoor events, and can enable the proactive establishment of conciliatory administrative actions in the event rescheduling or cancelation must occur due to severe wildfire smoke.

*Potential collaborators:*

Municipalities; special and temporary event permitting agenicies; outdoor event organizers; professional, collegiate, and intermural sports leagues and athletic associations; local, state, and federal parks and recreation agencies; local economic development agencies; local and state public health agenicies; local clean air agenicies; state environmental protection agencies.

*Implementation Feasibility:*

**Hard**

**Wildfire Smoke Response | Action Performance Measures**

- Number of cleaner air sites activated during wildfire smoke episodes to protect occupants from exposure to poor air quality.
- Number of partnerships formed to support distribution of personal protective equipment (PPE) kits to people living unsheltered during wildfire smoke events.
- Inclusion of severe air quality impacts due to wildfire smoke as a force majeure clause for event rescheduling or cancelation in special and temporary event permits for outdoor events.
- Estimated annual economic losses in revenue due to special and temporary event rescheduling or cancelation because of severe impacts to air quality due to wildfire smoke.

# 4 UNDERSTANDING THE CHALLENGE: WILDFIRE SMOKE IN THE PACIFIC NORTHWEST

Exposure to wildfire smoke is harmful to human health. Wildfire smoke is comprised of a complex mixture of pollutants, including particulate matter, carbon monoxide, nitrogen oxides, volatile organic compounds (VOCs), as well as many other toxics and trace elements. Its composition will vary from fire to fire depending on fuels, weather, and its duration in the atmosphere.[7,8,9]

*Figure 19. Man experiencing symptoms of eye irritaiton from wildfire smoke exposure.*

Symptoms of wildfire smoke exposure can range from headache to sore throat, coughing, burning eyes, dizziness, and wheezing. More serious health complications include asthma, cardiovascular complications, stroke, and kidney failure.[10,11,12,] Some populations are more sensitive to smoke exposure based on their age or health status, while others may be more impacted based on occupation, such as outdoor workers or environmental inequities due to the lingering effects of historic and institutional racism. Practices such as redlining and the placement of roads and industrial facilities in closer proximity to communities of color have resulted in higher rates of exposure among these communities in present day to sources of industrial and transportation-related emissions. It is important to prioritize the diverse needs of all of these groups when implementing actions intended to reduce the health risks of wildfire smoke exposure.

The science informing our understanding of wildfire smoke impacts on human health is still evolving. Over the past few years, a proliferation of academic literature and studies have highlighted the elevated risk to public health associated with short-term exposure to elevated concentrations of $PM_{2.5}$ from wildfire smoke. This section provides a brief summary of information available to date (see Appendix B for more detail). However, it is important to

[7] (Balmes, 2018)
[8] (Cascio W. E., 2018)
[9] (Urbanski, Hao, & Baker, 2009)
[10] (Xu, et al., 2022)
[11] (Ma, et al., 2023)
[12] (U.S. Environmental Protection Agency, 2023)

note that there are multiple components of wildfire smoke that we are still learning about, including delayed health impacts that occur long after exposure.

## 4.1 Impacts on Public Health

The primary pollutant of health concern in wildfire smoke is fine particulate matter known as $PM_{2.5}$. Comprised of particles that are less than 2.5 microns (µm) in diameter, $PM_{2.5}$ is roughly 20 times smaller than the width of a human hair. Because these particles are so small, they can be inhaled deep into the lungs and enter the bloodstream.[13] Many of the other pollutants in wildfire smoke are also classified as respiratory carcinogens and can become embedded in $PM_{2.5}$ originating from wildfire smoke.[14,15] As a result, if exposures to $PM_{2.5}$ from wildfire smoke were equal to that of other more common sources of $PM_{2.5}$, evidence suggests the health impacts of $PM_{2.5}$ from wildfire smoke may be greater than that caused by other sources of $PM_{2.5}$.[16,17]

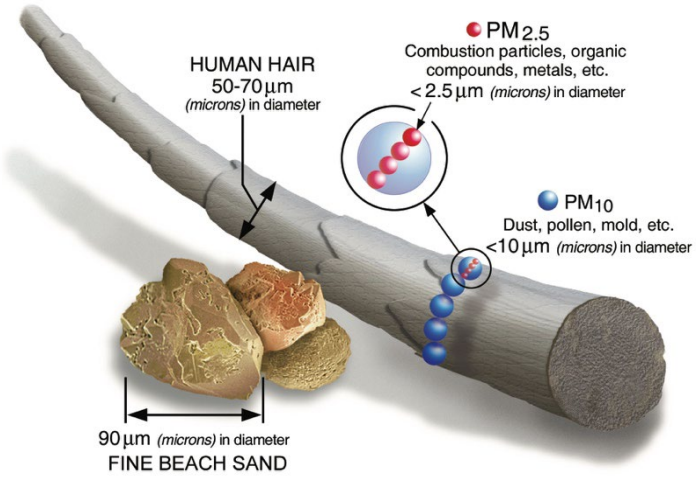


*Figure 20. Graphic illustration of size of PM2.5 in compairison to human hair.*

Smoke from wildfire activates inflammatory pathways in the body and can cause damage to DNA transcription processes, leading to a range of moderate to severe health impacts.[18,19] It has been associated with an increased risk of asthma-related emergency department (ED) visits immediately after and in the days following initial exposure.[20] A 2023 study found that approximately 30,108 all-cause deaths per year could be contributed to wildfire smoke exposure.[21]

[13] (U.S. Environmental Protection Agency, 2023)
[14] (Lopez, Pacheco, & Fendorf, 2023)
[15] (Urbanski, Hao, & Baker, 2009)
[16] (Noah, Worden, Rebuli, & Jaspers, 2023)
[17] (Aguilera, Corringham, Gershunov, & Benmarhnia, 2021)
[18] (Kim, et al., 2018)
[19] (Akids & Nadeau, 2022)
[20] (Doubleday, Sheppard, Austin, & Busch Isaksen, 2023)
[21] (Ma, et al., 2023)

Researchers at the University of Washington have found an association between exposure to wildfire smoke and non-traumatic mortality, with odds of mortality remaining elevated for the first few days following wildfire smoke exposure.[22] When further analyzed by subgroups, they identified a 35% increase in odds of same-day respiratory mortality for adults ages 45 – 65 years of age. These findings were observed to occur on days where $PM_{2.5}$ concentrations were greater than 20.4 μg/$m^3$, or when air quality using the U.S. EPA Air Quality Index (AQI) was rated as Moderate or worse.

Furthermore, when it comes to understanding the dose-response curve, or the level at which $PM_{2.5}$ concentrations associated with wildfire smoke can be observed resulting in adverse impacts to human health. Researchers at the British Columbia Center for Disease Control have found that wildfire smoke causes more harm, in terms of acute respiratory impacts, at lower concentrations that occur more frequently than during severe wildfire smoke episodes when $PM_{2.5}$ concentrations are more extreme.[23] Observing in British Columbia, that smoke concentrations over 100μg/$m^3$ are responsible for less than 20% of asthma-related physician visits, whereas more than 35% of asthma-related physician visits occur at smoke concentrations between 10 and 30 μg/$m^3$. Within the range that would be considered Moderate air quality according to the U.S. EPA AQI.

> *The U.S. EPA recently announced a new $PM_{2.5}$ standard by lowering the annual level of exposure from 12 μg/$m^3$ to 9 μg/$m^3$. For most residents, the result of these changes will be seen by air quality reaching Moderate AQI category (Yellow) more frequently than in the past, and when wildfires are affecting air quality it will reach Very Unhealthy (Purple) or Hazardous (Maroon) categories more often.*

Research on clinical health data has helped improve our awareness of some of the more severe health implications of wildfire smoke exposure. However, these findings underestimate the full extent of public health impact caused by exposure to wildfire smoke, as data on smoke-related health impacts such as impaired function, discomfort, and lost work and productivity is not readily available.[24] Additionally, a growing number of studies have begun to assess the long-term effects[25] and mental health impacts[26] of smoke exposure.

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[22] (Doubleday, et al., 2020)
[23] (Henderson, Nguyen, Yao, & Lee, 2024)
[24] (Cascio W. E., 2018)
[25] (Noah, Worden, Rebuli, & Jaspers, 2023)
[26] (Eisenman & Galway, 2022)

More recent research has begun to indicate higher levels of exposure to fine particulate matter may be associated with greater rates of incident dementia, especially for $PM_{2.5}$ generated from wildfire activity.[27] Studies on other sources of $PM_{2.5}$ have similarly begun to draw an association between air pollution and cognitive aging. For example, increased exposure to poor air quality later in life has been found to contribute to more rapid cognitive decline.[28]

The National Bureau of Economic Research (NBER) projects that climate-driven increases in wildfire smoke could result in 27,800 excess deaths each year by 2050 under a high warming scenario.[29] When monetized, NBER estimates that climate-induced deaths from wildfire smoke may result in annual damages of $244 billion by mid-century. If the health impacts are left unabated, the health costs of climate-driven wildfire smoke could be among the most significant and costly consequences of a warming climate in the U.S.

## 4.2 Populations at Risk

Climate change is a leading cause for the increase in recent wildfire activity across the western U.S.[30,31,32], along with other key factors including historical fire suppression and expansion of human activities into forested areas.[33] This means that wildfire smoke impacts on King County communities are likely to become increasingly common. However, the health impacts of wildfire smoke exposure are not borne equitably across the county's population, with factors such as race and socio-economic status playing an important role in the disparate burden of health impacts.[34,35]

*Figure 21. Child uses inhailer to ease asthma symptoms.*

When considering wildfire smoke impacts to populations, there are two categories of populations that face greater risk. The first is sensitive populations, such as children, pregnant people, people over 65 years of age, and people with medical conditions that make them more susceptible to health impacts resulting from exposure. The second is populations that are more impacted due to social

[27] (Zhang, et al., 2023)
[28] (Younan, et al., 2022)
[29] (Qui, et al., 2024)
[30] (Abatzoglou & Williams, 2016)
[31] (Zhuang, Fu, Santer, R.E., & Hall, 2021)
[32] (Holden, et al., 2018)
[33] (Radeloff, et al., 2018)
[34] (Ma, et al., 2023)
[35] (Reid, et al., 2023)

and other environmental stressors that make them more prone to adverse health impacts due to exposure, often referred to as inequities. To develop and appropriately tailor actions that can reduce the health impacts resulting from wildfire smoke exposure, it is important to explore how these factors contribute to population vulnerability.

Sensitivity can be viewed as how susceptible an individual may be to adverse health outcomes when they are exposed to wildfire smoke. The more sensitive an individual is to wildfire smoke, the more likely it is that they will begin developing symptoms at lower concentrations, or when exposed for shorter periods of time than others with less sensitivity. They may also develop more severe symptoms as a result of exposure. An individual's sensitivity to wildfire smoke can be understood primarily based on one's individual health and, secondarily, to individual behavior. Sensitivity differs for each person and can change from year to year. Common factors that can make an individual more sensitive include:

- Age (children and older adults are more sensitive)
- Pregnancy
- Pre-existing health conditions, such as asthma, chronic obstructive pulmonary disease, respiratory infection, hypertension, diabetes, obesity, and mental health disorders

Inequities describe additional stressors an individual may experience that can increase their risk of adverse health impacts from wildfire smoke exposure. Inequities stem from complex social and environmental factors, which can contribute to conditions that increase an individual's sensitivity, such as prevalence of pre-existing medical conditions. These inequities can also influence an individual's ability to take necessary precautions to reduce their risk of exposure. These factors include:

- Occupation
- Socio-economic status
- Housing status
- Communities of color

Understanding the factors that influence population sensitivity and inequity can inform the development of more focused interventions and approaches to reduce health impacts resulting from wildfire smoke exposure.

### 4.2.1 Age

Age is a prominent factor in determining an individual's sensitivity to wildfire smoke exposure. Both young children and adults 65 years of age and older are generally at higher risk of experiencing health impacts resulting from exposure to wildfire smoke than other age groups.

*Figure 22. Young child and elderly adult outdoors.*

Lung development continues until people reach 21 years of age,[36] meaning anyone under the age of 21 is more susceptible to health impacts resulting from smoke exposure. However, younger children, particularly those five years old and younger, are at increased risk due to their smaller airways, higher metabolic rate, and ongoing development,[37] Children also tend to have increased exposure to wildfire smoke as they spend more time outdoors, breathe more air relative to their body weight than adults, and can have a higher proportion of inhaled particles penetrate deeply into their lungs.[38,39]

Research on the health impacts of wildfire smoke on older adults (65 years and older) suggests that their increased risk is related to a higher prevalence of diagnosed and undiagnosed pre-existing health conditions that make them more sensitive to exposure.[40,41,42] Additionally, important physiological processes in the body decline with age, including immune defense mechanisms, increasing the risk of older adults to short-term smoke exposure.[43] Many older adults may also have fixed or lower incomes, limiting their ability to invest in interventions that would otherwise help reduce their exposure. They may also experience social isolation or be dependent upon a care provider for assistance, impacting their ability to use available interventions that can help protect their health during wildfire smoke episodes.[44]

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[36] (Narayanan, et al., 2012)
[37] (Henry, Ospina, Dennett, & Hicks, 2021)
[38] (Holm, Miller, & Balmes, 2021)
[39] (Bennett, Zeman, & Jarabek, 2007)
[40] (Zheng, 2023)
[41] (Aguilera, Corringham, Gershunov, & Benmarhnia, 2021)
[42] (Kim, Knowles, Manley, & Radoias, 2017)
[43] (U.S. Environmental Protection Agency, 2024)
[44] (Melton, De Fries, Smith, & Mason, 2023)

### 4.2.2 Pregnancy

*Figure 23. Pregnant woman outdoors wearing N95 mask.*

There is increasing evidence that wildfire smoke exposure during pregnancy increases risk of poor birth outcomes. Exposure to wildfire smoke during late pregnancy has been found to be associated with reduced birth weight and preterm birth, likely due to a combination of air pollution and psychological stress.[45] One pathway that links poor air quality to poor birth outcomes is the effect exposure to fine particulate matter has on pulmonary and placental inflammation during pregnancy. This affects gas and nutrition exchange and reduces the level of oxygen available to the fetus.[46,47,48] Ongoing research by the University of Southern California MADRES Center suggests that there may be a critical window during which exposure to ambient air pollution may affect in utero fetal growth. In particular, exposure to particulate matter in early to mid-pregnancy, between the 1st and 23rd week of gestation, may have critical implications for fetal growth.[49]

### 4.2.3 Pre-existing health conditions

Pre-existing health conditions can greatly increase an individual's health risk resulting from wildfire smoke exposure, particularly ailments related to the respiratory, cardiovascular, or renal systems of the body.[50,51,52,53,54] To date, the most well-established relationships between pre-existing health conditions and higher risk of adverse health outcomes following wildfire smoke exposure are associated with adult and pediatric asthma, chronic obstructive pulmonary disease, diabetes, hypertension, and obesity.[55,56,57,58,59,60] Some health impacts resulting from aggravation of preexisting health conditions occur immediately following

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[45] (Amjad, Chojecki, Osornio-Vargas, & Ospina, 2021)
[46] (Ghazi, Naidoo, & Chuturgoon, 2021)
[47] (Saenen, et al., 2019)
[48] (National Academies of Sciences, Engineering, and Medicine, 2024)
[49] (Peterson, et al., 2022)
[50] (Noah, Worden, Rebuli, & Jaspers, 2023)
[51] (Henry, Ospina, Dennett, & Hicks, 2021)
[52] (Doubleday, Sheppard, Austin, & Busch Isaksen, 2023)
[53] (Liu, et al., 2021)
[54] (Xi, et al., 2020)
[55] (Stowell, et al., 2019)
[56] (Bateson & Schwartz, 2004)
[57] (Mashin, Cabaj, & Saini, 2022)
[58] (Siregar, Idiawati, Pan, & Yu, 2022)
[59] (Reid, et al., 2016)
[60] (Jung, et al., 2024)

exposure, such as respiratory impacts, while others may lag and occur several days following exposure, such as cardiovascular impacts.[61] While multiple studies have established the relationship between wildfire smoke and cardiorespiratory symptoms in terms of emergency room visits and hospital admissions,[62] gaps remain in our understanding of the total sub-acute and sub-clinical health impacts of wildfire smoke exposure.[63]

*Figure 24. Elderly man outdoors experiencing chest pain.*

Limited research has been conducted assessing the effect of wildfire smoke exposure on mental health. However, from the limited studies that have been done, emerging evidence is beginning to suggest that exposure to episodes of chronic and persistent wildfire smoke may be associated with increases in anxiety, depression, and disrupted or poor sleep.[64,65,66] While preliminary in nature, this information begins to indicate a likelihood of increased sensitivity for individuals with existing mental health conditions, and an increased risk of adverse mental health outcomes resulting from exposure.

### 4.2.4 Occupation

Occupation has a significant influence on how much air pollution an individual may be exposed to during wildfire smoke episodes. Individuals who work outdoors, or in settings that require routine exposure to outdoor conditions, generally will experience higher levels of exposure to wildfire smoke than people who work in indoor settings.

*Figure 25. Outdoor workers at construction site.*

In 2024, the Washington State Department of Labor & Industries (WA L&I) enacted new permanent rules on wildfire smoke to protect outdoor workers during wildfire smoke events. These rules establish requirements for employers to help reduce outdoor workers' exposure while performing their job. The new rules require employers to routinely monitor outdoor air

[61] (Doubleday, Sheppard, Austin, & Busch Isaksen, 2023)
[62] (Youssouf, et al., 2014)
[63] (Cascio W. E., 2018)
[64] (Eisenman & Galway, 2022)
[65] (Rodney, et al., 2021)
[66] (Mirabelli, Vaidyanathan, Pennington, Ye, & Trenga, 2022)

quality, train and educate employees on the health risks of wildfire smoke exposure, and provide cleaner air areas and spaces where outdoor employees can seek temporary reprieve from wildfire smoke. Employers must now also make N95 filtering facepiece respirators (FFR) or other National Institute for Occupational Safety and Health (NIOSH)-approved respirators readily available to employees when smoke is present and provide reasonable accommodations for individuals with pre-existing health conditions that may make them more sensitive to wildfire smoke exposure.

When worn with a proper fit, an FFR such as an N95 can achieve a 10-fold reduction in wildfire smoke exposure.[67] However, the benefits of using an N95 FFR can range significantly, from a 90% reduction in exposure when properly fitted, to near 0% reduction if poorly fitted due to factors such as face shape and size, facial hair, improper use, or discontinuation of use due to discomfort.[68] As a result, other administrative measures such as staying indoors or avoiding heavy or prolonged physical activity may prove more effective at protecting outdoor workers during wildfire smoke events. A 2018 assessment on the benefits of various protective measures observed that staying indoors alone can achieve approximately a 50% reduction in exposure, but as previously discussed, building characteristics can result in wide fluctuations in the level of protection that staying indoors can provide. Actions aimed at avoiding heavy or prolonged physical activity were found to lower the levels of pollutants inhaled during wildfire smoke episodes, especially for outdoor workers, as pulmonary ventilation rates can increase 10- to 20-fold during heavy exertion. This makes this an effective method of preventing adverse health outcomes during wildfire smoke episodes.[69]

### 4.2.5 Socio-economic status

Socio-economic status also has an important influence on the health outcomes experienced during wildfire smoke episodes. Communities of lower socio-economic status often experience higher baseline levels of exposure to air pollution. This contributes to higher prevalence of pre-existing health conditions that can make individuals more sensitive to wildfire smoke exposure.[70,71,72]

Socio-economic status is also closely associated with the quality and condition of the built environment where people live. As discussed earlier, the protective qualities of indoor environments can vary significantly during wildfire smoke episodes. Lower-income households often experience higher levels indoor air pollution (when compared to higher-income households) during wildfire smoke episodes even when outdoor pollution levels are

[67] (Sbihi, 2014)
[68] (Laumbach, 2019)
[69] (Laumbach, 2019)
[70] (Hajat, Hsia, & O'Neil, 2015)
[71] (Morello-Frosch R. , 2002)
[72] (Banzhaf, Ma, & Timmins, 2019)

similar.[73] While strategies exist to reduce smoke infiltration and improve filtration of indoor air, the costs associated with the installation and use of these strategies can be cost prohibitive for lower-income households, and renters may face additional barriers due to constraints in their ability to modify their homes due to lease terms and conditions.[74]

### 4.2.6 Housing status

According to PHSKC's Healthcare for the Homeless Network, in 2023 there were an estimated 40,000 people experiencing homelessness in King County. While people experiencing homelessness generally face greater health disparities than the general population, less is known about the health of people who live unsheltered – sleeping in a place not intended for human habitation, such as cars, parks, sidewalks, abandoned buildings, or tents – in comparison to their sheltered counterparts. Whereas some people experiencing homelessness may be able to obtain temporary shelter and support services from homeless service providers, unsheltered individuals presumably experience additional health burdens relating to their exposure to weather, pollution, poor sanitation, exploitation, and the possibility of violence.[75] As a result, unsheltered individuals are more likely to experience adverse health impacts than individuals experiencing homelessness who are able to access services made available by homeless service providers.

*Figure 26. People experiencing homelessness camped under highway.*

According to a 2023 study assessing the social vulnerabilities of U.S. communities affected by wildfire smoke, Washington state, among several western states, witnessed over a 200% increase in the number of days people experiencing homelessness were exposed to heavy smoke between 2017 – 2021 in comparison to 2011 – 2015.[76] However, to date limited studies have assessed the unique health risks of people experiencing homelessness during wildfire smoke events.[77] People experiencing homelessness, in particularly those living unsheltered, experience a disparate risk of exposure to poor air quality during wildfire smoke episodes. People experiencing homelessness already face challenges associated with a lack of regular shelter availability, and often struggle with a lack of access to information

[73] (Krebs & Neidell, 2024)
[74] (Colmer, Hardman, Shimshack, & Voorheis, 2020)
[75] (Richards & Kuhn, 2023)
[76] (Lappe, Vargo, & Conlon, 2023)
[77] (Schwarz, et al., 2022)

and resources to adequately prepare for and respond to wildfire smoke impacts on air quality.[78]

### 4.2.7 Communities of color

Institutional racism has contributed to the presence of significant health disparities in King County. Where historic practices of redlining that denied people access to financial services based on their race, ethnicity, or where they lived, contributed to the segregation of communities that persists today. The siting of industrial land use sites more frequently in communities of color, in conjunction with closer proximity to high-traffic volume roadways and regional transportation hubs, has resulted in disproportionate exposure to air pollutants among communities of color.[79,80] Causing higher prevalence rates of pre-existing health conditions due to routine exposure to poor air quality that contribute to higher sensitivities to wildfire smoke. Income disparities can also result in limitations in self-determination of housing choices and limitations in the ability to afford access to interventions, such as portable air cleaners, that can reduce exposure to air pollution during wildfire smoke episodes.

*Figure 27. African-American man in wheelchair accessing information on computer.*

## 4.3 Behavior & risk perception

The behavior of individuals and their perception of the risks associated with wildfire smoke exposure is one of the greatest factors that influence their level of exposure. Behavior refers to the way in which people act in response to a particular situation and is determined by an individual's awareness, perception, access, and ability. Socio-economic conditions can influence an individual or household's access to and ability to utilize interventions that can help reduce exposure to wildfire smoke. Individuals vary in their knowledge and beliefs about the health risks posed by wildfire smoke, which influences the level of proactive actions they may take to protect their health.[81,82]

Risk perception commonly refers to an individual's perceived susceptibility to a hazard or threat. The higher the perceived risk, the more likely an individual is to seek out information

[78] (Lappe, Vargo, & Conlon, 2023)
[79] (Liu, et al., 2021)
[80] (Morello-Frosch & Lopez, 2006)
[81] (Santana, Gonzalez, & Wong-Parodi, 2021)
[82] (Rappold, et al., 2019)

and take action to reduce their risk. When making decisions about health, individuals generally navigate the choices they make by weighing the risk of consequences with the benefits of acting, where motivation is driven in part by the perceived probability that a health impact will otherwise result.[83,84,85] In behavioral motivation theory, individual decision-making is driven by three critical components that include 1) the perceived magnitude or severity of a hazard, 2) the probability of occurrence, and 3) the perceived efficacy of a protective response.[86] Furthermore, an individual's perception of risk is generally influenced by what information is most readily available and the frequency in which a threat is represented in media.[87,88]

While individuals may perceive wildfire smoke as a risk to their health, they may be less motivated to take actions that extend beyond simple measures, such as staying indoors to reduce exposure, and may not grasp the full extent exposure to wildfire smoke may impact their health. This was exemplified in a 2020 study on mortality associated with wildfire smoke exposure in Washington state assessing health outcome data between 2006 and 2017, which observed that the highest increase in odds of same-day respiratory mortality occurred among adults ages 45-65.[89] This highlights the occurrence of severe health outcomes among an age cohort that had previously not been considered to be a vulnerable age group. One hypothesis for this observation is that individuals within this age range may consider themselves to be young and healthy and do not perceive themselves to be at risk to wildfire smoke exposure and are thus less likely to take actions to protect their health during smoke episodes.

*Figure 28. Woman jogging outdoors in smokey conditions.*

Other behaviors and household activities can also increase an individual's risk of experiencing adverse health outcomes during wildfire smoke events. For instance, individuals who smoke are predisposed to having decreased lung capacity, making them more susceptible to acute health impacts resulting from wildfire smoke exposure.[90] Routine

[83] (Rogers, 1975)
[84] (Becker, 1974)
[85] (Ferrer & Klein, 2015)
[86] (Rogers, 1975)
[87] (Tversky & Kahneman, 1973)
[88] (Slovic, 1987)
[89] (Doubleday, et al., 2020)
[90] (Mirabelli, et al., 2009)

household activities such as cooking and cleaning with chemical sprays can also contribute to poor indoor air quality. When these activities coincide with wildfire smoke episodes, it can further increase the level of air pollution individuals may be subjected to, as common methods used to increase ventilation, such as opening windows, may not be viable.


*Figure 29. Accessing air quality information online.*

Having access to information necessary to enable individuals to make informed decisions regarding their behavior and activities during wildfire smoke episodes is paramount to mitigating health impacts that can otherwise occur because of exposure. Education tends to be one of the most effective intervention methods towards reducing adverse health impacts, as it can enhance risk perception levels and maximize the transformation of perception into actions and behaviors that can prevent impacts to health.[91] This is especially true for the health impacts posed by wildfire smoke, as people may struggle to differentiate it from other sources of air pollution and downplay their risk due to the perceived "natural" origin of wildfire smoke.[92]

## 4.4 Indoor Air Quality: Capabilities of the Built Environment

The average adult in the U.S. spends approximately 90% of their time indoors.[93] Because of this, research suggests that indoor air quality is more indicative of an individual's level of exposure to wildfire smoke than measures of outdoor air quality.[94] According to the American Lung Association, levels of indoor air pollution can be two to five times higher than outdoor levels across the U.S. Therefore, the use of ventilation with clean outdoor air is generally one of the best strategies to obtain healthy indoor air. However, during periods of wildfire smoke, this common best practice has the inverse effect, and it is best to reduce outdoor air infiltration, and increase indoor air filtration.

Fine particulate matter from wildfires can enter indoor environments through openings and small gaps around doors, windows, and utility access points due to pressure and temperature differences between outdoor and indoor environments.[95] As smoke makes its way into indoor environments over time (referred to as infiltration), without effective

[91] (Lou, et al., 2021)
[92] (Macey, 2008)
[93] (U.S. EPA, 2023)
[94] (Lou, Weng, Xu, & Sun, 2019)
[95] (Humphrey, et al., 2020)

processes to remove smoke from indoor air, it can reach outdoor concentrations within a matter of a few hours, and levels that are considered harmful to health.

There is a range of factors that influence infiltration of smoke into buildings due to differences in weatherization, ventilation, and operation. Key variables regarding the design, construction, operation, and maintenance of buildings significantly influence their indoor air quality and performance during smoke episodes.

### 4.4.1 Smoke infiltration into indoor environments

The infiltration rate at which smoke enters our indoor environments is influenced by building characteristics including age, condition, presence and type of ventilation system(s) or air filtration system(s).[96] Newer buildings are typically better sealed and have lower infiltration rates due to changes in building codes and improvements in insulation and energy efficiency. Older buildings are often less sealed and have higher rates of infiltration.[97,98]

Ventilation also has a significant role and can contribute to infiltration in two different ways, depending on the type of ventilation system:

> ***Natural ventilation*** – relies upon opening doors or windows to allow a flow of external air into an indoor space, leveraging the dynamics of natural forces. Because natural ventilation relies on allowing a free exchange between indoor and outdoor air, buildings that rely on the use of natural ventilation for passive cooling can have high infiltration rates, resulting in higher risk of occupant exposure to wildfire smoke than buildings that utilize mechanical ventilation systems with filters.
>
> ***Mechanical ventilation*** – relies upon mechanical systems, such as an exhaust fan typically found in a kitchen or bathroom and heating, ventilation, and air conditioning (HVAC) systems with an outdoor air intake and mechanical supply fan. Because these systems employ fans that can generate a high throughput of air, referred to as air flow, they can employ the use of filtration through a mesh of varying materials (referred to as filter media) to trap particles passing through them. This potentially reduces the infiltration of wildfire smoke.

The type of use a building is intended for and behavior of its occupants also are important factors that influence smoke infiltration rates. As noted above, natural ventilation can often be used for passive cooling, especially during hotter times of the year that tend to coincide with peak wildfire season. For many residents without air conditioning, there may be no other option to avoid the risk of overheating; however, doing so during episodes of wildfire smoke increases their exposure. Buildings that have higher occupancy rates may also be

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[96] (Chen & Zhao, 2011)
[97] (Xiang, et al., 2021)
[98] (Reisen, Powell, Dennekamp, Johnston, & Wheeler, 2019)

subject to increased smoke infiltration rates as people come and go more frequently, with smoke making its way indoors each time someone enters or exits a building.

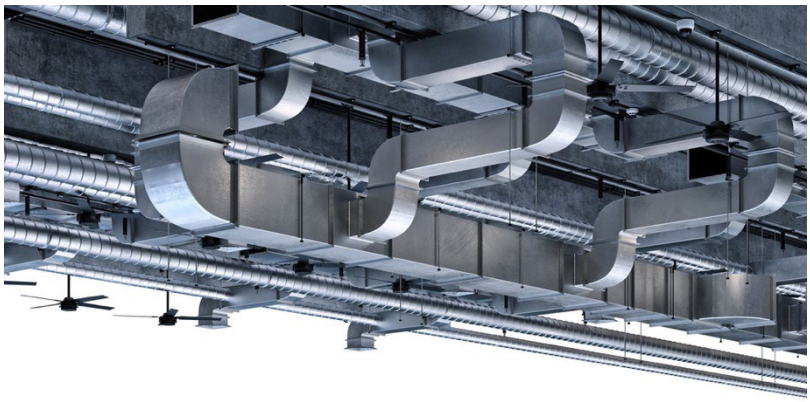

*Figure 30. Mechanical ventilation ducting.*

Actions that focus on improvements, such as closing dampers on the outdoor intakes of mechanical ventilation systems, and weatherization of existing structures, can help to reduce smoke infiltration rates. However, even in relatively airtight buildings and homes indoor pollutant levels will still increase over time, elevating the importance of indoor air filtration, especially during extended wildfire smoke episodes.[99] Making improvements that reduce infiltration rates alone may not be enough to reduce occupant exposure to harmful levels of air pollution.[100] but they can provide an opportunity to better control indoor air quality when wildfire smoke occurs. Care must also be taken to not reduce air exchange in buildings so much that humidity and indoor pollutant levels reach problem levels. High humidity is the key driver for mold growth, which can be a serious indoor air quality problem.

### 4.4.2 Filtration of indoor air

To remove wildfire smoke from indoor air it is necessary to use a filter media that is rated to remove the smallest particles (0.3 – 1.0μm) that are most common in wildfire smoke. Filter media (here forward referred to as filters) are generally defined by the level at which they can remove particulates from the air, otherwise known as their minimum efficiency reporting values (MERV). Filter MERV ratings range from 1-16, defined by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 52.2.[101] As MERV ratings increase from 1 to 16, so does the effectiveness of filters at removing particles, with filtration of the smallest particles and highest removal rates achieved by those with a rating of MERV-13 and higher.[102]

When preparing for wildfire smoke, filters with a rating of MERV-13 or higher are recommended to effectively reduce occupant exposure as these units can remove as much

[99] (Rajagopalan & Goodman, 2021)
[100] (Munro & Seagren, 2020)
[101] (ASHRAE, 2017)
[102] (Davison, et al., 2021)

as 95% of the particulates that pass through them.[103] The use of filters with a rating of MERV-11 and lower have been found to be ineffective in reducing indoor exposure to wildfire smoke.[104]

### 4.4.3 Current capabilities of residential indoor environments

In the Pacific Northwest, many homes are not equipped with mechanical ventilation systems that include any form of air filtration. A 2020 nationwide study by the U.S. Energy Information Administration reported that only about 30% of households in Washington state use central air handling systems for summer cooling that can accommodate the use of filters, while another 53% of households use a form of air conditioning that is not compatible with the use of filters, such as portable air conditioning units and ductless heat pumps.[105] However, even in instances where central air conditioning systems are present, many homes use low efficiency fiberglass filters that are one inch thick and are only rated between MERV-1 and MERV-8.[106]

Unfortunately, changing out filter media in an existing mechanical ventilation system (MVS) to accommodate higher rated filters is not a straightforward solution. Determining what filter rating a MVS can accommodate can prove challenging without consulting a professional technician. Changing existing filters for ones with a higher MERV rating can also increase system energy demands and reduce the system's operational lifespan as it must work harder to achieve the same level of airflow.[107] Ultimately, making a MVS compatible with the use of filters recommended for wildfire smoke may require major system upgrades that can be cost prohibitive for many.

### 4.4.4 Portable air cleaners

Portable air cleaners (PACs) are standalone devices generally equipped with either HEPA filters or electrostatic precipitators.[108] Whereas HEPA filters represent a rating of filter media efficiency (see section 3.2.2), electrostatic precipitators generate an electrostatic charge to attract and trap free floating particulates in the air. Although they have been shown to be effective at the removal of fine particulates, their use can result in the generation of ozone[109] at levels that can be harmful to human health. Therefore, their use and the use of ionizers is not recommended in homes or other occupied indoor environments. For the purposes of selecting a PAC, it is recommended to only use PACs that have received California Air Resource Board (CARB) certification and are designated as only having mechanical filtration,

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[103] (U.S. Environmental Protection Agency , 2024)
[104] (Dsouza & Zhong, 2023)
[105] (U.S. Energy Information Adminisration, 2023)
[106] (U.S. Environmental Protection Agency , 2024)
[107] (Shirman, Shirman, & Liu, 2023)
[108] (Barn, Roberecki, Jenkins, Hasselback, & Rideout, 2014)
[109] (Poppendieck, Rim, & Persily, 2014)

and avoiding units that are designated as having electronic filtration due to the poteintal release of harmful byproducts.

Use of PACs during wildfire smoke episodes have been estimated to reduce indoor $PM_{2.5}$ concentrations by a margin of 63% to 88%[110] and have been observed to reduce indoor $PM_{2.5}$ levels against outside concentrations by 65% (±35%).[111] While the most effective strategy to improve indoor air quality during smoke episodes would be to increase the filtration of MVSs to a MERV-13 or higher filter, in addition to the use or PACs. However, because increasing the filtration of an existing MVS in some instances be cost prohibitive, the use of PACs offer still offer several improvements.

*Figure 31. Young woman sites with dog next to HEPA portable air cleaner.*

PACs are typically more affordable than updating filtration in MVSs, they are often much easier to operate by building occupants and can be used to improve indoor air quality in nearly any type of home, apartment, or indoor environment.[112, 113, 114, 115] This makes them more accessible to tenants of renter-occupied housing. They also use less energy per unit of particulate removal than MVSs with upgraded filtration.[116, 117]

A common performance metric of PACs is their clean air delivery rate (CADR), a metric developed by the Association of Home Appliance Manufacturers (AHAM), based upon the measured decay rate of contaminant concentration with the air cleaner operating compared with the measured decay rate with the air cleaner turned off.[118] PACs that contain an AHAM Verified® mark have been independently tested for their ability to remove three common indoor pollutants - tobacco smoke, pollen, and dust - and have been verified to meet the California Air Resource Board (CARB) ozone emission limits. AHAM Verified® air cleaners will have a CADR rating for each of the three pollutants tested and this rating is

[110] (Hederson, Milford, & Miller, 2005)
[111] (Barn, et al., 2008)
[112] (National Academies of Sciences, Engineering, and Medicine, 2024)
[113] (Association of Home Appliance Manufacturers, 2022)
[114] (U.S. Environmental Protection Agency , 2024)
[115] (ASHRAE, 2021)
[116] (Fisk & Chan, Effectiveness and cost of reducing particle-related mortality with particle filtration, 2017)
[117] (National Academies of Sciences, Engineering, and Medicine, 2016)
[118] (Shaughnessy & Sextro, 2007)

generally prominently listed on the product label. When selecting a PAC for the intended purpose of filtering wildfire smoke, AHAM suggests the use of a unit that has a smoke CADR (rating for filtration of 0.09 micron and 1.0-micron particles) that matches the room size in which the unit will be used.[119] For example, an air cleaner with a smoke CADR of 150 would be appropriate for a 150 square-foot room during a wildfire smoke event, assuming the National Building Code (NBC) standard residential ceiling height of eight feet. In some instances, more than one PAC may be required to achieve the desired CADR for a single interior space, such as in homes or buildings that have lofted ceilings higher than the 8-foot residential standard or in homes or buildings with open concept floor plans that do not have partition walls separating rooms.

However, while effective, the behavior of residents regarding the operation and maintenance of PACs can make the applied performance of these units highly variable. Placement of a PAC can significantly influence how effectively the unit will filter particulates within a given space,[120] with their effectiveness being the greatest when placed in the center of a room and away from walls, furniture, and corners that can otherwise obstruct the airflow. Also there needs to be good general air circulation within the room. Noise generated by a PAC can also pose a nuisance to users, resulting in the units being operated at lower settings. However, at lower settings the airflow is reduced, and the units are less effective at removing particles from the air.[121] Over time, cumulative loading of the PACs filter(s) during normal operation will restrict airflow through filters, reducing its effectiveness. This requires periodic maintenance to check and replace loaded filters to maintain optimal operation.[122]

When assessing the protective qualities of indoor environments during wildfire smoke episodes, both infiltration (how much pollution can make its way indoors) and filtration (how much pollution can be removed from indoor air) must be independently considered. When it comes to implementing mitigation measures that aim to improve indoor air quality during wildfire smoke episodes, there is no one solution that will fit all situations. Just as the design of buildings vary greatly, actions must be tailored to the unique needs of each building.

## 4.5 Variations in wildfire smoke composition & toxicity

The geography in which a wildfire occurs and the proximity between wildfire smoke's point of origin and the location at which exposure occurs are important factors that influence its composition and toxicity.[123,124] Wildfire smoke is not homogeneous and its composition

[119] (Association of Home Appliance Manufacturers, 2022)
[120] (Novoselac & Siegel, 2009)
[121] (U.S. Environmental Protection Agency, 2018)
[122] (Azimi, Zhao, & Stephens, 2016)
[123] (Balmes, 2018)
[124] (Cascio W. E., 2018)

changes depending upon what is being burned. As a result, the specific toxicological profile of wildfire smoke varies from fire to fire, and it may change with changes in fire intensity and behavior as it burns.[125] Furthermore, wildfire smoke can be propelled high into the atmosphere and transported over vast distances. The longer wildfire smoke remains in the atmosphere and moves away from its origin, the more the smoke can affect air quality through formation of secondary pollutants such as organic aerosols and ozone.[126]

*Figure 32. Smoke from wildfire along mountain ridgeline.*

Wildfires occurring in areas with high temperatures and dry fuels can result in a more complete combustion of materials and contribute to higher levels of carbon dioxide ($CO_2$), ash, water vapor, nitrogen oxides ($NO_x$), and sulfur dioxides ($SO_2$). Fires occurring in cooler environments with wet fuels, such as peat, can result in partial oxidation of fuels, causing emissions that can be more toxic for human health, such as carbon monoxide (CO), hydrogen sulfide ($H_2S$), hydrogen cyanide (HCN), and ammonia ($NH_3$).[127] The severity or temperature at which a wildfire burns also influences how high into the atmosphere particulates can be carried. The hotter temperature that a fire burns along with a greater size of active fire area, the higher fine particles can be injected into the atmosphere, where they can remain for months and in turn affect large areas downwind from wildfires.[128]

Geology also influences the toxicity of wildfire smoke. Until recently, the health threats arising from fire-altered toxic metals found naturally in soils and plants have been under-recognized. However, a recent study in California discovered that high temperatures during wildfires can catalyze the transformation of naturally occurring chromium into its dangerous carcinogenic form, hexavalent chromium, in wind-dispersible soil and ash.[129] This was found most prevalent in areas with metal-rich geologies, such as serpentinite. The role geology plays in the potential catalyzation of naturally occurring minerals found in soils into more hazardous compounds during wildfires elevates the health risk of wildfire smoke exposure and raises important implications regarding lingering health risks that may be posed by wind-dispersible ash and dust following a wildfire.

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[125] (Urbanski, Hao, & Baker, 2009)
[126] (Jaffe & Wigder, 2012)
[127] (Sokolik, Soja, DeMott, & Winker, 2019)
[128] (Fromm, et al., 2010)
[129] (Lopez, Pacheco, & Fendorf, 2023)

Other factors influencing the composition and toxicity of wildfire smoke are associated with the proximity of wildfire activity to the wildland-urban interface (WUI). Fires that occur near or within the wildland-urban interface can result in greater losses of structures, infrastructure, vehicles, and other artifacts. The combustion of these anthropogenic materials emits numerous additional toxicants that increase the toxicity of wildfire smoke, including hydrogen cyanide, hydrogen fluoride, hydrogen chloride, isocyanates, polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, as well as a range of toxic organic compounds (benzene toluene, xylenes, styrene, and formaldehyde) and metals (lead, chromium, cadmium, and arsenic).[130] Additionally, due to the close proximity of the WUI to large population centers, wildfires occurring in the WUI can result in rapid impacts to air quality. This results in exposure to higher concentrations of smoke that can be imbued with additional toxicants detrimental to health.

## 4.6 Wildfire smoke: past, present, and future

Wildfire has been an important feature of the landscape, shaping ecosystems across the Pacific Northwest since the end of the last ice age and the beginning of the Holocene epoch, dating back roughly 11,000 years. The term fire regime is used to describe the general pattern in which fire naturally occurs in a particular ecosystem over an extended period of time. While recent increases in wildfire activity have contributed to several large wildfires over the past few decades, the total area burned by wildfires remains well below the historical fire regimes of the Pacific Northwest region, which includes the northwestern corner of the United States and the southwestern part of Canada.[131] When comparing the number of acres burned by large fires in the 30-year period between 1984 and 2015 against historical fire regimes, fire activity in the Pacific Northwest region has been in the range of 13.3 – 18.9 million hectares below historical fire activity, equating to an area between 51,351 – 72,973 square miles, roughly the same size as the entire state of Washington.[132] However, historical fire regimes consisted mainly of low and moderate severity fires that burned at lower temperatures and generally only burned the understory of a forest with minimal impact on overstory trees.

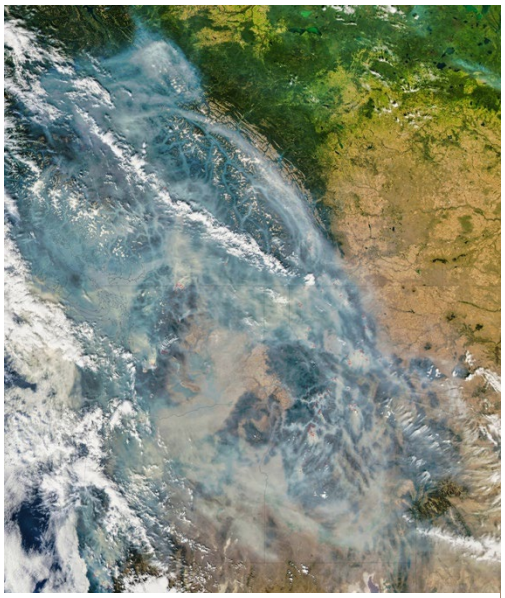

*Figure 33. Smoke blanketing western Washington.*

[130] (Holder, Ahmed, Vukovich, & Rao, 2023)
[131] (Reilly, et al., 2021)
[132] (Haugo, et al., 2019)

A confluence of factors including historical logging practices, fire exclusion and suppression including restrictions on cultural burning by tribal and indigenous communities who have been stewards of the land and practicing burns prior to the arrival of western settlers, urban development, and changing climatic conditions have drastically altered forest conditions across the Pacific Northwest over the past two centuries. This has resulted in an overaccumulation of vegetative fire fuels which have contributed to more than a 300% increase in the frequency of high severity fires that burn with greater intensity at higher temperatures, resulting in greater forest losses.[133]

Climate change is expected to increase the average temperature and decrease summer precipitation in the Northwest, contributing to drought conditions and drier vegetation, increasing the risk of wildfire.[134] As a result, researchers predict that the generation of wildfire smoke will likely substantially increase under future climate change. Average exposure across the U.S. population is predicted to increase 2-to-3 fold by 2050 relative to 2011-2020 and contributing to an estimated 12,000 additional excess deaths per year in the U.S. under a high greenhouse gas emissions scenario.[135] This suggests that increases in wildfire smoke could be one of the most consequential impacts of climate change on human health in the U.S.

The altitude a plume of wildfire smoke will rise to is determined in part by the amount of heat produced by the fire.[136] The higher the level of wildfire severity, the higher its plume of smoke will likely rise into the atmosphere and the farther from its source the smoke can be transported. As wildfire severity is anticipated to increase with climate change, surface level impacts to air quality are likely to increase across regional and continental scales as the wildfire smoke subsides and interacts with localized atmospheric conditions.[137,138] Wildfire smoke has the potential to decrease air quality across vast areas that extend far beyond boundaries and regions where wildfire activity may actively be occurring.[139] This is a phenomenon that has already been observed with wildfires in Siberia impacting air quality in the Pacific Northwest in 2012,[140] western U.S. wildfires in 2020 impacting air quality across

[133] (Serra-Diaz, et al., 2018)
[134] (USGCRP, 2023)
[135] (Qui, et al., 2024)
[136] (Wilmot, Mallia, Hallar, & Lin, 2022)
[137] (Hung, et al., 2020)
[138] (Val Martin, et al., 2010)
[139] (Brey, Ruminski, Atwood, & Fishcer, 2018)
[140] (Cottle, Strawbridge, & McKendry, 2014)

the US and Canada,[141] and Canadian wildfire activity in 2015, 2018, and 2023 impacting air quality across the East coast.[142,143,144]

## 4.7 AIR QUALITY MONITORING AND FORECASTING

Air quality monitoring refers to the continuous measurement of a specific pollutant. An air quality monitor is the device that is used to measure one or more specific pollutants. The pollutants an air quality monitor can detect and its sensitivity to detecting different levels of pollutant concentrations is based on the type of equipment. The accuracy of an air quality monitor depends on its calibration, placement, and maintenance.

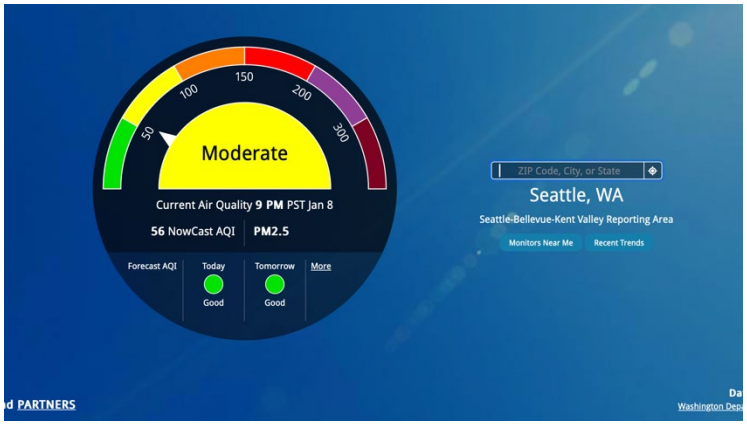


*Figure 34. Image of EPA AirNow website.*

The National Ambient Air Quality Standards (NAAQS) established in the Clean Air Act, specifies six pollutants for which state and local air quality regulators must keep ambient air quality concentrations below their respective thresholds. These six pollutants, also known as criteria pollutants, include particulate matter, ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, and lead (in particles). Each state, or legally designated local agency, is responsible for monitoring and reporting on air quality conditions for these criteria pollutants. In King County, Puget Sound Clean Air Agency (PSCAA) is the lead agency for air quality monitoring.

### 4.7.1 Wildfire Smoke Monitoring

When it comes to assessing the risk to public health from wildfire smoke, particulate matter is typically used as the most representative pollutant readily measurable. While wildfire smoke can also cause ozone impacts, particulate matter is generally considered to be the greatest pollutant of concern in wildfire smoke. Particulate matter itself is generally a term used to describe a mixture of solid particles and liquid droplets in the air and exists in a range of sizes, from those large enough to see down to sizes that can only be seen through a microscope.

[141] (Filonchyk, Peterson, & Sun, 2022)
[142] (Dreessen, Sullivan, & Delgado, 2016)
[143] (Hung, et al., 2020)
[144] (Debusmann Jr, Bailey, & Benn, 2023)

There are two different size categories of particulate matter defined as criteria pollutants and regularly monitored, known as $PM_{10}$ and $PM_{2.5}$. Particulate matter that is 10 micrometers and smaller (which includes $PM_{2.5}$) is known as $PM_{10}$ and is small enough to be inhaled. Particulate matter that is 2.5 micrometers and smaller is known as $PM_{2.5}$ and is small enough to be inhaled into the deepest part of the lungs and even pass through capillaries, allowing it to enter into the bloodstream. As a result, $PM_{2.5}$ poses the greatest risk to health as it has been shown to cause heart attack, strokes, and premature death. When assessing the health risk of wildfire smoke exposure, the $PM_{2.5}$ is considered to pose the greatest health risk of pollutants in wildfire smoke.

Under the Clean Air Act, the U.S. EPA has established health-based standards for exposure to $PM_{2.5}$. The standards are set at concentrations considered protective to human health, even for vulnerable populations. These standards consist of an annual average standard of 9 $\mu g/m^3$ and a short-term (24-hour or daily average) standard of 35 $\mu g/m^3$. To aid in the interpretation of how ambient air quality relates to these standards, the U.S. EPA utilizes the Air Quality Index (AQI), which consists of a color-coded numeric scale from 0 to 500 that relates $PM_{2.5}$ concentrations to six hazard levels for sensitive populations and the general population. While the AQI is calculated for each criteria pollutant using its respective standard, during wildfire smoke episodes, the AQI can be adjusted to intervals as short as 3 hours using what is called the NowCast algorithm. This assesses the latest hour of air quality conditions in comparison to data collected over the previous two hours and the rate of change in air quality conditions.[145] The NowCast algorithm was developed to help the AQI be more responsive to short term spikes that maybe reflective longer-term shifts in air quality conditions.

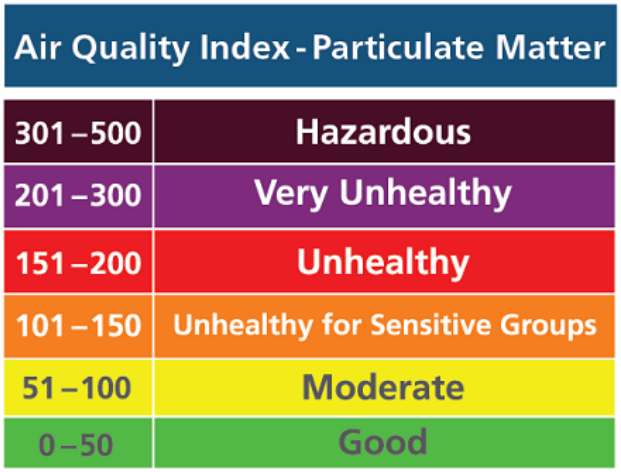


*Figure 35. U.S. EPA Air Quality Index categories.*

Given the simplicity of the AQI's color-coded numeric values as a tool for communicating health risk posed by wildfire smoke exposure, the AQI is used as the basis for public health recommendations established by state and local agencies. It helps inform community members and policy decision-makers on when to take necessary actions to reduce potential impacts to public health, such as when to reduce strenuous outdoor activities, when to limit exposure outdoors, when to cancel outdoor events and activities, and when to cancel schools.

[145] (Delp & Singer, 2020)

### 4.7.2 Air Quality Monitoring Stations

The existing network of air quality monitoring stations (AQMS) operated by state and local air quality agencies provides the most accurate and reliable information on trends and the status of air pollutants across a range of locations. The monitors are placed in locations of highest emissions from different sectors, including near major freeways, areas impacted by residential wood burning, and industrial valleys. However, there are fewer AQMS located in areas of the wildland-urban interface, which can affect the availability of air quality data in areas further removed from where these stations are located.[146]

*Figure 36. Regulatory air quality monitoring station.*

AQMS used for ensuring Clean Air Act compliance must adhere to strict certification requirements regarding the equipment's sensitivity to detecting changes in pollutant concentrations, placement, and calibration for standard temperature and humidity conditions applicable to the location in which they are placed. This requires technical specialists to provide frequent upkeep and maintenance. As a result, regulatory grade monitoring stations are expensive to establish and maintain.

To help increase the availability of air quality data, low-cost sensors (such as PurpleAir sensors) are used to help provide air quality information for areas where no AQMSs already exist.

### 4.7.3 Low-Cost Air Quality Sensors

The low cost and ease of use of low-cost air quality sensors has led to a proliferation in their use by organizations and individuals who are interested in monitoring air quality.[147] Low-cost sensors can be used to estimate hyper-local concentrations in fine particulate matter, assess regional dispersion of pollutants, and assess health risks of $PM_{2.5}$ exposure resulting from wildfire smoke.[148] Although, there are several caveats that apply to their accuracy, they can be an important tool for assessing community health risk during wildfire smoke episodes by providing real-time information on air quality conditions where data may otherwise not be available.

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[146] (Holder, et al., 2020)
[147] (Kelleher, Quinn, Miller-Lionberg, & Volckens, 2018)
[148] (Delp & Singer, 2020)

Low-cost sensors typically use photometers to optically monitor, measure, and translate the scattering of light passing through a group of particles into real-time mass concentrations.[149, 150] The intensity of scattered light depends on aerosol properties (e.g., size, shape, density, refractive index, type, and composition).[151, 152] Sensors that utilize photometers must be calibrated for a defined aerosol to interpret the scattering of light caused by a single particle passing through a laser. Calibration enables the device to translate the amount of scattered light to a mass concentration or a particle count based on assumptions about the particles shape and optical properties.[153] As a result, both the algorithm used by a sensor to translate information about the size and count of particulates to determine concentrations, as well as the physical configuration of a sensor, have a significant role in determining the sensor's accuracy of data.[154]

Variations in the design and detection method used by low-cost air quality sensors, combined with non-standardized calibration methods used by various manufacturers, contribute to a high degree of variance in the accuracy of these sensors. $PM_{2.5}$ derived from wildfire smoke differs significantly in its optical properties from typical urban and industrial sources of $PM_{2.5}$. This typically requires the application of a smoke-specific adjustment or calibration factor to data from the device to accurately assess the level of smoke in a manner comparable to that of an AQMS.

*Figure 37. Low-cost air quality sensor.*

When used with the appropriate adjustment factors, low-cost sensors can be used to better understand ambient air quality conditions due to wildfire smoke. This can help inform people of their health risk and when to take actions to reduce exposure to $PM_{2.5}$ by filling in large spatial gaps in the network of AQMSs.[155, 156] However, without the use of appropriate adjustment factors, these devices can be a source of significant confusion as large discrepancies can exist between data obtained from regulatory AQMS and low-cost sensors. Differences in the default time averaging periods for reporting on data obtained

[149] (Thomas & Gebhart, 1994)
[150] (Wallace, et al., 2011)
[151] (Sorensen, Gebhart, O'Hern, & Rader, 2011)
[152] (Wang, et al., 2009)
[153] (Delp & Singer, 2020)
[154] (Holder, et al., 2020)
[155] (Delp & Singer, 2020)
[156] (Holder, et al., 2020)

from low-cost sensors can also contribute to confusion when comparing low-cost sensor data to AQMS data. Additional complications arise as the necessary adjustment factor can change depending on location and may differ from one wildfire smoke episode to another. As a result, it may be necessary to routinely identify and apply short-term adjustment factors by comparing the previous several hours of data from a low-cost sensor to that of a nearby air quality station, if one is available.[157]

### 4.7.4 Wildfire Smoke Forecasting

The complex interrelationships between fire behavior, the type of fire fuel (grass, shrub, forest, structure), weather (wind direction, temperature, humidity), topography of the terrain where a fire is occurring, and the source of a fire (human activity or lightning) make predicting and forecasting wildfire smoke impacts on air quality complicated.[158] There are substantial uncertainties just in predicting basic fire behavior due to uncertainty in the fuel (biomass) amount and type, and its moisture. These greatly affect the quality (completeness) of combustion, and the amount of heat generated, which influences the amount of particulate matter that is generated. The amount of heat generated then affects how high the smoke plume rises and can affect the winds and air flow around the fire and move or spread the fire in ways that would otherwise not occur without fire.

Mixing height describes how high surface air will vertically mix over the course of minutes to about an hour. The mixing height normally cycles daily, increasing in height in the morning and afternoon as the sun warms the surface, and dropping much lower to the surface as the sun sets. The mixing height for a specific day and location will vary depending on the surface and atmospheric conditions, but often will grow to 3,000 feet or more in the afternoon, and then drop to around 100 feet at night.

When a wildfire smoke plume rises into the atmosphere and is transported downwind from a wildfire, it's potential impact on surface air quality is determined by the altitude a smoke plume reaches and the mixing height If the mixing height reaches the height of the smoke plume, smoke will begin mixing down to ground level, causing significant impacts to surface level air quality conditions. On the other hand, if the altitude at which a smoke plume is traveling, there will be no direct impact on surface air quality. Also, for some fires, a significant amount of smoke may remain below the mixing height and simply move to, and immediately impact, neighboring areas with the prevailing surface winds.

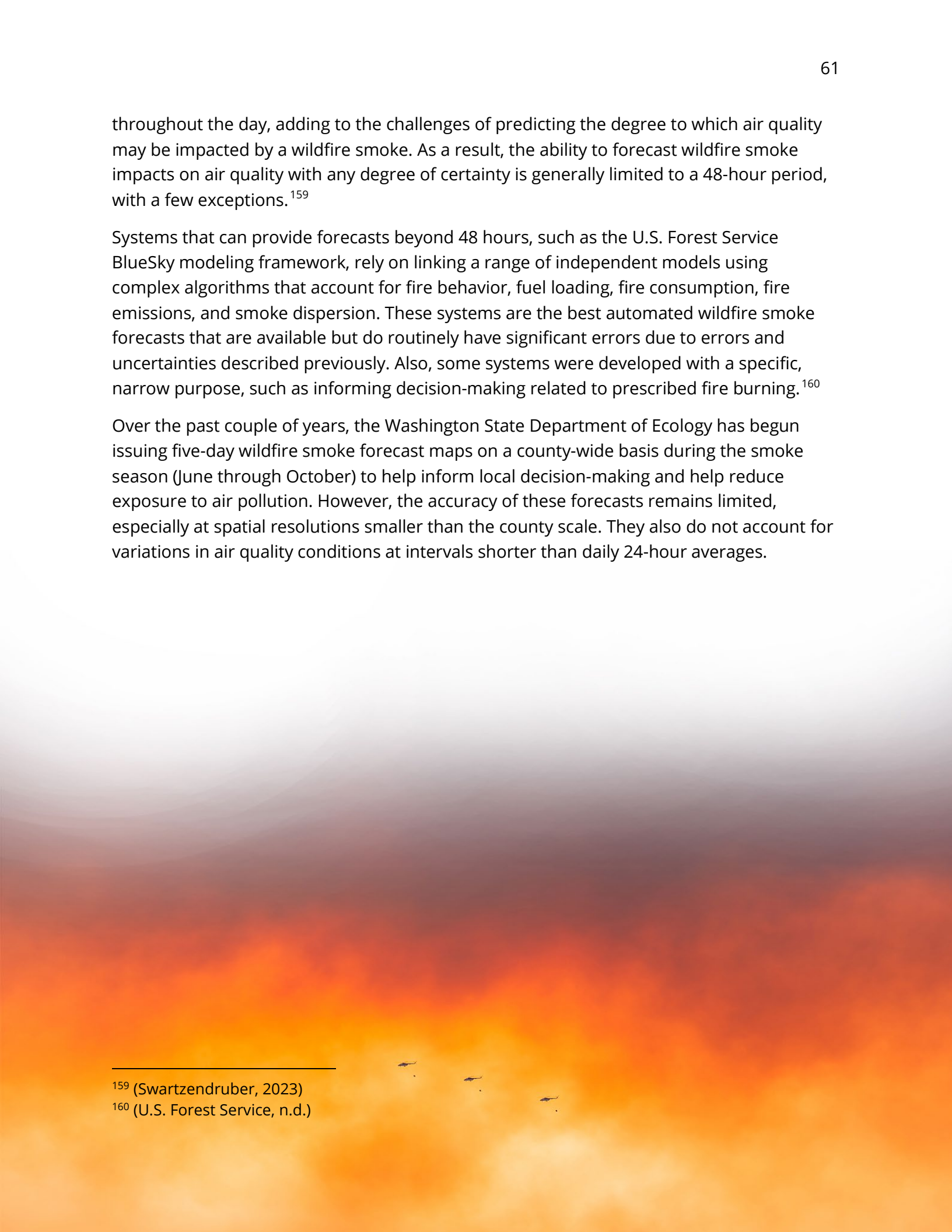
Forecasting air quality impacts during wildfire smoke episodes therefore requires understanding of multiple variables, including the amount of smoke that is generated by a fire, the altitude smoke plumes reach, the distance it travels, and mixing height of the areas over which it travels. Complicating matters further, mixing heights of the air column shift

[157] (Delp & Singer, 2020)
[158] (Balmes, 2018)

throughout the day, adding to the challenges of predicting the degree to which air quality may be impacted by a wildfire smoke. As a result, the ability to forecast wildfire smoke impacts on air quality with any degree of certainty is generally limited to a 48-hour period, with a few exceptions.[159]

Systems that can provide forecasts beyond 48 hours, such as the U.S. Forest Service BlueSky modeling framework, rely on linking a range of independent models using complex algorithms that account for fire behavior, fuel loading, fire consumption, fire emissions, and smoke dispersion. These systems are the best automated wildfire smoke forecasts that are available but do routinely have significant errors due to errors and uncertainties described previously. Also, some systems were developed with a specific, narrow purpose, such as informing decision-making related to prescribed fire burning.[160]

Over the past couple of years, the Washington State Department of Ecology has begun issuing five-day wildfire smoke forecast maps on a county-wide basis during the smoke season (June through October) to help inform local decision-making and help reduce exposure to air pollution. However, the accuracy of these forecasts remains limited, especially at spatial resolutions smaller than the county scale. They also do not account for variations in air quality conditions at intervals shorter than daily 24-hour averages.



[159] (Swartzendruber, 2023)
[160] (U.S. Forest Service, n.d.)

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# APPENDIX A:
# ACTIONS TAKEN SINCE STRATEGY PROPOSAL

Development of the *Wildfire Smoke Health Mitigation Strategy* was proposed in 2019. Since then, there have been several significant developments and initiatives that have helped improve King County community preparedness to the increasing risks posed by wildfire smoke. The following provides a detailed outline of actions taken to date since the development of this strategy was first proposed.

## COVID-19 & INCREASE IN INDOOR AIR QUALITY AWARENESS

The COVID-19 pandemic brought greater community awareness to the importance of indoor air quality. While the hazards of wildfire smoke differ from that of a global pandemic in a number of substantive ways, their common call for the need to improve the filtration capabilities of indoor environments speaks to a critical consideration that has long been overlooked. The COVID-19 pandemic, along with the compounding hazards that continued to unfold simultaneously throughout the duration of the pandemic, contributed to a rapid increase in the availability of federal, state, and local guidance, assessment methodologies, funding, and resources to improve indoor air quality.

Prior to the COVID-19 pandemic, most public guidance during wildfire smoke episodes directed the public to stay indoors to minimize risk of exposure or to seek shelter at places with better indoor air quality. However, no comprehensive assessments had been conducted to assess how well the sites that people were being directed to performed during episodes of wildfire smoke.

COVID-19 health recommendations for air quality measures in shelters and other communal or congregate spaces, as well as residential settings, also increased awareness of portable indoor air cleaners and their value. Previously, they were often only considered a necessity for households with individuals who were among the most vulnerable to health impacts arising from wildfire smoke exposure. They were often perceived to be a luxury rather than a common household appliance due to the high prices associated with purchasing and maintaining portable air cleaners through regularly buying replacement filters. This raised significant equity implications when it came to who had access to these devices. Since the height of the COVID-19 pandemic, commercial manufacturing of portable indoor air filtration units has increased, resulting in broader market competition and decreases in the price for these units, improving their accessibility and increasing the prevalence of their use.

## RESOURCE DISTRIBUTION & INDOOR AIR QUALITY GUIDANCE

Beginning in fall 2020, in recognition of the restrictions the COVID-19 pandemic had on the accessibility of public indoor spaces and given the overlap in populations most vulnerable to COVID-19 and wildfire smoke, PHSKC sought to help protect the health of frontline communities[161] by directly distributing air filtration resources to help residents create a clean air room at home. By adopting a model that had been utilized by Puget Sound Clean Air Agency and leveraging funding made available by the federal government through the Coronavirus State and Local Fiscal Recovery Fund, PHSKC began distribution of Do-It-Yourself (DIY) Box Fan Filter kits as a low-cost equitable alternative to the more expensive portable air cleaners available at the time. By weaving together additional funding opportunities, PHSKC was able to sustain these distribution efforts from 2020 to 2023, resulting in the distribution of approximately 4,700 DIY Box Fan Filter Kits to King County residents by working in partnership with close to 40 community-based and faith-based organizations. Each partnering organization was provided with educational training on the importance of indoor air quality and guidance on behavioral interventions that can be used to improve indoor air quality during wildfire smoke episodes. Distribution material included factsheets on the use of air filtration equipment that have been translated into 28 languages.

Throughout these distribution processes, PHSKC engaged in routine process evaluation and focus group discussions with community partners as part of its continuous improvement planning process. This led to ongoing refinement of guidance and logistical processes for coordinating the distribution of resources with community partners.

In 2021, in partnership with the University of Washington, PHSKC also initiated a pilot study to assess the effectiveness of the DIY box fan filter kit as an intervention for improving indoor air quality. The initial pilot focused on the identification of potential household barriers to using and maintaining the DIY kits that had been distributed. In 2023, PHSKC was able to leverage a funding opportunity from the Centers for Disease Control and Prevention (CDC) to expand its 2021 pilot to assess the efficacy of DIY box fan filter kits using a community participatory science framework. Participating residents were provided with a DIY box fan filter kit and a low-cost air quality sensor to obtain quantitative data on unit performance when applied in residential settings. These efforts, in collaboration with the University of Washington, are set to continue through 2025 and will include the assessment of additional interventions intended to help residents improve indoor air quality during wildfire smoke episodes.

In addition to the distribution of DIY box fans filter kits to residential settings, during the COVID-19 pandemic, PHSKC was able to help support non-residential settings including homeless service providers, senior centers, childcare service providers, food establishments, and other essential service sectors with implementation of indoor air quality improvements as part of its Environmental Health COVID-19 Recovery Program that operated from 2021 through 2023. During this time, Environmental Health Services Division staff supported facility operators by providing indoor air quality assessments and portable air cleaners equipped with high efficiency particulate air (HEPA) filters. While funding for this program ended in 2023, the guidance on improving indoor air quality developed during this program's operation remains available.

Over the past few years, several other county efforts have also worked to improve indoor air quality and increase the availability of guidance. In 2022, PHSKC launched its school environmental health safety program, which provides dedicated guidance and technical assistance to improve the operating conditions of public schools and childcare settings throughout the county. In 2023, King County Metro upgraded cabin air filters for all of their buses to filters with a minimum efficiency rating value (MERV) of MERV-13, the best possible filtration available for transit vehicles capable of filtering wildfire smoke particles as well as airborne viruses. In the years since the beginning of the COVID-19 pandemic, the filtration systems of several county buildings have been upgraded to accommodate filters that can help filter wildfire smoke. Draft language has also been included in the 2024 King County Comprehensive Plan update to encourage the use and incorporation of indoor air filtration technologies and building envelope improvements in new development to further help mitigate air quality impacts on indoor environments during wildfire smoke episodes.

## Public Health Recommendations & Response Coordination

In 2020, severe wildfire smoke set new air pollution records across the region and jurisdictions struggled to respond to rapid changes in air quality conditions. As a result, in 2021, PHSKC developed *Public Health Recommendations during Wildfire Smoke Events* to improve regional coordination of emergency response efforts and to provide jurisdictions with guidance on when to initiate actions such as opening cleaner air sites and when to recommend cancellation of outdoor events and activities based upon risks posed to public health. Since this guidance was developed, it has been updated annually and is routinely disseminated to emergency management partners at the beginning of each wildfire smoke season.

PHSKC continues to expand its communications networks to ensure these recommendations also reach other critical sectors that fall outside of the scope of traditional emergency management structures, such as childcare service providers, youth camps and sports leagues, and outdoor event and concert organizers. Additionally, since

the development of these recommendations, King County Office of Emergency Management (KCOEM) has also developed standard operating guidelines (SOGs) for convening wildfire smoke and extreme heat public information officer (PIO) coordination calls, to improve coordination and alignment of preparedness and response public messaging and risk communications ahead of and during wildfire smoke episodes resulting in air quality impacts across the county.

## WA Labor and Industry (WA L&I) Rulemaking

Outdoor and agricultural workers are at disproportionate risk of health impacts during wildfire smoke episodes. Following the record-breaking air quality impacts in fall 2020, Washington State Department of Labor and Industries (WA L&I) initiated a permanent rulemaking process to address the occupational hazards associated with wildfire smoke exposure for outdoor workers. The new permanent rule, titled *Wildfire Smoke & Workplace Safety and Health*, became effective on January 14, 2024.

The rule established a new chapter in the Washington Administrative Code (WAC), Chapter 296-820 WAC, Wildfire Smoke, and duplicated these requirements in Chapter 296-307 WAC, Safety Standards for Agriculture. The provisions of the rule now require employers of outdoor workers to ensure measures are in place to monitor air quality during wildfire smoke episodes, provide employee training on the health risks of wildfire smoke exposure, and utilize physical and administrative exposure controls to protect the health of employees during wildfire smoke episodes – including the provision of facial respirator masks (FRMs), such as N95 respirators, for voluntary use by employees.