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ECOLOGICAL RESTORATION INSTITUTE

Working Paper 40

Resources for Predicting and Mitigating Smoke Impacts of Wildland Fires

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SOUTHWEST FIRE SCIENCE CONSORTIUM

Intermountain West Frequent-Fire Forest Restoration

Ecological restoration is a practice that seeks to heal degraded ecosystems by reestablishing native species, structural characteristics, and ecological processes. The Society for Ecological Restoration International defines ecological restoration as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability…. Restoration attempts to return an ecosystem to its historic trajectory" (Society for Ecological Restoration International Science and Policy Working Group 2004).

Most frequent-fire forests throughout the Intermountain West have been degraded during the last 150 years. Many of these forests are now dominated by unnaturally dense thickets of small trees, and lack their once diverse understory of grasses, sedges, and forbs. Forests in this condition are highly susceptible to damaging, stand-replacing fires and increased insect and disease epidemics. Restoration of these forests centers on reintroducing frequent, low-severity surface fires—often after thinning dense stands—and reestablishing productive understory plant communities.

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of frequent-fire forests of the Intermountain West. By allowing natural processes, such as low-severity fire, to resume self-sustaining patterns, we hope to reestablish healthy forests that provide ecosystem services, wildlife habitat, and recreational opportunities.

The Southwest Fire Science Consortium (SWFSC) is a way for managers, scientists, and policy makers to interact and share science. SWFSC's goal is to see the best available science used to make management decisions and scientists working on the questions managers need answered. The SWFSC tries to bring together localized efforts to develop scientific information and to disseminate that to practitioners on the ground through an inclusive and open process.

ERI working papers are intended to deliver applicable science to land managers and practitioners in a concise, clear, non-technical format. These papers provide guidance on management decisions surrounding ecological restoration topics. This publication would not have been possible without funding from the USDA Forest Service and the Southwest Fire Science Consortium. The views and conclusions contained in this document are those of the author(s) and should not be interpreted as representing the opinions or policies of the United States Government. Mention of trade names or commercial products does not constitute their endorsement by the United States Government or the ERI.

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Cover photo: Fire managers monitor the Wallow Fire near Eagar, Arizona. The Wallow Fire of 2011 was the largest fire in Arizona history. Extreme smoke impacts from the fire provided significant lessons regarding public and firefighter health and safety impacts, further crystallizing efforts that led to the development of the Wildland Fire Air Quality Response Program (WFAQRP). *Photo courtesy of ERI*

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Executive Summary

Fire managers use prescribed fire and some wildfires to meet resource management objectives, like restoring and maintaining ecological processes, watershed function, and wildlife habitat, as well as to reduce fuels and mitigate the risk of severe wildfires. However, public concerns about smoke impacts are often a limiting factor for accomplishing fuels reduction and ecological restoration goals. It is vital that agency land managers mitigate smoke impacts from wildland fire for the health and safety of the public. The Wildland Fire Air Quality Response Program (WFAQRP) has smoke impact assessment and forecast tools to assist agencies in managing fire incidents and predicting and messaging smoke impacts to communities. New smoke modeling tools, along with technical specialists called Air Resource Advisors (ARAs), can help inform fire management operations and provide important information to air quality, public health, and safety officials and the public. This working paper describes how ARAs use smoke modeling and monitoring tools to build a toolkit for fire managers and to improve public communication.

Introduction

Managed fire is a valuable tool used by land managers to mitigate the risk of severe wildfire and to meet other resource management objectives, such as restoring and maintaining ecological processes, watershed function, and wildlife habitat. Fire managers use prescribed fire and some wildfires to accomplish these goals. However, public concerns about the impacts of smoke emissions are often cited by fire managers as a limiting factor for accomplishing fuels reduction and ecological restoration goals (Toman et al. 2014). The smoke produced from fire management actions can have negative consequences for public health and safety and regional economics (Fowler 2003), which creates an imperative for agency land managers to mitigate smoke impacts from wildland fires (Lahm 2018).

In recent years, the development of the Wildland Fire Air Quality Response Program (WFAQRP) has helped develop smoke impact assessment and forecast tools, as well as other resources, to assist agencies in managing fire events while mitigating smoke impacts to communities (wildlandfiresmoke.net). Modeling tools use a variety of information sources to project the location and concentration of smoke emissions. Deployment of emergency portable monitoring equipment provides site-specific information regarding concentrations of harmful particulates. Analysis of this data, and that of permanent monitors, serve as the basis for public health messaging and evaluation of model outputs. For wildfire incidents, technical specialists called Air Resource Advisors (ARAs) are trained and developed by the program. They help organize this information and coordinate with the public and air regulatory agencies. Ordering an ARA is similar to ordering an Incident Meteorologist. When needed, an ARA is requested by name as a technical specialist (THSP) through the WFAQRP leader. The order is then placed into the national Resource Order and Status System (ROSS). Specialists like ARAs can help inform fire management operations and agency administrators. They also provide important information to air quality, public health, and safety officials and the public.

Understanding the applications of the best available tools and resources can help agencies and fire management teams better meet fire/fuels management and ecological restoration goals while mitigating the impacts of smoke. While there is a need for fire management programs to develop strategies to mitigate smoke impacts (Lahm 2018), there is a gap between many fire management operations and the most recent smoke management tools and resources (Figure 1). This working paper focuses on how ARAs use smoke modeling and monitoring tools to build a toolkit for fire management operations to better communicate internally and with incident management teams, cooperators, and the public. By examining the ARA toolkit, we highlight some of the best practices for predicting and mitigating smoke impacts on individuals and communities. During smaller wildfire events, which have less smoke impacts and do not warrant use of a higher cost incident management team (IMT) or ordering an ARA, these tools and practices can be employed by local land managers to alert the public and mitigate smoke impacts. Prescribed fire managers can also use these tools and practices to help address smoke impacts on the public.

Smoke Impacts and Public Perception

Smoke can negatively impact human health and is of particular concern when the duration of exposure is prolonged and concentrations are high (Fowler 2003). Certain segments of the population are at greater risk of smoke exposure. Approximately one-third of US households have someone with existing respiratory health issues at risk of experiencing serious medical issues with prolonged breathing of the fine particulate matter ($PM_{2.5}$) found in smoke (McCaffrey and Olsen 2012). Besides the health impacts of smoke, it can also lead to reduced visibility on roadways, which has been a factor in fatal traffic accidents throughout the US. Additionally, smoke can be a serious problem when it affects airports and transportation corridors (Matthews 2018).

In addition to public health and safety concerns, smoke emissions can have economic and social impacts. One recent study indicates that smoke impacts on outdoor recreation, scenery, and school recess can be of greater concern to the public than impacts to personal health, particularly in rural communities (Blades and Hall 2012). As many communities in the western US are shifting to amenity-based economies (Winkler et al. 2007), there is increasing public concern about smoke effects on tourism and outdoor recreation (Blades et al. 2012). There are also increasing concerns surrounding smoke impacts on firefighter health (NWCG 2012a, NWCG 2012b, Domitrovich et al. 2017).

Public perceptions about smoke are variable and complex. While some members of the public perceive the use of fire as discretionary (Lahm 2018), one longitudinal study focusing on the wildland-urban interface (WUI) showed that the public is generally supportive of fuels reduction treatments, including the use of fire to accomplish management goals (Toman et al. 2013). Certain factors are known to increase public tolerance

of smoke. These key factors include public understanding of fuel treatment practices and the positive effects of fire, levels of trust in land management agencies, and measures taken by fire management operations to mitigate smoke impacts (Blades et al. 2018, Toman et al. 2014). As Blades et al. (2018) describe in the National Wildfire Coordinating Group (NWCG) Smoke Management Guide for Prescribed Fire, "Reinforcing and improving public understanding about the role of fire in improving ecosystem health and reducing community wildfire risk should be a focal point of public communication aimed at increasing public tolerance of smoke."

While education about fuels and fire management strategies is important, advanced warning was identified in one study as the most important aspect of public tolerance of smoke from wildland fire (Blades et al. 2012). Forecasting smoke impacts is a valuable tool to protect public health and help communities cope with wildland fire smoke (Rappold et al. 2014). Timely smoke impact information and predictions reduce the public safety risk and can change behaviors and health outcomes (Lahm 2017). If people know what to expect, they can plan and react accordingly, especially those sensitive to high air pollution levels (Rappold et al. 2014). While early messaging and intervention is important, it is also important that messages are consistent between agencies.

Studies emphasize the importance of smoke messaging, but traditionally it has not been a high priority for land management agencies. A multi-region analysis found that most agency smoke emissions and management communications efforts lacked funding and strategic focus, and were not well coordinated across agencies (Toman et al. 2014). According to Lahm (2018), "A lynchpin to addressing the future role of fire, whether through wildfires or use of prescribed fire, will likely depend upon land managers proactively communicating about and responding to public concerns about air quality." Increasingly, the public expects timely communication about wildfire events, including smoke impacts. During wildfires, it is critical that land management agencies are proactive, as the public trusts the agencies and IMTs to provide that outreach (Steelman et al. 2014).

The Role of Air Resource Advisors

Air Resource Advisors emerged in 2013 (Larkin 2013) as the need grew for technical specialists with expertise in air quality and smoke dispersion science. The USDA Forest Service created the Wildland Fire Air Quality Response Program (WFAQRP) with key cooperators, such as the National Park Service and the Environmental Protection Agency (EPA), as a direct response to the public and firefighter health and safety risks posed by wildfire smoke. A key component of this program are ARAs. They are trained in monitoring, data analysis, air quality, meteorology, computer simulation modeling and interpretation, and effective communication on the health and safety impacts of smoke. They are deployed nationwide during large wildfire events, often at the direct request of IMTs or agency administrators. According to the NWCG, their objective is to use best available science to provide IMTs with timely smoke impact and forecast information (NWCG 2017).

"A lynchpin to addressing the future role of fire, whether through wildfires or use of prescribed fire, will likely depend upon land managers proactively communicating about and responding to public concerns about air quality."

Air Resource Advisors use their diverse skillset to analyze, summarize, and communicate smoke impacts to IMTs, agency administrators, air quality regulators, public health agencies, and the public (Figure 1). Some of their many duties include:

- Determining and addressing specific wildland fire smoke risks at incidents.
- Monitoring air quality to determine effects on public safety and health.
- Working with state, tribal or local air regulators and health departments to determine impacts from smoke and $PM_{2.5}$ and develop joint messages to aid in reducing public exposure to smoke. This includes working closely with IMTs in the Planning Section under the Planning Section Chief (PSC) with Fire Behavior Analysts (FBANs) and Incident Meteorologists (IMETs) so the most accurate information about fire growth, fuels, emissions, and atmospheric dispersion including local and long-range downwind impacts all support the public messages.
- Working directly with Public Information Officers (PIOs) to disseminate the daily smoke outlook to the public, develop smoke mitigation plans when needed that address public exposure and transportation safety; and participate in public meetings to address local concerns.
- Working within the IMT to support key personnel participating in cooperator, planning and command meetings as needed so that key strategic and possibly tactical decisions consider smoke impacts when possible and appropriate.
- Routinely collecting and exchanging smoke information within the IMT, with the agency administrator and cooperating agencies to ensure dissemination of accurate information.
- Producing reports, and documentation of smoke impacts to support decision making and post-fire analysis of exceedances of air quality standards.
- Helping to address agency administrator smoke concerns and objectives as outlined in the respective Wildland Fire Decisions Support System (WFDSS) objectives and decisions.
- Interpreting weather forecasts, fire behavior predictions, smoke dispersion prediction models, remote sensing tools, and different monitoring sources to evaluate smoke impacts.
- Notifying incident team members, including the Safety Officer (SOF), of conditions that contribute to hazardous smoke levels to fire personnel.
- Providing projected smoke impacts to transportation roadway visibility through the incident SOF to law enforcement, public safety, emergency management, and state transportation departments to alert motorists and fire personnel of smoke and possible unsafe driving conditions due to smoke reducing roadway visibility (NWCG 2017).

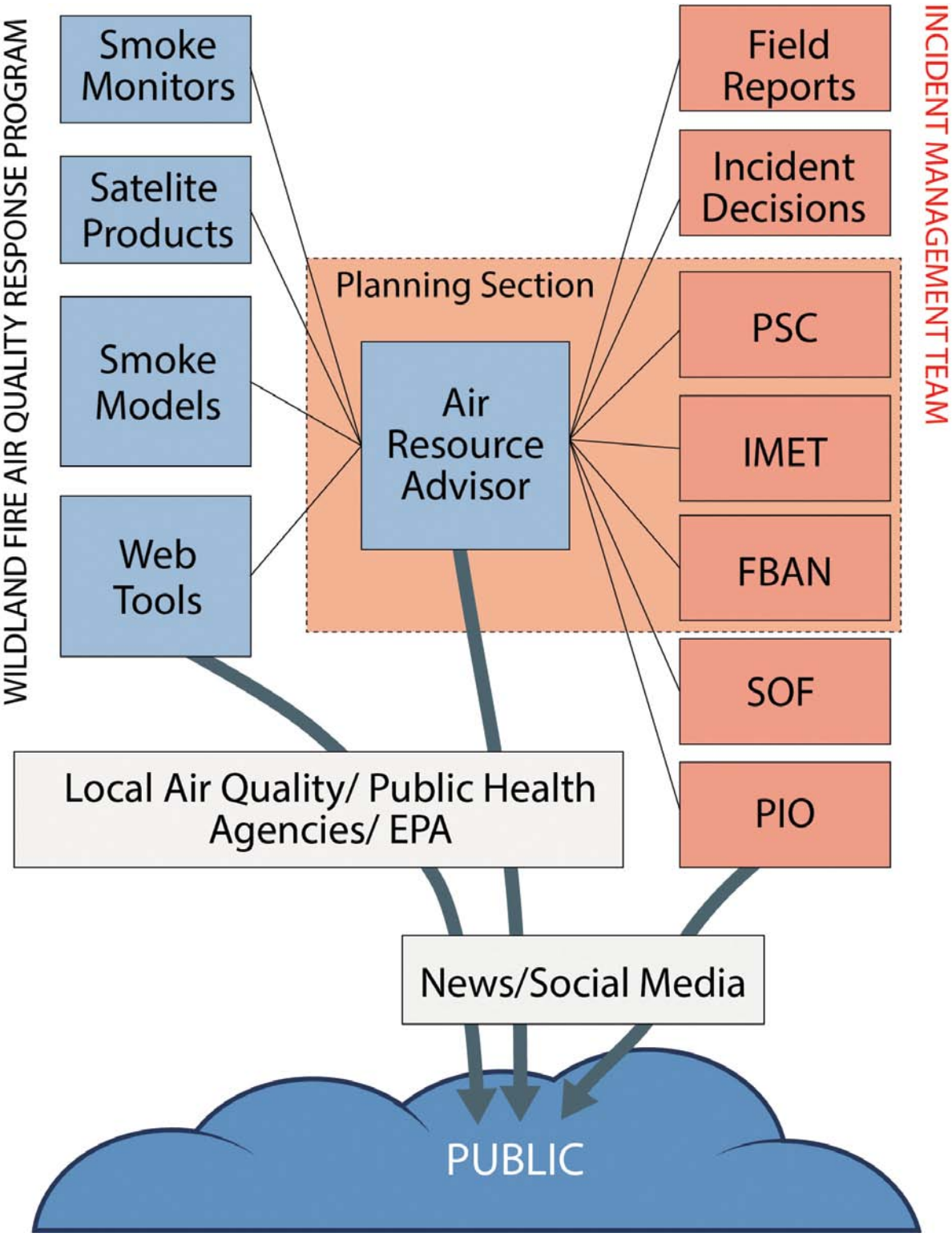


Figure 1. Flow chart showing critical positions within the IMT planning section where the ARA works most effectively, information flow within the IMT, and how the elements of the WFAQRP support the ARA and IMT (Lahm 2017).

The ARA Toolkit: The Three "M"s

Air Resource Advisors use a number of tools to predict and mitigate smoke impacts. While technology and its applications are constantly evolving, there are three key elements ARAs use to accomplish their task — modeling, monitoring, and messaging (Figure 2).

Modeling

Fire managers have traditionally used simple approximation systems to model smoke, such as fire location information and weather observations. However, there have been significant advances in smoke prediction science over the past decade. According to Strand et al. (2018), "These advances can be attributed to faster, more sophisticated wildland fire emissions and smoke plume modeling systems, enhanced databases of on-the-ground fuels, and the use of new technologies that allow for direct user interaction and input with smoke prediction tools via computer applications and the web." Using new developments in technology, these complex and sophisticated smoke modeling frameworks take into account multiple types of models that influence smoke emissions, and combine the information to develop refined predictions for smoke location and concentrations (Figure 3). While it is impossible to accurately predict the timing, location, and concentration of smoke from a fire, complex modeling frameworks exhibit a major improvement from simple approximation systems, but also emphasize the need to have a trained ARA interpreting their outputs

One of the most commonly used smoke prediction tools for wildfires and prescribed fires is known as the BlueSky modeling framework (www.airfire.org/bluesky) developed by the USDA Forest Service's Pacific Northwest Research Laboratory and its AirFire Team. BlueSky is an evolving modeling framework that is accessible by ARAs, air resource managers, prescribed burn bosses, and the public. It integrates relevant outputs from multiple models and datasets that interact to influence smoke emission outputs (Figure 4). BlueSky represents a highly complex modeling framework that maximizes the quality of the prediction, integrating different modeling fields such as fire information, fuel loadings, consumption modeling, emissions modeling, time

Figure 2. The three "M"s that ARAs utilize to predict and mitigate smoke impacts – modeling, monitoring, and messaging.

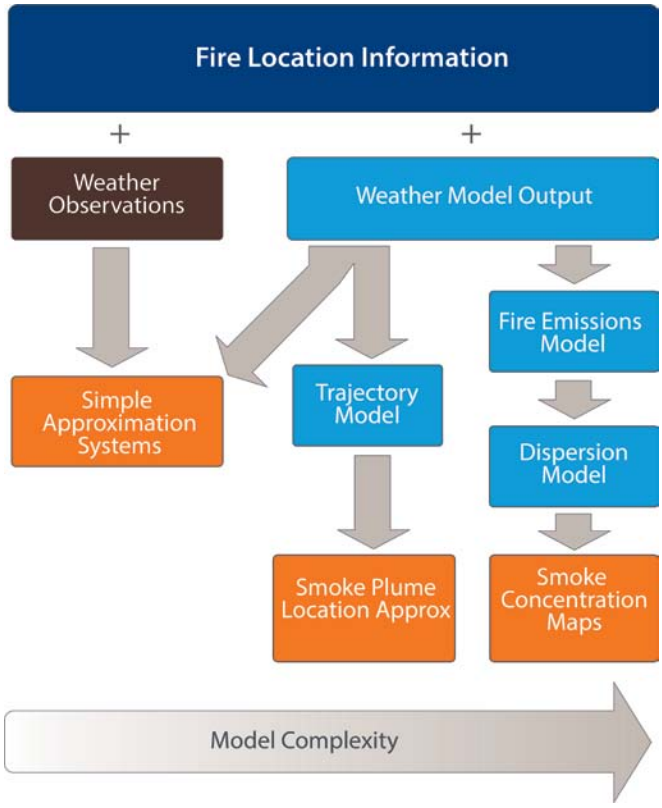


Figure 3. Simple model types require less information (left side) while more complex model types require additional information (right side) (Strand et al. 2018).

rate of emissions modeling, plume height estimations, smoke trajectory, and dispersion modeling (Figure 4) (Larkin 2017). The smoke modeling field is changing rapidly due to new field study programs and new modeling techniques (Strand et al. 2018), and one major benefit to the BlueSky framework is that it can incorporate the latest developments in these fields. Air Resource Advisors are highly trained in the use of the framework as well as other smoke modeling tools. BlueSky can visually display smoke predictions on different scales, and represents a sophisticated smoke model that provides information on ground-level smoke location and concentration. The BlueSky model and BlueSky Playground, which models for individual fire smoke impacts, are both useful for assessing smoke impacts of wildland fires.

Monitoring

Smoke impacts are monitored through a variety of methods, from visual estimates based on how far one can see in low humidity areas to quantitative measuring devices (EPA 2016a). In addition to using permanent air quality monitoring site data, which are maintained by states and tribes to demonstrate compliance with the EPA's National Ambient Air Quality Standards (NAAQS), ARAs have access to a national cache of emergency monitoring equipment that measures $PM_{2.5}$. These monitors can be deployed in strategic locations to monitor smoke impacts in communities near wildfire incidents and are used by ARAs to support operational smoke forecasting, including validating and improving model performance.

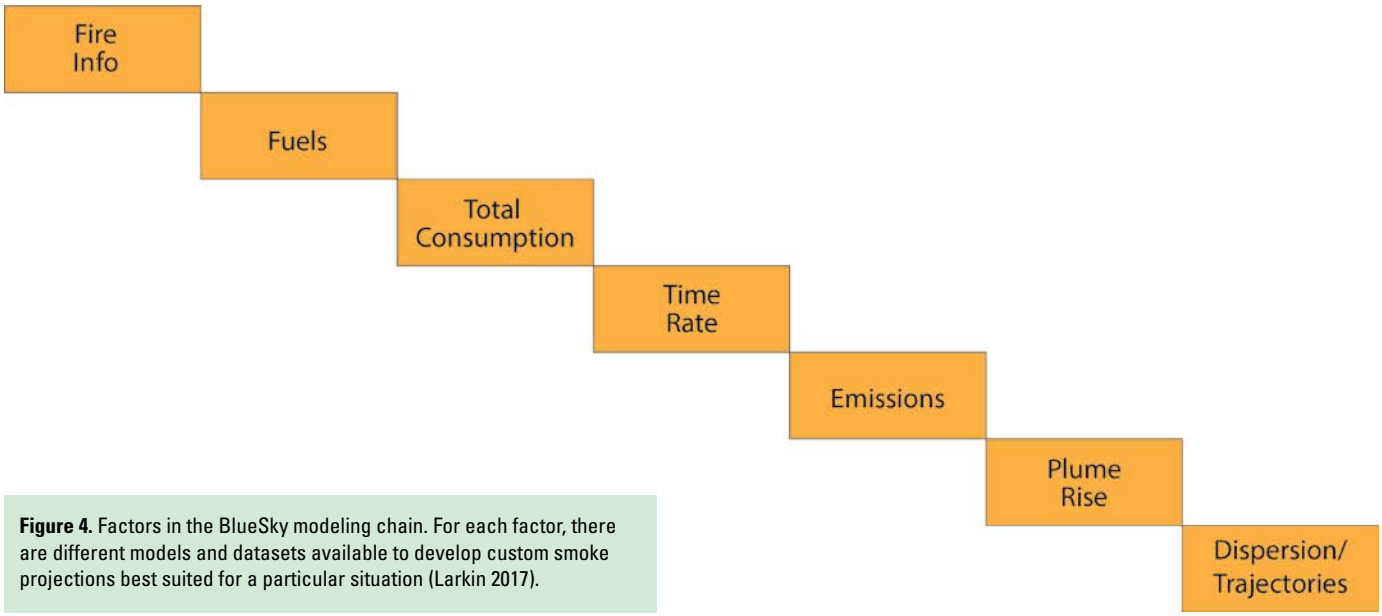


Figure 4. Factors in the BlueSky modeling chain. For each factor, there are different models and datasets available to develop custom smoke projections best suited for a particular situation (Larkin 2017).

Generally, orders for monitors are tied to the overall emergency response of a wildfire through the interagency supply ordering systems that support IMTs (wildlandfiresmoke.net). Air Resource Advisors set up air quality monitoring equipment on fires to determine whether air quality standards set by state and federal agencies are exceeded and to better understand the level of smoke impacts affecting a population in a given area.

While monitoring equipment provides valuable information about smoke concentrations in a small number of key locations, it may not capture the range of impacts to a wide area. Due to their limited number, monitoring equipment is assembled in strategic locations and other monitoring tools are used to fill in information gaps. Air Resource Advisors and many air quality regulatory agencies use a program called Monitoring v4.0 (https://tools.airfire.org/monitoring/v4/) developed for the WFAQRP by the AirFire Team to analyze the monitoring data and understand when smoke impacts peak and subside on a daily basis. This critical information forms part of the ARAs daily Smoke Outlook and can guide the public on when to avoid the peak smoke periods, thereby reducing their exposure to fine particulates. Personal visual observation guidelines of smoke may be helpful for the public to understand snap-shot air quality conditions, but they do not provide the quantifiable data needed to verify against EPA air quality index thresholds based on health impacts for $PM_{2.5}$ concentrations. There is increased use of low-cost personal air quality sensors, some of which are helpful to understand current air quality impacts, but they are limited in accuracy and difficult to align to EPA's thresholds. When the information tracks with nearby quantitative methods, both methods can help guide the public on when to reduce exposure. On a wildfire, ARAs combine air quality data gathered from the temporary and fixed monitors along with weather observations and forecasts, fire behavior analyses, satellite imagery, webcams, aircraft observations, field observations, and community feedback.

Messaging

Air Resource Advisors organize modeling and monitoring information into a daily Smoke Outlook (Figure 5), which is crucial for communication and coordination. These daily reports illustrate smoke modeling projections and potential impacts for communities that are likely to experience ground-level concentrations of fine particulates in smoke. The simple format of the one-page daily Smoke Outlook is designed to maximize usefulness as a communication tool for public audiences so they can plan and understand when smoke will be at its worst and when to use averting behavior to minimize exposure. These reports use the same language, classification metrics, and color-scheme as the EPA Air Quality Index and NowCast (https://airnow.gov/) to provide for cross-boundary and national consistency in messaging.

Effective communication and coordination—both internally within the IMT, with the agency administrator, and externally—is central to the role of an ARA. Within the IMT, ARAs tie-in daily with operations personnel (Figure 1) to understand the latest incident decisions and fire situation. Air Resource Advisors enter the most current fire information, i.e., fuels, fire weather, fire behavior prediction data, and fuel consumption, into their models to predict smoke impacts and relay that information to the IMT and outward to cooperators. If requested, ARAs can offer guidance and advice to the IMT regarding likely smoke impacts to base camp and nearby roads, and they can provide the public with information about different fire management strategies.

Communications for the PIO is in the form of the daily Smoke Outlook. The PIO then disseminates that information to the public through a variety of outlets. Air Resource Advisors assist the PIO in message development and communications regarding smoke impacts and often attend public meetings to relay that messaging directly to the public. Air Resource Advisors coordinate with transportation safety agencies to help predict

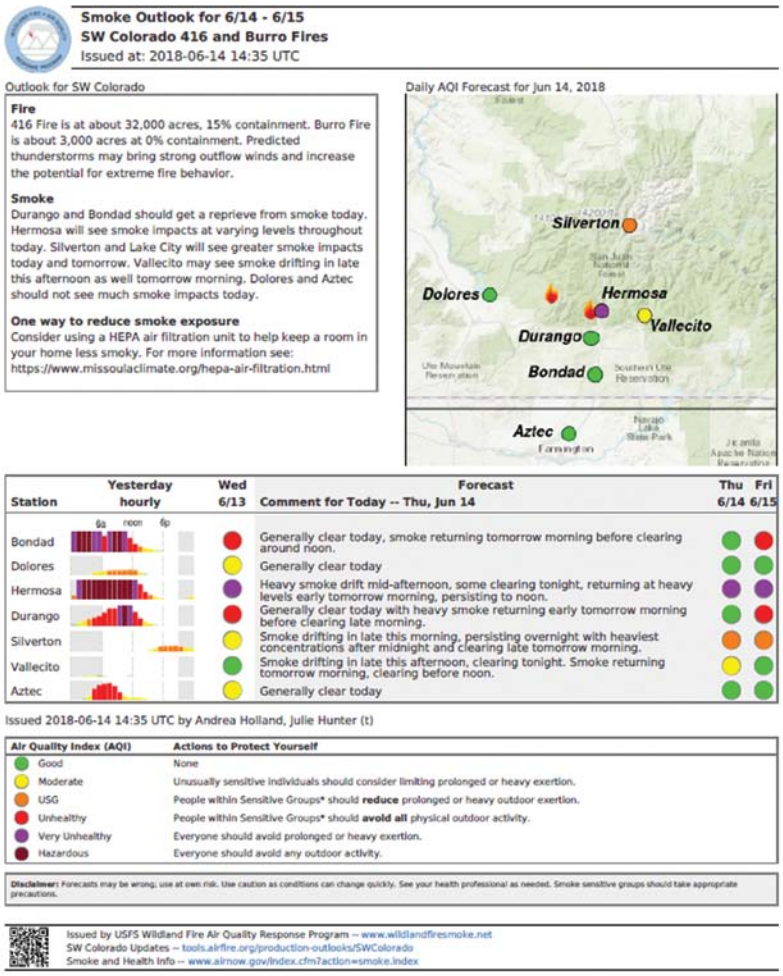


Figure 5. An example daily Smoke Outlook from the 2018 Burro and 416 fires near Durango, Colorado (www.wildlandfiresmoke.net).

smoke impacts to roadways and transportation corridors. This coordination helps agencies warn motorists of smoke impacts and set potentially life-saving traffic control measures.

Coordination with state, tribal, and local air quality regulatory agencies and health departments is another critical function performed by ARAs. In addition to the Smoke Outlook, ARAs frequently provide a more in-depth report on fire growth, emissions data, and projected smoke impacts to air quality regulatory agencies, which have their own monitoring, information, and outreach networks. These agencies and departments distribute information to community institutions and organizations, such as schools, that are concerned with populations vulnerable to smoke. Often ARAs need to coordinate far beyond the immediate areas of the fire, at times reaching out to multiple states impacted by smoke. Air Resource Advisors also coordinate with states that may have to address EPA requirements and documentation associated with the Clean Air Act (wildlandfiresmoke.net) and the Exceptional Event Rule, which is used to document when exceedances of NAAQS are caused by natural events such as wildfires.

Examples from ARA Deployments

With specialized training in smoke impact assessment and mitigation, ARAs add significant value to an IMT. Air Resource Advisors can relieve the burden of trying to monitor and predict the ever-changing smoke situation away from the IMT and fire boundary. The public typically has many questions about smoke and often raises concerns at community meetings hosted by the land management agency and IMT. The ARAs can help provide answers to questions by the public about smoke and how to avoid and mitigate its effects. The integration of ARAs into IMT structures is becoming typical on large, long-duration, smoke-producing incidents and smaller fire events that may significantly impact nearby towns or cities. In cases where smoke could adversely impact visibility on roads used by firefighters and/or the public, ARAs can help address this safety hazard. In some infrequent situations, smoke may impact base camp and result in concerns about personnel smoke exposure; again, ARAs may be able to forecast smoke levels and provide useful mitigation strategies in concert with appropriate personnel, such as the IMT's safety officer. Smoke forecasts can also be used to help fire managers and IMTs relocate firefighting aircraft to helibases and airports with a better chance of "clean" air so that flight operations do not get suspended due to poor visibility.

Just as every wildfire is unique, so is every ARA deployment. As the WFAQRP and the development of ARAs are fairly new, the technical tools, monitoring equipment, and roles of ARAs are evolving with each wildfire year. For every ARA deployment, there are opportunities for dialogue with communities and cooperators. Case studies are illustrated in Boxes 1 and 2 to highlight where ARAs added value to IMT functions and helped mitigate smoke impact on two separate wildfires.

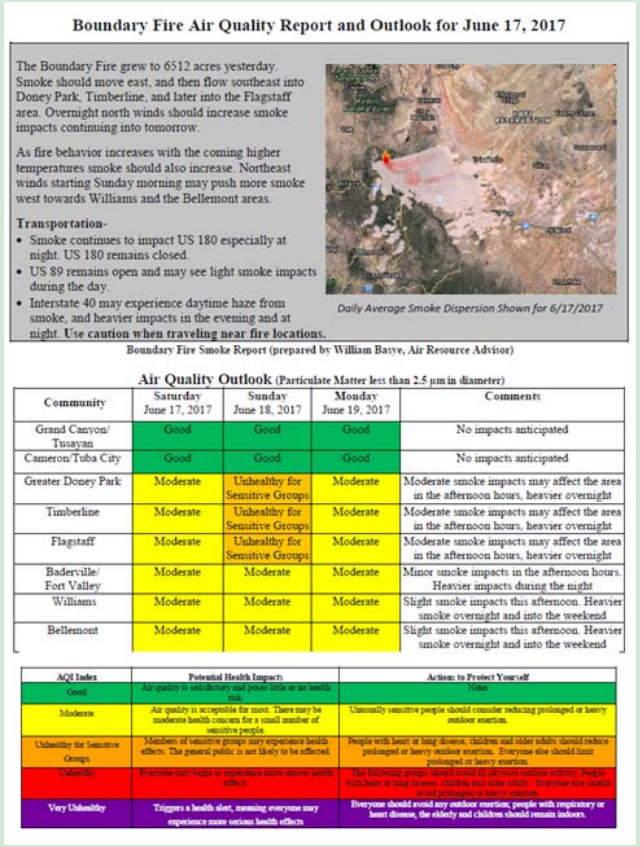
Box 1. The Boundary Fire

Location: Coconino and Kaibab national forests, Arizona
Incident type: Wildfire
Cause: Lightning
Date of ignition: June 1, 2017
Date of completion: July 11, 2017
Total acres burned: 17,788*

The Boundary Fire originated with a lighting strike in early June 2017, the height of tourist season in northern Arizona. Fire managers initially used indirect suppression tactics for firefighter safety and to meet resource objectives; however, the incident management team (IMT) and agency administrators understood that the fire was going to burn for a few weeks and smoke would impact several nearby communities. Smoke also was going to impact a heavily used road leading to Grand Canyon National Park. With the importance of smoke recognized, smoke and air quality objectives were included in the Wildland Fire Decision Support System (WFDSS) objectives by the agency administrator to ensure clear understanding of the issue by the IMT, cooperators, partners, and even the public.

Kaibab National Forest Supervisor and the fire's designated Agency Administrator Heather Provencio noted there may be similar smoke effects to those that occurred during the 2015 Sitgreaves Fire, during which the public had been very concerned about smoke impacts. Provencio recognized the need to inform community members about Boundary Fire smoke impacts. "Right away we knew it would be important to bring in an Air Resource Advisor (ARA) to help us tell that story, to help us manage those expectations," she said. Provencio said the ARA was especially skilled in communicating with the public. "We were able to get great soundbites from him as we put out (our) public messages," she said. "He had some wonderful tools that helped the public understand, and had recommendations for what to do if you were going to have heavy smoke impacts."

According to Provencio, the ARA also provided valuable three-day predictive smoke outlooks that allowed managers to communicate when heavy smoke would be present and what the community could do to mitigate the impacts. Another benefit to having an ARA was communicating operational tactics to minimize smoke, she said. "The ARA was a huge asset to the entire incident management team," Provencio said. "That position reported out at each of our briefings, and helped everyone who was on the line understand the story behind smoke, and be able to relay that as we talked with partners, as we talked with the public, and to think about how we might shift our tactics on the fire to reduce those impacts."



Boundary Fire Air Quality Report and Outlook for June 17, 2017

The Boundary Fire grew to 6512 acres yesterday. Smoke should move east, and then flow southeast into Doney Park, Timberline, and later into the Flagstaff area. Overnight north winds should increase smoke impacts continuing into tomorrow.

As fire behavior increases with the coming higher temperatures smoke should also increase. Northeast winds starting Sunday morning may push more smoke west towards Williams and the Bellemont areas.

Transportation-

- Smoke continues to impact US 180 especially at night. US 180 remains closed.
- US 89 remains open and may see light smoke impacts during the day.
- Interstate 40 may experience daytime haze from smoke, and heavier impacts in the evening and at night. **Use caution when traveling near fire locations.**

Boundary Fire Smoke Report (prepared by William Basye, Air Resource Advisor)

Air Quality Outlook (Particulate Matter less than 2.5 µm in diameter)

Community	Saturday June 17, 2017	Sunday June 18, 2017	Monday June 19, 2017	Comments
Grand Canyon/ Tusayan	Good	Good	Good	No impacts anticipated
Cameron/Tuba City	Good	Good	Good	No impacts anticipated
Greater Doney Park	Moderate	Unhealthy for Sensitive Groups	Moderate	Moderate smoke impacts may affect the area in the afternoon hours, heavier overnight
Timberline	Moderate	Unhealthy for Sensitive Groups	Moderate	Moderate smoke impacts may affect the area in the afternoon hours, heavier overnight
Flagstaff	Moderate	Unhealthy for Sensitive Groups	Moderate	Moderate smoke impacts may affect the area in the afternoon hours, heavier overnight
Baderville/ Fort Valley	Moderate	Moderate	Moderate	Minor smoke impacts in the afternoon hours. Heavier impacts during the night
Williams	Moderate	Moderate	Moderate	Slight smoke impacts this afternoon. Heavier smoke overnight and into the weekend
Bellemont	Moderate	Moderate	Moderate	Slight smoke impacts this afternoon. Heavier smoke overnight and into the weekend

AQI Index	Potential Health Impacts	Actions to Protect Yourself
Good	Air quality is satisfactory and poses little or no health risk	None
Moderate	Air quality is acceptable for most. There may be moderate health concern for a small number of sensitive people	Unusually sensitive people should consider reducing prolonged or heavy outdoor exertion.
Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	People with heart or lung disease, children and older adults should reduce prolonged or heavy outdoor exertion. Everyone else should limit prolonged or heavy exertion.
Unhealthy	Everyone may begin to experience more serious health effects	The following groups should avoid all physical outdoor activity: People with heart or lung disease, children and older adults. Everyone else should avoid prolonged or heavy exertion.
Very Unhealthy	Triggers a health alert, meaning everyone may experience more serious health effects	Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly and children should remain indoors.

The Boundary Fire Air Quality Report and Outlook for June 17, 2017.

Kaibab National Forest Fire Management Officer Art Gonzales agreed that an ARA was a huge benefit to the fire team. "We knew from the beginning that we wanted an ARA on this fire," Gonzales said. "It was so nice to have someone who was just solely focused on smoke, relieving that burden from other IMT members."

Ron Sherron, USDA Forest Service smoke coordinator for the state of Arizona, works as a liaison between federal and state land managers and the Arizona Department of Environmental Quality (ADEQ). Sherron helped order the ARA for the Boundary Fire, and by working with the ARA and ADEQ, he helped coordinate messages from the incident to communities and the county emergency response team. Sherron said the ARA was particularly valuable for reaching out to impacted communities on tribal lands. "For the first time, the smoke outlooks were translated into the Navajo language to help those communities understand when the smoke impacts were likely going to happen and what the magnitude of those impacts would be."

**Boundary Fire information from InciWeb, https://inciweb.nwcg.gov/*

Box 2. Beaver Creek Fire

Location: Medicine Bow-Routt National Forests, Colorado
Incident type: Wildfire
Cause: Human
Date of ignition: June 19, 2016
Date of completion: October 13, 2016
Total acres burned: 38,380*

The Beaver Creek Fire was located approximately 24 miles northwest of Walden in north central Colorado, just south of Wyoming. It burned in heavy beetle-killed lodgepole pine timber in the Medicine Bow-Routt National Forests and Bureau of Land Management lands. Agency administrators recognized the fire would be a long duration event and that smoke would eventually become an issue, and they made the decision to bring on an Air Resource Advisor (ARA). Concerns were raised from the Wyoming governor via the state forester that the wildfire smoke could have impacts on Cheyenne and its famous Frontier Days, which could have had substantial economic impacts on the region. The ARA was assigned to work for the agency administrator but was also tied into the incident management teams (IMTs).

Andrea Holland was the first ARA to work on the fire. Holland had a solid background as an agency public information officer on wildfires as well as air quality experience. When she came on board, she first introduced herself and explained that her role as ARA was to model, monitor, and message smoke impacts. She said she stressed to the team that she was not there to regulate smoke, but to communicate and be a part of the team. She asked, "How can I help your team be successful with its mission?" Once this "circle of trust" was established, Holland said it helped ensure the success of the entire mission.

One of the biggest challenges on the fire was tracking smoke dispersal because the winds kept changing direction and impacts were not always significant. When smoke did have significant impacts, the ARA would communicate them with the appropriate entities. When acres are burning without significant air quality impacts, an ARA can help convey the critical message that fire can be used to meet resource objectives while not burdening local communities with air pollution. This relieved some of the pressure from the IMT and the agency administrator.

Mike Broughton, Forest Service smoke coordinator in Colorado and ARA, worked remotely to provide regional oversight. Broughton said that ARAs can act as a bridge between an agency and local communities. "Having an ARA on the fire even during times when the smoke plumes were not that active," he said, "created a significant amount of positive public good will."

Hahns Peak/Bears Ears District Ranger Chad Stewart said he believed that trust was built with the ARAs' modeling outputs, products, and communications. "It was superior to anything seen before and very useful for public information officers," Stewart said. "The products were very relevant and well received by the public."

Jeremiah Zamora, an agency administrator and district ranger for the Parks Ranger District, said the ARAs spent a lot of time "chasing the smoke" on the Beaver Creek Fire. Monitoring equipment was shifted to try and match where the smoke was hitting. By August, a few smoke warnings were issued in Laramie, Wyoming, and the ARAs were advising schools when to keep children indoors for sport practice, as there were some days when smoke impacts could have impacted their health.

"Smoke and air quality are major concerns here, as we have lots of Class I Airsheds," Zamora said. Class I Airsheds are Parks and Wilderness Areas established prior to 1977 and greater than 5,000 acres. They are given special protection status under the Clean Air Act for protection of visibility and other air pollution impacts. He added that his experience with the ARAs was a positive one. "I trusted them and their knowledge of where to place monitors," he said. "They worked through PIOs directly and helped to calm people down." Zamora said he would consider using ARAs on fires in the future and would recommend them to other agency administrators.

**Beaver Creek Fire information from InciWeb, https://inciweb.nwcg.gov/*

Lessons from the WFAQRP for Prescribed Fires and Smaller Wildfires

Smoke impacts are an important consideration in the use of prescribed fire. Smoke impacts influence decisions on how much to burn, when to burn, or whether special public events, like holidays and graduations, allow for burning at all. Because minimizing smoke impacts is an important aspect of prescribed fire operations, smoke impacts are often relatively minor compared to the severe air quality impacts that often result from large, high-severity wildfires (Lahm 2018). Smoke management requirements and policies are well-defined for federal agencies that use prescribed fire in their agency specific manuals and the NWCG's "Interagency Prescribed Fire Planning and Implementation Procedures Guide" where the use of Basic Smoke Management Practices is directed (EPA 2016b).

Efforts to mitigate smoke impacts can help managers not just in the planning stage, but also during implementation, including contingency measures that address unplanned effects (Lahm 2018). The use of prescribed fire is gaining support among communities, and even air regulatory agencies, because of its ecosystem health benefits and effectiveness

in wildfire prevention (Hardy and Peterson 2018). However, according to Hardy and Peterson (2018), "this tentative support will only continue and expand if fire practitioners commit to continuously learning and applying the best science and methods for protecting air quality as well as emphasizing public communications and outreach to address concerns." Building upon the WFAQRP approach of monitoring, modeling, and messaging to address smoke impacts, there are critical tools and lessons for smaller, less impacting wildfires and prescribed fires that can help land managers meet their fire objectives while addressing public concerns about smoke.

Monitoring Lessons

On these less impacting fires, monitoring of smoke impacts, whether through quantitative measures provided by a $PM_{2.5}$ monitor or by qualitative observation, is critical to understanding the effects of smoke in terms of duration and level of impact. Monitoring data, whether from a fixed long-term site or from a temporary monitor, is useful for prescribed fire managers to quantitatively understand the degree to which smoke is impacting an area. A prescribed burn boss can utilize the monitoring tool, Monitoring v4.0, to understand when smoke concentrations are at their peak so they can effectively develop messages to inform the public, which will help them cope with the impact and time their daily activities accordingly.

Modeling Lessons

On large wildfires, an ARA will forecast potential smoke impacts by assessing weather predictions, evaluating potential smoke production, and modeling smoke emissions. The same predictive models such as BlueSky Playground and other tools used by ARAs are available to prescribed burn bosses and fire effects monitors on prescribed fires or smaller, less impacting wildfires. Federal prescribed burn bosses (RXB1 and 2) should have exposure to some of these tools through their required NWCG's RX-410 Smoke Management Techniques class. While weather and wind forecasts can provide fire managers with a simple approximation of smoke impacts during a fire, more complex modeling systems (i.e., the BlueSky modeling framework and BlueSky Playground), can provide the best estimations regarding the location and concentration of smoke emissions (Strand et al. 2018). BlueSky Playground is designed for rapid and simple assessment of a single fire based on many assumptions; or it can be customized for greater accuracy to give results on the location of projected impacts and their duration and severity. The model now has extensive help screens to assist in understanding options in use, and it is tied to finer scale weather grids allowing for improved performance. This impact information can be the basis for deciding whether to ignite a prescribed burn or to conduct a burnout operation on a smaller wildfire.

Messaging Lessons

On prescribed fires or small wildfires, land management agencies can use monitoring and modeling information as critical inputs to develop a message for the public on possible smoke impacts. The prescribed burn boss communicating useful smoke impact information to their respective public affairs office is the same method used by ARAs on larger incidents so that the public can reduce their smoke exposure. Communicating in advance with the public so they can respond accordingly to minimize their exposure to smoke and particulates has been very successful for larger wildfires and can help build public support for prescribed fire operations and on less impacting wildfires. Even when a burn is not ignited because of potential adverse smoke impacts, or if ignited and smoke was of little impact, it can provide useful public information and build long-term trust with the agency. The principles of the one-page Smoke Outlook, where information about smoke impact and timing of impacts is outlined, can be mimicked by combining the smoke impacts information from a model run along with information on how to reduce exposure with messages crafted by a public information or public affairs offices. This approach can be a valuable communication and coordination tool to engage with communities impacted by prescribed fire smoke. These skills and tools are not just relevant for prescribed fire operations, but also for smaller wildfire operations that do not necessarily warrant an ARA.

Conclusion and Management Implications

Ecologists and land managers understand that the increased use of prescribed fire and some wildfire is needed to improve ecosystem health and to reduce the threat of catastrophic wildfire. However, the public, including regulators, place a high value on clean air and at times lack an understanding of the use of fire for ecosystem health (Lahm 2018). As land managers increase the use of fire to restore landscapes, public concern about smoke impacts will likely increase (Toman et al. 2014).

Air Resource Advisors can add much-needed capacity during wildfire incidents. An agency administrator can include smoke and air quality objectives into the WFDSS decision for an incident, which provides a clear direction to the IMT, fire managers, cooperators, and the public about this critically important impact. For prescribed fire and smaller, less impacting wildfires, managers can use the ARA toolkit and lessons from the WFAQRP to build skills for predicting smoke impacts and creating valuable public messages about smoke to mitigate impacts. While not all fire managers need to be certified as an ARA technical specialist, there are many training opportunities, tools, and resources to help build smoke management capacity. The available modeling, monitoring, and messaging tools and lessons allow fire and land managers to help the public anticipate, mitigate, and cope with smoke impacts while achieving fire and fuels management goals.

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