NASA Science Mission Directorate (SMD) Wildfire Stakeholder Engagement Workshop: Summary and Key Findings

1. Introduction

Wildfire is a growing problem in the United States. In 2020 alone, there were over 58,000 wildfires resulting in over 10M acres burned. 5-year average fire suppression costs are about $2.35B, not including costs associated with property damage and impacts to human health, which are estimated to be far greater[1]. The wildfire problem and associated costs are only expected to grow under projected climate change. Therefore, it is critical to understand and manage wildfires across their entire lifecycle which includes the pre-fire, active fire, and post-fire environments. Improved understanding of these environments can lead to enhanced wildfire management including pre-fire risk reduction, efficient active fire suppression, and effective post-fire hazard mitigation, ultimately reducing negative ecosystem impacts and damage to property and people. Currently wildfire is managed across its life cycle by state, federal, and tribal agencies who leverage various information sets to make informed management decisions. However, these information sets are sometimes of limited utility for a myriad of reasons including accuracy, resolution, latency, effectiveness, and degree of technical innovation, among others. Given these constraints, the wildfire management problem could benefit from a new paradigm that takes full advantage of the best available science, technology, and capabilities to help overcome current barriers to more efficient and effective wildfire management: new science and technology are fundamental to anticipate and manage the new reality of extreme fires in a warming world.

In February of 2022, NASA hosted a two-day wildfire stakeholder engagement workshop with an objective of learning understanding barriers to wildfire management currently faced by federal, state, local, tribal, and territorial land management agencies in the United States. The ultimate goal is to use this information to inform how NASA science and technology can be more effetely applied to support timely decision making and operations in pre-, active and post-fire management environments. The workshop was comprised of a series of expert panel discussion and breakout groups that address different aspects of pre-, active, and post-fire management. The primary findings and emerging themes from these sessions are presented herein.

2. The Pre-fire Environment

2.1 Pre-fire weather and climate

[1] An EPA report estimates that the cost of long-tern health exposures related to US wildfires from 2008 to 2012 was $450B, while the insurance industry estimates that the total cost of fire suppression and insurance claims for property loss in 2017 were $14B in California alone.

The impact of fire weather and climate on wildland fires represents a multiscale problem, where microscale meteorology can influence how a fire moves across a landscape, synoptic scale meteorology drives regional-scale severe multiple fire scenarios, and climate determines wildland fire trends over the next year to decades. Given this level of complexity in the data products and information needed to inform decision-making activities, the integration of fire weather, climate, and fuels data into useful, accessible information and tools is essential. The panel discussion and break-out session identified key goals and barriers to effectively characterizing the pre-fire environment as it relates to fire weather, fuels, and climate. There is a need for improved research to operations integration, a centralized and consolidated hub of vetted information, enhanced data resolution with lower latency, and improved communications. Following is a discussion of the most pertinent stakeholder barriers, challenges, and directions gathered from the panelists, audience interaction, and break-out discussions.

2.1.1 Research-to-operations integration

Mechanisms and capabilities to validate cutting-edge research and emerging tools to support Research-to-operations (R2O) processes and procedures is "embarrassingly slow". Recognizing that 'new' is not necessarily useful, a need exists to validate short- and long-term fire-related forecasts (all areas fire - weather, fuel, fire potential, etc.) with truth. Otherwise, enhancements are near impossible and leads to a lack of confidence in data and information by fire and land management. Notable gaps in timely and integrated weather-to-fuels information includes: understory and canopy data; green-up; snow cover; accurate land cover types (agriculture/cropland -distinguish orchard vs. brush); and soil moisture data, especially in connection to organic soils and deep duff. Calls for training and/or education to make the data and information useable were highlighted. If the abundant information provided by predictive services is not confidently translated and forecasts are not targeted to the appropriate scale, then fire fighters will rely on intuition and experience, even when more useful information may be available.

2.1.2 Leverage agency partners for coordinated, centralized, and consolidated information

Decision support tools require comprehensive fire components (e.g., air quality, fuel, weather) and a consolidated approach to provide useful information to the field. Disparate sources and a lack of a consolidated hub for validated and vetted information inhibits communication and decisions. R2O is unnecessarily complex and siloed within and between agencies, resulting in unnecessary confusion and inaction. R2O requires mutual agreement on how to verify and validate fire and land products, a single-source share for particular applications, and an acceptable hand-off from operational management (e.g., operational resources) to fire spread, prevention, and control (e.g., planning tools) management. There are three distinct, requisite times scales: short-range safety and immediate fire management (hours, day); mid-range forecasts for longer-term strategies and resources (days, weeks); and long-range forecasts (pre-season, climate), where probability, risk assessments, and confidence are requirements.

2.1.3 Data: Decrease latency and increase data resolution and computing capabilities

There is a need to integrate forecast and climatology at a reasonable resolution. Fine resolution data (fire-scale; less than 0.25 or 0.5 degree) are needed to resolve microclimates (e.g., under canopy deviates from seasonal) in all aspects of fire including but not limited to weather, fuel, soil moisture, and fire danger, that influence fire conditions near and below the surface. Global partnerships to deliver fuels status (e.g., SMAP, Optical data, NRT Fuel moisture) would be beneficial. In another example, the LANDFIRE fuel model has a latency of 2 years, but fire managers require an update at least every 6 months. Precise, accurate, and consistent wind forecasts at the necessary resolution were also noted as a data need.

2.1.4 Preparing for the future: Prescribed burning, risk, and balance with Air Quality (AQ)

Prescribed fire represents a substantial portion of fire weather forecasting, and it is essential to support increased prescribed fires. However, there are multiple barriers that impede burn decisions that include: human and model resources; community and political fear; and integration of agency support. Fires will burn, so the choice is whether we burn under controlled prescribed conditions or when fire danger is extreme, leading to unhealthy extreme smoke and fires that are uncontrollable. Here is where agencies must work together to allow ecosystem-dependent local decisions, where the knowledge exist. To safely identify 'windows of burn opportunities', requires allocated personnel, enhanced computing resources and integrated fuels-meteorology-smoke transport models at the required micro-landscape scale. At a larger scale, enhanced forecasts for seasonal/monthly planning that integrate climate-weather and fuels are necessary, while balancing Air Quality (AQ). Comprehensive risk assessments that convey to fire management and communities fall into two categories: static (current community risk); and dynamic (changing fuel/fire over next days). Probabilistic forecasts were suggested as valuable to accurately assess future risks. An integrated solution is one that requires: accurate and useful risk assessments; enhanced computing resources and science for model development at both local and regional scales; and social science to enhance community understanding of prescribed smoke and to provide a basis to motivate local building codes and political will.

2.1.5 Antiquated Communications

Fundamentally, there is two-tiered need: 1) incident fire teams are often active in remote locations, without access to updated information [(e.g., no cell towers and only communicate by radio (VHF) - possible link to iridium satellites, balloons]; and 2) fire management teams, making decisions in the field, are hampered by an overabundance of data, often without perspective, rather than useful information. The information and forecasts from predictive services are not targeted at the appropriate scale, which when compounded with the lack of available communication systems leads to a disconnect between available and actionable information.

2.2 The pre-fire environment (fuels and ignitions) panel and breakout discussions

The pre-fire environment is a key driver of fire hazard and fire risk and, also influences fire impacts to ecosystems and communities. The composition, structure, and moisture status of fire fuels, along with topography and weather, interact to drive fire behavior, while the proximity of hazardous fuels conditions to valuable assets (homes and infrastructure) is a key component of fire risk. Having an accurate characterization of the pre-fire environment can help managers mitigate fire risk (e.g., fuels treatment) and also aid in the management of active fire. The panel discussion and breakout group on this topic identified several challenges to enhanced mitigation of fire risk, increased community resilience, and enhanced forecasting. Importantly, building fire-resilient landscapes and settlements is more than a challenge to ecosystem management, but equally involves human settlements, community and indigenous values and social tolerance for differing risks. The following paragraphs detail some of the most relevant barriers to more effective management of the pre-fire environment.

2.2.1 Communication and trust

As fires of growing seriousness affect increasingly vulnerable populations, the attention of the fire community is becoming more focused on mitigating pre-fire risk and increasing the resilience of human communities. Fuels management, which is typically achieved via removal of fuel via mechanical techniques or prescribed fire, is an important aspect of building fire-adapted communities. Despite the evidence supporting the use of prescribed fire as a fuels management strategy, it is still largely underutilized in fire-prone regions because of negative community perceptions of fire and smoke. A monumental shift in these negative perceptions is required before treatment can be realized at scales large enough to make significant impacts, and this ultimately requires communication strategies that build trust among communities and between communities, scientists, and land managers.

2.2.2 Key risk metrics, biophysical infrastructure and social, near and long term

There is not yet a standard set of risk and resilience metrics. Information on risk and resilience involves consideration of risk on multiple time scales. At the longest time scale, risk is affected by ecosystem structure and human settlement patterns. On seasonal and shorter time scales, fine fuels and fuel moisture affect potential fire behavior. On very short time scales, ignition sources, lightning, wind affecting powerlines and human presence all affect ignition risk. Finally, managing for resilience requires looking forward and predictive tools projecting landscape and climate changes may inform present-day decision-making. Our observations and understanding of climate, ecosystems and human geography are all inadequate for addressing these time-scales within a management framework given the rapidly changing environment. First, tools and models for assessing fire risk, and how much mitigation action might reduce that risk need to be more robust, especially in the case of changing climate, changing ecological communities, and changing settlement patterns. Second, data to inform such tools, as they are developed, are not widely available, are often out of date and may or may not actually characterize the key ecological, moisture and infrastructural parameters affecting risk and resilience. While new remotely observed and sensor data may fill some of these gaps and better inform models of risk, considerable work needs to be done with stakeholders to determine the most informative observations, integrate them into robust models and partner with user communities to ensure acceptance.

2.2.3 Operational: latency, refresh, formats, ease of use, training

Participants expressed needs for improved data delivery and usability. For data to be useful it needs to characterize current conditions, and have been collected contemporaneously, meaning that data should be routinely and frequently collected, especially data that characterize phenomena that change frequently. Once collected, data must also be transferred to users in a timely manner so that the information informs current conditions. Analysis and quality control must not create long delays between acquisition and distribution. Once distributed, data must be "fit for purpose" or application-ready to minimize the burden on users, especially when decisions are time-critical. That means data should not require extensive additional analysis and processing once delivered, be in easily used formats and units, and have sufficient contextual information (uncertainty) that users know the degree to which they can rely on a given data source.

2.2.4 Information content: do we really have the tools to assess the delta risk for any given mitigation

As new data become available with advancing technology, from satellite, UAS, citizen and sensor network platforms, models and analysis tools must be available, tested and accepted for use to enable these new data to enter decision processes. As models advance, they may become more demanding of data, equally as data become more informative, resolved in time and space and widely available, models need to advance to make use of the increasing information content. Neither data nor models/analysis tools should be advanced for their own sake, rather user needs and analyzed cases where inadequate information prevented effective decision making should guide priorities for new approaches. Referring to 1) above, co-development of observing systems and analysis tools/models needs to be done within communities of practice, teaming resource professionals, community leaders, scientists, and the broad fire-affected communities.

2.4.5 Values—individual values, communities, and wilderness values

Reaching agreement on mitigation of fire risk involves not only technical decisions but also choices involving deeply held values. Mitigating landscape fire risk involves balancing individual and community welfare, always a challenging arena. Reducing risk to natural ecosystems and adjacent human settlement involves landscape scale management, often in treasured landscapes. Deciding whether to allow natural processes to proceed, in the face of changing conditions to preserve one vision of wilderness can conflict with active management to reduce fire impacts, restore a natural fire cycle, or protect treasured regions from catastrophic fire. Debate continues about pre-settlement fire regimes, the natural occurrence of megafire and the role of indigenous fire management. This means that management of both red zone, urban-wildland interfaces and extensive forest or range land involves multiple stakeholders, multiple worldviews and priorities, indigenous values and knowledge and a host of other competing positions. Building a fire-resilient landscape involves science, but equally culture, values, and community priorities.

3. Active Fire

3.1 Topic Fire Detection & Tracking

The detection and characterization of active fires are fundamental to supporting real-time applications for fire management and supply information on fire behavior and severity needed to advance fire science and applications. Satellite-based Earth Observation (EO) instruments provide routine coverage to help identify and track active fires, and current capabilities provide either moderate spatial resolution and infrequent coverage (e.g., VIIRS, MODIS) or coarse spatial resolution and frequent coverage (e.g., GOES). Gaps in moderate resolution coverage currently limit advances in fire science and applications needed to support the management of extreme fire events and their unprecedented impacts on communities, ecosystems, and air quality. In addition to these observation gaps, NASA SMD Wildfire Stakeholder Engagement Workshop Panel 2 and Breakout Session 2 participants collectively identified five (5) key barrier "themes" of active fire detection and tracking:

3.1.1 Data interoperability, to maximize the utility of current & future fire detection data

Presently, fire data are produced in a range of data formats, based on inconsistent definitions and product standards. A community-wide effort to adopt a common format for analysis-ready data (consistent with CEOS and/or OGC Standards) could streamline the process to ingest and analyze fire data from different platforms. Consistent definitions and quality assurance would assist the end user in data selection and analysis. Further reductions in data latency would benefit a range of stakeholders who depend on real-time fire data, regardless of whether those are delivered from satellite platforms, airborne assets, or ground networks.

3.1.2 Close communications gaps between data producers and users

Fire management occurs at a local level, involving hundreds of stakeholders. This can and does lead to information being siloed and not available to all who would need it. Communicating life-saving information to the front lines will require improvements in communications to remote crews with limited connectivity (cellular, radio, WiFi) to data / information sources and services (Incident Command Center, web-services, etc.). Specific needs include regular updates on the fire location and behavior, forecasts, and other management activities. In addition to communication during a fire event, closing the communication gaps between data producers and data users will require further training and support for new data products and a two-way sharing of data between research and analysis teams and fire suppression efforts. For example, fire spread forecasts could be more accurate if they account for planned fire suppression efforts.

3.1.3 Leverage new and emerging data sources and complementary remote sensing data

Advances in fire detection and tracking can benefit from a range of new and emerging data sources and analytic techniques. Source data systems and applications need to continue to improve the ease of access/use of data and help users better understand limitations/caveats of data products. Ground-based camera networks provide rapid detection information for the WUI and other high-value infrastructure but require improved analytics techniques for rapid data reduction and then incorporation into operational decision-making processes with other observation / information sources. Machine learning (ML) and artificial intelligence (AI) show great promise for rapid analysis of data across a range of platforms and may accelerate the delivery of downscaled products for specific end users, including climate data needed to forecast fire spread in complex terrain. Smoke and wind data offer complementary information about fire spread, including stereo-derived estimates of smoke plume height to identify and respond to PyroCB events. Given the diversity of efforts to support fire management in recent decades, it is also paramount to learn from past trials of new technology.

3.1.4 Improve fire tracking and forecasts of fire spread

Knowledge gaps in fire behavior undermine effective fire management. Regular observations of the fire front and smoldering fuels behind the fire front are necessary to support fire suppression efforts and improve estimates of fire emissions and air quality impacts from large fire events. Real-time, accurate geolocation of fire detections is especially critical in the Wildland-Urban Interface (WUI), where tens to hundreds of meters matter. Synthesizing fire data as events, not pixels, is an important step towards a common denominator for fire science and fire management. Fire behavior information is also critical to understand the conditions under which PyroCBs form and collapse, as both conditions represent critical events for fire management and public safety. Finally, key gaps remain in fire detection and tracking in the WUI, where current models do not fully account for fuels in the built environment.

3.1.5 *Support the transition from Research to Operations*

Coordination is critical for fire management in the US. At the national level, this could include stronger leadership awareness of the technology and science emerging from the research and applications community, in order to champion and best harness and combine existing R&D into the operational context through existing institutional fire management training programs. At the agency level, this could include strengthening and sustaining training efforts on how to use new tools and technology, and the strengths, limitations, and complementary nature of new information. For fire science, the path from research to operations could include a testbed environment to benchmark and quantify the advances from specific data or model improvements in support of stakeholder needs.

3.2 Active Fire - Emissions, Air Quality, and Fire Weather

During an active fire, satellite data provide the information needed to estimate smoke emissions and to understand and predict fire weather in near real time, helping scientists and environmental managers better serve communities downwind of the fire. Despite many advances, this is a very challenging area that can involve combining satellite data with information from *in situ* sensors and merging observational data with multiple types of models to make predictions, with stringent requirements on turning out high quality information, quickly. Experts representing federal government agencies, regional air quality management, private industry and university affiliated fire research laboratories highlighted barriers in using Earth information in the weather and air quality aspects of fire management. Major themes included:

3.2.1 Data products with improved spatial and temporal resolutions

Insufficient resolution of data products remains a barrier for many potential users. Air quality managers would benefit from updates throughout the day to help local communities plan for smoke events and at spatial scales capable of representing gradients within urban areas and fire perimeters. Long latencies typical of many satellite data products are a major barrier limiting their integration into fire weather forecast models.

3.2.2. Information on plume height, PBL dynamics, and plume composition

Though multiple observations provide information on total column aerosol and trace gases, the lack of vertical information identifying the height of a plume makes it difficult to accurately incorporate this information into forecast models and can greatly reduce predictive skill. Insufficient information about boundary layer height and its diurnal evolution also limits the ability of air quality managers and fire weather forecasters to provide reliable information about near surface impacts of smoke plumes, particularly at night. In densely populated areas where WUI fires are becoming more common, lack of information on the composition of smoke plumes, particularly those that may include toxic compounds not traditionally associated with wildland fires, is a pressing issue not well addressed by current observations.

3.2.2 Improving the research to operations (R2O) pipeline

There has been substantial progress in many aspects of modeling and observing fire weather, including development of coupled fire-atmosphere models, new approaches to simulating plume rise, and the use of mobile radar observations during active fires. However, such research approaches often face major challenges that limit their adoption in operational systems. It can be difficult to distribute new types of information to government agencies and to integrate experimental data into national weather forecasting tools that favor established data streams. Collaboration between government, university, and industry partners can help expedite R2O transitions, but support for technical approaches including co-development of shared code and data repositories and workflow tools is critical.

3.2.4 Improved data access and services

Air quality and fire weather managers face many technical barriers when they attempt to incorporate Earth observations into decision-making. Standardized formats and centralized locations for data are needed to serve all communities, particularly those serving on the front lines who are forced with making time sensitive decisions. More robust coordination of data services would also support integration of observations into forecast models and help users combine multiple existing datasets in the near term.

3.2.5 Continued work understanding user needs and communicating science to diverse audiences

Providing uniform warnings and services for fires across the country, which face geographic differences, complex regulatory environments that span federal, state, local, tribal, and territorial agencies, and varying levels of fire expertise in field office staff, is a major challenge. Improving communication of existing tools and services is critical in making sure that advances truly serve the communities they are intended to support. The panel strongly emphasized the value of working closely with social scientists to find better ways to communicate risk and inform the public without creating panic and to address equity and social justice concerns.

4. Post-Fire

4.1 Landslides and Water Quality

This breakout group focused on the cascading hazards of landslides and negative effects on water quality that can occur as a result of wildfires. By focusing on scientific information gaps and structural or other actionable implementation barriers the group identified a few overarching issues related to a lack of communication, personnel, resources, and access to the necessary data products. Although the group primarily focused issues related to data needs, these issues are all inter-related.

4.1.1 Data Access

Depending on the agency and sector involved, the group identified that it can be difficult to impossible to access the data necessary to do a post-fire assessment or even to know what types of data are available to do a post-fire assessment. There are many reasons for this, in some cases not enough observations are collected and made available post-fire, and if data are available there are firewalls related to when data can be shared and what data are shared between agencies. For example, consulting CalFIRE or other similar agencies can sometimes lead to access of preliminary data. However, agencies limit these data due to fears of potential misinterpretation and collateral impacts. No data are shared until they are thoroughly assessed for verification and all data types must be well-defined before sharing to prevent confusion. The group noted that the process to apply for these data can be complicated and confusing. Researchers can get discouraged during the application process and this acts as a barrier to access.

4.2.2 Data Harmonization

Harmonizing different types of data represents a significant gap in the wildfire community. These different types of data could be integrated as layers that with a data mapping platform. The data types mentioned by the group that would be useful in post-fire analysis were: vegetation data, geologic map information, burn severity maps, high resolution imagery, soil type and moisture information, above ground structure locations, as well as spectral, photogrammetry, and topographic data. The group mentioned it would like to see satellite (Landsat and Sentinel), SmallSat (high resolution NIR and TIR) and airborne data included in the database. These data were associated with science gaps including difficulty capturing small-scale cultural features in existing imagery, and reliability of remote warning capabilities for soil moisture, precipitation, and flow monitoring.

4.2.3 Data Discoverability

The group made a strong case for the need for a centralized database of wildfire related data. They would like this database to mention the types of data available and how they could be used on the front page to increase the “discoverability” of data types they may not be familiar with. To increase accessibility of the data, the group suggested the database be formatted similar to existing well-known mapping portals such as: [GWIS-Current Situation .](#) The group also suggest that if NASA joined or collaborated with the Joint Fire Science Program there would be increased outreach of the NASA data products available.

4.2.4 Lack of personnel and resources

Remotely acquired wildfire data are typically stored locally and need to be directly shared with those requesting access. However, many wildfire agencies suffer from a lack of resources and little to no dedicated remote sensing personnel that can process, classify, and share these data. This result in delays to scientific and public data access and can limit capacity to fully utilize actionable information to identify post-fire risk within the period where data are needed.

4.2.5 Communication within Scientific Community

Between agencies and within the wildfire scientific community there is a lack of communication that results in critical information not being shared. There is a need for a clear and well-established communication pathway to requesting information that agencies and researchers can utilize to better understand what data are available and how to acquire these data. These lines of communication need to connect groundcrews and those researching and monitoring post-fire cascading hazards with the existing databases and networks of data. This would also help the community to better understand the state-of-the-art of wildfire monitoring.

4.2.6 Communication to the Public

Once the scientific community has worked with the data and determined the risk associated with post-fire cascading hazards this information must be communicated the public through different websites, maps, and venues. One method brought up was to share the impact wildfires have on downstream areas as a color coded (red to green) risk probability map. This would help both the public and scientific community to better conceptualize an issue that is often unclear. There is also a need for established methods for sharing these data with the public. This could be resolved if there were a common understanding of when data can be shared, and where it should be shared. The location of this information would then need to be advertised to the public with special attention given to those that may be in high-risk areas.

4.2 Post-Fire Impacts on Ecosystems and Infrastructure

Wildfires are an increasingly common threat in the US, destroying lives, property, and natural resources. The vegetation regrowth and plant succession after fires will depend on various factors such as fire severity, disturbance history, topography, site characteristics, and local weather. Ecological studies combined with remote sensing data can provide valuable information on these variables useful for restoration efforts. Addressing fires in wildland urban interface (WUI) areas requires immediate attention within minutes to hours to save lives and infrastructure; thus, essential demographics and infrastructure information are necessary in advance. Developing Decision Support Systems (DSS) integrating ground-based and remote sensing data with advanced artificial intelligence (AI) algorithms and models could help fire detection, tracking, evacuation, assessment of post-fire impacts, and restoration measures. It is also essential to conduct integrated social studies that capture people's perceptions to address post-fire management and rehabilitation efforts. This summary highlights some barriers, challenges, information needs, and priorities shared by the stakeholders during the wildfire workshop, which are useful to address post-fire impacts on ecosystems and infrastructure.

4.2.1 Vegetation

High severity and high-intensity fires can alter vegetation structure and function at rapid timescales (<week to a month). Vegetation regrowth and plant succession after fires can depend on various factors such as local weather, topography, ecological site characteristics, fire disturbance history, and fire severity (intensity, duration, type, size, season). In particular, fire-adapted invasive species can expand and degrade natural ecosystems. Also, the regenerated vegetation can be fuel for the next wildfire. Thus, knowledge of pre-fire vegetation composition along with the capability to characterize the composition of vegetation regrowth and regrowth trajectories at various spatial scales is central to determining both future fire risk and post-fire management decisions. In addition, new vegetation can govern water infiltration capacities, affecting downstream water supply, but we lack details on the timing and scale of these impacts. Therefore, we need information pre-wildfire and then rapidly post-wildfire on site characteristics, vegetation, and ecological condition to focus restoration efforts. Specific to restoration, priority should be on the most impacted watersheds. It is also challenging to decide what to reseed, how much land to reforest as well as where and at what scale? Hence, more research is needed to address these issues.

4.2.2 Infrastructure

The wildland urban interface (WUI) is where houses and wildland vegetation meet. WUI fires create unique challenges for emergency responders as community needs must be met within minutes to hours to save lives and property. A spatially explicit long-term dataset on building footprints, defensible space, and demographics is needed to address WUI fires during preparatory, recovery, and post-recovery phases. Very high-resolution remote sensing data could be helpful here. Approaches that promote defensible space, coupled with home hardening, are essential to improve any home's chance of surviving a wildfire. Specifically, owners of tribal lands and cultural heritage do not have proper early warning systems (EWS) before the fire hits them; thus, developing EWS should be a priority. For infrastructure issues, psychology and economics are likely as important as traditional fire science; thus, socioeconomic surveys are a must for successful management. Further, community-level adaptation and policy studies can help understand post-fire impacts and improve responses to wildfire at the WUI.

4.2.3 Data, Tools, and Approaches

Data from very high-resolution remote sensing, hyperspectral, fine-resolution LIDAR, and unmanned aerial systems (UAS)—all combined through data fusion algorithms—would provide valuable information on pre- and post-fire vegetation, site characteristics and infrastructure impacts. More detailed, better resolution and faster data are essential for effective fire management. Their absence currently constitutes a barrier. The data should be linked to freely accessible decision support systems (DSS) useful to land managers and the public. The DSS should integrate robust artificial intelligence algorithms and models useful for evaluating fire risk to people, vegetation, infrastructure, and fire impacts. In addition, citizen science ideas should be promoted for effective fire management. CALFIRE is partnering with local, county, and statewide authorities on "Emergency Fire Alert Systems," useful for evacuation planning. Also, the "CA Wildfire and Forest Resilience Task Force" has been formed, which focuses on developing a datahub useful for fire management. The services from national Monitoring Trends in Burn Severity (MTBS) and Burned Area Emergency Response (BAER) systems are beneficial for post-fire management and restoration efforts; however, more such programs with better data latency are needed to address wildfire problems.

4.2.4 Management

It is vital to conduct integrated social studies that capture people's perceptions for successful rehabilitation efforts. Both short-term and long-term plans are required to address post-fire issues. Instead of focusing on suppression alone, proactive approaches towards prescribed fires and fuel treatments are needed—but these require buy-in from landowners and other stakeholders. For example, some landowners do not like prescribed fires as they might affect their land's aesthetics, livestock, and the risk of fire escape. In such cases, effective communication can help. It is important to stress that fire suppression/exclusion can lead to fuel build-up and that prescribed fires can reduce fuel loads making wildfires less damaging.

Specific to capacity building, a unified approach across bureaus and agencies on remote sensing, geospatial tools, Unmanned Aerial Systems (UAS), and information technology (IT) is needed. Meeting staffing needs and building expertise on all aspects of fire management within different agencies is a priority. Research to operations and applications – transitioning, onboarding, and offboarding are other major issues in several agencies that need addressing. Consistent funding for programs that leverage academic, federal, and non-federal agencies with social science components is critical. Public-private partnerships are a must for successful wildfire management.