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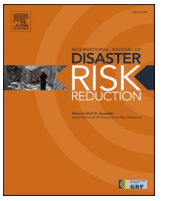

Understanding unmet needs during community wildfire recovery: A case study of smoke damage impacts after the 2021 Marshall Fire

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ABSTRACT

Efforts to understand, assess, and address diversifying recovery needs have growing relevance as wildfires continue to impact communities. However, little is known about social experiences navigating gaps in assistance funding and support or "unmet needs" in post-fire spaces, particularly for indirect impacts like smoke damage. Determining how affected residents access available information and make decisions related to unmet needs can aid the development of resources and programs that support rapid identification of, and response to, emergent or undocumented impacts during recovery processes. This study explores household experiences with smoke damage as an unmet need during recovery following the 2021 Marshall Fire in Boulder County, Colorado, USA. Semi-structured interviews with residents and professionals who dealt with smoke damage revealed a wide spectrum of impacts. Decisions to act on smoke damage were influenced by risk perceptions and personal capacity to undertake self-guided recovery in the absence of a formalized process for navigating remediation. These experiences underscored a distinct absence of scientific and management expertise, legal protections or standards, and assistance related to smoke damage identification and remediation, catalyzing distrust in officials and ambiguity regarding whether smoke damaged homes could become safe again. Together, these conditions created cascading uncertainties for residents with smoke damaged homes that motivated long-term health concerns. Unmet needs after wildfire appeared to emerge because of misconceptions about impact severity, limited professional capacity, and adherence to rigid recovery structures that restrict professionals' ability to identify and incorporate non-traditional impacts into existing processes. Findings informed suggestions for improving smoke damage recovery processes, inviting consideration of policy and more inclusive assistance to support recovery from indirect wildfire impacts.

1. Introduction

Household impacts and subsequent needs are continually diversifying in community wildfire recovery processes as changes in fire occurrence and behavior layer over evolving local social contexts [1–4]. However, difficulty consistently identifying and documenting how social impacts manifest and endure after wildfire means that efforts to support community recovery may unintentionally overlook opportunities to anticipate and assist those affected at different points in local recovery trajectories [5–7]. Efforts to uncover and

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incorporate unmet needs (i.e., outcomes for which there are not clear response or recovery mechanisms) into disaster frameworks and organizational response are central to more comprehensive and inclusive programs and processes in post-fire recovery [8,9]. Building a more comprehensive catalogue of impacts and related needs after wildfires can help identify which entities are best suited to anticipate and assist those affected while also aiding pro-active development of tailored resources to accelerate recovery.

Smoke damage is one often-overlooked consequence of wildfire in or near developed areas, meriting further exploration. Wildfires increasingly burn developed areas and ignite urban conflagrations, producing smoke that originates from non-organic materials used in residential and commercial structures and their contents, vehicles, and public infrastructure [10–13]. Particulate matter from these sources contains hazardous chemicals that can cause or exacerbate preexisting human health issues, pollute soil and water, and render residential structures unsafe [14–17]. Smoke damage typically occurs over larger areas than direct wildfire impacts given the geography of wind transportation; for instance, the 2019–2020 Black Summer in Australia produced widespread declines in air quality far beyond the fire area. Recent "urban firestorms" in the United States such as the 2018 Camp Fire, CA, the 2023 Lahaina Fire, HI, and the 2025 Los Angeles Fires, CA, have all entailed smoke damage complications to the structures that remained, but resources and guidance on how to navigate these consequences in the aftermath of a fire are typically absent [18–20]. This includes safe residential re-entry and return procedures and instructions for identifying and remediating smoke damage for structures still standing within or near burn scars that may have been immersed in smoke for hours, days, or weeks. The full array of social consequences related to smoke damage are not well documented, warranting further study to both establish a baseline understanding of resident (re)actions and inform processed for navigating post-fire outcomes.

This study documents recovery processes surrounding smoke damage following the 2021 Marshall Fire in Boulder County, Colorado, USA, to understand how residents and professionals determined impacts, navigated risks, and made remediation decisions. Semi-structured interviews were conducted fifteen months after the fire with individuals engaged in recovery efforts to address smoke damage in homes within and near the fire footprint to provide insights into impacts and unmet needs. The concept of a "Risk Society" [21], in which technological advancement diversifies societal risks and produces uncertainty around scientific information, provides a theoretical framework to analyze how impacted residents process and act on information (or lack thereof) about smoke damage to their homes. This research seeks to make scientific and management contributions by: (1) documenting how the recovery process unfolds for residents with unmet needs, (2) providing a foundational qualitative understanding of experiences among residents with smoke damaged homes, and (3) exploring the potential long-term consequences of unmet needs at the household level during post-fire recovery. Findings can inform wildfire planning, response, and recovery efforts among local, state, and federal governments and insurance companies related to smoke damage, as well as providing guidance and considerations for supporting residents with unmet needs after future fires.

1.1. Evolving community needs during wildfire recovery

Social impacts caused or exacerbated by wildfire are wide ranging, and in many instances, difficult to quantify [5,7]. These impacts emerge at different points in time and in different combinations across fires, influenced by local social contexts comprised of past fire experiences, social dynamics, and relationships with the land among other considerations [22,23]. While some impacts are well represented in recovery processes, such as structure loss, infrastructure functioning, and temporary displacement [24–26], other outcomes such as loss of place attachment, declines in mental health and wellbeing, and financial insecurity benefit from tailored, impact-specific support [27–29]. Community and household wildfire recovery trajectories are not linear, and access to and relevance of recovery assistance programming has emerged as a significant factor [1,2,8,30,31]. However, recovery assistance often follows pre-determined processes, frameworks, or approaches that were developed to address commonalities in impacts across numerous hazards (e.g. hurricanes, flooding), catering to more "traditional" impacts like economic disruption and structure loss [32–34]. Difficulty anticipating and adapting resources to meet novel, place-specific needs within existing recovery process means that assistance programs and the individuals or entities that oversee them must be nimble and able to improvise beyond these constraints to respond appropriately [8,35,36]. These conditions are often complicated by conflict, unintentional overlap, or absence of coordination between the broad range of entities that often respond after wildfire. Responders can include multiple departments within local, state, and federal governments, non-governmental organizations such as non-profits, and local organizations such as church groups [1,4,37]. Identifying and addressing unmet needs in socially and bureaucratically complex post-fire spaces is therefore often delayed or difficult to prioritize [38].

Both formal avenues like federal assistance, disaster case management, and insurance claims, and informal avenues like information sharing via social media, collective problem solving, and leveraging social networks are critical for community recovery [1,2,4,8,39,40]. Informal efforts tend to emerge when formal, structured approaches don't meet local needs, external capacity to support those affected is not present, or adequate information about formal processes is not readily available. These experiences are often exacerbated by both preexisting conditions, such as community cohesion and trust in responding entities, and interactions with previously unfamiliar entities, such as insurance companies and organizations involved in recovery [4,41]. Efforts to understand and cohesively respond to diverse recovery needs identified in formal and informal spaces often result in the formation of long-term recovery groups, identification of recovery leaders, and novel programs that help retain engagement among recovery professionals and community members [1,2,8,42]. When such organization is not present, grass-roots efforts to access and interpret information may emerge in the form of community-led events, support groups, and other strategic knowledge exchange or networking efforts [43,44]. One consistent challenge in these cases is incorporating informal solutions and adapting lessons learned into formalized processes to ensure unmet needs are addressed during future events [8]. Characterizing and improving processes for both identifying and responding to unmet needs offer avenues to improve existing frameworks for recovery, as well as designing new programs to encourage

more inclusive efforts to support communities where uncommon wildfire impacts may emerge.

1.2. Characterizing smoke damage and its implications

The social impacts of smoke produced by burning vegetation from both wildfires and land management techniques are becoming well documented, particularly regarding health outcomes [45–47], adaptation resources [48–50], tolerance [51,52], and risk communication [53–55]. However, it is not yet clear whether these findings translate to smoke damage in residential areas after wildfire, or the extent to which impacts and risk mitigation activities parallel one another for this kind of hazard.

Smoke damage caused by wildfire occurs when materials are burned, producing soot, char, and ash that are blown downwind or settle while structures are enveloped in smoke plumes. In urban or wildland-urban interface fires, these deposits can contain Volatile Organic Compounds (VOCs), toxins, heavy metals, and other toxic, mutagenic, or carcinogenic content from structures that are more hazardous to human health than smoke produced by burning vegetation alone [12,56–58]. Much of the existing science surrounding wildfire smoke damage measures the presence of these hazardous chemicals at different points in time [57,59]; less research directly studies the health of those living in smoke damaged homes [14]. Particulate matter associated with smoke damage can be difficult to detect without formal testing as it may not be visible to the human eye and can become trapped in hard-to-reach spaces such as insulation inside walls and attics, taking longer to identify and address [60]. Testing techniques to determine the presence of pollutants introduced via smoke damage are diverse, ranging from ambient air quality testing inside a home to swabs, wipes, or tape lifts to collect material deposited on surfaces [61]. These efforts are often conducted or reviewed by industrial hygienists, who are tasked with assessing contamination and recommending courses of action. Across existing studies published on smoke damage chemicals and consequences, researchers consistently call for further investigation to examine potential relationships between the presence and severity of smoke damage and potential health consequences [62].

While the potency of chemicals introduced by smoke from urban wildfires declines over time, smoke damage can linger inside homes for months to years continuing to off-gas during warmer temperatures or resuspend particulate matter as airflow changes, underscoring the importance of rapid identification and remediation of smoke damage to limit potential health consequences [63,64]. Existing Federal Emergency Management Agency (FEMA) guidance developed in the aftermath of the Marshall Fire categorizes smoke damage as heavy, moderate, or light and prescribes remediation techniques relative to these impacts [60]. This guidance suggests that heavy smoke damage typically requires filing insurance claims and contracting professional remediation companies, while light to moderate smoke damage may be feasible for a resident to clean themselves with appropriate cleaning supplies and personal protective equipment by opening windows to increase ventilation, installing a clean air filter, using activated charcoal to absorb odors, and cleaning soft goods [57,60,65]. Smoke damage can be difficult to remove from many household items and construction materials with permeable surfaces such as clothes, upholstered furniture, mattresses, or insulation in walls and attics, sometimes warranting professional cleaning. Evidence to support the effectiveness of various smoke remediation strategies is varied; for example, some studies indicate that increased ventilation in smoke damaged homes resuspends hazardous chemicals, while others suggest active surface cleaning activities (vacuuming, mopping, dusting) are more effective and enduring than portable air cleaners [56,65,66]. Documenting how residents determine smoke damage severity and decide whether to navigate subsequent remediation, insurance claims, and related processes can inform improved re-entry safety guidelines and post-fire recovery that incorporates diverse impacts and trajectories within the same affected community.

1.3. Smoke damage in a risk society

Rapid technological innovation has facilitated societal development and expansion while simultaneously producing new, often unanticipated risks associated with the introduction of new chemicals, toxins, and related human-made materials [67–69]. These risks transcend local social and economic dynamics to become global as adoption of new technologies spread, making them difficult to quantify or characterize across spatial and temporal scales [68,70,71]. Technological hazards, which include nuclear radiation and dam failures, are considered risks that exist because of human activity and advancement and are inherently preventable [72,73]. Many social theories, frameworks, and conceptualizations have emerged to interpret societal responses to technological risks, often seeking to uncover patterns or explanations for human behavior across varied scales [74,75]. The “Risk Society,” a theory developed by sociologists Ulrich Beck and Anthony Giddens [21,76], seeks to explain human relationships with modernization-related risk, and in particular, the role that technological hazards play in negotiations with uncertainty. Beck posits that the Risk Society is defined by the distribution of wealth, power, and negative societal consequences (such as pollution) tied to technological hazards. Exploring smoke damage produced from burning human-made materials during urban wildfires as a technological hazard offers a framework for examining risk and uncertainty in post-fire environments.

Characterizations of the Risk Society are founded on four cascading propositions [77]. First, continued industrialization increases the likelihood and scale of catastrophe, placing more people at risk over time as technological advancement expands [21,78]. Second, the unpredictability and uncertainty surrounding these risks then produces a loss of trust or faith in experts and science to mitigate or eradicate such threats to the public [79,80]. Third, these conditions result in a growing number of competing knowledge claims that erode expert consensus over time as the limits of available science are exposed [81,82]. Together, these three phases influence a fourth: uncertainty about technological hazards, producing complex social dynamics that can lead to conflict over divergent understandings of the same risk [83–85]. Experiencing technological hazards in a Risk Society can erode ontological security–the removal of perceived stability and safety as previously held beliefs about risk and the ability of institutions to prevent them are brought into question [86,87]. Across these conditions, members of the public begin to experience heightened risk awareness focuseed on future risk and safety

outcomes that can produce individualized responses driven by independent interpretations of potential exposure [88,89]. Organizations and institutions responsible for managing and responding to these new risks may be ill-equipped for their emergent and evolving nature, which are increasingly becoming globalized. The potential for urban wildfires that trigger technological hazards is heightened as global wildfire activity continues to expand, underscoring the relevance of the Risk Society as a framework for exploring institutional response and resident sense-making in smoke damaged communities [87,90–92].

Calls to document diverse social impacts after wildfire, including unmet needs and related community recovery trajectories, invite exploration of smoke damage to promote improved post-fire support. Resident and professional experiences navigating smoke damage impacts, remediation, and recovery at the household level remain undocumented, yet can provide critical insights into recovery needs and processes for at-risk communities internationally. The research presented here seeks to address these gaps in the literature by answering the following research questions.

1. How do residents and professionals navigate wildfire recovery surrounding an unmet need?
2. What characterizes household experiences with smoke damage after an urban wildfire?

2. Methods

2.1. The 2021 Marshall Fire

The Marshall Fire began on December 30th, 2021, spreading rapidly to burn 6026 acres in Boulder County, Colorado, USA, and trigger the evacuation of at least 37,500 residents [93]. Approximately 1084 homes were destroyed, predominantly in Superior, Louisville, and unincorporated Boulder County, making the Marshall Fire the most destructive wildfire in state history [94]. The wind-driven nature of the fire combined with suppression efforts and variation in housing and development conditions resulted in a substantial number of unburned homes left standing within the burn scar [95,96]. The prevalence of these surviving homes, many of which were later identified as having smoke damage, provided ample opportunities to understand resident experiences and response to this underexplored secondary hazard and related recovery needs [14,65]. The full extent of smoke damage from the fire is unknown, although some estimates place it at between 13,000–14,000 homes across a 15 square mile area [97].

An interdisciplinary body of research has emerged given the proximity of the Marshall Fire to numerous federal research offices and universities, allowing timely exploration of fire behavior [98–101], patterns of (infra)structure loss or impacts [96,102], risk communication [103,104], health impacts [14,105], environmental contamination [15,106] and policy implications [107,108] among other topics. A subsection of this research engages with air quality and report varied assessments of risk produced by smoke damage, providing context for the study presented here. Elevated concentrations of Environmental Protection Agency (EPA) priority toxins, metals, and VOCs were detected in homes from five weeks to six months after the fire, and resuspension of these particulates caused by movement and human activity remained a threat, though implications for human health were not clear [56,57]. Over 65% of respondents whose homes were still standing after the fire reported finding ash inside upon return, and over 61% reported that their home smelled differently (a known indicator of VOC presence), both of which were related to self-reported health issues [14]. Social science research following the Marshall Fire has predominantly focused on interview case studies of professional response (e.g., Ref. [107]) or studies of residential recovery experiences utilizing survey data from the multi-phase Marshall Fire Unified Research Survey (e.g., Ref. [14]). There remains a need for qualitative research with residents affected by smoke damage to better document their experiences and provide opportunities for self-articulation of post-fire needs.

2.2. Approach

The author conducted 49 interviews with 58 people after the 2021 Marshall Fire, predominantly in March 2023, 15 months after the fire. Of these, 23 interviewees were residents who had standing homes within or near the burned area or professionals involved in supporting the remediation and recovery of these residents. Insights from the remaining interviewees, the majority of whom lost homes ($n = 22$) and consistently compared their experiences to those of residents with smoke damage, are also included and analyzed as they helped contextualize and provide contrasts in experience and understanding of unmet needs. Given the significant ongoing mental health impacts associated with the Marshall Fire, initial resident recruitment efforts invited potential participants to self-identify and contact the author to participate [109]. The author shared information about the study on local mailing lists and social media pages to allow interested individuals who felt they had the capacity to share their experience to come forward [110]. The author was then able to engage in chain referral recruitment (whereby interviewees recommend others suitable for participation) with high success by building trust with early participants; many affected residents had well-established informal communication networks built around shared wildfire impacts, supporting a more representative dataset [111]. Interviewees with smoke damaged homes often referred to themselves as members of the “standing home” community; this term is used herein to reference this group. Professionals were recruited via theoretical sampling, which entailed identifying key individuals with relevant jobs or experience related to the Marshall Fire, smoke damage, and resident recovery processes (e.g., county or municipal government employees, emergency management professionals), in addition to chain referral. The author conducted interviews in-person wherever possible at a location of the interviewee's choice, typically at their home, rental home, workplace, or public spaces like coffee shops [112]. A small number were conducted via phone or videoconference platforms where in-person meetings were not an option (for example, in one case, the interviewee had moved away from the area due to the impacts they experienced).

Interviews followed a semi-structured interview protocol to allow elaboration and exploration of emergent themes that supported

the development of an in-depth, comprehensive dataset[1] [113,114]. Initial questions asked about: (1) personal experiences with the Marshall Fire, including evacuation, re-entry, and recovery; (2) how the interviewee identified smoke damage and related risks upon return; (3) interviewee decision-making and information gathering related to remediation and engagement with insurance companies during this process; and (4) lessons learned and resource needs for those experiencing smoke damage during recovery from future wildfires. Interviews lasted between 33 min and 3 h 21 min, with an average length of 1 h 14 min. Many interviewees brought photos, videos, insurance documentation, test results, and letters to interviews unprompted, providing invaluable additional context to conversations.[2],[3] Several participants invited the author to attend three meetings: a community town hall event about Marshall Fire recovery and two meetings of the standing homes support group, which helped the author ensure that interview themes were broadly representative of resident experiences [115]. At the end of each day of fieldwork, the author compiled detailed notes related to interview and meeting content and emergent themes, using this process to adjust or deepen lines of inquiry as needed in subsequent interviews [116]. Interviews continued until theoretical saturation–the point at which no new information emerges regardless of questioning and themes have become consistent–was attained [117,118]. Interviews were audio recorded with consent and transcribed verbatim for analysis. Two interviewees declined to be recorded; in these cases, the author took comprehensive handwritten notes instead.

The author qualitatively coded interview transcriptions and notes in social science software QSR NVivo. Coding entails assigning segments of interview material to common topics that emerge across participants in order to understand patterns and advance interpretation of the data [119]. Here, an iterative, three-phase coding process was implemented. In the first round of coding, descriptive codes were assigned to help categorize data into like-kind topics that provided a comprehensive catalog of discussion content across interviews [120]. The second round of coding was structured, seeking to identify the presence of the four elements of Risk Society described earlier to confirm the theoretical relevance of this theory to the case study [121]. Finally, a third round of coding developed and applied theoretical codes, which involves describing higher level concepts or findings that emerged in the data and enrich understandings of the data by describing relationships, causes, or insights that underpin the study at hand [122]. Throughout the first and third round of coding, each segment of text was assessed to determine whether it aligned with an existing code or if a new code needed to be created in a process known as progressive falsification [123]. The coding process was guided by a combination of analytic induction and thematic analysis. Analytic induction involves developing causal explanations about events, observations, and processes using increasingly restrictive rounds of coding to characterize the foundation or substance of those experiences [124]. Thematic analysis occurs simultaneously, identifying alignment and divergence across interviewees' experiences to better characterize how widespread or nuanced a phenomenon is [125]. Together, these coding efforts help document and explain both the breadth and depth of interview findings. At the end of the coding processes, representative quotes were selected to demonstrate key findings in the results section below.

3. Results

3.1. Characterizing a spectrum of residential smoke damage

Interviewees consistently described the extent and consequences of smoke damage caused by the Marshall Fire as both "unprecedented" and challenging to identify in the aftermath, indicating that the lack of precedent for such extensive damage made these conditions unfamiliar. Wildfire and related smoke damage were previously believed to be beyond the realm of possibility among interviewees given the urban nature of Louisville and Superior, meaning that prior knowledge about community smoke risks and impacts were limited. Initial relief that resident interviewees' homes were still standing after the fire turned to concern as they began to interact with one another, realizing that soot, ash and char inside their homes were sourced from the structures adjacent to them and that the chemical composition of these materials and associated health risks were, at that time, unknown. One resident described:

> *I'm looking at the porous walls and what's going on around us and trying to listen and understand the best I can. Knowing, like I said, my neighbor [with a destroyed home], when we talked and I told her what was in the house … She said, "My house is in your house now." I said, "It is." That's the hot water heater and whatever was in the walls, the insulation, it's every plastic, it's her stove, it's her refrigerator. All those things were gone. They were incinerated.*

Realization that smoke damage originated from human-made materials motivated resident interest in determining scientifically supported thresholds at which they should be concerned, both about their health and about the level and kinds of remediation required. At the outset, it was unclear who was responsible for assessing smoke damage, with some calling it a "bureaucratic nightmare" as the State, FEMA, Boulder County, local governments, and insurance companies went back and forth trying to determine financial responsibility. Local officials described how they initially sought access to testing in residential areas to address these concerns, but a lack of clarity regarding suitable testing approaches and protocols given the diversity of smoke impacts from house to

[1] This study was approved by the Northern Arizona University Institutional Review Board #1806004.

[2] These documents were not photographed, collected, or analyzed because of the private nature of their content.

[3] Data from the interview data shared here demonstrate a range of risk perceptions, approaches, and strategies for smoke remediation for which the author is not qualified to determine their appropriateness; instead, the focus of this study is on experiences with these conditions rather than the scientific accuracy of perceptions or objective level of risk posed. Regardless of symptoms and scientific studies, these concerns are no less valid for the people who experience them and the trauma that uncertainty surrounding health consequences creates.

house made it difficult to translate findings into appropriate public advisories. Among these interviewees, there was a perception that testing was overly scientific without practical relevance and only captured isolated elements of the overall post-fire environment, preventing a comprehensive understanding. Without clear guidance from trusted officials, residents described difficulty determining whether the smoke damage they observed was substantial enough to raise concern upon re-entry:

> *A lot of us didn't understand what smoke damage looks like … I think people think your whole place needs to be covered in smoke and you would come in and be like, "Oh my gosh, it looks like a volcano erupted in here," versus [soot] just gathered on our windowsills. And I remember looking at that and wondering, "Is that a big deal? Was that not a big deal?" I had no idea.*

Uncertainty regarding the presence of smoke damage led to varied interpretations of risk and the necessity of remediation. The timeline under which the extent of the damage became apparent also varied significantly; some interviewees described identifying visible smoke damage immediately upon reentry, while others learned of the potential risks via word of mouth from other standing home families. Interviewees therefore described a wide spectrum of self-reported responses to smoke damage driven by different characteristics or indicators within their home, ranging from little concern or action to damage assessed as so severe that the only viable solution was to either demolish their home or tear it down to the studs and rebuild the interior. Quotes below provide examples:

> *My home was in the smoke plume and I didn't get it tested. I didn't do anything, right? And I think I probably am even personally in that spectrum of, well, I wasn't impacted, and I wouldn't know what to do with it, and I don't feel like battling my insurance company, and I'm fine. I'm not sick.*

> *My house was very deceptive. We got all the heat damage, but the smoke damage was very non-obvious. When I went there the day after the fire, my house looked like it was the day before … As it warmed up, it really got obvious. But our walls only had a thinnest layer of ash on. You could barely see it. You would have to rub your finger on it, see the discoloration. But our insulation was full of it and stuff like that because the houses next to us burned so sufficiently, thoroughly.*

> *[The industrial hygienist] said, "I can only say this over the phone because insurance is going to be really difficult, but technically if I were you, I would just take a wrecking ball to your home."*

Interviewees highlighted how pre-existing assumptions of what smoke damage entailed, including that there would be homogeneity in damage severity, were dispelled by their own experiences and discussions with other standing home residents. However, both professionals and residents also felt that the level of smoke damage exhibited in some households after the Marshall Fire was more extreme than what had been observed after other wildfires. One resident summarized:

> *I think it's a misnomer, "smoke damaged." Smoke damaged is when you live in Boulder, and the fire was in Louisville, and your house still smells a few weeks later, and you had to wipe your windows off and stuff. That's smoke damaged. What happened here, that's smoke destroyed. These are destroyed homes. Just because it's got a roof and some studs, doesn't mean it's livable. I think it's even more dangerous.*

This spectrum of indicators, impacts, and interpretations related to smoke damage created cascading uncertainty as the recovery process advanced. Standing home interviewees consistently described a shift from initial relief that their home had survived to enduring frustration over time that their impacts were not well understood relative to structure loss:

> *It's just so black and white [with destroyed homes]. The house is gone or burned to the ground and nobody can not see that. But when you see a standing home and you look on the outside, everything looks hunky dory and people are saying "aren't you lucky. You're so lucky, you have a standing home, you home didn't burn to the ground" and it's like, f*ck that. I mean, so many people [with standing homes] just wish that it had.*

3.2. Navigating remediation amidst uncertainty

Once resident interviewees reached a tipping point at which smoke damage was perceived of as enough of a concern to act, they typically took one of two pathways to remediation. The first approach entailed residents independently cleaning the home using unspecialized equipment and materials (often without personal protective equipment like N95 masks) because they either perceived their risk as low or did not have interest or capacity to interact with insurance companies. This usually resulted in the interviewee moving back home within several days to weeks of the fire once they personally deemed their own home clean enough. The second approach was formal remediation conducted by a contractor while the interviewee stayed in a hotel or rental longer-term, often initiated by third party chemical testing or an inspection by an industrial hygienist as a mechanism to open an insurance claim. One interviewee described how, regardless of which remediation pathway a standing home resident chose, the approaches implemented appeared inconsistent:

> *Everybody did drastically different things … everybody's just haphazard. I just got the feeling that everybody is doing their own thing and guessing what's the best approach. There shouldn't be guess work. It should be very clear cut on what were suitable protections, and the whole process would be not so painful.*

By this point, there was a growing understanding that smoke damage could be present and potentially harmful whether there was visible evidence or not, and that testing might provide more information. Some insurance companies would not cover the costs of initial testing for those who took the more formal route to remediation, requiring residents to pay out of pocket to acquire evidence to

initiate a claim. The cost was prohibitive for many, encouraging informal test results sharing; if one person in a neighborhood acquired testing, they would post the results on social media platforms and nearby neighbors could use it as a proxy to determine potential contamination in their own homes. However, interviewees who acquired testing had reservations regarding whether the testing they had received was appropriate for assessing smoke damage contamination, as one resident described:

> *The first test we had of our house was an air quality test. And then it came back with all this mold data and whatever, and I'm like, "This isn't helpful." … The air quality can also include VOCs, but they should be taking [surface] samples. Some things are in the air and then they settle, and some things will settle and then will come back up; this [surface] is slightly porous …*

Interviewees sought guidance interpreting whether test findings merited further action, and if so, what kinds of remediation strategies might be most effective for their specific circumstances. In the absence of formal information from trusted sources, interviewees independently gathered information to determine their personal risk thresholds to begin advocating for themselves, often influenced by the actions of other nearby standing home residents. Several competing factors affected personal determinations of whether to initiate remediation, including ability to translate available knowledge (e.g. academic journal articles, guidance available from other fires) to their own contexts, perceived health risk, personal bandwidth to interact with insurance companies, pre-existing health conditions, and level of action a renter could take as dictated by a landlord. Self-guided research often produced conflicting or confusing information that required additional searching to understand. Without clear standards to measure remediation success against, other interviewees began to question whether professional action was a worthwhile investment, with one interviewee saying "*It's like, well, what's the point in cleaning? I mean, the point is, is it ever clean?"*

Interviewees described a lack of official guidelines about the standard to which a smoke damaged home should be remediated toin order to be considered "safe" for residential use after remediation. This meant that access to, and completion of, contracted remediation work was largely at the discretion of insurance companies who had their own internal benchmarks about what might trigger approval of a claim, and often appeared unwilling to honor test results interviewees had acquired. This challenge also revealed that there was no mechanism through which a resident could hold an insurance company accountable for a certain level of testing or raise concerns about whether remediation efforts were truly adequate. One resident described a conversation with a remediation company contracted by their insurance agent:

> *I started to ask questions, "How do you know when it's clean?" And they said, "Oh, when you can't see it anymore." And I said, "Certainly there's something more scientific and data driven that can prove that." And they're like, "No, that's just, if you can't see it or smell it's safe" … That was my first kind of like, "Oh, this industry has no regulations" … I felt like I had gotten to the holy grail by having testing. And then I realized everything is then up to interpretation.*

That ambiguity about whether contractors were conducting effective and appropriate remediation mirrored broader conversations about difficulty identifying who could be trusted and had the "right" solution to resolve the consequences of smoke damage. Interviewees described being approached on their properties by unqualified contractors or companies demanding upfront payment to remediate in the immediate aftermath of the fire, which also caused confusion in the absence of official guidance from trusted government sources.

3.3. Smoke damage as an unmet recovery need

Over time, agreement emerged among interviewees that the insurance claim process for a smoke damaged home was far more complex and challenging to navigate than the process for a destroyed home because of cascading uncertainties. Insurance activities for standing home owners were further complicated by the difficulty of having to personally sort through contaminated belongings and throw them away, rather than just documenting items lost for adjustors. Lack of information from trusted officials and absence of clear guidelines for claim approval from insurance companies further exacerbated these challenges. An interviewee whose home was destroyed shared how standing home residents' experiences compared to his own:

> *The horrible thing about [smoke damage] is you're in more red tape than you are with a total loss. And your insurance company is twice the pain in your ass that it is when you have a total loss because they have a lot more wiggle room to make your life miserable. And this guy put it to me, he said the problem with the partial loss is that you don't have your house either, and you don't have any of your possessions. They might be there, but you can't get to them and you may never get to them … There is a cleanliness about a total loss, a definitiveness to it.*

As costs to remediate standing homes began to accumulate, interviewees realized that their financial pathway to recovery might necessitate more than just insurance payouts in order to cover cleaning, loss of belongings, and alternate living arrangements. Interviewees described finding out that smoke damage was not considered an eligible impact for federal recovery assistance through FEMA only after spending a significant amount of time preparing and submitting application materials.

Financial assistance via other avenues like non-governmental organizations was also scarce. Interviewees initially received gift cards from national non-profits in the immediate aftermath of the fire, before being removed from assistance lists at the Disaster Recovery Center once it was determined that their homes were still standing. This created confusion about where those with smoke damage could go for help while also distancing the standing home community from broader recovery efforts. Diversifying funds to remediate smoke damage and return home therefore became another responsibility for standing home residents to pursue. Mobilizing to seek new channels for assistance took more than a year for some, particularly those who had extensive insurance challenges. One resident described:

> *We felt kind of invisible in the midst of all the stuff with a lot of the people who've lost homes, started GoFundMe pages within a week, and some of them were raising upwards of fifty and a hundred thousand dollars to help. And we didn't even realize we were going to be financially screwed until what, December [2022]? January [2023]? Truly. So I'm halfway to starting a GoFundMe right now … that is one of the kind of feelings is almost like in versus out. [Standing home families were] Outsiders from the very beginning.*

Professional interviewees shared similar reflections, describing how difficulty accessing knowledge about smoke damage to inform response could have caused unintended exclusion of the standing home community. Realization that the standing home community's recovery needs were more diverse and complex than initially anticipated emerged among recovery organizations several months to a year after the fire, when debris removal for destroyed homes was complete and rebuilding had begun. One local-level professional reflected:

> *[Smoke damage] was probably our biggest unmet need. That's where I think [organization name], we did not rise to the challenge on understanding, connecting with, meeting those needs … Looking back, I was oblivious to them. I mean, it wasn't on my radar as far as how hard and what their challenges are … But those people, they were very gracious. They were not demanding. They were really just kind of silently navigating through on their own because their situations were so different and very unique.*

Amidst scientific uncertainty throughout smoke damage identification and remediation phases and a lack of access to recovery resources compared to those who experienced total losses, a core group of standing home residents began to build their own informal community for knowledge exchange. This included sharing information regarding science related to smoke damage they had identified independently, and tips and tricks for navigating insurance challenges. This culminated in both a Facebook group and weekly in-person meetings among other communication channels for networking to begin developing their own recovery process. One interview described:

> *It's not only a place for getting advice and to help others navigate through and to talk about what works and what doesn't work, but it's also a place where you can vent and you have somebody there understanding what you're going through. Because I noticed when we talk to friends that didn't have, they're a little bit further away, they didn't have this amount of smoke damage or toxic damage to their home, they don't quite understand it.*

3.4. The consequences of an undefined recovery process

Enduring uncertainty related to characterizing and remediating smoke damage left lingering questions about long-term risk exposure after interviewees moved back into their standing home. Some interviewees described vomiting, nosebleeds, fatigue, and headaches among other health concerns that emerged after short visits to their standing homes or other smoke damaged buildings such as schools in the weeks and months following the fire. These experiences laid the foundation for concerns about long-term health consequences that might result from inhabiting smoke damaged homes, with some likening the area to a Superfund site (locations federally managed to address hazardous waste contamination). Inherent in these conversations was a perceived absence of accountability among government officials to take appropriate action, both in terms of sharing information and assistance for remediation. Interviewees described shouldering that responsibility themselves, indicating that selling a standing home without due diligence via thorough remediation was unethical. One interviewee who had experienced health complications after each visit to their standing home said:

> *We'll be the whatever the cancer of the day is from the Marshall Fire. And I do unfortunately believe that. I do. See all the little kids running around the neighborhood? Some of my neighbors sold their homes. They made really big money. They wiped the walls down and sold at $1.3, $1.6 million because there was no place to live. There's little kids in those homes. Their yards are just as contaminated as mine.*

Interviewees eventually found the health uncertainties related to living in a standing home so overwhelming that it was easier to stop questioning potential risk. Standing home families typically reached this point when Additional Living Expenses (ALE), commonly provided in homeowners insurance policies to cover the costs of a hotel or rental property while the policy holder's home is being rebuilt or remediated, was no longer available. The financial cost of paying the mortgage for an uninhabited home in while self-funding a second residence was infeasible for interviewees, in part because the Boulder area housing shortage was further exacerbated by the Marshall Fire, causing substantial rent increases. One resident described their decision to move back in to their smoke damaged home:

> *[Insurance company] said they wouldn't let us leave again unless we had something like COPD (Chronic Obstructive Pulmonary Disease), some major respiratory thing that we could prove with the doctors, then we would be able to leave again. And so it's just one thing after another, and that's just the beginning of the story. But it's been like that, it's just been one trauma and another, and I think we just gave up, just like, "Okay, fine, we're living here [in our smoke damaged house]"*

Without a clear way to document or assess the validity of health-related consequences from smoke damage, interviewees who had moved back into standing homes commonly expressed feelings of frustration and hopelessness about their perceived inability to characterize and control potential risks. This manifested in several ways, including difficulty feeling safe during day-to-day activities:

> *Walking on the trails, being outside, things I used to enjoy; now I'm worried about pollutants, about another fire starting. My whole sense of safety is completely destroyed, and you're trapped here [as a standing home owner].*

Standing home interviewees' outlook on risk during future fires was generally fatalistic, stemming from a belief that based on their experiences, there was no way to proactively mitigate for smoke damage prior to a fire and no way to effectively remediate it after the damage had occurred. Interviewees therefore indicated a preference for a total loss instead of smoke damage given the emotional and financial impacts that they had experienced. One resident interviewee who had been working to remediate their home for more than a year and was yet to move back in shared:

> *If anybody ever asks me whether they should mitigate the fire damage around their house, my answer will be no, do not do it. Seriously. Do not do it. Do not mitigate it. Do not take down the brush. Do not make those clearings. Do not cut your grass. Do not do it. Plant some juniper. Hope your house burns down.*

4. Discussion

Research to understand, assess, and address diversifying recovery needs after wildfire has growing relevance as wildfires continue to initiate urban conflagrations, yet little is known about social experiences navigating unmet post-fire recovery needs in these spaces. This study presents a preliminary effort to qualitatively document resident recovery experiences with "standing homes" – structures that survived the Marshall Fire but received smoke damage that proved difficult to address over the following months. Findings provide progress towards science, practice, and policy surrounding post-fire recovery and smoke damage in several ways. First, findings illustrate how unmet needs in federal, state, local, and insurance processes create enduring barriers to household and community recovery, inviting broader interpretations of "loss" in recovery assistance and programming after wildfire. Next, this research helps better characterize smoke damage as a spectrum across which resident decisions to remediate vary depending on divergent risk perceptions and capacity to act, revealing the complexity of decision making in undefined recovery processes. Finally, this study reveals that resident experiences navigating unmet needs can prompt cascading uncertainty caused by scientific ambiguity, distrust in officials, and difficulty ascertaining health risks, causing enduring mental health and wellbeing consequences long after returning home. The discussion below explores insights for other unmet needs after wildfire, examining smoke damage specific recommendations and applying a Risk Society lens [21,76] to better contextualize responses and solutions.

Exploring smoke damage impacts as an example of an unmet need during wildfire recovery reveals that the absence of an impact-specific recovery process has cascading social consequences for those affected. Interviewees consistently called for the development of a framework or process for addressing smoke damage; commonalities in these requests and resident descriptions of their own approaches provide an emergent structure for responding to unmet needs more broadly. This process could include, but is not limited to: (1) developing an approach for assessing the extent of novel impacts that is ideally agreed upon before a fire by both government, private, and non-profit entities coordinating post-fire recovery; (2) rapidly incorporating unmet needs related to that impact into existing recovery assistance programs, or where necessary, establishing a new program if capacity allows during a fire; (3) designing science-based best practices or options for addressing the impact, which may entail strategic partnership or knowledge exchange from areas that have also experienced that impact; (4) developing scientifically-grounded standards or methods for determining when the impact has been resolved; and (5) establishing long term mechanisms to support and monitor recovery from that impact. Essential to the development of a process for identifying and addressing an unmet need is multi-directional communication; for instance, citizen science efforts that provide monitoring in smoke damaged homes and allow residents to share personal observations could both empower residents while identifying nuances in recovery processes and related decision-making [126,127]. Evidence also suggests that any process developed to begin addressing unmet needs after disaster must also incorporate flexibility and the ability to iteratively improve that process over time as new impacts, considerations, and solutions emerge [128,129]. Paired with the development of an unmet need recovery process is the importance of developing and providing training, education, materials and resources, and capacity building efforts to pro-actively prepare for the incorporation of unmet needs into emergency management and recovery planning [62]. These conditions are essential to limit decision fatigue and avoid overburdening and isolating affected individuals.

Residents with smoke damaged homes found themselves ineligible for traditional disaster assistance avenues and excluded from accessing other recovery programs and resources because these initiatives were historically tailored towards those with structures that were completely destroyed during a wildfire. However, interviewees felt the level of smoke damage to their homes produced equal, if not more severe, loss in the months that followed the fire. In the absence of government or non-profit assistance, a specialized, self-led support group for standing home families emerged after the Marshall Fire. The establishment of informal groups for other unmet needs, especially when the spectrum of reported impacts is wide, has been shown to have a positive effect on personal recovery [1,2]; however, the high level of education that aided interpretation of information and capacity to self-advocate that was critical in Boulder County may not always be present in other fire-affected populations. This study therefore calls for broader interpretations of what is considered "loss" after wildfires when determining social and infrastructural impacts. Incorporating outcomes like smoke damage as a wildfire impact necessitates moving away from use of binary metrics (e.g., whether a house was destroyed or not) to determine whether an individual qualifies for assistance to acknowledge the vaiable ways that secondary impacts manifest [5,38,130,131]. This might entail adopting a more comprehensive constellation of indicators that better capture the need for assistance after fire. For example, test results related to smoke damage, duration of displacement from home, and individual capacity to navigate smoke damage may all be helpful considerations for determining the need for a disaster case manager, ensuring access to mental health resources, or providing financial support for displacement during remediation.

Several common misconceptions related to smoke damage from wildfire were identified and dispelled by interviewees. Assumptions that smoke damage would be obvious upon return led to initial beliefs that there was no impact; however, interviewees emphasized that smoke damage manifested in wide-ranging ways based on structure characteristics, distance from the fire, and smoke

plume behavior among other factors. This suggests that some wildfire impacts are best represented as a continuum rather than categories, meriting systematic data collection to document qualitative elements associated with environmental change in post-fire environments [5]. Interviewees also shared a sentiment that total structure loss from a wildfire was more manageable emotionally and recovery was more streamlined compared to smoke damage because of the clear recovery pathways that had already become standardized for total losses. This challenges implicit assumptions that recovery progress centers on the process of rebuilding destroyed structures [132]. Together, these misconceptions demonstrate how existing recovery processes and frameworks may unintentionally prevent detection and inclusion of unmet needs. These findings indicate that unmet needs after wildfire often become overlooked at the outset of the recovery process because of several conditions: first, an assumption that an impact isn't present or isn't severe enough to warrant coordinated efforts; second, unspoken agreement that some impacts should be prioritized or are more urgent than others; and third, a lack of professional capacity or expertise to engage comprehensively with more complex and undefined recovery needs. Proactively anticipating and planning for unmet needs therefore requires criticaly examining pre-existing contexts that may be influential; for instance, the conditions for smoke damage from the Marshall Fire were established in part through development patterns and building codes that allowed construction of homes in close proximity to one another [23,107].

Scientific uncertainty about risk exposure and remediation, difficulty with insurance claims, and denial of recovery assistance underscored how smoke damage was not well understood as an impact or represented in post-fire recovery processes. These experiences can inform policy and regulation development, specifically regarding the need to establish national standards for both identifying hazardous conditions in standing homes and provide thresholds for their effective remediation. Calls for standardization emerged from a need for accountability from insurance companies and their contractors, indicating that post-remediation testing should also be conducted by third party professionals such as industrial hygienists or government health officials to increase trust and ensure that proposed standards were met. Such efforts could also improve response consistency across insurance companies given the broad spectrum of testing support and remediation techniques interviewees experienced after the Marshall Fire [133]. Existing research also shows somewhat conflicting or uncertain assessments of the impacts of smoke damage to health, often pointing to a lack of science that focuses on impacts of VOCs for humans in post-fire contexts, indicating a sustained need to pair health studies with post-hazard residential contamination [56,57]. Enduring uncertainty among interviewees about ongoing health risks before and after remediation highlights the value of testing from trusted sources to retain a baseline level of ontological security upon moving back home, advancing emotional recovery and wellbeing [134].

Risk Society provides a theoretical framework for understanding how uncertainty and the absence of a process affects recovery for those with unmet needs after disaster [21]. Interviewees discussed experiences that reflect core elements of the Risk Society and illustrate how urban wildfires and related smoke damage may more closely reflect the conditions surrounding technological or hybrid hazards rather than natural hazards [77]. The urban nature of the Marshall Fire led to combustion of structures and their contents, including lithium batteries and asbestos, exemplifying how technological advancement and industrialization place more people at risk over time [68]. Uncertainty and unfamiliarity surrounding smoke damage risks experienced by both residents and professionals produced a loss of faith in experts to meaningfully guide standing home recovery, leading to dissensus about how smoke damage remediation and recovery should unfold [81,82]. Conflicting information paired with the absence of a clear process for navigating smoke damage placed the onus for decision making on standing home residents in a way that those with destroyed homes did not have to experience. These cascading conditions caused the erosion of ontological security that spanned both time and space; interviewees navigating professional remediation still felt that their risk was high after returning home, and several had yet to return because they felt there was not yet enough evidence that their homes were safe or that available remediation efforts were adequate to mitigate the threat [86]. This case study also raises questions about the longer-term consequences of loss of faith in local officials, as heightened awareness of potential risks may exacerbate potential conflict or further isolate of those with unmet needs over time. Developing practical and scientific expertise related to unmet needs and providing transparency about the need to collaborate to build a process where one does not yet exist remain key actions for improving disaster response. Unmet needs after wildfire may increasingly stem from technological advancement, meaning that identification of parallels with smoke damage may provide a template for problem solving related to emergent resident needs after future fires.

5. Conclusion

Unmet needs after wildfire continue to evolve as impacts diversify during community recovery. This study investigated smoke damage after the 2021 Marshall Fire as an unmet need, uncovering both key considerations for developing a process to identify and address unmet needs after wildfire while also illuminating the cascading social consequences of uncertainty such as loss of faith in experts and erosion of ontological security. Unmet needs after wildfire appear to emerge from misconceptions about impact severity, limited professional capacity, and adherence to rigid recovery structures that restrict professionals' ability to identify and incorporate non-traditional impacts into existing processes. Findings indicate that broadening academic and practitioner understandings of what impacted individuals consider "loss" after wildfire can provide more intentional pathways to community recovery. There is also a need to begin developing and incorporating expertise related to unmet needs into recovery processes to build trust, particularly when the consequences are likely enduring and can cause long term uncertainty about personal health or safety, extending the "social lifespan" of a hazard event. Continued research that targets documentation and mechanisms for inclusion of unmet needs after wildfire is imperative to ensure that linkages between impacts are comprehensively addressed for inclusive and effective community recovery.

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Data availability

The data that has been used is confidential.

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