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Understanding household experiences with flooding in post-fire environments: risk perceptions, perceived drivers, and mitigation actions

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ABSTRACT

Flood events in post-fire environments produce cascading social and ecological consequences that are challenging to anticipate, mitigate, and manage. Engaging private property owners in mitigation is complex, and the drivers that motivate action or inaction are not yet well defined. We analyse household survey data collected after multiple rainfall events that triggered flooding on and adjacent to the 2019 Museum Fire burn scar in Flagstaff, AZ, USA, to explore relationships between risk perceptions, drivers of flood risk, and mitigation actions in post-fire environments. We received 623 usable questionnaires (16% response rate) that were analysed using chi square, ANOVA, regressions, and factor analyses. Relationships between risk perceptions and mitigation strengthen after a post-fire flood event but perceived drivers of flood risk have limited influence. We also replicate and expand existing measures of individual and collective action to address flooding in post-fire environments, finding that the inclusion of locally specific actions improves their reliability. These efforts reveal growing public understanding regarding the complexities of flood risk in post-fire environments and reflect the need for communication about cascading hazards to embrace messaging that emphasises layered drivers of risk and their longevity.

Policy highlights

- Relationships between risk perceptions and mitigation strengthen after flood events in post-fire environments.
- Perceived drivers of flooding motivate the uptake of select household mitigation actions.
- Communication of flood risk and mitigation recommendations at the household level can focus resources where they are most needed.
- Clearer connection between mitigative actions and their benefits for sheltering in place during floods can prevent overreliance on insurance as a substitute for risk reduction.

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1. Introduction

Communities in and adjacent to steep slopes across the western US face flood risk in a matter of hours to days following uncharacteristic wildfires, forcing residents and municipalities to rapidly adapt (Neary and Leonard 2019; Rijal et al. 2024). Wildfires modify soil characteristics to increase hydrophobicity, remove vegetation, and erode slope stability, introducing ideal conditions for rapid flood events including debris flows and mudslides once precipitation begins (DeBano, Neary, and Ffolliott 2005; Koestner, Koestner, and Neary 2011; Rengers et al. 2020). The timing, location, and severity of post-fire flood events are often difficult to predict, particularly in areas with volatile weather patterns and complex topography, creating time-sensitive conditions for social and ecological adaptation immediately after wildfire (Cafferata, Coe, and Short 2021; Lopez et al. 2024). At-risk communities may already have underlying flood risk exacerbated by climate change, ranging from development in flood plains to vulnerability from intense rainfall events, monsoons, rain-on-snow events, and snowmelt (IPCC 2023; Schiefer and Schenk 2024). Additional catalysts can include recent forest management efforts, interactions with older burn scars, and water-related infrastructural issues (Jong-Levinger, Houston, and Sanders 2024; Sankey et al. 2024; Sutanto et al. 2024). Detangling post-fire flood risk from concurrent pre-existing sources of flood risk in these spaces is difficult, and it is unclear how well residents can differentiate between different drivers of risk to their home and determine appropriate action. The cascading and recurring nature of post-fire flood events means that unified action across jurisdictions can support more comprehensive and sustained risk mitigation efforts; however, this can be challenging to coordinate in an effective and timely manner given the limited formal guidance currently available (AghaKouchak et al. 2018; Driscoll and Friggens 2019; Serra-Llobet et al. 2023; Youberg et al. 2019).

Managing flood risk caused by wildfires requires strategic, coordinated mitigation activities across diverse jurisdictions and organisational capacities (Burns, Taylor, and Hogan 2008; Kinoshita et al. 2016; McGuire et al. 2021; UNDRR 2024). While post-fire flood mitigation is well-defined on public lands, private property owners can also take action; however, there is ambiguity about how best to prepare properties as risks often diverge from traditional flood events (Houston et al. 2024; Jakob et al. 2005; Rengers et al. 2020). As a result, residents often rely on communication from officials, which can entail dissemination of modelled risk maps based on likely flood scenarios, face-to-face communication via property visits, or public meetings, among other modes, to determine whether and how to mitigate (Edgeley and Colavito 2022). Abbreviated timeframes between wildfire ignition and the first rainfall over a burned area drives variable risk reduction between households based on their capacity to respond financially, physically, and mentally under short notice (Edgeley et al. 2024a). Risk perceptions also have a significant influence on if, how, and when residents engage in both individual and collective mitigation actions – that is, actions both on their own property and in coordination with others across jurisdictions (Burnett and Edgeley 2023; Edgeley et al. 2024a). Determination of how residents characterise risk based on perceived drivers that cause or exacerbate flood conditions is unexplored and constitutes an important next step in developing more honed post-fire planning and response. Household-level research can highlight gaps in preparation, allowing greater precision in outreach programmes and communications.

This study analyses 623 survey responses following a series of flood events in the neighbourhoods below the 2019 Museum Fire burn scar in Flagstaff, Arizona, USA to investigate relationships between risk perceptions, perceived drivers of flooding, and mitigation activities. Rainfall events in 2022 led to repeated flooding that stemmed from both the 2019 burn scar and extreme monsoonal activity on adjacent lands, complicating preparation and risk communication. This context is ideal for understanding how members of the public detangle drivers of post-fire flooding from drivers of regular pluvial flooding. Findings can inform tangible planning and communication recommendations for professionals working with the public, often on unpredictable timescales, to improve public safety in post-fire landscapes. We also provide novel insights on how households at the intersection of numerous different drivers of flood risk are motivated by different perceived causes of flood risk to better guide messaging. Exploration of how households anticipate, experience, and recover from post-fire flooding fills a critical and often overlooked niche in hazards planning; this study represents a next step towards establishing a body of post-fire flooding social science research.

2. Literature review

2.1. Risk perceptions and flooding in post-fire environments

Cognitive processing of flood risk occurs in two phases: (1) establishment of risk perceptions (also known as threat appraisal) through evaluation of event probability and potential consequences, followed by (2) coping appraisal, during which the individual evaluates the benefits and feasibility of possible mitigative actions (Bubeck, Botzen, and Aerts 2012; Rogers 1983). Risk perceptions related to post-fire hazards are affected by interpretation of both subjective and objective information and can shift over time. Varied experiences with different facets of a wildfire event and its cascading consequences are particularly influential, producing spectrums of resident concern that affect support for forest management related to wildfire risk (Edgeley and Colavito 2022; Shao et al. 2017). Other factors affecting divergent flood risk perceptions include gender, age, level of education, income, and ethnicity, though the influence of these factors varies significantly across local contexts (Atreya, Ferreira, and Michel-Kerjan 2015; Cannon et al. 2020; Eryılmaz Türkkan and Hırca 2021; Landry and Jahan-Parvar 2011). Repeated emergency warnings of post-fire flooding or debris flows without large adverse impacts can lead to complacency and higher risk tolerance (Goto et al. 2021; Santi et al. 2011), further substantiating the role of hazard experience in post-fire risk perceptions. Efforts to catalog both factors that drive risk perceptions and the impacts that risk perceptions have on mitigation activities related to post-fire flooding are scarce but can offer important insights into accelerating mitigation on public and private lands (Burnett and Edgeley 2023; Edgeley 2023; Edgeley and Colavito 2022; Kinoshita et al. 2016).

Several research efforts document the role of risk perceptions as a driver of resident behaviour in post-fire environments. A survey of Flagstaff, AZ households conducted shortly after the 2019 Museum Fire found that approximately 25% of respondents thought a post-fire flood would damage their home in the next 10 years; many of these respondents lived outside of modelled flood risk areas and had little to no risk, indicating that perceptions were misaligned and were instead influenced by different experiences with the fire event itself (Edgeley and Colavito 2020). Post-fire flood risk perceptions

have also been found to influence evacuation behaviours, although trust in officials was eroded when post-fire debris flow damage occurred in areas not modelled as having risk (Goto et al. 2021). Both studies indicate challenges associated with risk communication based on modelling to motivate action, a concern that has begun to emerge across wildfire and hydrology research more broadly (Edgeley et al. 2024b; Houston et al. 2024). Parallels between the existing flood and fire literature and recent research on post-fire flooding are emerging, introducing opportunities to test these more established bodies of literature in post-fire environments. High risk perceptions were identified as a significant motivator of both household and community post-fire flood mitigation action following the 2010 Schultz Fire (Burnett and Edgeley 2023), a finding that aligns with broader wildfire and flood literatures (e.g. Bubeck, Botzen, and Aerts 2012; Henstra et al. 2019; Olsen et al. 2017; Paveglio and Shriner-Beaton 2024). Risk perceptions also motivate uptake and retention of insurance in areas recently affected by wildfire, with many households opting not to renew their policy around the two-year mark following a fire due to lower perceived cost–benefit relative to the price of coverage (Edgeley et al. 2024a). Relationships between risk perceptions and place attachment have yielded more varied results, and in some instances suggest that high attachment influences lower risk perceptions as a form of protective denial (Houston et al. 2024).

2.2. Flood mitigation in post-fire environments

Diverse and enduring social and ecological consequences tied to post-fire flooding have been documented more than a decade after wildfire events, including financial loss, mental health consequences, recreation change, and ecological degradation, underscoring the importance and return on investment of mitigative measures (Belongia et al. 2023; Hjerpe et al. 2023; Jones et al. 2022; Mueller et al., 2018; Ortega-Becerril et al. 2022; Warziniack and Thompson 2013). Mitigation actions must occur on both public lands (e.g. Burned Area Emergency Response activities, rain gauge installation to inform early warning systems, sediment retention basin construction, drainage construction and maintenance, channel stabilisation) and private lands (e.g. sandbag or other barrier placement, purchasing insurance, clearing local drainages, raising utility connections and structures, installing flood openings in foundations or enclosure walls) to maximise cross-boundary risk reduction within a watershed (Qiu et al. 2024). Beyond coordination, cost to mitigate is another challenge; one study found that the average household spent $7,227 on mitigation over a 10-year period, with a further $3,620 in costs to upkeep those mitigations (Hjerpe et al. 2023). However, 'cross-over effects' related to the interconnectivity between wildfire, floods, and mudslides indicate that funds, time, and effort invested in post-fire flood mitigation can help bolster preparation for other risks simultaneously (Houston et al. 2024). Understanding what factors influence household engagement at different scales in post-fire environments can therefore support multi-hazard mitigation efforts that extend beyond flooding and wildfire.

Hazard mitigation actions can be conducted across a spectrum of scales, from individually on a single property to collectively across property lines and jurisdictions, often characterised by both formal and informal public engagement. Burnett and Edgeley (2023) developed survey measures for both individual and collective action, determining that engagement at one scale motivated engagement in the other,

establishing a baseline for subsequent post-fire studies. Direct experience with post-fire flooding and perceived duration of related risk were both significant motivators of resident engagement. Mitigation activities led by government entities like reseeding or infrastructure-based mitigation are often supported by the public, although there is a risk that these treatments like might be perceived as 'solving' post-fire threats and causing inaction on private lands, regardless of their documented effectiveness (Santi et al. 2011; Serra-Llobet et al. 2023; Wagenbrenner et al. 2006). The perceived efficacy of mitigations conducted prior to a flood event often influence engagement in future mitigation activities, indicating the importance of communicating the value of mitigation activities consistently over time in post-fire environments (Bubeck et al. 2012). Demographic variations appear to expose and exacerbate inequities in capacity to mitigate risk within and between downslope communities after fire (Edgeley et al. 2024; Santi et al. 2011). However, research to determine the influence of these factors on uptake of post-fire flood mitigation activities finds that their influence is varied, often indicating that broader experiential considerations such as risk perceptions, trust in government entities managing flood risk, and personal flood experience are more important (Burnett and Edgeley 2023; Edgeley et al. 2024). It is also important to note that mitigation is not necessarily synonymous with adaptation, as actions may not prompt sustained behavioural change or have the temporal longevity and flexibility needed to overcome more chronic hazards connected to wildfire and flooding (e.g. drought, climate change) (Essen et al. 2023; VijayaVenkataRaman et al. 2012).

The relationship between risk perceptions and mitigation is well documented for many hazards, but it is unclear whether patterns in resident behaviours hold true for actions in post-fire environments. Understanding the extent to which these are connected, and whether perceptions of flooding causes influence that relationship, can advance the social science literature surrounding post-fire flooding as the threat to communities rises. We explore two research questions in response to the growing need to better document post-fire conditions across the western US:

1. What factors influence post-fire flood risk perceptions?
2. How do households prepare for anticipated post-fire flood risk?

3. Methods

3.1. Study area

Flagstaff, Arizona, is a city of approximately 75,000 full-time residents located near the San Francisco Peaks and surrounded by the Coconino National Forest. Community members consistently support diverse management efforts for forest restoration, fire management, and flood mitigation (Colavito et al. 2023; Edgeley and Colavito 2020, 2022), and these attitudes appear stable regardless of fire cause due to an extensive history of collaborative, cohesive messaging between professionals and the public (Edgeley and Colavito 2022; Mottek Lucas 2015).

Several significant wildfires have impacted the Flagstaff area in recent years, including the 2010 Schultz Fire, 2019 Museum Fire, and 2022 Tunnel and Pipeline Fires. The Schultz Fire was the first to produce significant post-fire flooding, demonstrating an assortment

of diverse impacts to downslope communities (Hjerpe et al. 2023). The Museum Fire was caused by a spark from forest thinning equipment (despite adherence to safety protocols) associated with ongoing fuel treatments intended to protect watershed health on steep slopes adjacent to Flagstaff, burning 1,961 acres. The fire occurred in late July, which is typically during the summer monsoon rain season. However, there was uncharacteristically low monsoon activity in 2019, and it was not until the summer of 2021 that monsoon activity returned to the area, producing flooding over both the Museum Fire burn scar and adjacent unburned slopes (National Weather Service 2019; Schiefer and Schenk 2024). Flooding converged on downslope neighbourhoods, resulting in significant social and infrastructural impacts. It became difficult to distinguish between post-fire flooding and flooding from extreme rain unrelated to the burn scar due to the proximity of burned and unburned slopes. These conditions were well suited for investigating the influence of perceived flood drivers on risk perceptions and mitigation activities.

3.2. Approach

We developed and administered a mixed-mode survey of Flagstaff households approximately one year after the flood events of 2021.[1] We developed an exploratory survey instrument[2] in consultation with key informants from city and county government and the U.S. Department of Agriculture Forest Service, producing questions spanning five topics: (1) experiences with recent flooding events; (2) flood risk perceptions and perceived drivers of local flooding; (3) flood risk mitigation; (4) flood, wildfire, and forest management; and (5) demographic information. Questions used five-point Likert scales, multiple choice, and binary formats. Flood risk perception questions asked about perceived flood risk to the respondent's property, anticipated duration of flood risk in their area, perceived severity of the 2021 flood events, and the degree to which different factors or drivers influenced those flood events. To better understand mitigation actions, we replicated an existing pair of scales designed to assess individual and collective actions that support collaborative risk reduction to address post-fire flooding from Burnett and Edgeley (2023) and expanded them with additional actions that reflected local resources and opportunities after the Museum Fire. Because 2021 flood events were driven by numerous often overlapping factors, generic language about 'flooding' was used throughout the instrument (instead of 'post-fire flooding,' 'monsoon-driven flooding,' or other specific cause-based language) to avoid biasing respondents.

This study follows a previous survey conducted immediately after the Museum Fire in 2019 that sought to understand resident experiences with the fire and anticipated flooding. The sample included sampling of residents in the 2019 modelled flood area representing a potential 3-inch in 45-minute rainstorm (Edgeley and Colavito 2022). The sample frame for the 2022 study included all post-fire flood addresses from the 2019 study but was also expanded to include all residential addresses in areas that had experienced recent flooding from both the burn scar and other sources, primarily those from Route 66 north to the Museum Fire burn scar (Figure 1). This expansion was determined using preliminary flood risk maps modelled by local contractor JE Fuller Hydrology and Geomorphology, Inc., review of news articles and photographs from the 2021 flood events, and discussions with our key informants about which areas were affected. This effort resulted in a sample frame of 3,825 residential addresses, representing a census

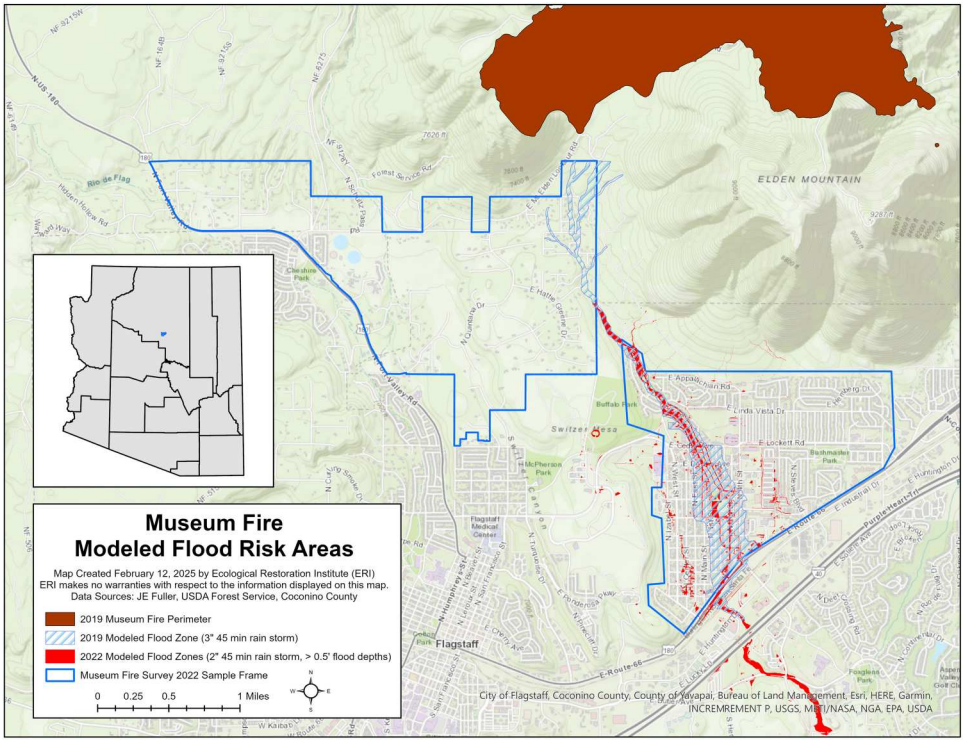

Figure 1. Map depicting survey sample frame relative to the Museum Fire burn scar and modelled post-fire flood risk scenarios.

sample of all properties within the resulting area shown in Figure 1. Following survey data collection, JE Fuller released new post-fire flood risk maps projecting refined impacts from assorted hypothetical rainfall events over the Museum Fire burn scar. We used these data to identify which respondents in our survey area lived in the new modelled flood risk areas and determined that the storm scenario representing 2-inches of rain in 45 min was most appropriate. Results from that modelling were then simplified to show inundation limits with depths greater than 0.5 feet of flooding to determine that a given property was at risk of flooding. Using these data, we were able to classify respondents into those without post-fire flood risk, and those with post-fire flood risk at the time that the survey was administered.

Survey administration was initiated via mail during the summer of 2022. Following Dillman et al.'s (2014) tailored design method, we sent materials to sample frame addresses in three phases, each sent two weeks apart: (1) a survey packet containing an introductory letter describing the study, a survey booklet, and a pre-paid return envelope, (2) a reminder postcard, and (3) a final reminder postcard. Each mail item also included a link to an identical Qualtrics survey to maximise response rates for those who preferred to participate online. A total of 623 completed questionnaires were returned between June and October 2022 for a 16% response rate. Reporting in the sections below occasionally reflects a lower n in cases where respondents did not answer all questions. There were no statistically significant differences between early and late survey

respondents (determined by running chi square and t-tests on select questions for the first 25% and last 25% of surveys received); however, respondent demographics were not always representative when compared with Flagstaff Census data (Census Bureau 2021), which may be a limitation of mixed-mode survey administration (Beebe et al. 2012).

3.3. Analysis

Survey data were analysed using SPSS, a social science data analysis package. We first ran descriptive statistics, summarising response frequencies to better understand the content of our dataset. A second round of analysis focused on more exploratory statistical tests entailing chi square tests with post-hoc z-tests and a Bonferroni correction to identify significant groupings, Fisher's exact tests, and Analysis of Variance (ANOVA) to potential explore relationships between variables. Outputs from efforts to reproduce and extend existing composite measures for individual and collective mitigation actions described above were entered into a linear regression. A linear regression was deemed suitable for these variables because the individual and collective composite variables were continuous, created by tallying number of actions taken. The regressions used composite mitigation measures as the dependent variables and data on experiences with post-fire flooding and risk perceptions as independent variables. A Hosmer-Lemeshow test was used to confirm goodness of fit for each regression. Additionally, we conducted a factor analysis with a Varimax rotation and a Kaiser normalisation to group respondents based on Likert scale responses regarding perceptions of various human and environmental drivers on post-fire flooding. We retained principal components with an Eigenvalue of one or above. We then applied a K-means cluster analysis to remaining principal components to sort survey respondents into like-kind groups.

4. Results

Approximately 47.8% of respondents identified as male, 51.9% as female, and 0.3% as another gender identity. Respondents were Caucasian (82.5%), Hispanic or Latino (12.6%), American Indian or Alaskan Native (3.9%), Asian (1.9%), Black or African American (0.9%), Native Hawaiian or Pacific Islander (1.1%), or other race/ethnicity (2.5%). The average respondent had lived in the Flagstaff area for 29 years. Approximately 89.5% of respondents owned their property, and 92.7% of respondents resided at their property full time.

4.1. 2021 flooding experiences and risk perceptions

Approximately 9% of respondents were concerned about flood risk when they moved into their Flagstaff property; 12.9% reported that flood risk was disclosed to them at that time. About 16.2% of respondents reported experiencing some level of flooding on their property prior to 2021. At the time of this survey in 2022, 6.1% characterised flood risk to their property as extreme, 15.7% as high, 27.5% as moderate, 40.2% as low, and 10.4% reported no risk (Table 1). This contrasts modelled flood risk, which indicated that 58.2% of respondents lived at properties in flood risk areas caused by the Museum Fire. Three quarters (75.6%) of respondents reported some level of flooding in

Table 1. Descriptive statistics for flood risk perception variables.

Variable	Response options	%	*N*
Was respondent in 2019 and/or 2022 modelled flood risk areas?	Yes	58.2%	623
	No	41.8%	
Was your property flooded between June 2019 and when you received this survey?	Yes	28.8%	569
	No	71.2%	
To what extent did flooding during the summer of 2021 align with your expectations for the Flagstaff area?	Flooding was far more severe than I expected	60.8%	567
	Flooding was somewhat more severe than I expected	25.6%	
	Flooding was about what I expected	10.6%	
	Flooding was somewhat less severe than I expected	1.8%	
	Flooding was far less severe than I expected	1.2%	
How would you characterise current flood risk to your property?	Extreme	6.1%	603
	High	15.8%	
	Moderate	27.5%	
	Low	40.1%	
	There is no flood risk to my property	10.4%	
How long do you anticipate that flood risk will last in your area?	Flood risk is no longer present	6.3%	584
	1–5 years	26.0%	
	6–10 years	21.4%	
	11–25 years	11.6%	
	25–50 years	3.9%	
	51–100 years	1.7%	
	More than 100 years	3.4%	
	Flood risk in this area is permanent	25.5%	

their area in 2021. Respondents were asked to share the closest that flooding got to where they live; 25.8% reported flooding in their neighbourhood, 21.3% on their street, 21.3% on their property, and 7.2% inside their home. Approximately 30.2% of respondents reported property damage caused by 2021 flood events. Non-structural damage (e.g. driveways, landscaping, fencing) was most common among this group (83.7%), while 21.9% indicated flooding caused damage to the interior of their home. Almost half (47.5%) of respondents stated that they sheltered in place at their home during a flood event, compared to 1.3% who evacuated.

Table 1 reviews key variables related to flood risk perceptions. Most respondents described 2021 flooding as 'far more severe' (60.9%) or 'somewhat more severe' (25.7%) than expected. Respondents who experienced flooding on their property in 2021 were significantly more like to report flooding as 'far more severe' than expected ($p = .003$). When asked how long they anticipated flood risk lasting in their area, 25.5% reported that they believed flood risk was permanent. Few responded that flood risk was no longer present (6.3%), while most respondents thought it would last 1–5 years (26.0%) or 6–10 years (21.4%). Those in modelled flood risk areas were more likely to report longer durations of flood risk ($p = .007$). Most respondents characterised current flood risk to their property as low (40.1%) or moderate (27.5%). Those who had experienced flooding on their property since the Museum Fire characterised their risk as higher ($p = <.001$). Respondents outside the modelled flood risk area still believed their property was at risk: of the 42.1% of respondents who were not in modelled flood risk areas, 86.2% still reported flood risk to their property (extreme: 2.0%, high: 12.6%,

moderate: 26.8%, low: 44.9%). The longer the perceived duration and the more 2021 flooding exceeded respondent expectations, the higher the perceived current flood risk to property ($p = <.001$). No significant difference emerged between those within and outside the modelled flood area regarding the extent to which 2021 flooding exceeded expectations, but there was regarding duration ($p = .007$) – those who were not in modelled flood risk areas were more likely to report that flood risk is no longer present, while those in the flood risk area typically reported that flood risk would last up to 10 more years.

Approximately 22.3% of respondents purchased flood insurance, typically shortly after the Museum Fire in 2019. A majority (63.8%) had retained coverage continuously until the time of the survey in 2022. Respondents were more likely to intend to renew their insurance if they were in the 2019 modelled flood risk areas and if they perceived a higher likelihood of flooding on their property in the next 10 years ($p = .027$).

4.2. Perceived drivers of 2021 flooding

Respondents were asked how influential they thought various potential drivers of flood events were in 2021 (Table 2). The Museum Fire burn scar was considered most influential (70.1%), followed by monsoonal rain (54.1%). However, when chi square and ANOVA test outputs for each variable were compared, variation emerged among respondents. Those who reported climate change was extremely influential were more likely to be renters ($p = .001$), identify as female ($p = <.001$), have a higher level of education ($p = .012$), and anticipate flood risk lasting longer ($p = <.001$). Respondents who reported that burn scars from other older fires were more influential were also more likely to feel that flooding was far more severe than expected ($p = .004$), perceive that flood risk would last longer ($p = .028$), and identify as female ($p = .004$) and Native American or Alaskan Native ($p = .008$). Full time residents ($p = .007$) and female respondents ($p = .017$) were more likely to believe that the Museum Fire burn scar was extremely influential. Respondents who had completed higher levels of education were less likely to perceive recent forest management events as influential ($p = .011$), but more likely to suggest that blockages or overflow of existing storm water infrastructure was influential ($p = .008$).

Table 2. Responses to the question 'Please indicate how influential or uninfluential you think the following factors were on flooding in Flagstaff during the summer of 2021.' Data is shown as percentage of all respondents.

	Not influential at all	Slightly influential	Moderately influential	Very influential	Extremely influential	*N*
Monsoonal rainfall events	0.7%	4.9%	11.5%	28.8%	54.1%	590
The Museum Fire burn scar	2.0%	1.2%	4.5%	22.1%	70.1%	596
Burn scars from other fires (e.g. 2010 Schultz Fire, 1977 Radio Fire)	21.1%	19.6%	21.4%	20.1%	18.9%	562
Recent forest management efforts	17.0%	23.5%	26.9%	15.9%	16.8%	554
Blockages or overflow of existing storm water infrastructure	3.6%	9.9%	19.4%	29.5%	37.6%	583
Climate change	11.0%	12.2%	15.6%	25.0%	36.3%	584

Full time residents were most likely to believe monsoon rainfall events were extremely influential ($p = .014$).

ANOVA testing further explored flood risk perceptions and their relationships with perceived drivers of flooding. Respondents who reported higher flood risk to their property were more likely to indicate that recent forest management ($p = <.001$), blockages or overflow of existing storm water infrastructure ($p = .006$), monsoonal rainfall events ($p = .011$), and climate change ($p = .017$) were the most significant drivers of flood risk. A similar relationship emerged regarding whether 2021 flooding exceeded respondents' expectations: those who reported that it did were more likely to associate flooding with blockages or overflow of existing storm water infrastructure ($p = <.001$), the Museum Fire burn scar ($p = <.001$), monsoonal rainfall events ($p = .004$), and recent forest management ($p = .022$). Perceptions of longer flood duration shared significant relationships with climate change ($p = <.001$), burn scars from other fires ($p = .002$), and the Museum Fire ($p = .005$) as influential on flooding.

We conducted a factor analysis that revealed three variable groupings of perceived flooding influences: (1) human activity drivers, including recent forest management and blockages or overflow of existing stormwater infrastructure (2) acute environmental drivers, including monsoonal rainfall events and the museum fire burn scar, and (3) chronic environmental drivers, including burn scars from older fires and climate change. Using a k-means cluster analysis, we assigned each respondent to one of these factors based on their responses (Table 3). Respondents who believed human activity drivers were the primary cause of flooding were more likely to find their friends and family ($p = .004$) and social groups ($p = .008$) to be trustworthy information sources. They also were most likely to report negative impacts to their wellbeing related to 2021 flooding experiences, including having trouble relaxing ($p = .044$), experiencing significant stress ($p = .036$), and that their mental health suffered because of flood risk ($p = .015$). Respondents who believed acute environmental drivers were the primary cause of flooding were more likely to identify as male ($p = .033$), to have sheltered in place in their home during the 2021 flooding ($p = .032$) and use multiple sources to understand impending flood risk including rain gauges ($p = .002$) and county emergency alerts (p

Table 3. Mean Likert response by factor group for the question, 'how influential or uninfluential were the following factors in the 2021 flood events?' where 1 = no influence and 5 = extremely influential. Bold text indicates factor loading groups from the factor analysis. Only survey respondents that answered all questions included in the variable list were included in the factor analysis ($n = 505$) to ensure accuracy.

Variable	Group 1: Human activity drivers ***N*** = 158 (31.3%)	Group 2: Acute environmental drivers ***N*** = 163 (32.3%)	Group 3: Chronic environmental drivers ***N*** = 184 (36.4%)	All groups ***N*** = 505 (100%)
Monsoonal rainfall events	4.11	**4.82**	4.04	4.31
The Museum Fire burn scar	4.46	**4.87**	4.50	4.60
Burn scars from other fires (e.g. 2010 Schultz Fire, 1977 Radio Fire)	3.20	1.94	**3.60**	2.94
Recent forest management efforts	**3.96**	2.26	2.67	2.94
Blockages or overflow of existing storm water infrastructure	**4.39**	3.86	3.40	3.86
Climate change	2.95	3.48	**4.43**	3.66

= .036). Respondents who believed chronic environmental drivers were the primary cause of flooding were more likely to identify as female ($p = .033$) and as an ethnicity or race other than Caucasian ($p = .037$).

4.3. Preparation for flooding after fire

Respondents were asked to report mitigation-related actions they took to address post-fire flood risk (Table 4). Using these variables, we tested and expanded two related measures: one for individual actions and another for collective actions, following Burnett and Edgeley (2023). In total, respondents engaged in an average of 2.50 individual actions ($n = 295$), and an average of 2.95 collective actions ($n = 411$). Those who undertook individual actions were more likely to engage in collective actions, and vice versa ($p = <.001$). Property owners were more likely than renters to have encouraged their neighbours to purchase flood insurance ($p = .045$) while renters were more likely to have volunteered to help with flood mitigation efforts ($p = .045$). Respondents in the 2019 and/or 2022 modelled flood risk areas were significantly more likely to participate in both individual actions and collective actions ($p = <.001$). Respondents were asked to provide the reasoning behind any mitigation inaction; most (66.5%) reported that their property's flood risk was too low to warrant action, action was not as necessary because their property was insured (56.8%), or a lack of skill or physical ability to perform mitigation work (53.9%).

Table 4. Individual and collective actions taken to address post-fire flood risk.

Composite measures with Cronbach's alpha	Variables	% respondents that completed each action
Individual mitigation actions (***α*** = .726)	Place sandbags around structures on my property	38.5% ($n = 240$)
	Constructed barriers around my home	15.6% ($n = 98$)
	Ensured the lower levels of my home were waterproofed	17.5% ($n = 109$)
	Installed flood openings in foundation and/or enclosure walls	3.9% ($n = 24$)
	Elevated my home's electricity, gas, and/or water sources	1.4% ($n = 9$)
	Signed an MOU with the City of Flagstaff to place sandbags on my property	8.8% ($n = 55$)
	Placed belongings at higher points inside my home	11.8% ($n = 70$)
	Parked vehicles off the street	23.9% ($n = 142$)
	Built an emergency 'stay kit' of important items for sheltering in place	16.3% ($n = 97$)
	Cleared flood debris from drainage areas, roads, and/or sidewalks	36.9% ($n = 219$)
Collective mitigation actions (α = .790)	Talked with my neighbour(s) about mitigation efforts	41.4% ($n = 249$)
	Attended a meeting in person or online about flood risk mitigation efforts	23.5% ($n = 141$)
	Helped my neighbour(s) with work on their property	28.8% ($n = 173$)
	Shared tools or resources with my neighbour(s)	25.5% ($n = 153$)
	Worked with my neighbors to coordinate our mitigation efforts	15.3% ($n = 92$)
	Encouraged my neighbour(s) to purchase flood insurance	12.3% ($n = 74$)
	Donated an easement for flood mitigation	1.8% ($n = 11$)
	Helped collect, fill, and/or place sandbags	41.6% ($n = 250$)
	Volunteered to help with flood mitigation efforts	11.8% ($n = 71$)

Table 5. Chi square significance between perceived influences on 2021 flooding and individual and collective actions taken. Only actions with a significant outcome were retained for this table. Probabilities are significant at: *, $p < .05$; **, $p < .01$; ***, $p < .001$. All assumptions were met in goodness-of-fit tests.

	Monsoonal rainfall events	The Museum Fire burn scar	Burn scars from other fires	Recent forest management efforts	Blockages or overflow of existing storm water infrastructure	Climate change
Place sandbags around structures on my property	.655	.656	.085	.058	**<.001*** **	.199
Constructed barriers around my home	.368	.728	.137	**.023***	**<.001*** **	.784
Ensured the lower levels of my home were waterproofed	.506	.286	.511	**.007****	**.003****	.419
Signed an MOU with the City of Flagstaff to place sandbags on my property	.510	.365	.240	.275	**.006****	.544
Built an emergency 'stay kit' of important items for sheltering in place	.376	.280	.247	**.038***	.097	.275
Cleared flood debris from drainage areas, roads, and/or sidewalks	.373	.534	.579	**<.001*** **	**.003****	**.044***
Talked with my neighbour(s) about mitigation efforts	**.027***	.237	.316	.068	**.003****	.213
Encouraged my neighbour(s) to purchase flood insurance	.417	**.009****	.072	**.003****	.091	**.005****
Shared tools or resources with my neighbour(s)	.146	**<.001*** **	.553	**<.001*** **	**.003****	.183
Helped my neighbour(s) with work on their property	.280	**<.001*** **	.318	**.006****	**.004****	.164
Helped collect, fill, and/or place sandbags	.144	.060	.193	**.025***	**.032***	.104
Worked with my neighbours to coordinate our mitigation efforts	.220	**.021***	.088	**<.001*** **	**<.001*** **	.080
Attended a meeting in person or online about flood risk mitigation efforts	.239	.103	**.029***	**.017***	**<.001*** **	.192
Volunteered to help with flood mitigation efforts	.780	.425	.756	.700	**.003****	.061

Engagement in mitigation varied across respondents and shared relationships with perceptions of flood drivers (Table 5). Perceptions of the Museum Fire burn scar as extremely influential was only a motivator of discussions with neighbours, while blockages or overflow of existing storm water infrastructure as a driver influenced the uptake of the highest number of activities. Those who engaged in individual actions were more likely to believe that the Museum Fire burn scar ($p = .035$), recent forest management ($p = .022$), and climate change ($p = .035$) were extremely influential on 2021 flooding. Those engaged in collective actions were more likely to perceive monsoonal rainfall events ($p = .005$), recent forest management ($p = .003$), and blockages or overflows of existing storm water infrastructure ($p = .005$) as extremely influential.

Respondents who experienced flooding between 2019 and 2022 were significantly more likely to engage in all individual actions (all $p = <.001$) except elevating their home's gas, water, or electrical boxes and the creation of a stay kit, neither of which were significant. Collective actions such as talking with neighbour(s) about mitigation, sharing tools and resources with neighbour(s), helping neighbour(s) with work on their property, coordinating mitigation with neighbour(s), and attending meetings were associated with 2019–2022 flooding on respondents' properties (all $p = .001$). Those who engaged in more individual actions ($p = .036$) and collective actions ($p = <.001$) were more likely to have sheltered in place in 2021. When entered into individual regressions, property damage (Individual: $p = .049$, $\beta = .140$; Collective: $p = <.001$, $\beta = -.381$) and current perceived flood risk (Individual: $p = .013$, $\beta = .169$; Collective: $p = <.001$, $\beta = -.232$) were both influential on uptake of protective actions. Factor analysis groupings surrounding perceived drivers of flooding had no influence on whether respondents engaged in individual or collective action.

5. Discussion

Efforts to better understand resident experiences with flooding in post-fire environments, including relationships between risk perceptions and uptake of mitigation activities on private property, represent a critical step for advancing more comprehensive communication and planning for cascading hazards after uncharacteristic wildfires. The research presented here contributes to this need in three ways. First, we documented perceived post-fire flood risk *after* flood events in a post-fire landscape, allowing a clearer temporal picture to emerge regarding the role of personal experience with flooding and attitudes toward mitigation. Second, we connected flood risk perceptions and uptake of mitigation activities to perceived drivers of flood events, providing new context to support risk messaging. Lastly, we tested and extended an existing set of measures for post-fire individual and collective mitigation actions to support insights into potential variations in willingness to collaborate between different post-fire contexts. These contributions respond to broader calls for clearer understandings of the interplay between wildfire, water processes, and society (Kinoshita et al. 2016). Below, we discuss how our findings relate to existing wildfire, flooding, and post-fire research and provide recommendations for professionals working to engage the public in post-fire mitigation activities.

Survey respondents consistently underestimated local post-fire flood risk; for instance, 60.9% of respondents reported that flooding was far more severe than expected. At the same time, 86.2% of respondents who were not in modelled flood risk areas still reported

that they believed their property was at some level of risk. This led to varied responses regarding both engagement in individual and collective mitigation actions, and a wide spectrum of anticipated flood risk duration. Communicating about not only the probability of a flood event (in Flagstaff, this was shared through the likelihood of different flood depths), but also the extent or scale of a potential flood event and confidence in such mapping, is important to improve discernment of property-level flood risk. This survey also reveals limited resident understandings about what post-fire flood events might entail; dissemination of basic information about how floods in post-fire environments might differ from other types of flooding can help underscore potential differences in appropriate mitigation actions and better aligning resident risk perceptions with the diversity of potential hazards (e.g. debris movement, water quality impacts) (Burnett and Edgeley 2023).

Respondents living outside the modelled flood area often reported their own risk as high, reinforcing the need for more nuanced and targeted messaging about flood risk that supports more consistent availability and accessibility. These efforts can maximise efficient resource distribution, as respondents external to flood risk areas may be depleting communal resources such as sandbags unnecessarily (Gaynor et al. 2019). It is important to note that maps illustrating flood risk used for these comparisons depict post-fire flooding changes and differ from flood plain maps posted and accessible on the Federal Emergency Management Agency (FEMA) website: there are some areas in the 500-year FEMA flood plain that do not show flood risk at 0.5-foot flooding depths depicted on the 2022 flood maps for Flagstaff. The flood maps used in this study therefore differ from what was available to residents at the time of the survey and utilise a rational but arbitrary cut-off of flooding depth of 0.5 feet. Responses to the survey are thus based on residents' differing knowledge of flood patterns and what they perceive as an acceptable level of risk.

We found that respondents tended to favor one of three emergent groupings of perceived drivers causing flooding: human drivers, acute environmental drivers, or chronic environmental drivers. Membership across these groups was influenced by perceived risk, experiences with flood events, trusted communication channels, gender, and ethnicity. Full-time residents connected flooding more directly to monsoonal rains compared to part-time residents, demonstrating the value of leveraging local ecological knowledge in wildfire communication (Emard et al. 2024). Flooding can have discrete and discontinuous impacts within the same area (i.e. properties on the same street may experience different flood impacts depending on fine small location and topography characteristics) (Chakraborty et al. 2014; Forrest et al. 2020; Houston et al. 2021). Therefore, property locations relative to actual flooding may not be as influential as residents' general perceptions of risk and the other drivers identified here. Perceived flood driver groupings had no influence on uptake of individual or collective mitigation actions using the measures discussed above. These relationships indicate that uptake of post-fire flood mitigation activities is specific to select perceived drivers.

While uptake of mitigation actions was generally high among respondents, they tended to focus on low commitment actions such as talking with neighbours or placing sandbags as opposed to more involved efforts such as structural modifications. This finding echoes other post-fire studies and reinforces calls to explore potential funding mechanisms and outreach programmes that can encourage more

comprehensive planning for cascading wildfire hazards (Burnett and Edgeley 2023; Colavito et al. 2023). Encouraging property owners to engage in more substantive mitigation activities may also support long term post-fire risk reduction regardless of resident turnover, as wildfire mitigation studies indicate that residents tend to upkeep the mitigation efforts already present when they moved into their home (Edgeley and Paveglio 2019). Municipalities with the potential for post-fire flood risk could benefit from establishment of building codes or other similar strategic development considerations that take cascading hazards into consideration. While most respondents recognised the importance of actions on private properties, they also saw government entities (city, county, and Forest Service) as largely responsible for flood mitigation. This perception of responsibility, paired with greater perceived effectiveness for agency-led mitigation, could also limit homeowner mitigation activities (Houston et al. 2024). Further examination of this potential disconnect should seek to understand whether uptake of mitigation actions at varying scales also indicate or demonstrate progress towards social adaptation to post-fire hazards over time or repeated flood events (VijayaVenkataRaman et al. 2012).

Individual and collective actions to mitigate post-fire flooding were connected to risk perceptions and anticipated duration of post-fire flood risk, upholding findings from prior studies on post-fire flooding (Burnett and Edgeley 2023; Edgeley et al. 2024a, Edgeley and Colavito 2022). We extended existing measures produced by Burnett and Edgeley (2023), discovering that these survey questions remained accurate and cohesive both (1) when studying a separate fire event and (2) with the addition of new actions under each measure that reflect local response and resources. More than half of respondents saw insurance coverage as an alternative to mitigation, despite respondents also noting high expenses not covered by insurance, underscoring the importance of emphasising underinsurance after fire when communicating about risk reduction (Edgeley et al. 2024a; Hjerpe et al. 2023; UNDRR 2025). These findings also demonstrate the importance of diversifying mitigation activities, both physical and social, to support more resilient neighbourhoods in post-fire environments during and after a flood event.

Mitigative actions (or lack thereof) did not always align with respondents' behaviours during flood events; 47.5% of respondents reported sheltering in place during a flood, yet only 16.3% had prepared a 'stay kit' of emergency supplies to support this decision. We suggest that communication about post-fire mitigation should more explicitly pair actions with anticipated behaviours to support safer household decision-making during flood events, emphasising that both temporary and permanent modifications can enhance household members' safety when sheltering in place is recommended (Haynes et al, 2018). Communication about risk mitigation in post-fire environments must extend beyond minimising structural impacts to emphasise human safety during a post-fire flood event.

We conducted a similar survey in 2019 immediately after the Museum Fire before any flooding occurred that provided a foundation for longitudinal insights into how first-hand flood experiences shift resident perceptions in post-fire environments (Edgeley and Colavito 2020, 2022). Perceived likelihood of flood events at larger scales increased in the 2022 survey; however, the perceived likelihood of a flood event damaging the respondent's home decreased (38.9% in 2019, 32.4% in 2022). We suggest that this change may be motivated by both a lack of personal impacts since the fire and the increased accessibility of maps depicting flood risk in the area. This finding may also capture evidence of spatial

optimism bias – the perception that risk on the respondent's property is lower than elsewhere – in post-fire flood contexts, meriting discussion about how to 'recalibrate' potential misalignment in risk perceptions from parcel to parcel during messaging to encourage sustained mitigation activities (Gifford et al. 2009; Milfont et al. 2011). Future research that explores spatial relationships, such as risk perceptions relative to distance from a burn scar, could further examine this observation (Ali et al. 2022). We also found evidence that individual mitigation actions rose significantly in the years following the fire; for instance, the number of respondents placing sandbags on their property doubled between surveys (13% in 2019, 27% in 2022). These paired surveys also demonstrate misalignment between expectations and reality regarding emergency notifications; in 2019, 40.1% of respondents expected to be notified in-person about the need to evacuate, but less than 1% of respondents in the 2022 survey reported experiencing this, instead relying on phone notifications and personal observations. Together, both surveys illustrate how post-fire flood risk perceptions and engagement in related actions fluctuate with time since a fire and the presence or absence of perceived flood drivers. These shifts reinforce existing calls for longitudinal social science research in post-fire environments (Edgeley 2023; Hjerpe et al. 2023), while also hinting at the beneficial impact of risk communication on self-efficacy towards mitigation at both individual and collective levels (Babcicky and Seebauer 2017; Remenick 2018).

Professionals supporting uptake of private property mitigation and risk communication in post-fire environments can leverage relationships uncovered in this study to encourage resident action. Demographic characteristics rarely influenced risk perceptions or mitigation actions, emphasising the importance of examining and incorporating broader local social contexts when crafting messages. Respondents who perceived issues with storm water infrastructure and recent forest management efforts as drivers engaged in a greater diversity of mitigation activities, suggesting that communication may need to include a variety of mitigative actions that engage residents with varied perceptions. Additionally, our documented relationships between trusted information sources and perceptions of flood drivers align with broader research on climate change (Cologna and Siegrist 2020), indicating that message framing, content, and messenger are all important considerations for bridging transitions from risk perceptions to mitigative action surrounding cascading hazards (Dallo et al. 2022). Together, our findings indicate that communication in post-fire contexts should (1) acknowledge the layered nature of flood drivers to unify efforts across private property lines, as oversimplification of risk source messaging can lead to mistrust or conflict, (2) consistently emphasise the continued risk long after the fire event for several years to encourage people to retain insurance, implement mitigation measures, and maintain realistic expectations for continued flood risk, and (3) use messaging that emphasises the complexities of local ecosystems given the high environmental literacy of residents in this study area. However, not all communities may be able to draw on such experiences to understand post-fire environments, meaning that professionals must assess resident understanding and initiate communication at an entry point that aligns with current local knowledge (Eriksen and Prior 2011; Spano et al. 2021). One core challenge may lie in divergent reporting regarding flood drivers by media; coordinating press trainings around cascading hazards may help improve reductionist approaches to reporting in post-fire environments. Future studies should explore decision-making processes regarding the uptake of specific

mitigation activities, understand behaviours during a post-fire flood event, and capture qualitative data that describe the role of local social context and ecological knowledge in post-fire spaces. Given that post-fire flooding is a cascading consequence of wildfire, future research may also benefit from multi-hazard approaches or the development of recommendations that highlight overlap in mitigation for diverse hazards simultaneously (Shah et al. 2023; Wang et al. 2020).

6. Conclusion

Factors driving resident engagement in post-fire flood mitigations is not well understood within the environmental hazards literature. This study surveyed residents in areas affected by post-fire flooding in 2021 downslope from the 2019 Museum Fire in Flagstaff, Arizona. Findings reinforced the role of risk perceptions in decisions to engage in mitigation activities on private property, while also underscoring the relationship between collective and individual actions for collaboratively scaling up mitigation efforts across boundaries. We also provide new insights on the role of flood risk drivers for motivating action, finding limited evidence of its influence among select groups. Our findings indicate that residents need additional financial or technical support to engage in more involved property mitigation such as structural medication, inviting grant or partnership programmes organised through local government entities (e.g. county flood control districts). Respondents were motivated by varied factors to undertake mitigation, which suggests that messaging efforts related to post-fire flood mitigation should seek to acknowledge some level of hazard complexity while focusing on future risks rather than past drivers. Together, these efforts reveal growing public understanding regarding the multifaceted nature of flood risk in post-fire environments and reflect the need for communication about cascading hazards to embrace messaging that emphasises layered drivers of risk and their longevity.

This study has several limitations that can inform future post-fire flood research design and invite multi-hazard comparisons. Flagstaff, AZ, has a unique and storied history with wildfire and post-fire flooding that has resulted in high levels of ecological literacy and unwavering support for forest management (Edgeley and Colavito 2020, 2022). Findings are likely translatable to similarly minded populations that are experienced with wildfire (e.g. Ashland, OR, Missoula, MT), but additional research is needed in other local social contexts to begin teasing out nuances in perceptions and messaging, particularly outside the United States. Comparison of respondent demographic data with recent census data indicates that while our data is representative of gender, it underrepresents renters, racial and ethnic minorities, and younger populations, likely due to the high student population in the Flagstaff area (Census Bureau 2021). We note that renters are often unable to conduct mitigative action on their properties and surveys about event-based experiences often do not elicit high response rates from rental property owners who often are not locally based, indicating that future research should explore rental property owners' mitigation actions to determine if there are significant differences. Finally, our survey instrument was exploratory given the lack of existing social science research on post-fire flooding, meaning that variables did not directly align with existing theories and related frameworks. Others interested in conducting research on household-level post-fire flooding responses and experiences may consider designing their survey

instrument to test compatibility with Protection Motivation Theory or similar concepts to examine (mis)alignment between resident behaviour towards post-fire flooding and other hazards such as heatwaves, landslides, and avalanches.

Notes

1. This study was approved by the authors' Institutional Review Board (#1487940). The survey packet cover letter explained that by returning the completed survey, participants were providing informed consent.
2. The full survey instrument is available in Appendix 1 of Colavito, Edgeley, and vonHedemann (2023).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data presented here are protected by the researchers' Institutional Research Board and cannot be shared without compromising participant identities.

References

AghaKouchak, A., Huning, L. S., Chiang, F., Sadegh, M., Vahedifard, F., Mazdiyasni, O., Moftakhari, H., & Mallakpour, I. (2018). How do natural hazards cascade to cause disasters? *Nature*, *561*(7724), 458–460. https://doi.org/10.1038/d41586-018-06783-6

Ali, A., Rana, I. A., Ali, A., & Najam, F. A. (2022). Flood risk perception and communication: The role of hazard proximity. *Journal of Environmental Management*, *316*, 115309. https://doi.org/10.1016/j.jenvman.2022.115309

Atreya, A., Ferreira, S., & Michel-Kerjan, E. (2015). What drives households to buy flood insurance? New evidence from Georgia. *Ecological Economics*, *117*, 153–161. https://doi.org/10.1016/j.ecolecon.2015.06.024

Babcicky, P., & Seebauer, S. (2017). The two faces of social capital in private flood mitigation: Opposing effects on risk perception, self-efficacy and coping capacity. *Journal of Risk Research*, *20*(8), 1017–1037. https://doi.org/10.1080/13669877.2016.1147489

Beebe, T. J., McAlpine, D. D., Ziegenfuss, J. Y., Jenkins, S., Haas, L., & Davern, M. E. (2012). Deployment of a mixed-mode data collection strategy does not reduce nonresponse bias in a general population health survey. *Health Services Research*, *47*(4), 1739–1754. https://doi.org/10.1111/j.1475-6773.2011.01369.x

Belongia, M. F., Hammond Wagner, C., Seipp, K. Q., & Ajami, N. K. (2023). Building water resilience in the face of cascading wildfire risks. *Science Advances*, *9*(37), eadf9534. https://doi.org/10.1126/sciadv.adf9534

Bubeck, P., Botzen, W. J. W., & Aerts, J. C. (2012). A review of risk perceptions and other factors that influence flood mitigation behavior. *Risk Analysis*, *32*(9), 1481–1495. https://doi.org/10.1111/j.1539-6924.2011.01783.x

Burnett, J. T., & Edgeley, C. M. (2023). Factors influencing flood risk mitigation after wildfire: Insights for individual and collective action after the 2010 Schultz Fire. *International Journal of Disaster Risk Reduction*, *94*, 103791. https://doi.org/10.1016/j.ijdrr.2023.103791

Burns, M. R., Taylor, J. G., & Hogan, J. T. (2008). Integrative healing: The importance of community collaboration in postfire recovery and prefire planning. In W. E. Martin, C. Raish, & B. Kent (Eds.), *Wildfire risk: Human perceptions and management implication* (pp. 81–98). Routledge.

Cafferata, P. H., Coe, D. B., & Short, W. R. (2021). Sixty years of post-fire assessment and monitoring on non-federal lands in California: What have we learned? *Environmental & Engineering Geoscience*, *27*(4), 409–422.

Cannon, C., Gotham, K. F., Lauve-Moon, K., & Powers, B. (2020). The climate change double whammy: Flood damage and the determinants of flood insurance coverage, the case of post-Katrina New Orleans. *Climate Risk Management*, *27*, 100210. https://doi.org/10.1016/j.crm.2019.100210

Chakraborty, J., Collins, T. W., Montgomery, M. C., & Grineski, S. E. (2014). Social and spatial inequities in exposure to flood risk in Miami, Florida. *Natural Hazards Review*, *15*(3), 04014006. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000140

Colavito, M. M., Edgeley, C. M., & vonHedemann, N. (2023). *Public experiences with wildfire and flooding: A case study of the 2019 museum fire near Flagstaff, Arizona. ERI White Paper – issues in forest restoration*. 57p. Ecological Restoration Institute, Northern Arizona University.

Cologna, V., & Siegrist, M. (2020). The role of trust for climate change mitigation and adaptation behaviour: A meta-analysis. *Journal of Environmental Psychology*, *69*, 101428. https://doi.org/10.1016/j.jenvp.2020.101428

Dallo, I., Stauffacher, M., & Marti, M. (2022). Actionable and understandable? Evidence-based recommendations for the design of (multi-) hazard warning messages. *International Journal of Disaster Risk Reduction*, *74*, 102917. https://doi.org/10.1016/j.ijdrr.2022.102917

DeBano, L. F., Neary, D. G., & Ffolliott, P. F. (2005). Soil physical properties. In D. G. Neary, K. C. Ryan, & F. L. DeBano (Eds.), *Wildland fire in ecosystems: Effects of fire on soil and water* (pp. 29–51). USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-42-vol. 4.

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: The tailored design method*. John Wiley & Sons.

Driscoll, K. P., & Friggens, M. (2019). Assessing risk in a postfire landscape: Are currently available tools good for the local land owner? *Natural Areas Journal*, *39*(4), 472–481. https://doi.org/10.3375/043.039.0410

Edgeley, C. M. (2023). Social science to advance wildfire adaptation in the southwestern United States: A review and future research directions. *International Journal of Wildland Fire*, *32*(12), 1647–1662. https://doi.org/10.1071/WF23102

Edgeley, C. M., Cannon, W. H., Pearse, S., Kosović, B., Pfister, G., & Kumar, R. (2024b). Five social and ethical considerations for using wildfire visualizations as a communication tool. *Fire Ecology*, *20*(1), 45. https://doi.org/10.1186/s42408-024-00278-8

Edgeley, C. M., & Colavito, M. M. (2020). *Local experiences with the 2019 museum fire and associated flood risk: A survey of Flagstaff-area residents. ERI white paper – issues in forest restoration*. 40p. Ecological Restoration Institute, Northern Arizona University.

Edgeley, C., & Colavito, M. (2022). Characterizing divergent experiences with the same wildfire: Insights from a survey of households in evacuation, postfire flood risk, and unaffected areas after the 2019 museum fire. *Journal of Forestry*, *120*(6), 660–675. https://doi.org/10.1093/jofore/fvac018

Edgeley, C. M., Colavito, M. M., vonHedemann, N., & Burnett, J. T. (2024a). Voluntary uptake of flood insurance in post-fire landscapes: Insights from household surveys after two wildfires in northern Arizona. *Environmental Research Communications*, *6*(6), 061006. https://doi.org/10.1088/2515-7620/ad5647

Edgeley, C. M., & Paveglio, T. B. (2019). Exploring influences on intended evacuation behaviors during wildfire: What roles for pre-fire actions and event-based cues? *International Journal of Disaster Risk Reduction*, *37*, 101182. https://doi.org/10.1016/j.ijdrr.2019.101182

Emard, K. A., Edgeley, C. M., Hazard, C. A. W., Sarna-Wojcicki, D., Cannon, W., Cameron, O. Z., Hillman, L., McCovey, K., Lombardozzi, D., Pearse, S., & Newman, A. J. (2024). Connecting local ecological

knowledge and earth system models: Comparing three participatory approaches. *Ecology and Society*, *29*(4), Article no. 43. https://doi.org/10.5751/ES-15570-290443

Eriksen, C., & Prior, T. (2011). The art of learning: Wildfire, amenity migration and local environmental knowledge. *International Journal of Wildland Fire*, *20*(4), 612–624. https://doi.org/10.1071/WF10018

Eryılmaz Türkkan, G., & Hırca, T. (2021). The investigation of flood risk perception as a quantitative analysis from socio-demographic perspective. *Natural Hazards*, *106*(1), 715–733. https://doi.org/10.1007/s11069-020-04488-6

Essen, M., McCaffrey, S., Abrams, J., & Paveglio, T. (2023). Improving wildfire management outcomes: Shifting the paradigm of wildfire from simple to complex risk. *Journal of Environmental Planning and Management*, *66*(5), 909–927. https://doi.org/10.1080/09640568.2021.2007861

Forrest, S. A., Trell, E. M., & Woltjer, J. (2020). Socio-spatial inequalities in flood resilience: Rainfall flooding in the city of Arnhem. *Cities*, *105*, 102843. https://doi.org/10.1016/j.cities.2020.102843

Gaynor, K. M., Brown, J. S., Middleton, A. D., Power, M. E., & Brashares, J. S. (2019). Landscapes of fear: Spatial patterns of risk perception and response. *Trends in Ecology & Evolution*, *34*(4), 355–368. https://doi.org/10.1016/j.tree.2019.01.004

Gifford, R., Scannell, L., Kormos, C., Smolova, L., Biel, A., Boncu, S., Corral, V., Güntherf, H., Hanyu, K., Hine, D., & Kaiser, F. G. (2009). Temporal pessimism and spatial optimism in environmental assessments: An 18-nation study. *Journal of Environmental Psychology*, *29*(1), 1–12. https://doi.org/10.1016/j.jenvp.2008.06.001

Goto, E. A., Gray, S., Keller, E., & Clarke, K. (2021). Evacuation choice before and after major debris flows: The case of Montecito, CA. *International Journal of Disaster Risk Reduction*, *62*, 102400. https://doi.org/10.1016/j.ijdrr.2021.102400

Haynes, K., Tofa, M., Avci, A., van Leeuwen, J., & Coates, L. (2018). Motivations and experiences of sheltering in place during floods: Implications for policy and practice. *International Journal of Disaster Risk Reduction*, *31*, 781–788. https://doi.org/10.1016/j.ijdrr.2018.07.011

Henstra, D., Thistlethwaite, J., Brown, C., & Scott, D. (2019). Flood risk management and shared responsibility: Exploring Canadian public attitudes and expectations. *Journal of Flood Risk Management*, *12*(1), e12346. https://doi.org/10.1111/jfr3.12346

Hjerpe, E. E., Colavito, M. M., Edgeley, C. M., Burnett, J. T., Combrink, T., Vosick, D., & Sanchez Meador, A. (2023). Measuring the long-term costs of uncharacteristic wildfire: A case study of the 2010 Schultz Fire in Northern Arizona. *International Journal of Wildland Fire*, *32*(10), 1474–1486. https://doi.org/10.1071/WF23036

Houston, D., Pérez Figueroa, O., Jong-Levinger, A., Schubert, J. E., & Sanders, B. F. (2024). Spatial optimism and cross-over effects in the perceptions of interconnected wildfire, flood, and mudslide hazards. *Environment and Behavior*, *56*(1–2), 19–58. https://doi.org/10.1177/00139165241275482

Houston, D., Werritty, A., Ball, T., & Black, A. (2021). Environmental vulnerability and resilience: Social differentiation in short-and long-term flood impacts. *Transactions of the Institute of British Geographers*, *46*(1), 102–119. https://doi.org/10.1111/tran.12408

IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp.

Jakob, M., Hungr, O., Cannon, S. H., & Gartner, J. E. (2005). Wildfire-related debris flow from a hazards perspective. In H. O. Jakob (Ed.), *Debris-flow hazards and related phenomena* (pp. 363–385). Springer.

Jones, K. W., Gannon, B., Timberlake, T., Chamberlain, J. L., & Wolk, B. (2022). Societal benefits from wildfire mitigation activities through payments for watershed services: Insights from Colorado. *Forest Policy and Economics*, *135*, 102661. https://doi.org/10.1016/j.forpol.2021.102661

Jong-Levinger, A., Houston, D., & Sanders, B. F. (2024). Estimating post-fire flood infrastructure clogging and overtopping hazards. *Water Resources Research*, *60*(8), e2023WR036522. https://doi.org/10.1029/2023WR036522

Kinoshita, A. M., Chin, A., Simon, G. L., Briles, C., Hogue, T. S., O'Dowd, A. P., Gerlak, A. K., & Albornoz, A. U. (2016). Wildfire, water, and society: Toward integrative research in the "Anthropocene". *Anthropocene*, *16*, 16–27. https://doi.org/10.1016/j.ancene.2016.09.001

Koestner, K. A., Koestner, P. E., & Neary, D. G. (2011). Estimating Post-Fire Peak Flows Following the Schultz Fire, Coconino National Forest, Arizona. *Hydrology and Water Resources in Arizona and the* Southwest [collection], p. 25–29. Available: https://repository.arizona.edu/handle/10150/296989

Landry, C. E., & Jahan-Parvar, M. R. (2011). Flood insurance coverage in the coastal zone. *Journal of Risk and Insurance*, *78*(2), 361–388. https://doi.org/10.1111/j.1539-6975.2010.01380.x

Lopez, M., Margolis, E., Tillery, A., Bassett, S., & Hook, A. (2024). Pre-fire assessment of post-fire debris-flow hazards in the Santa Fe Municipal Watershed. *International Journal of Wildland Fire*, *33*(9), Article no. WF23065. https://doi.org/10.1071/WF23065

McGuire, L. A., Rengers, F. K., Oakley, N., Kean, J. W., Staley, D. M., Tang, H., de Orla-Barile, M., & Youberg, A. M. (2021). Time since burning and rainfall characteristics impact post-fire debris-flow initiation and magnitude. *Environmental & Engineering Geoscience*, *27*(1), 43–56. https://doi.org/10.2113/EEG-D-20-00029

Milfont, T. L., Abrahamse, W., & McCarthy, N. (2011). Spatial and temporal biases in assessments of environmental conditions in New Zealand. *New Zealand Journal of Psychology*, *40*(2), 56–67.

Mottek Lucas, A. (2015). *Flagstaff watershed protection project: Creating solutions through community partnerships. ERI White Paper – issues in forest restoration*. 28p. Ecological Restoration Institute, Northern Arizona University.

Mueller, J. M., Lima, R. E., Springer, A. E., & Schiefer, E. (2018). Using matching methods to estimate impacts of wildfire and postwildfire flooding on house prices. *Water Resources Research*, *54*(9), 6189–6201. https://doi.org/10.1029/2017WR022195

Neary, D. G., & Leonard, J. M. (2019). Physical vulnerabilities from wildfires: Flames, floods, and debris flows. In H. Naser (Ed.), *Human impact on the environment* (pp. 1–17). IntechOpen.

Olsen, C. S., Kline, J. D., Ager, A. A., Olsen, K. A., & Short, K. C. (2017). Examining the influence of bio-physical conditions on wildland–urban interface homeowners' wildfire risk mitigation activities in fire-prone landscapes. *Ecology and Society*, *22*(1), 21. https://doi.org/10.5751/ES-09054-220121

Ortega-Becerril, J. A., Garrote, J., Vicente, Á, & Marqués, M. J. (2022). Wildfire-induced changes in flood risk in recreational Canyoning areas: Lessons from the 2017 Jerte Canyons disaster. *Water*, *14*(15), 2345. https://doi.org/10.3390/w14152345

Paveglio, T. B., & Shriner-Beaton, A. R. (2024). Exploring support and opposition to regulatory approaches for wildfire risk management: Requirements, voluntary actions, and tailored local action. *Natural Hazards*, *120*(14), 12869–12907. https://doi.org/10.1007/s11069-024-06702-1

Qiu, C., Su, L., & Geng, X. (2024). A precipitation downscaling framework for regional warning of debris flows in mountainous areas. *Natural Hazards*, *120*(2), 1979–2004. https://doi.org/10.1007/s11069-023-06279-1

Remenick, L. (2018). The role of communication in preparation for wildland fire: A literature review. *Environmental Communication*, *12*(2), 164–176. https://doi.org/10.1080/17524032.2017.1346519

Rengers, F. K., McGuire, L. A., Oakley, N. S., Kean, J. W., Staley, D. M., & Tang, H. (2020). Landslides after wildfire: Initiation, magnitude, and mobility. *Landslides*, *17*(11), 2631–2641. https://doi.org/10.1007/s10346-020-01506-3

Rijal, M., Luo, P., Mishra, B. K., Zhou, M., & Wang, X. (2024). Global systematical and comprehensive overview of mountainous flood risk under climate change and human activities. *Science of The Total Environment*, *941*, 173672. https://doi.org/10.1016/j.scitotenv.2024.173672

Rogers, R. W. (1983). Cognitive and physiological processes in fear appeals and attitude change: A revised theory of protection motivation. In J. R. Cacioppo & R. E. Petty (Eds.), *Social psychology: A sourcebook* (pp. 153–176). Guilford.

Sankey, T. T., Tango, L., Tatum, J., & Sankey, J. B. (2024). Forest fire, thinning, and flood in wildland-urban interface: UAV and lidar-based estimate of natural disaster impacts. *Landscape Ecology*, *39*(3), 58. https://doi.org/10.1007/s10980-024-01811-5

Santi, P. M., Hewitt, K., VanDine, D. F., & Barillas Cruz, E. (2011). Debris-flow impact, vulnerability, and response. *Natural Hazards*, *56*(1), 371–402. https://doi.org/10.1007/s11069-010-9576-8

Schiefer, E., & Schenk, E. (2024). Changed seasonality and forcings of peak annual flows in ephemeral channels at Flagstaff, Northern Arizona, USA. *Hydrology*, *11*(8), 115. https://doi.org/10.3390/hydrology11080115

Serra-Llobet, A., Radke, J., Kondolf, G. M., Gurrola, L., Rogers, J. D., Lindbergh, S., & Douvinet, J. (2023). Risk as a process: A history informed hazard planning approach applied to the 2018 post-fire debris flows, Montecito, California. *Frontiers in Environmental Science*, *11*, 1183324. https://doi.org/10.3389/fenvs.2023.1183324

Shah, S. S., Rana, I. A., & Ali, A. (2023). Multi-hazard risk perception: An empirical study of the remote Gilgit city, Hindukush-Karakorum-Himalayan (HKH) region, Pakistan. *International Journal of Disaster Risk Reduction*, *96*, 103996. https://doi.org/10.1016/j.ijdrr.2023.103996

Shao, W., Xian, S., Lin, N., Kunreuther, H., Jackson, N., & Goidel, K. (2017). Understanding the effects of past flood events and perceived and estimated flood risks on individuals' voluntary flood insurance purchase behavior. *Water Research*, *108*, 391–400. https://doi.org/10.1016/j.watres.2016.11.021

Spano, G., Elia, M., Cappelluti, O., Colangelo, G., Giannico, V., D'Este, M., Lafortezza, R., & Sanesi, G. (2021). Is experience the best teacher? Knowledge, perceptions, and awareness of wildfire risk. *International Journal of Environmental Research and Public Health*, *18*(16), 8385. https://doi.org/10.3390/ijerph18168385

Sutanto, S. J., Janssen, M., De Brito, M. M., & del Pozo Garcia, M. (2024). The effect of wildfires on flood risk: A multi-hazard flood risk approach for the Ebro River basin, Spain. *Natural Hazards and Earth System Sciences*, *24*(11), 3703–3721. https://doi.org/10.5194/nhess-24-3703-2024

UNDRR (United Nations Office for Disaster Risk Reduction). (2024). *Forensic insights for future resilience, learning from past disasters. Geneva*. 75pp.

UNDRR (United Nations Office for Disaster Risk Reduction). (2025). *Global assessment report on Disaster Risk Reduction 2025: Resilience pays: Financing and investing for our future. Geneva*. 253pp.

VijayaVenkataRaman, S., Iniyan, S., & Goic, R. (2012). A review of climate change, mitigation and adaptation. *Renewable and Sustainable Energy Reviews*, *16*(1), 878–897. https://doi.org/10.1016/j.rser.2011.09.009

Wagenbrenner, J., Macdonald, L., & Rough, D. (2006). Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. *Hydrological Processes*, *20*(14), 2989–3006. https://doi.org/10.1002/hyp.6146

Wang, J., He, Z., & Weng, W. (2020). A review of the research into the relations between hazards in multi-hazard risk analysis. *Natural Hazards*, *104*(3), 2003–2026. https://doi.org/10.1007/s11069-020-04259-3

Warziniack, T., & Thompson, M. (2013). Wildfire risk and optimal investments in watershed protection. *Western Economics Forum*, *12*(2), 19–28.

Youberg, A. M., Loverich, J. B., Kellogg, M. J., & Fuller, J. E. (2019). Before the fire: Assessing post-wildfire flooding and debris-flow hazards for pre-disaster mitigation. *Natural Hazards and Earth System Sciences Discussions*, *2019*, 1–21. https://nhess.copernicus.org/preprints/nhess-2019-74/