PLANNING FOR AND MITIGATING EMERGENT POST-FIRE FLOODING RISK IN THE WESTERN UNITED STATES

by

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A THESIS

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Post-fire flooding (PFF) is an increasing concern for communities throughout the western United States – with intensifying fire seasons throughout the West. PFF is an emergent hazard risk due to ecological changes on burned landscapes and changes in climate. PFF events can occur immediately after a fire, but risk remains for years after a fire event. With the emerging threat of PFF hazards, emergency managers, hazard mitigation planners, hazard recovery planners, and other professionals are navigating what management and mitigation measures are most effective at minimizing PFF risk. Existing literature regarding PFF initiation, mitigation, and hazard management is based on studies from past PFF events in Southern California. Little is known about the behavior and occurrence of these hazards outside of the Southern California region. Limited literature details the development and effectiveness of PFF mitigation strategies. This study begins to address what gaps exist in PFF research, what strategies are being used in PFF mitigation initiatives, and what professionals need to better manage future PFF hazard risk by conducting phone surveys with field professionals. Surveys addressed measures of PFF experience, PFF risk, mitigation strategies, and mitigation strategy development processes.

Respondents reported high levels of risk awareness and moderate levels of preparedness to future PFF hazards. They reported that a lack of experience, insufficient funding, and gaps in PFF hazard and hazard management literature to be major limiting factors to implementing PFF mitigations and improving preparedness for future hazards. By identifying the patterns, strategies and deficiencies in hazard planning and mitigation for PFF hazards, this study determines what is needed to promote mitigation and preparedness for future PFF hazards.

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Glossary

BAER= Burned Area Emergency Response Team

BLM= Bureau of Land Management

CWPP= Community Wildfire Protection Plan

HMP = Hazard Mitigation Plan

PFF = Post-fire flooding

USGS = United States Geologic Survey

USFS = United States Forest Service

FEMA = Federal Emergency Management Agency

OM = Organic matter

WERT = Watershed Emergency Response Teams

JFSP = Joint Fire Science Program

Keywords

- Post-fire flooding
- Post-fire flooding mitigation
- Post-fire debris flows mitigation
- Post-fire landslides mitigation
- Hazard mitigation planning
- Cross-jurisdictional hazard management
- Post-fire hazard management

Pre-Chapter

Joint Fire Science Program Project

This thesis project is a part of a larger study funded by the Joint Fire Science Program award 23-2-03-2 titled “Pre-Fire Planning for Post-Fire Hazards: Barriers and Opportunities Across Jurisdictions” to gain an understanding of how states in the western United States of America (U.S.) are planning for increasing post-fire flood risk, navigating multi-jurisdictional hazards, and implementing recovery measures in response to post-fire flooding (PFF) events. In the first stage of this study (Phase 1), researchers at Northern Arizona University performed a document analysis systematically cataloguing over 200 state- and county-wide Hazard Mitigation Plans (HMPs) – documents utilized by state, county, and tribal-level governments to mitigate the impact of natural hazard to reduce loss of life and property. Major elements of these documents include risk identification, strategy development, and future mitigation implementation to reduce threats to people and property (FEMA, 2025). Each county HMP was categorized based on its inclusion or exclusion of post-fire flood mitigation strategies, as well as its history (or lack thereof) of post-fire flood events. This phase of the study sought to document the occurrence of mitigation strategies in hazard planning documents across the western United States. Expanding the scope of this study, the research presented here entailed phone surveys designed for professionals with experience in hazard management or PFF. Recruitment of these professionals was informed by the HMPs identified in Phase 1. HMPs included in this sample either a) included mitigation strategies, or b) were from a county that had experienced an event but did not include post-fire flood mitigation strategies in the HMP.

Defining post-fire flooding

Throughout each phase of this study, researchers utilize the term "post-fire flooding" to encompass all large water and sediment movements on or adjacent to recently burned landscapes (Burnett & Edgeley, 2023; Colavito & Edgeley, 2022). Some of the most common hazards grouped under this definition include floods, debris-flows, landslides, and mudslides (Burnett & Edgeley, 2023; Colavito & Edgeley, 2022). In post-fire hazards and related literature, each of these terms have distinct characteristics, effects, and management strategies. For example, post-fire floods and post-fire debris flows are distinct from each other due to the conditions that lead to their initiation, and the means of destruction that follow (Cannon & DeGraff, 2008). Post-fire floods are a post-fire hazard that encompasses mass movement of water. Post-fire debris flows are the mass movement of water-saturated sediment and debris across or adjacent to a wildfire burn scar (Cannon & DeGraff, 2008; Costa, 1984). Post-fire debris flows may also be referred to as post-fire mudslides. These hazards are distinct from landslides as the conditions needed to initiate the hazard and the movement of the hazard vary (DeGraff, 2018; Highland & Bobrowsky 2008; Jackson & Roering, 2009; Rengers et al., 2020). Landslide events occur on landscapes with or without a recent burn (Highland & Bobrowsky 2008; Rengers et al., 2020). The occurrence of landslides is extremely dependent on the slope, topography, and soil stability of an area (DeGraff, 2018; Highland & Bobrowsky 2008; Jackson & Roering, 2009; Rengers et al., 2020). Slope and soil stability measures can be worsened by the effects of a wildfire via changes to soil stability and water infiltration capabilities. Both of these effects lead to increased likeliness of post-fire landscape hazards (Jackson & Roering, 2009)

We acknowledge that each of these hazards have specialized literature, result from unique, yet sometimes overlapping, conditions (Table 1), and have distinct effects across landscapes and communities. However, this study is focused on social and political implications of these findings rather than ecological variations and outcomes. A broad definition permits data to be collected from a wide range of jurisdictions, landscape types, and professions impacted by or affiliated with post-fire related or exacerbated conditions. Additionally, had each post-fire hazard been differentiated in the survey, it would have become cumbersome for participants and could have resulted in decreased participation.

Post-fire flooding hazards

	Floods	Debris-flows	Landslides
Hazard conditions	Hydrophobic properties of post-fire soils	Hydrophobic properties of post-fire soils	Hydrophobic properties of post-fire soils
	Low vegetation cover	Low vegetation cover	Low vegetation cover
	Degrading root networks	Degrading root networks	Degrading root networks
	Steep slopes	Steep slopes	Steep slopes
Hazard initiation	High intensity, short duration rainfall	High intensity, short duration rainfall	High intensity, short duration rainfall
		Low intensity, long duration rainfall	

	Snowmelt, or rain on snow	Snowmelt, or rain on snow	Rainfall or slope instability
		Shallow landslides	
Temporal risk after fire	Most likely to occur **0-5 years** post-fire	Most likely to occur within **1st year** post-fire	Most likely to occur **3-5 years** post-fire
	Communities downstream from burn scars are at risk for **0-5 years** post-fire	Communities downhill of the burn scars are at risk for **5+ years** post-fire depending on vegetation cover and soil types	Risk of post-fire landslides occurs for **5 years** post-fire

Table 1: PFF hazards

Post-fire conditions

Ecosystem response to fire events vary based on local circumstances. One proxy for impact is fire severity – a measure of how much organic matter (OM) is lost above and below ground, including OM soil compositions and vegetation loss (Keeley 2009). Fire severity can influence soil composition, hydrologic processes, vegetation and canopy cover, and root networks (Jackson & Roering, 2009; Keely 2009). For example, high severity fires tend to cause higher decay of OM and root networks in burned landscapes (Jackson & Roering, 2009; Keely

2009). These factors are foundational to hydrologic processes on landscapes, and the post-fire changes lead to higher PFF risk conditions (Jackson & Roering, 2009; Keely 2009). Biotic factors, such as vegetation cover/type and OM compositions, and abiotic factors, such as climate, all influence ecosystem response outcomes following a wildfire (Peterson and Ryan, 1986; Neary et al., 1999; Moody and Martin, 2001; Pérez-Cabello et al., 2006; Keeley 2009). Additional factors such as soil composition, hydrologic capabilities, and vegetation cover on post-fire landscapes all influence the susceptibility of a landscape to PFF hazards (Garfin et al., 2016; Williams et al., 2014; White et al, 2022; Rengers et al., 2020; Youberg et al., 2019).

Due to high temperatures, wildfire has the capacity to transform absorbent soils into soil with water-repellent properties. Affected soils turn hydrophobic, causing soil layers to repel rather than absorb water (Garfin et al., 2016; Jackson & Roering, 2009; Youberg et al., 2010). This resulting change in soil properties and landscape erodibility dictates that less water will be needed on a post-fire landscape to initiate a flooding event than on a similar unburned landscape (Garfin et al., 2016; Jackson & Roering, 2009; Rengers et al., 2020; Youberg et al., 2010).

After a wildfire event, low-magnitude rainfall can initiate a post-fire flood due to reduced ground cover as a result of vegetation loss in the fire and the hydrophobic properties of fire-affected soils (Garfin et al., 2016; Youberg et al., 2010). A post-fire landscape will have distinct runoff and watershed capabilities to the same landscape pre-fire (Garfin et al., 2016; Rengers et al., 2020; Youberg et al., 2010). High-intensity fires (fires that burn very hot and release a lot of energy during combustion) often lead to high plant mortality on the affected landscape and can kill seeds stored in the soil (seed bank), which can impact post-fire vegetation recovery or require post-fire seeding to restore vegetation to the landscape in certain cases (Maia et al. 2012). In the months post-fire, the root structures of the burned plants begin to decay (Jackson &

Roering, 2009; Rengers et al., 2020; Williams et al., 2014). In higher intensity burns, there will be greater root deterioration over the six months following the burn (Ramirez et al., 2024). The loss of root structure greatly reduces soil stability, increasing the landscape's erodibility (Jackson & Roering, 2009; Rengers et al., 2020; Williams et al., 2014; White et al, 2022). The loss of root structures holding soils in place leads to changes in hydrologic processes on the landscapes and can increase risk of post-fire floods. A compounding effect of vegetation loss is the reduced rainfall interception (rainfall captured by leaves and branches) across a landscape (Rengers, 2020). As a result, slopes that are experiencing heightened instability, are also interfacing with increased water exposure during precipitation events (Rengers, 2020).

Burned soils can exhibit hydrophobic properties (Garfin et al., 2016; Jackson & Roering, 2009; Youberg et al., 2010). Depending on the fire intensity, organic matter in the soil and burning vegetation release waxy volatile hydrophobic substances (Li et al., 2021; Williams et al., 2014). These substances soak through the soil, forming a water-repellent coating over soil particles as the area cools down post-fire (Li et al., 2021; Williams et al., 2014); instead of allowing water to saturate percolate through, hydrophobic soil repels water. Landscapes in this state have increased hydrologic vulnerability and be more prone to PFF events) including increased run-off and erosion throughout the burned watershed (Jackson & Roering, 2009; Williams et al., 2014; Youberg et al., 2013).

Burned soil's inability to absorb water can be compounded by the loss of invertebrate populations, microorganisms, and fungi mycorrhizal networks when soils reach fatal temperatures during a fire event, further reducing soil's water infiltration capacity (Williams et al., 2014). In healthy pre-fire soils, these organisms manipulate the soil structure, working to maintain pore structure that allows for moisture retention and water infiltration. In post-fire landscapes, without the structural work of invertebrates, microorganisms, and mycorrhiza, burned soil loses water retention capacity (Williams et al., 2014). Altogether, the state of some post-fire soils may not be conducive to structural stability or water infiltration, both of which can drive increased potential for PFF events (Garfin et al., 2016; Li et al., 2021; Williams et al., 2014).

Post-fire flooding

Under burned landscape conditions, flood events can be more easily initiated. PFF events typically occur in mountainous terrains due to the vegetation and soil composition changes that occur post-fire (Garfin et al., 2016; Jackson & Roering, 2009; Li et al., 2021; Staley et al., 2020; Williams et al., 2014). Post-fire flood hazards are distinct from usual flooding hazards for the low-margin of rainfall required to begin a PFF event (Elliott & Parker, 2001; Staley et al., 2020). Rather than requiring significant rainfall over a longer period of time, post-fire flood events are often started by short but heavy storms (Elliott & Parker, 2001; Oakley, 2021; Staley et al., 2020). Climate change and over a century of fire-suppression and exclusion policies that have led to unnatural fuel loads on fire-prone landscapes are increasing both wildfire frequency and intensity (Gedalof et al., 2005). Climate change is also promoting variations in local weather that are yielding thunderstorms with higher precipitation intensities (Cannon & DeGraff, 2008; Ryan et al., 2024). These weather pattern shifts contribute to increasing PFF risks on western landscapes by increasing the likelihood and frequency of high-intensity, short duration precipitation events that can trigger PFF events (Burnett & Edgeley, 2023; Ryan et al., 2024).

Experts in the biophysical and engineering sciences largely consider post-fire floods distinct from debris-flow and landslides movement, as PFFs are considered to be mass water movement hazards that do not transport mass amounts of sediment. In contrast, debris-flows and landslides hazards cause a significant amount of sediment movement during an event (Cannon & DeGraff, 2008; Kean et al., 2011). In the biophysical hazards literature, PFFs are characterized as a type of flash flood that can move at immense speeds and can inundate low-lying areas in minutes to hours (Collier, 2007) (see Table 1). We discuss the unique attributes of debris-flows, mudflows, and landslides as compared to PFFs in the two sections below.

Debris-flows and mudflows:

A debris-flow is a slurry of water, sediment material, boulders, and other material fragments that flows down from higher elevations (Cannon & DeGraff, 2008; Costa, 1984). They are particularly hazardous due to the immense speed (average velocity of 10 *m/s,* maximum velocities recorded at 45 *m/s* on steep slopes) at which they travel, and the weight (tons per cubic meter (t/m^3)) of the sediment movement (Cannon & DeGraff, 2008; Iverson et al., 2011; Kean et al., 2011; Zheng et al., 2022). Debris-flows can occur on both burned and unburned landscapes. Decreased vegetation cover and increased soil hydrophobicity increase debris-flow risk on recently burned landscapes (DeGraff, 2018; Jackson & Roering, 2009; Kean et al., 2011; Staley et al., 2012; Rangers et al., 2020). Post-fire debris-flow research in Southern California has observed the highest likelihood of occurrence within the first year after a fire. Most commonly in this region, post-fire debris flow risk remains for 1-4 years post-fire, but depending on soil and vegetation types, risk can persist for much longer (Cannon et al., 2008; Cannon & DeGraff, 2008; DeGraff et al., 2015; Kean et al., 2011). In Southern California, where debris-flows have been most extensively studied, vegetation regrowth has been shown to considerably reduce debris-flow risk after 2 years (Cannon et al., 2008; Kean et al., 2011). In the years following initial vegetation regrowth, debris-flow occurrence is still likely but rather than initiated by rainfall runoff, the events are triggered by shallow landslides (DeGraff, 2018; Jackson &

Roering, 2009; Kean et al., 2011; Rengers et al, 2020). The intensity and duration of rainfall needed to initiate a debris-flow vary across regions due to topographical, vegetation, and soil composition variation (Jackson & Roering, 2009; Kean et al., 2011; Staley et al., 2012).

Landslides

The United States Geologic Survey (USGS) defines landslides as "...the downslope movement of soil, rock, and organic materials under the effects of gravity and also the landform that results from such movement" (Highland & Bobrowsky, 2008, p. 4). Landslide risk exists on burned and unburned landscapes. However, the risk of landslide hazards increases on burned hillslopes due to soil hydrology changes and vegetation loss (Rengers et al., 2020). While distinct from a debris-flow event, landslides do have the potential to turn into debris flows (DeGraff, 2018; Jackson & Roering, 2009; Kean et al., 2011), especially moderate and high burn severity wildfires (Rengers et al., 2020). Similar to PFF and debris flow events, dead vegetation leaves landscapes more at risk to landslides due to weakening root networks and decreased rainfall interception (DeGraff, 2018; Jackson & Roering, 2009; Rengers et al, 2020). Landslide risk on post-fire landscapes is highest three years post-fire and decreases five years post-fire due to the establishment of new vegetation and the return of pre-fire soil hydrologic conditions, which both contribute to restabilizing slopes and reducing landslide risk (Rengers et al., 2020).

Literature Review

Post-Fire Flooding

Due to over 100 years of fire exclusion and suppression, poor forest management, extended drought, and worsening effects of climate change, wildfires are increasing in extent and intensity across the western United States (Fried et al., 2004; Gedalof et al., 2005; McKenzie et al., 2004; Steel et al., 2015). By extension, wildfires are increasingly affecting human cities and towns as populations encroach into wildland areas (Kolden & Henson, 2019; Youberg et al., 2019). The Wildland Urban Interface (WUI) is the fastest growing area of land use and development in the United States (US) (Kolden & Henson, 2019; Radeloff et al, 2017). The WUI encompasses the transition zone where urban areas are intermixed with or adjacent to unoccupied wild landscape (Mell et al., 2010). Concurrent with increasing risks of high-severity fires in western landscapes is increasing concerns over cascading hazards, such as post-fire flood (PFF) events (Burnett & Edgeley, 2023; Edgeley et al., 2024; Elliott & Parker, 2001; Skilodimou et al., 2021; Staley et al., 2020). PFF events are extremely costly hazards and post risk to people and property (Edgeley et al., 2024; Combrink & Rousse, n.d.; Hjerpe et al., 2023). While the biophysical and hydrologic processes that cause PFF have been extensively studied (Garfin et al., 2016; Jackson & Roering, 2009; Rengers et al., 2020; Youberg et al., 2010), little is known about how managers and communities are preparing for increased incidences of post-fire flood events (Burnett & Edgeley, 2023; Edgeley et al., 2024; Skilodimou et al., 2021).

In this study, we use “PFF events” to represent a range of water and sediment movement hazard types in areas recently affected by wildfire, specifically: “debris-flows, mudslides, and other large water or sediment movement events in or adjacent to burn scars” (Edgeley & Colavito, 2022; Burnett & Edgeley, 2023). PFFs are a unique hazard as compared to related land, debris, and water movement hazards because the risk of PFF arises only after a wildfire event (Burnett & Edgeley, 2023; Staley et al., 2020; Williams et al., 2014). As a result, post-fire flood hazards can affect communities that are not accustomed to or prepared for managing a flood event (Burnett & Edgeley, 2023). Burn scars are traditionally considered to be susceptible to PFF for up to five years after the fire, with post-fire debris-flows most commonly occurring four years post-fire (Williams et al., 2014). Despite the amassed biophysical and biogeographical knowledge, few empirical efforts exist to develop the field of PFF social science, or explore how communities prepare for, react to, and are affected by PFF hazards.

Post-Fire Flooding Social Science

There is an immense gap in literature regarding the social impacts and implications of PFF in human communities (Burnett & Edgeley, 2023; Edgeley et al., 2024; Skilodimou et al., 2021). PFF social science work has considered how public awareness and risk perception of hazards influence the motivation of public and private sectors to take mitigative action (Burnett & Edgeley, 2023; Edgeley et al., 2024; Serra-Llobet et al., 2023). Little research has been conducted on building prediction models, flood risk assessment models, hazard notification and warning systems, public awareness, or mitigation efforts related to PFF (Skilodimou et al., 2021). Without better assessment tools and public knowledge of the risk to these hazards, communities that live near these areas will remain unaware of their risk and exposure to future PFF hazards (Edgeley et al., 2024; Skilodimou et al., 2021). Developing these strategies will prove crucial in combating the increasing risk and exposure to PFF events (Burnett & Edgeley, 2023; Edgeley et al., 2024; Serra-Llobet et al., 2023).

PFFs are geographically, economically, structurally, and socially destructive hazards (Burnett & Edgeley, 2023). Flood risk in recently burned areas remains high immediately after the burn to four and five years post-fire until vegetation returns to the landscape (Cannon et al., 2008; FEMA, n.d.; Kean et al., 2011; Rengers et al., 2020; Williams et al., 2014). PFF floods can also occur during wildfire events or less than one year after a fire (Edgeley & Colavito, 2022). At the onset of a PFF event, communities recently impacted by a wildfire event are often still recovering from the impacts of the earlier wildfire event (Mockrin et al., 2022). Social issues such as collective grief and loss of community remain for years after a wildfire event and can impact individual and collective adaptive capacity when addressing cascading or new hazards (Mockrin et al., 2022). Similarly, residents in a fire-affected area may have unresolved housing, insurance, and financial security issues due to the fire event (Edgeley et al., 2024; Mockrin et al., 2022) that can keep them susceptible to subsequent hazards, including PFF. Even if a downstream or slope community had no negative impacts from the previous wildfire event, a PFF event can expose those individuals to injury, death, property loss, and loss of community (Burnett & Edgeley, 2023; Kean et al., 2019)–impacts which are likely to be worse when pre-PFF planning, mitigation efforts, or public awareness to the hazard has not been established.

Floods are some of the most expensive and fatal natural disasters (Burnett & Edgeley, 2023; Edgeley et al., 2024; Hjerpe et al., 2023; Kean et al., 2019). Communities with the highest exposure to PFF hazards are located adjacent to, or downstream of a burned area (Burnett & Edgeley, 2023; Youberg et al., 2019). The areas most at risk are situated in canyons, at the base of steep hillsides, or near excavated slopes. Even areas at distance from a burn scar (e.g., if they are downstream in a watershed) can be inundated by PFF (Burnett & Edgeley, 2023; Youberg et al., 2019). Areas that were not previously at risk of flooding (determined by maps and assessments made by the Federal Emergency Management Agency (FEMA)) may be at risk to PFF hazards due to the changes in topography, soil stability, and soil hydrophobicity (Burnett & Edgeley, 2023; FEMA, n.d.; Skilodimou et al., 2021; Staley et al., 2020; Williams et al., 2014; White et al., 2022; Vojtek, & Vojteková, 2016).

Residential areas near Flagstaff, Arizona in Coconino County were affected by the Schultz Fire in 2010 (Edgeley & Colavito, 2022; Youberg et al., 2010). A month after the burn, summer monsoonal rains came through the area, causing a number of flooding events on the recently burned landscape (Edgeley & Colavito, 2022; Youberg et al., 2010). These post-fire floods resulted in extensive property, infrastructure damage, and one death (Edgeley & Colavito, 2022). The areas most affected by the 2010 Schultz Fire floods had not been in a FEMA flood-risk classified zone (Burnett & Edgeley, 2023). However, due to the post-fire properties of the landscape the areas flooded one month after the fire (Burnett & Edgeley, 2023). To improve mitigation tactics and hazard warning systems, researchers recommended stronger PFF prediction, erosion, and hydrologic models be developed, and that areas recently affected by fire should be immediately evaluated for flood risk to better inform nearby communities of their risk to potential hazards (Burnett & Edgeley, 2023).

Post-fire hazard planning documents

Hazard Planning Documents	**Document Description***	**Use in PFF hazard planning**
Maps of wildfire risk	Maps classifying the severity of wildfire potential (WFP) as very low, low, moderate, high, and very high (Dillon et al., 2015)	Used to identify future areas of PFF risk - as PFF risk is inherently related to wildfire risk (Skilodimous et al., 2021)
Maps of post-fire risk	Maps classifying the location	Used to identify post-fire

	of soil, vegetation, and hydrologic changes on post-fire landscapes (Mallinis et al., 2009; Staley et al., 2017)	changes to determine conditions that would influence the initiation of a PFF (Friedel, 2011; Kinoshita et al., 2014)
Disaster recovery plans	Documents developed to promote social, community and landscape recovery after a disaster (Berke et al., 2015)	Developing hazard responses improves preparedness to future hazards promoting resiliency (Berke et al., 2015)
Hazard mitigation plans	County and statewide documents developed to mitigate future hazards (Berke et al., 2012)	Preparing plans for mitigating community and ecological risk to PFF hazards, step towards implementing mitigation strategies (Berke et al., 2012)
Protocol/plans for flood risk	Maps and plans for monitoring flood risk, and developing response to future flooding hazards (Albano et al., 2017)	General flood plans can be applied to PFF hazards so communities know how to respond and recover from mass water-movement events
Community wildfire protection plans (CWPP)	Community-based wildfire risk reduction projects designed to change intensity	Increased public awareness and decreased wildfire risk improves mitigation

	and path of wildfires, and build community resilience (Jakes & Sturtevant, 2012)	implementation and decreases wildfire risk (Burnett & Edgeley, 2023; Jakes & Sturtevant, 2012)

Table 2: Hazard planning and risk assessment documents

*for additional details on the development and purpose of these documents, please refer to cited authors

Hazard Mitigation Plans

Hazard Mitigation Plans are actionable documents designed and enacted by government officials for local areas to mitigate risk to hazards in the area (Berke et al., 2012; Frazier et al., 2013), including PFFs. The goals of HMPs are to identify, prepare for and reduce risks for communities and infrastructure susceptible to certain hazards (Berke et al., 2012; Frazier et al., 2013; Youberg et al., 2019). Via the Disaster Mitigation Act, FEMA requires states and counties across the U.S. to develop HMPs. FEMA declares the role of HMPs to keep natural hazards (the threat of a negative event) from becoming natural disasters (the negative impacts of an event) (FEMA, n.d.), and allows municipalities and counties with HMPs to become eligible for a variety of FEMA grant programs. While HMPs are government documents written and acted upon for the community, research and policymakers have described that planning documents are most useful when public and private stakeholders are involved in describing and implementing mitigating actions (Berke et al., 2012; Oregon.gov, n.d.). HMPs can be developed locally or across multi-jurisdictional areas (Berke et al., 2012; Frazier et al., 2013) and may be nested into additional layers of local, cross-jurisdictional, or state-wide disaster and hazard mitigation planning (Jakes et al. 2007).

HMPs are best broken down into sections of risk assessment and mitigation strategy (Oregon.gov, n.d.). Other sections include a capability assessment and plan maintenance strategies (Planning for Hazards, n.d.). The risk assessment portion of a HMP often includes descriptions of the local hazards, assessing exposure and summarizing the risk to the jurisdiction (Berke et al., 2012; Frazier et al., 2013). This section intends to determine how the community would be affected economically, infrastructurally, and socially in the event of a natural hazard. A mitigation strategy encompasses mitigation goals, capability assessments, mitigation actions, and an implementation plan (Srivastava & Lurian, 2006). This portion of the HMP will outline how physical and educational action throughout the community can effectively mitigate and reduce community risk to the specified hazard (Oregon.gov, n.d.). Different communities are at risk to distinct hazards, and therefore should develop locally specific plans for the hazards that most affect them (Berke et al., 2012; Frazier et al., 2013; Srivastava & Lurian, 2006). Many areas affected by PFF already have wildfire, debris-flow, and, potentially, flood HMPs in place (Burnett & Edgeley, 2023; Edgeley et al., 2024). However, there is an immense gap in literature surrounding the existence, development, and enactment of PFF mitigations in HMPs and other planning documents (Burnett & Edgeley, 2023; Edgeley et al., 2024).

States and counties across the U.S. are required to have HMPs in place to prepare for future disasters and reduce human and societal losses during those disasters (FEMA, n.d.). However, there is a lack of requirements and guidelines for HMP development outlined in the Disaster Mitigation Act (Frazier et al., 2013). Without requirements for developing and implementing PFF mitigation strategies, only a small number of counties in the western U.S. include PFF mitigation strategies in their HMPs (informed by Phase 1 of this study, see Pre-Chapter for additional details) (Frazier et al., 2013). The absence of PFF mitigation and PFF hazard preparations is likely due to a lack of risk awareness (Burnett & Edgeley, 2023; Youberg et al., 2019). Additionally, the presence and history of a wildfire does not always result in a PFF event. In addition to fire history, PFF events are dependent on wildfire severity, local hydrology, topography, vegetation, and regional climates (Cannon et al., 2008; FEMA, n.d.; Kean et al., 2011; Rengers et al., 2020; Williams et al., 2014). With these considerations, not every community affected by wildfire will be affected by PFF, making risk assessment and awareness dependent on consideration of other environmental factors. Without knowledge of risk to a PFF hazard, communities likely do not have PFF mitigations included in the local HMP, or implemented in their area. Discourse and design of flooding prediction models is relevant to the design of PFF mitigations in HMPs as they can better inform policy makers of the threats that face their communities (Skilodimou et al., 2021). Without the mitigating strategies and preparations that come with the development of a HMP, an at-risk community may experience higher severity floods and more extensive damages (Berke et al., 2012; Youberg et al., 2019).

To improve mitigation and preparation strategies for PFF events, this study will seek to determine how public planning officials approach the creation of HMPs in their jurisdictions, and how PFF hazards are considered included in hazard mitigation planning. Beyond the development of HMPs, which have demonstrated varying levels of effectiveness when engaging in hazard mitigation and response, this study aims to determine how counties plan and mitigate emergent hazards. By determining how PFF hazards are considered in HMPs, what managers need for future mitigation development, and what strategies exist stronger PFF mitigation strategies can be developed to reduce risk and exposure to future hazards.

Existing Prediction and Mitigation Strategies of Post-Fire Floods

Many consider fire and flood prediction modeling to either be understudied (Serra-Llobet et al, 2023; Skilodimou et al., 2021) or underdeveloped given the diversity of contexts in which these hazards occur – rapidly changing wildfire and flood risk circumstances. Without proper mapping and prediction methods, communities may not know their risk or likelihood of being affected by fire or PFF (Friedel, 2011; Serra-Llobet et al., 2023; Skilodimou et al., 2021). A lack of knowledge of risk can lead to a lack of proper preparation and mitigation initiative (Burnett & Edgeley, 2023; McCaffrey & Kumagai, 2007; Rogers, 2006; Serra-Llobet et al., 2023). Individual and community risk perception blends the physical risks of a hazard with social response to the hazard (Serra-Llobet et al., 2023). Higher individual risk perceptions prompt private landowners to act on mitigation projects regardless of public action or policy to reduce personal and social risk (Burnett & Edgeley, 2023). Community risk perceptions are often changed through triggering events (i.e., the actual occurrence of the hazard event), a "near miss," or through word-of-mouth or changing social norms within interpersonal networks that galvanize interest in adaptation (McCaffrey & Kumagai, 2007; Rogers, 2006). Additionally, wildfires and post-fire floods do not act according to jurisdictional boundaries; therefore, to minimize future impacts it is crucial to consider how private and public collaboration could improve mitigation efforts (Burnett & Edgeley, 2023).

Post fire flooding risk assessments

Burned Area Emergency Response team post-fire assessments are crucial in determining post-fire treatment decisions (Kruse et al., 2004; Robichaud et al., 2009). BAER team assessments are deployed to a landscape if a fire burns at least 500 acres. Response specialists utilize landscape assessments and predictive modeling to determine which treatments are needed based on vegetation types, burn severity, topography, climate, and other factors (Robichaud et al., 2009). In some instances, these assessments do not recommend any remediation or restabilization actions if no human interests are at risk – potentially limiting their effectiveness in PFF mitigation. These assessments are intended to aid in preventing immediate hazards on post-fire landscapes, but do not mitigate long-term hazards (Robichaud et al., 2009). BAER assessments are crucial to PFF mitigation as these assessments factor in to determining what kinds of mitigation techniques need to be applied to the landscape (Kruse et al., 2004; Robichaud et al., 2009). With preparation for implementation post-fire mitigation techniques, BAER reports are crucial to determining what measures, if any, are appropriate for remediating the affected landscape (Kruse et al., 2004; Robichaud et al., 2009).

Current mapping and prediction methods to determine post-fire flood exposure utilize biophysical, geographical, and social science measures (McCaffrey & Kumagai, 2007; Serra-Llobet et al., 2023). Biophysical measures include details of a fire's severity, vegetation loss, hydrophobic soils, and soil structure changes (National Interagency Fire Center, n.d.; Robichaud et al., 2009; Serra-Llobet et al., 2023). Geographic measures include the type of terrain, hillside steepness, and watersheds (National Interagency Fire Center, n.d. Robichaud et al., 2009; Serra-Llobet et al., 2023). Social measures are equally important in predicting the effects of post-fire flood to navigate human reactions and response to a hazard (Cerulli et al., 2020; Heller et al., 2005). Existing flood prediction models are useful in the prediction of water transport (Oakley, 2021; Skilodimou et al., 2021). However these models can not be relied on for predicting PFF due to the number of additional variables that cause a post-fire flood (Skilodimou et al., 2021). The most effective existing PFF model considers the changes in soil properties, increased runoff and existing topography in predicting the hazard (Oakley, 2021; Skilodimou et al., 2021). Post-fire flood specific mapping and prediction technologies need to be further developed to support community preparedness and the development of mitigation strategies.

Slope stabilization measures

Mulching practices involve layering straw or wood mulch over the slopes (Girona-Garcia et al., 2021). Mulching is an immediate implementation stabilization measure that increases landscape absorbency and prevents infiltration of rainfall or water into burned soils (Girona-Garcia et al., 2021). The effectiveness of this technique is largely reliant on the amount of time that the mulch remains in place on the stabilization site (Girona-Garcia et al., 2021; Vega et al., 2013). Mulching is one of the most common slope stabilization measures applied to post-fire landscapes due to the ease of application and cost effectiveness of this strategy (Girona-Garcia et al., 202).

Seeding is a delayed-response stabilization measure, with little to no stabilization impact made in its first year of implementation (Girona-Garcia et al., 2021). Seeding reaches maximum effectiveness five years after implementation (Peppin et al., 2010; Girona-Garcia et al., 2021). When considering the timelines of PFF hazards, seeding is potentially most effective at mitigating debris-flows as opposed to landslides or flood events. Effectiveness of seeding is also dependent on rainfall patterns, as heavy rainfall events can wash away the seeds before they are established (Girona-Garcia et al., 2021). Further issue with seeding practices is the spread of invasive grass species (Robichaud & Elliot, 2006).

Wattles and contour felling are slope stabilization measures designed to introduce physical barriers onto the landscape. The effectiveness of barrier stabilization measures is inconclusive with results depending on annual rainfall (Girona-Garcia et al., 2021). They are designed to slow water movement and increase infiltration (Santos et al., 2020). Additionally, they are intended to capture and slow run-off, confining erosion effects to a lesser area (Robichaud & Elliot, 2006). Barriers include hay bales, fallen trees (which are an abundant resource on burned landscapes), or man-made barriers (Girona-Garcia et al., 2021; Robichaud & Elliot, 2006; Santos et al., 2020).

Sediment or debris control measure

Check dams are a standard mitigation strategy utilized to mitigate risk and damage from debris-flows (Xiong et al., 2016). Dam strategies intend to trap particles to minimize sediment transport and slow the flow of the hazard (Xiong et al., 2016). Effectiveness of these structures rely on the size of the structure, the size of the hazard, and the quality of the structure build (Xiong et al., 2016). Check dams are most effective on smaller slopes, as they cannot withstand the force of larger debris flows. In between events, check dams accumulate sediment and if they fail during a debris flow event, can contribute even more sediment to the flow (Xiong et al., 2016). Dredging and debris removal, is the physical removal of existing debris on a landscape. This strategy intends to reduce the amount of sediment and additional debris that is swept up in the event of a PFF hazard (Robichaud & Elliot, 2006; Xiong et al., 2016). Little literature exists on the efficiency and effectiveness of dredging and debris removal on PFF mitigation.

Public safety measures

Public hazard awareness fluctuates significantly over time, rising immediately after an event, before awareness gradually declines as time passes (Cerulli et al., 2020; Heller et al., 2005). Public awareness cannot be reliant on the recency of a local hazard. Proactively raising public awareness via education and signage initiatives is crucial to maximizing the effectiveness and efficiency of other mitigation strategies and maintaining public safety (Cerulli et al., 2020; Pearce, 2003; Shaw, Takeuchi & Rouhban, 2009). Public education to improve awareness has a myriad of benefits for advancing mitigation strategies (Pearce, 2003). Public education leads to the implementation of mitigation strategies on private lands, maximizes efficiency of preparedness, and protects human life by raising awareness to response measures in the event of a hazard (Cerulli et al., 2020; Peace, 2003). Additional strategies informing awareness and promoting public safety include the installation of rain gauges (which send risk alerts in at-risk areas after a rainfall threshold is reached), and enactment of road closures (Dalziell & Nicholson, 2001; Dao et al, 2020; Montesarchio et al., 2009). Road closures, while costly, are effective at managing risk of injury and threat to human life (Dalziell & Nicholson, 2001). The installation of rain gauges serves primarily as an indicator of PFF risk based on rainfall accumulation which influence PFF prediction capabilities (Jong-Levinger et al., 2024).

In contrast, a lack of general knowledge of how to prepare and respond to a hazard leads members of the public into states of avoidance and denial – effectively curbing mitigation efforts at protecting public safety (Heller et al., 2005; Peace, 2003). Strategies to improve hazard, mitigation, and response awareness include public training and meetings, warning notifications, social network dissemination, warning signage, and media coverage (Cerulli et al., 2020; Heller et al., 2005; Shaw, Takeuchi & Rouhban, 2009). Public education and awareness of PFF hazards is crucial due to the immediate development of PFF risk after a fire, and the substantial threat to public assets and human life. Improving these elements of public hazard awareness (PFF specific) may lead to increased mitigation action on private lands – further minimizing cross-boundary risk to PFF hazards and protecting human assets and safety.

Wildfire risk reduction measures

The risk of post-fire floods is inherently influenced by wildfire risk and occurrence (Cannon & DeGraff, 2008). By mitigating wildfire risk, the risk and occurrence of post-fire flood events are mitigated as well (Cannon & DeGraff, 2008; Kolden & Hence, 2019). Vegetation fuel treatments and prescribed burning are mitigation tactics utilized to reduce wildfire risk (Burnett & Edgeley, 2023, Youberg et al., 2019). Vegetation and fuel reduction treatments include the construction of fuel breaks, fuel mastication, and thinning treatments (Ager et al., 2015). These strategies intend to reduce fuel loads to minimize ignition, fire intensity, and spread (Ager et al., 2015). Prescribed burns are another method of fuel and wildfire management (Fernandes & Botelho, 2003; Penman et al., 2011). Prescribed burns are applied strategically to manage fuel load inorder to minimize the intensity and spread of wildfire (Fernandes & Botelho, 2003; Penman et al., 2011). While these efforts of fuel load management do not eliminate the risk of wildfire, their implementation has improved the manageability of wildfires that occur in treated areas (Fernandes & Botelho, 2003; Penman et al., 2011). With improved wildfire management abilities, wildfires on treated areas exhibit lessened burn severity and a smaller burned area (Fernandes & Botelho, 2003). In these areas, the risk of PFF events will be reduced as an additional mitigating effect of fuel load management techniques (Rengers et al., 2020)

Direction of Research

Alongside a lack of PFF hazard inclusion in HMPs, there is a severe lack of post-fire flood specific mitigation strategies. For at-risk communities to be better prepared and to reduce the infrastructural and social damages, post-fire flood specific mitigation strategies need to be developed alongside prediction and warning notification models. This research intends to further determine how Hazard Management Plans are developed throughout the 11 western states, how PFF hazards are considered in the development of HMPs, what mitigative actions are taken to reduce PFF risk, and what resources are needed to improve future mitigation of these events. The outcome will be able to better inform public and private planning managers on assessing post-fire flood risk and how to take mitigative action within their jurisdictions.

Research Questions

1. How do managers **perceive PFF risk** in their area?
   a. See Table 3
2. What **mitigation strategies are being utilized and how effective are they?**
   a. See Table 4
3. What do mitigation planners **need to feel better prepared for future PFF events?** And to **develop PFF mitigation strategies?**
   a. See Table 5

Methods

Study Area and Scope

This study explores how mitigation strategies and emergency management plans related to PFF develop and are implemented across an array of local contexts. PFF was defined in the survey as "debris-flows, mudslides, and other large water or sediment movement events in or adjacent to burn scars," (Burnett & Edgeley, 2023). The study area of this project covers 11 western states, specifically Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. These states were ideal for our PFF study due to their elevated wildfire activity and wildfire intensity, which makes them inherently at higher risk for PFF than other regions (Burnett & Edgeley, 2023; Edgeley et al., 2024; Gedalof et al., 2005; Skilodimou et al., 2021; Westerling et al. 2002 Westerling et al., 2006). The variety of climates, ecosystems, geologic, and socio-political contexts across these areas permit us to explore PFF adaptations and needs across a diversity of landscape and community types (Westerling et al., 2006) and begin to build theory in the otherwise nascent field of PFF social science.

Survey Recruitment

In a prior portion of this study, researchers from Northern Arizona University identified which county-level HMPs throughout the western 11 states included PFF mitigation strategies in their plans. To begin selecting for recruitment, researchers utilized a purposive sampling approach, selecting participants based on their experience or adjacent experience to managing post-fire flood risk and mitigation (Campbell et al., 2020; Tongco, 2007). Recruitment sample frame development began by finding contacts from counties that had historical occurrence of a post-fire flood event or from HMPs which include post-fire flood specific mitigation strategies. Initial contact was made via email or phone to the publicly-listed contact information in the county HMPs. If contacts were willing to participate, a phone survey was scheduled. If the contact did not wish to participate, were not available (e.g., retired, moved on to a new job), or felt that they did not have the relevant experience to the survey (e.g., did not have expertise in PFF but were involved in the HMP as an agency liaison) they were asked who they would recommend participate on the within their jurisdiction to ensure survey representation from their area. This referral mechanism is called snowball sampling (aka: chain referral) and it is utilized to broaden and deepen the scope of a sample frame by identifying additional participants based on preliminary contact recommendations (Tongco, 2007).

Snowball sampling was also used at the end of the survey. A concluding question in the phone survey asks for other individuals within the participant's field or jurisdiction that has relevant expertise and should be invited to participate in the study (Tongco, 2007). This recruitment step intended to identify individuals whose information was not publicly available or who were not contacted in the first round of purposive sampling (Tongco, 2007). This study sought representative participants from various states, jurisdictions, and hazard management roles. Every participant gave consent for voluntary participation and received no compensation for their contribution to the study. This study was approved by the University of Oregon Institutional Review Board (IRB) protocol.

Phone Survey Methodology

The data collection approach of this study was phone survey administration (Dillman et al., 2014; Groves, 1990). The "phone" surveys were conducted over the phone or on a Zoom or

Teams video call platforms. Phone surveys are ideal for navigating both qualitative and quantitative data collection across large geographical areas (Couper, 2017; Dillman et al., 2009). They are an economical alternative to face-to-face survey, and allow for purposive sample frames (Couper, 2017). As opposed to web or mail-based surveys, phone surveyors are able to ensure that respondents complete the survey (limiting responses such as "I don't know," "n/a," or "No response") for a robust data sample (Couper, 2017; Dillman et al., 2009), and to allow for additional context collected through unscripted discussion with respondents. Phone surveys are known to exhibit low response rates, but nonresponse bias can be minimized if respondents and nonrespondents do not differ on key demographic variables (Couper, 2017; Dillman et al., 2009; Dillman et al., 2014; Groves, 1990). Survey practice was to receive oral consent to participation at the beginning of each survey (Barata et al., 2006). Each open-ended answer was recorded and/or transcribed with the participant's consent to allow for later qualitative analysis, quality checking of manual survey data entry by the researcher(s), and AI and/or human transcription. Surveys were completed in 30-60 minutes and averaged approximately 45 minutes. The survey was conducted by reading aloud each question and corresponding answer options. If necessary, participants could opt to skip or decline to answer questions (Dillman et al., 2014). Giving participants an opportunity to skip or decline an answer is important maximize accuracy of results if respondents do not know the answer, or to protect the privacy of respondents if there is information that they are not comfortable sharing.

Survey Protocol Development

The survey protocol was drafted while considering risk perception of PFF, development of HMPs, PFF mitigation strategies, historical PFF events, and the challenges respondents encountered when planning for PFF. The survey was initially tested with a small number (n=3) of key informants the researchers knew well to collect feedback on the efficacy of the drafted protocol (Batterhorn & Hale, 2020) as well as preliminary data. The survey protocol was modified accordingly, including generating a consistent definition of PFF and modifying some response choices. Overall, the survey instrument consisted of 26 questions including dichotomous (e.g., yes/no), single-answer multiple choice (i.e., "please select only one answer choice), Likert-scale (e.g., responses on scale of 1-5) and open-ended questions (see Appendix for complete protocol questions) (Dillman et al.,2014). The key categories of the survey included 1) Participant background 2) Risk Perceptions 3) Planning for PFF 4) Navigating post-fire flood response and 5) Feedback and contact snowballing.

Likert scale questions were designed to determine participants' level of knowledge, perceptions, and attitudes towards their experiences in hazard mitigation planning (Batterton & Hale, 2017, Dillman et al., 2014). Likert-scale questions are particularly useful for collecting standardized data on human opinion and experience across varying degrees (Boone & Boone, 2012). The Likert 1-5 scale facilitates results that express a "greater than" or "less than" relationship of survey measures – exactly quantifying measures of opinion or experience are not relevant (Boone & Boone, 2012). Our Likert-scale questions can be viewed in Table 3, Table 4, and Table 5 (see Appendix to reference additional measures).

Dichotomous "yes or no" response questions were designed to determine general trends and occurrence of survey variables (Dillman et al., 2014), such as, "Does your county have a history of post-fire flooding?" Multiple choice, single-answer questions were designed to determine more specific responses to survey variables from predetermined options (Dillman et al., 2014). These variables were often categorical in nature and often do not have an ordinal or scalar component to them (e.g., professional field, access to resources, resource usefulness questions). Finally, while largely a quantitative data collection survey, several open-ended questions were built into the protocol to allow for more detailed understandings of managers' perspectives and experience on PFF (Dillman et al., 2014). This is especially important because our work in PFF social science is largely exploratory, with little known about the topic from which to draw testable hypotheses (Burnett & Edgeley, 2023; Edgeley et al., 2024; Skilodimou et al., 2021). As a result, permitting the addition of rich qualitative data to uncover trends and needs was a key component of our data collection effort.

Statistical Analysis

Descriptive statistics were the primary statistical tests utilized in the data analysis portion of this study. The program Statistical Package for Social Sciences (SPSS) version 30 (IBM, 2024) was utilized to organize and compile the data and statistical results. Variable sums, averages, and recode commands were employed to derive descriptive statistics that covered the variables for each research question (see Tables 6, 7, 8, & 9). Analysis was then conducted based on the minimum, maximum, mean, and standard deviation values of the selected variables for each research question. Dichotomous variables from the survey were recoded from 1=No and 2= Yes, to 0=No and 1=Yes to better reflect the presence or absence of certain variables.

To combine listed variables to generate composite scores, the SPSS command “Compute Variable” was utilized to create new variables. This strategy was used for converting the documents respondents had available, into a total sum of documents each respondent had access to. This new variable was derived with intent to determine how influential planning documents are in relation to a respondent’s perceived preparedness for a future PFF event, and to better understand what respondents use when planning mitigations. Additional computed variables included a summation of mitigation strategies implemented in a county to determine how many total measures counties are implementing in relation to their perceived preparedness for an event. The "Compute Variable" command was also utilized in computing average responses for determining how easy or difficult it is for respondents to access resources needed for advancing post-fire flood hazard management. This variable also intends to inform how resource availability might influence mitigation strategy activity and resulting perceived preparedness for an event.

Survey Protocol Variables

Please see Table 3, 4, and 5 for the survey protocol variables included in the statistical analysis of this study.

Research Question 1: How do managers **perceive PFF risk** in their area?		
Variable names	**Measures**	**Response option(s)**
History of PFF	**Does your county have a history of post-fire flooding?**	1 = Yes 0 = No
Frequency of PFF events	**How often does your county experience post fire floods?**	Fill in the blank, # in years
Wildfire risk	**Which of the following best describes the current level of wildfire risk in your county?**	1 = Very low 2 = Low 3 = Moderate 4 = High 5 = Very high
Perceived flood risk	**Which of the following best describes the current level of post-fire flood risk in your county?**	1 = Very low 2 = Low 3 = Moderate 4 = High 5 = Very high
Perceived preparedness	**How prepared do you feel your county is for a future post-fire flood event**	1 = Not at all prepared 2 = Somewhat prepared 3 = Moderately prepared 4 = Very prepared
Tenure in county	**How long have you worked and/or lived in your county?**	Open-ended, years

Tenure in PPF-related positions	**How many years of experience do you have in positions related to planning, response, or recovery for post-fire flooding?**	Open-ended, years
Access to resources	**Do you currently have access to any of the following items related to fire and post fire risks?** ● A map of wildfire risk for you county ● A map of post-fire risk for your county ● A disaster recovery plan for your county ● A hazard mitigation plan for your county ● A protocol or plan for addressing flood risk for your county ● A community wildfire protection plan (CWPP) for your county ● Other documents: describe	1 = Yes 0 = No 0 = I don't know
Implemented mitigations	**In the last five years, has your county implemented XXX mitigation?** ● **Post-fire flooding risk assessments, such as** Burned Area Emergency Response (BAER) Team post-fire assessments, economic or hydrologic	1 = Yes 0 = No 0 = I don't know

	modeling, flood prediction, or engineering analyses? • **Slope stabilization measures**, such as mulching, seeding, wattles, or contour felling? **Sediment or debris control measures**, such as dam installation, dredging, or debris removal? • **Public safety measures**, such as area or road closures, installation of warning signage, or installation of rain gauges • **Wildfire risk reduction measures**, such as prescribed fire or thinning • **Other:** describe	
Need for response revisions	**For the documents we just discussed*, to what extent are revisions needed for better response and efficacy in the future?**	1 = Significant revisions are needed 2 = Moderate revisions are needed 3 = Some revisions are needed

		4 = No revisions are needed

Table 3: Survey variables for RQ 1

*Documents covered earlier in the survey that this measure is referring to include: *Map(s) of wildfire risk for jurisdiction, Map(s) of post-fire risk for jurisdiction, Disaster recovery plan, Hazard Mitigation Plan, Community Wildfire Protection Plan (CWPP) for jurisdiction, and Other*

Question 2: What **mitigation strategies are being utilized and how effective are they?**		
Variable names	**Measures**	**Response Options**
History of PFF	**Does your county have a history of post-fire flooding?**	1 = Yes 0 = No
Multi-jurisdictional effects	**Did past PFF event(s) impact multiple jurisdictions (e.g. private or public land, city and federal land, etc.)?**	1 = Yes 0 = No 888 = I don't know
Perceived flood risk	**Which of the following best describes the current level of post-fire flood risk in your county?**	1 = Very low 2 = Low 3 = Moderate 4 = High 5 = Very high
Implemented mitigations	**In the last five years, has your county implemented XXX mitigation?**	1 = Yes 0 = No

	• **Post-fire flooding risk assessments, such as** Burned Area Emergency Response (BAER) Team post-fire assessments, economic or hydrologic modeling, flood prediction, or engineering analyses? • **Slope stabilization measures**, such as mulching, seeding, wattles, or contour felling? **Sediment or debris control measures**, such as dam installation, dredging, or debris removal? • **Public safety measures**, such as area or road closures, installation of warning signage, or installation of rain gauges • **Wildfire risk reduction measures**, such as prescribed fire or thinning • **Other:** describe	0 = I don’t know

Table 4: Survey variables for RQ 2

Question 3: What do mitigation planners **<u>need to feel better prepared for future PFF events?</u>** And to **<u>develop PFF mitigation strategies?</u>**		
Future preparedness	**How helpful or unhelpful would the following resources be for advancing post-fire flooding hazard management in your county?** ● Collaborative response drills with cooperators Collaborative tabletop or scenario-exercises ● Shared training days ● Memorandums of understanding (MOUs) for post-fire flood response ● Mutual Aid Agreements for post-fire flood response ● Proactive establishment of shared communication channels ● Shared equipment for post-fire flood ● Grants specifically to support post-fire flood mitigation ● Cost shares specifically to support post-fire flood mitigation	0 = I already have access to this 1 = Helpful 0 = Unhelpful

	● Support or resources to accelerate mitigation activities ● Other measures: describe	
Ease of Access	**How difficult or easy has it been to access the following resources to advance post-fire flood risk reduction in your county?** ● Funding to support mitigation ● Staffing capacity ● Local expertise on post-fire flooding or related topics ● Public support ● Political support ● Coordinate mitigation across jurisdictions ● Contractors or skilled workers to execute mitigation activities ● Other resources: describe	1 = Very difficult 2 = Somewhat difficult 3 = Neither easy nor difficult 4 = Somewhat difficult 5 = Very easy
Need for response revisions	**For the documents we just discussed*, to what extent are revisions needed for better response and efficacy in the future?**	1 = Significant revisions are needed 2 = Moderate revisions are needed

		3 = Some revisions are needed 4 = No revisions are needed

Table 5: Survey variables for RQ 3

*Documents covered earlier in the survey that this measure is referring to include: *Map(s) of wildfire risk for jurisdiction, Map(s) of post-fire risk for jurisdiction, Disaster recovery plan, Hazard Mitigation Plan, Community Wildfire Protection Plan (CWPP) for jurisdiction, and Other*

Results:

Respondent characteristics

Survey respondents were recruited from professionals who work in the western United States. While repeated contact efforts were attempted with 110 potential participants, our results discuss findings from our 13 responses completed at the time of writing. Participants (n=13) were from California (39%), Oregon (47%), and Arizona (15%). Respondents typically had more work experience in their field (M=14.51 years, SD = 10.91 years) than in the subfield of managing PFF hazards (M= 11.46 years, SD = 10.58) (Table 6). The professional and educational backgrounds of respondents included emergency management (62%), land management (8%), engineering (8%), and something other than what was listed (23%). Roughly 85% of survey participants (n=13) worked and lived in counties that have experienced at least one post-fire flood event (Table 6).

Influences on perceived preparedness for PFF

Respondents described the frequency of PFF events in their county to be once every 2-5 years (*M* = 3.30, SD = 1.34). Of the respondents, 31% reported experiencing PFF events every year, and 23% respondents reported experiencing PFF events less than once every 10 years. Respondents, on average, perceived their current wildfire risk as high (*M* = 4.17, SD = 0.84) and their PFF risk to be moderate (*M* = 3.31, SD = 1.18) (Table 6, Figure 4). Of the respondents, 23% reported their PFF risk to be very high, and 8% of respondents reported their current risk of PFF events to be very low (Figure 4). Approximately 15% of respondents reported that a PFF is very unlikely, while 23% reported that it is very likely for a PFF event to occur somewhere in their county in the next 5 years (Figure 2). On average, participants reported that it is neither likely nor unlikely that a PFF event will occur in their county in the next 5 years, although the standard deviation shows a high degree of variation between respondents. This deviation is potentially dependent upon whether there have been recent wildfires or the participant perceives their fire risk to be high (*M* = 3.54, SD = 1.27) (Figure 2).

Respondents have worked in their field for an average of 14.51 years (SD = 10.91) and have an average of 11.46 years (SD = 10.58) of experience managing PFF hazards. Respondents had a maximum tenure of 34 years, and minimum tenure of 1 years of field experience, with maximum PFF experience of 40 years, and minimum PFF experience of 1 years. Of the six kinds of documents associated with PFF planning and mitigation, respondents had access to a minimum of 4 and a maximum of 6 documents (*M*= 5.33, SD = 0.78). Of the 6 kinds of PFF mitigation strategies tested in this study, respondents reported a minimum of 3 mitigations, and a maximum of 6 mitigations implemented in their county (*M*=4.77, SD = 1.01) had been implemented in the respondents' counties.

In regards to the available PFF mitigation, planning, and response documents discussed in this survey, respondents who reported county and tenure history of a PFF event reported on the efficacy of mitigation and response related documents. Respondents in this category (n=8) reported that moderate revisions are needed (M = 2.75, SD = 0.89) for better response and efficacy (Table 6).

Manager Perception of Local PFF Risk			
Survey Variables	N	Mean (SD)	Survey measures
County history of PFF	13	0.85(0.38)	1=Yes 0=No
Frequency of PFF events	10	3.30(1.34)	1=More than once a year 2=Once a year 3=Once every 2-5 years 4=Once every 6-10 5=Less than once every 10 years
Perceived wildfire risk	12	4.17(0.84)	1=Very low 2=Low 3=Moderate 4=High 5=Very high

Perceived PFF risk	13	3.31(1.18)	1=Very low 2=Low 3=Moderate 4=High 5=Very high
Perceived preparedness for a future PFF event	13	2.85(0.80)	1=Very low 2=Low 3=Moderate 4=High 5=Very high
Likelihood of a future PFF event	13	3.54(1.27)	1=Very unlikely 2=Somewhat unlikely 3=Neither likely nor unlikely 4=Somewhat likely 5=Very likely
Tenure in position	12	14.51(10.91)	Years
PFF-specific experience	13	11.46(10.58)	Years
Number of hazard planning documents	12	5.33(0.78)	Sum of hazard planning documents that respondents had access to
Total Mitigation Strategies	13	4.77(1.01)	Sum of strategies implemented in

Implemented in County			jurisdiction (total = 6)
Number of future revisions needed to existing documents (n=8)	8	2.75(0.89)	1=Significant revisions are needed 2=Moderate revisions are needed 3=Some revisions are needed 4=No revisions are needed

Table 6: Descriptives on Manager Perception of local PFF Risk

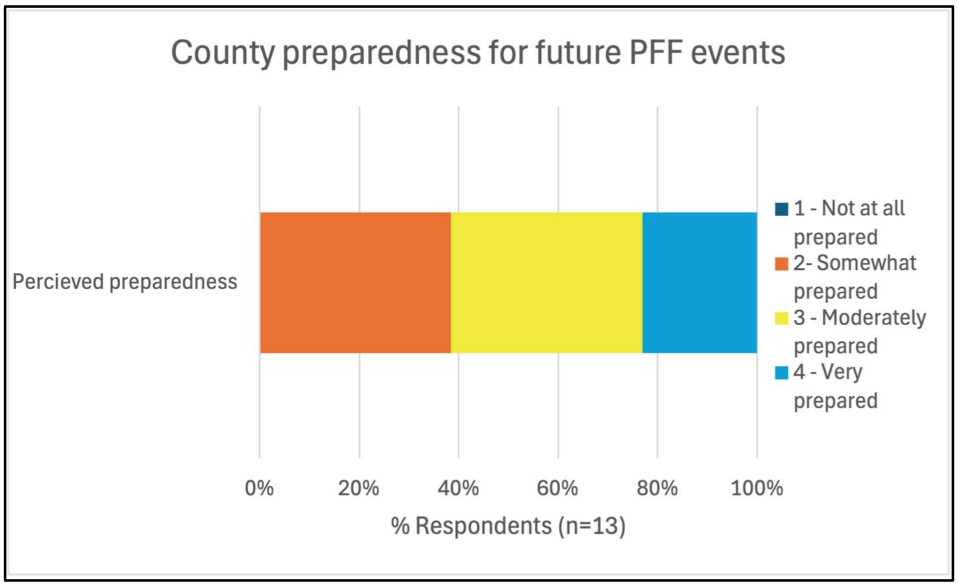

Figure 1: County preparedness for future PFF events

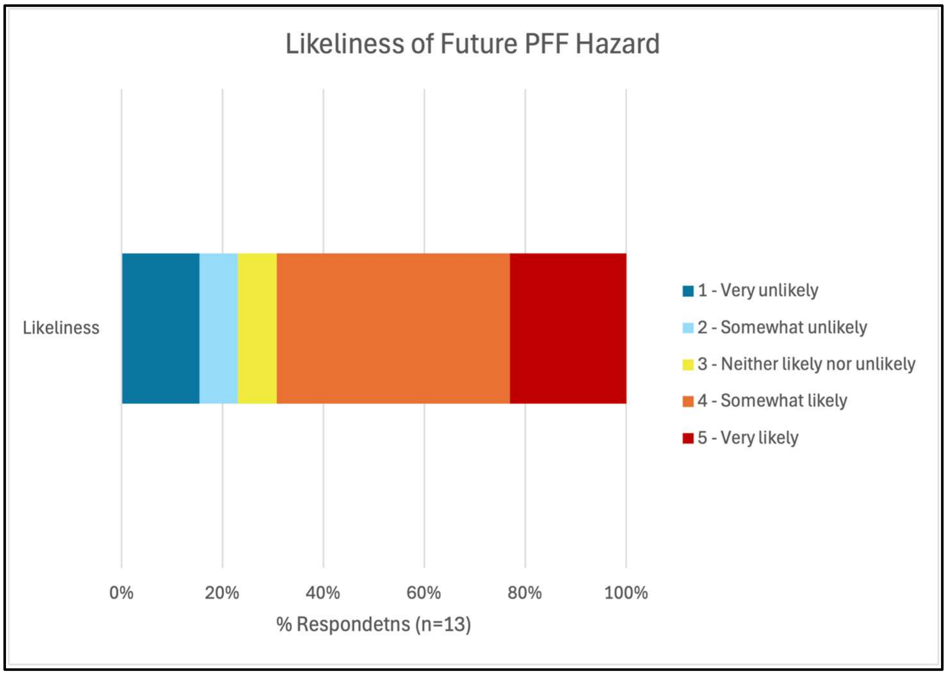

Figure 2: Likeliness of Future PFF Hazard. Respondents' perceived likeliness of future PFF hazard in their jurisdiction

Influences on PFF mitigations

Approximately 85% of respondents reported that their county has experienced a past PFF event. Of the past events reported by the respondents, 69% (SD = 0.48) of these events impacted multiple jurisdictions (Table 7). Of the 6 kinds of PFF mitigation strategies tested in this study, respondents reported a minimum of 3 mitigations, and a maximum of 6 mitigations implemented in their county. On average, 4.77 PFF mitigations (SD = 1.01) had been implemented in the respondent's county. Respondents, on average, perceived their current PFF risk to be moderate (M = 3.31, SD = 1.18) (Table 7, Figure 4). Approximately 17% of respondents reported their PFF risk to be very high, and 8% of respondents reported their current risk of PFF events to be very low (Figure 4). On average, respondents reported that their counties were somewhat prepared for managing future PFF hazards (M = 2.85, SD = 0.80) (Figure 1).

Implementation of PFF Mitigation Strategies		
Survey Variable	Mean (SD)	Survey Measures
County history of PFF	0.85(0.38)	1=Yes 0=No
Perceived PFF risk	3.31(1.18)	1=Very low 2=Low 3=Moderate 4=High 5=Very high
PFF effect across multiple jurisdictions	0.69(0.48)	1=Yes 0=No
Perceived preparedness for a future PFF event	2.85(0.80)	1=Not at all prepared 2=Somewhat prepared 3=Moderately prepared 4=Very prepared
Total Mitigation Strategies Implemented in County	4.77(1.01)	Sum of strategies implemented in jurisdiction (total = 6)

Table 7: Descriptives on Implementation of PFF Mitigation Strategies, n=13

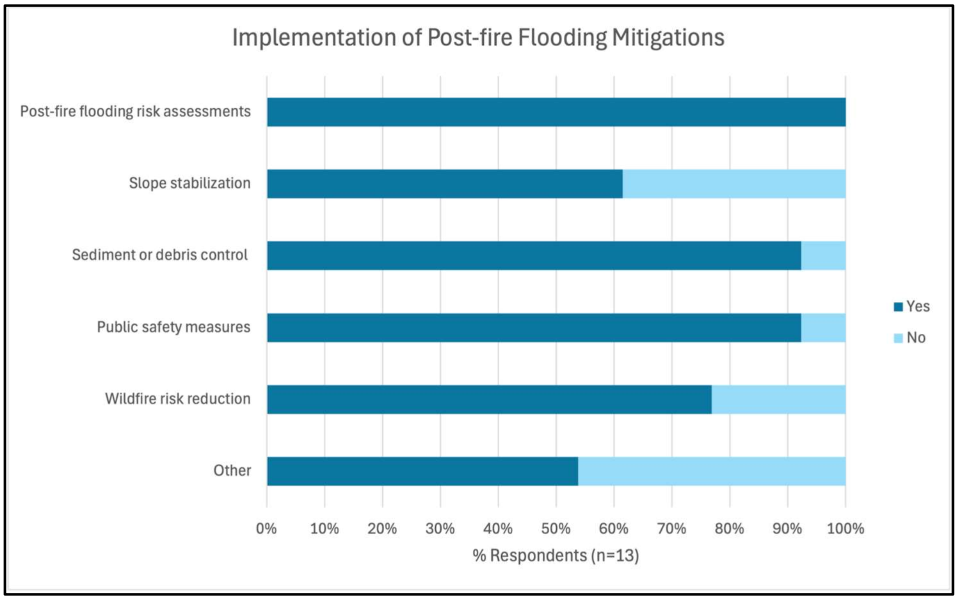

Figure 3: Implementation of Post-fire Flooding Mitigation Strategies

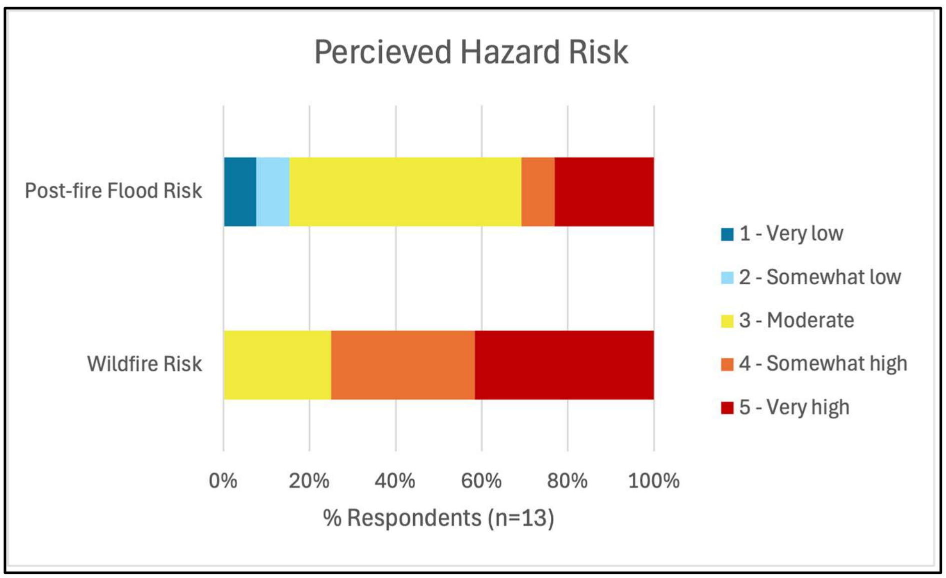

Figure 4: Perceived Hazard Risk. Respondents' perceived hazard risk of PFF and wildfire hazards in their jurisdiction

Promoting PFF preparedness across the U.S. West

In regard to how easy or difficult it is to access resources needed for implementing and executing PFF mitigations, respondents reported on average that these resources were neither easy nor difficult to access (M = 3.13, SD = 0.77) (Table 8, Table 9, Figure 7). Specifically, respondents rated from very difficult to access (1) to very easy (5) for: accessing local expertise on PFF or related topics (M = 4.31, SD = 0.95), finding contractors or skilled workers to execute mitigation activities (M = 3.70, SD = 1.06), public support (M = 3.62, SD = 1.19), political support (M = 3.46, SD = 1.45), coordinating mitigation across jurisdictions (M = 2.69, SD = 1.32), funding to support mitigation (M = 2.46, SD = 1.13), other resources (M = 2.43, SD = 0.79) or staffing capacity to support PFF management (M = 2.23, SD = 1.17) (Figure 7).

Over 70% of respondents had access to existing documents related to PFF (Figure 5). For future revisions needed to mitigation planning documents, respondents in this category (n=8) reported that moderate revisions are needed (M = 2.75, SD = 0.89) for better response and efficacy (Figure 6). Qualitative responses to what kind of revisions are needed for better response and efficacy were improved monitoring and modeling techniques, post-event revisions, developing clear communication and command channels, and instating frequent updates to integrate new research into current plans.

Promoting Future PFF Mitigation Implementation		
Survey Variable	Mean (SD)	Survey Measures
Preparedness for a future PFF event (n=13)	2.85(0.80)	1=Not at all prepared 2=Somewhat prepared

		3=Moderately prepared 4=Very prepared
Number of helpful strategies (n=13)	7.23(2.65)	Sum of strategies marked helpful (total = 11)
Average ease of accessing resources to support PFF mitigation (n=13)	3.13(0.77)	Average rate of ease of access to resources to support mitigation 1=Very difficult 2=Somewhat difficult 3=Neither easy nor difficult 4=Somewhat easy 5=Very easy
Number of future revisions needed to existing documents (n=8)	2.75(0.89)	1=Significant revisions are needed 2=Moderate revisions are needed 3=Some revisions are needed 4=No revisions are needed

Table 8: Descriptives on Improving Preparedness

Ease of Access to Resources for Advancing PFF Mitigations		
Survey Variables	N	Mean (SD)
Funding to support mitigation activities	13	2.46 (1.13)
Staffing capacity	13	2.23 (1.17)
Local expertise on post-fire flooding or related topics	13	4.31 (0.95)
Public support	13	3.62 (1.19)
Political support	13	3.46 (1.45)
Coordinate mitigation across jurisdictions	13	2.69 (1.32)
Contractors or skilled workers to execute mitigation activities	10	3.70 (1.06)
Other (n=7)	7	2.43 (0.79)

Table 9: Descriptives on Ease of Access to Resources. Likert scale: 1=Very difficult, 2=Somewhat difficult, 3= Neither easy nor difficult, 4=Somewhat easy, 5=Very easy

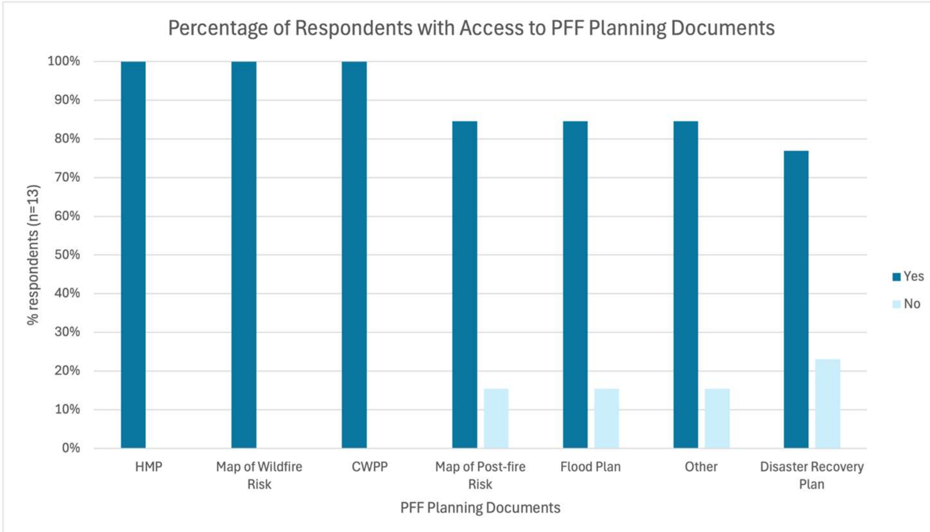

Figure 5: Percentage of Respondents with Access to PFF Planning Documents. Respondents' access to hazard management and risk-assessment documents related to PFF.

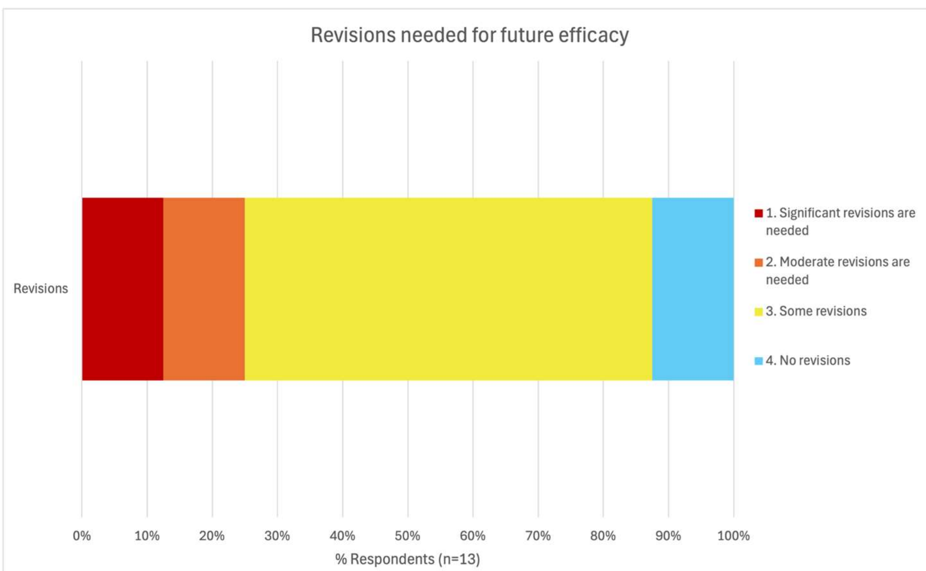

Figure 6: Revisions needed for future

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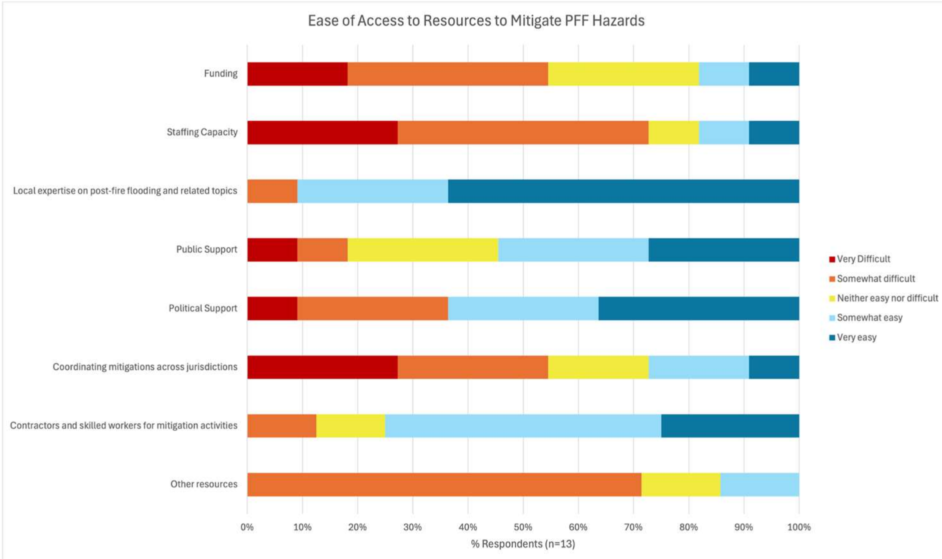

Figure 7: Ease of Access to Resources to Mitigate PFF Hazards

Notable Respondent Quotes

A respondent from Benton County explained their experience with PFF,

> "…it's something that Benton County, at least, hasn't really experienced. Which is a good thing because we haven't had a ton of fires here, but also a bad thing because whenever it does happen, we kind of don't know exactly what to expect… We try to learn a lot from Land County and other counties that experience this more, but it's kind of one of those things that you don't really know until it happens."

Figure 8: Qualitative Response 1

An Oregon post-fire debris flow specialist speaks to the lack of region-specific research on PFF while reflecting on the deadly 2021 post-fire debris-flow in Multnomah County (the first of its kind in this region),

> "How post-fire effects places like Western Oregon, which are - if you didn't know - extremely different from Southern California. So different that we weren't even sure that we were going to have post-fire effects here… but we think there are effects. They're just really different than what we see in Arizona, New Mexico, and even Colorado and Southern California."

> "We've only had about five years' worth of big fires and the ability to study them, so I'd say we've got a long ways to go." Other officials from Multnomah County also reported on the region's unfamiliarity of PFF mitigation and response due to the recent emergence of the issue in western Oregon."

Figure 9: Qualitative Response 2

A fire professional of 40 years in Santa Barbara County (a county with extensive PFF history, and PFF-specific mitigations in place) describes the challenges of implementing grant funded mitigation projects,

> "… its encumbered money that's tightly managed. Most of it disappears… And if you have a project that's funded with grant money, well, how do you sustain it after the fact? Now it's just – to do one specific project… but most of this stuff needs constant maintenance and upkeep, that costs money, and the money's not there…"

Figure 10: Qualitative Response 3

Discussion

Considering PFF events are increasingly occurring and destructive hazards, this study sought to determine how emergency and hazard mitigation professionals consider jurisdictional PFF risk, approach the implementation of PFF mitigation strategies, and what influences the development and implementation of PFF mitigation strategies. Findings from this study aim to inform future research and planning steps to better understand the nature of PFF events and what managers need to adequately prepare and manage PFF hazards in the future.

Respondents in this study demonstrated recognition of their relative risk to PFF hazards as it relates to wildfire activity, rainfall and watershed dynamics in their jurisdiction. Despite recognition of these risks, and the likelihood of a PFF event in the near future, respondents did not express confidence in their preparedness for the hazards. Approximately 23% of respondents reported that their jurisdictions are "Very prepared" for a future PFF event. However, in consideration of both the small sample size of this study and limited representation of geographic ranges, our preparedness-findings may not represent the greater portion of the western U.S. It is possible that general levels of preparedness across the western states is lower than what was reported in this study, since respondents in this study were sampled from contributor lists in county-level HMPs that either a) included PFF mitigations or b) were implemented in counties with recorded histories of PFF. This sample frame excludes counties that have PFF risk but have not had a prior event, and have not included any PFF mitigation strategies in their most recent HMPs. As such, there is a significant portion of the at-risk population that remains unsampled in relation to their recognition of risk and perceived preparedness for future PFF events. To address this in future research, additional respondents should be recruited from all regions where there is noted PFF risk despite their history of the hazard, or existing PFF mitigation plans.

In consideration of existing literature relating to hazard mitigation and preparedness, and input from respondents, without a history of a specific hazard, it is especially challenging to garner the support, resources, and expertise needed to develop mitigation strategies for PFF hazards. With increasing fire risk, and changing weather patterns, PFF hazards are becoming increasingly frequent, and risk is developing in areas where it was not formerly present. Regardless, PFF research and mitigation is not prioritized across counties where there has not been prior risk - nor do managers report high levels of preparedness (McCaffrey & Kumagai, 2007, Rogers, 2006). Repeatedly, managers noted that while they are aware of the rising prevalence and danger of PFF events, without a trigger event, there is little expertise and few resources to dedicate to developing plans for PFF hazards. This sentiment that past hazard experience is essential in a community's preparedness is reflected in Figure 8 (Burnett & Edgeley, 2023; McCaffrey & Kumagai, 2007; Rogers, 2006).

In contrast to areas like Benton County that have yet to experience a PFF event, in 2022, Santa Barbara County experienced a post-fire debris-flow event that killed 23 people and destroyed over 500 structures (Burns, 2022). Despite having experienced a trigger event, and having a number of years of mitigation and response experience post-disaster, respondents in this region also recorded only moderate levels of preparedness for future PFF events. The lack of influence of a trigger event on county preparedness leads to the assumption that other factors must be inhibiting PFF preparedness: the development of PFF-specific prediction models and mitigation strategies. This finding is significant because it indicates that there are other barriers that managers face in increasing preparedness for future hazards beyond a lack of prior experience in responding to the hazard. To mitigate PFF risk and other post-fire hazard risks, counties have well developed planning documents, and have mostly integrated some level of post-fire hazard mitigations on landscapes when it is needed. However, many of these mitigation strategies are not PFF specific, and the extent of their effectiveness and breadth of implementation is not known.

Of the areas sampled in this study, respondents reported a mixture of implemented mitigation strategies. Despite varying levels of perceived risk, mitigations were implemented widely across the study sample. The types of mitigations that have been implemented did not follow any predictable pattern. Additionally, some respondents reported that mitigations (which in this study are classified as PFF mitigations) were implemented to mitigate non-PFF hazards. In consideration of the use of mitigation strategies for non-PFF hazard mitigation, and the reported lack of regional, and landscape specific PFF mitigation strategies, we can infer that there is a need for further research of PFF-specific mitigation strategies, and education for managers to utilize these strategies in their area. A potential future direction for more effectively mitigating PFF risk, would be to classify and prioritize existing mitigation strategies that mitigate multiple hazards in addition to PFF hazards.

I further theorize that the lack of knowledge and preparation is due to the emergent nature of the PFF hazard mitigation to areas in the western United States which is reflected in Figure 9. Research regarding PFF mitigation and response has been largely conducted in Southern California – due to the more extensive history of PFF occurrence in this region. As opposed to the arid, Mediterranean climate of Southern California, western Oregon experiences a drastically different climate (with low intensity, long duration rainfall seasons). The seasonality, vegetation type, soil type, and topography of western Oregon and other western regions have not been considered in prior research. Respondents from western Oregon regions had high perceptions of risk but low familiarity with managing PFF hazards. Despite efforts to familiarize themselves with mitigations and response, the research to support these efforts simply does not yet exist for the region. To better prepare managers across the western US for increasing risk to PFF hazards, PFF occurrence and mitigation research must be conducted across regions with varying climate, soil types, vegetation types, and topography. Expanding what is known about this hazard would allow for more comprehensive understandings of how to respond to PFF areas based on the characteristics of its ecosystem.

The primary existing barriers to further implementation of mitigation strategies to increase county preparedness, include a lack of site-specific PFF research, and hazard-specific mitigation strategies. Respondents in this study had extensive access to existing hazard and risk-related documents (HMPs, disaster recovery plans, CWPPs, risk maps, etc.). However, access to these documents is not sufficient for mitigating PFF-hazard risk. Managers reported needs for improved access to training, communication channels, and funds to facilitate the steps needed for further adapting to PFF risk which is reflected in Figure 10. An absence of professional education and funding is further limiting the development of hazard mitigation for post-fire floods.

Regarding the effectiveness of existing hazard-related documents (such as county HMPs, disaster response plans, CWPPs, risk maps, or other documents), respondents reported a need for revisions to the documents they have previously used in mitigation and recovery processes. The most requested types of revisions are document updates with PFF-related research, and post-disaster response updates. Temporal, staffing, research, and funding challenges all contribute to the limitations that these documents have for managing PFF. Ultimately, planners need better access to PFF-specific research, assessment, modeling, and prediction tools to better assess their jurisdictional risk to the hazards. To better execute future mitigations, education and funding measures such as community information sessions, professional trainings, and PFF-specific grants need to be expanded to support the preparedness for future PFF risk. Additionally further improvements to the effectiveness of HMPs could include the implementation of a standardized list of hazards via FEMA that must be considered in a community's HMP. This list would include established and emergent hazards, hoping to encourage early mitigative action and combat the reliance that jurisdictions have on trigger events when preparing for future hazard events.

As PFF risk increases throughout the western United States, increasing preparedness and improving mitigation strategies is crucial to reducing environmental, social, and economical impact of future hazards. PFF remains a new and emerging issue in much of the western US, with many respondents in this survey reporting that their jurisdictions are at risk but have never experienced a PFF event. Considering the role that trigger events have on preparedness, government engagement, and public awareness, areas without a history of PFF exhibit are less prepared for future hazards. To counter the immense role of trigger events in hazard preparedness, additional prediction and hazard modeling systems need to be developed with regional specifics and increased accuracy. Areas with frequent PFF events, such as Coconino County in Arizona, utilize a rain gauge warning system to indicate increased risk related to rainfall duration and intensity, and notify officials of imminent risk. These predictions and models could be included in post-fire assessments (such as those conducted by BAER or California's Watershed Emergency Response Teams (WERT) teams) to determine future risk. With results from these assessments, areas with determined risk should then implement rain gauges with rainfall thresholds developed based on the soil and vegetation types, burn severity, and hydrology of the area. These are tangible steps that could be implemented into existing measures that would increase future and immediate awareness to PFF risk.

Additional challenges for building jurisdictional preparedness if the absence of PFF-specific mitigations, modeling, and prediction models in current literature. Without access to this research, professionals have been unable to implement region and hazard specific strategies to mitigate PFF risk. Further research, mitigation strategy development, and funding are needed to overcome these barriers to better inform professionals on PFF hazards. With these steps, regions with known risk but little experience such as Multnomah County, can begin to install and implement region-specific mitigation strategies to limit the threat and impact of future hazards.

Limitations

The primary limiting factor of this study was the timeline and challenges faced during recruitment. Due to delays in the Institutional Review Board (IRB) process for approving research with human subjects, the recruitment and surveying stages of data collection for this study could not be carried out until March 2025. The deadline for the completion of this thesis was May 30th, 2025. Recruitment began in March 2025, and continued until May 2025 for survey data included in this iteration of the project. Further recruitment will continue during Summer 2025 to develop a more extensive sample frame for future publication and iterations of this project.

During the recruitment phase, the recruitment response rate to outreach for this study was 8%. Despite utilizing multiple modes of contact via email and phone calling, response rates were significantly lower than anticipated. To improve response rates, we revised the follow-up scripts and were persistent with follow-up outreach measures. Snowballing recruitment measures, which were applied at the end of the survey, proved to be somewhat helpful, but regularly resulted in redirection to previously reached contacts. Responses to emails and phone calls were frequently redirected to other departments or professionals, who also responded with redirections to others. In the months of this first phase of recruitment, it took three to four responses to connect with a willing participant. Now, as the thesis stage of this project is concluding, researchers have more appropriately identified the departments and professionals to contact for continued surveying.

Respondents to the study detailed the impacts of how many federally funded grants were being cut at the time of data collection (including the Building Resilient Infrastructure and Communities (BRIC) grant, a federal grant designed to support governments reduce hazard risk), whole departments are being shuttered, NPS and USFS employees being laid off (Crow, 2025; Treisman, 2025). These drastic changes and the pressure from the federal government in the early months of 2025, have made continued research, and implementation of PFF mitigation strategies increasingly difficult. The nature of this issue adds to the challenges professionals in this field are already facing, potentially reducing their willingness to volunteer to participate in this study.

An additional challenge of recruitment was the prevalence of recent fire and PFF events in areas intended to be included in the study. Recruitment was not conducted in counties that had recently experienced or were actively experiencing wildfires or post-fire flood events. Some of these counties included Josephine County and Baker County in Oregon, which were actively experiencing post-fire flood and landslide events during the recruitment phase of this study. Recruitment was also withheld from Los Angeles, Ventura, and Orange Counties which were devastated by the Palisades and Eaton fires in January 2025, and facing imminent threats of PFF hazards. In contrast, professionals from counties that have not yet faced PFF events were hesitant to participate in this study due to a lack of experience. Potential respondents in these areas often stated that they did not feel adequately educated to respond to the survey request with experience of a prior event, or PFF-specific background and training. To improve engagement and recruitment processes, it could be beneficial to rephrase how we describe this study to potential participants to emphasize the emergent nature of this research.

The lack of engagement and small response rate proved a challenge for the project to reach enough respondents for sample frame numbers to become statistically significant in data analysis. A lack of a statistically significant number of respondents resulted in a redirection from the originally intended correlative statistical analysis. With the survey sample, analysis was refocused on descriptive statistics and qualitative thematic analysis of the survey results and transcripts. The reason for such low engagement in the study is unclear but I surmise that recruitment for this study was exceedingly challenging due to the political and economic instability (many participants cited a lack of funding, and departmental cuts as being a difficulty in expanding PFF preparedness), active response and recovery to PFF events during the time of recruitment, and the relative newness of PFF hazards to much of the Western US.

A further limitation to this study is the novelty of PFF modeling, prediction, and mitigation research. Respondents noted the deficit of PFF research beyond the heavily studied PFF incidents in Southern California. Counties in Southern California have had some of the most destructive and costly PFF events along the West Coast. As a result, most PFF research has been focused in this area. Multiple Oregon respondents declared this a major challenge to the development of PFF management and mitigation strategies. Oregon soils types, vegetation types and cover, seasonality, topography, snowmelt, and rainfall vary greatly from the types and extent of PFF-related measures observed in Southern California. These measures are the driving variables in determining fire severity and the resulting PFF risk. Variations in these measures also impact the methods of mitigation and management that are most effective on the landscape. However, without PFF trigger events in other regions and counties across the U.S., there has been little urgency for PFF modeling, prediction, and mitigation research. Without additional research on PFF events outside of Southern California, site specific mitigation strategies have not been developed and managers have not become familiar with PFF hazard in their areas.

Future Research

While this study has yet to reach its full potential, a strong framework of research, contact base, and survey protocol has been developed for continuing research, case study work, and manuscript development under expansive or adjacent scopes of study. Work on this project will likely be continued by undergraduate researchers throughout the summer months in 2025. The immediate next step for this project is conducting the next phase of recruitment to expand survey participation. To achieve statistically significant results, and to conduct correlative tests, an additional 20-30 surveys will need to be conducted. With knowledge of the challenges faced in the first round of recruitment, future researchers should focus the next phase of recruitment on connecting with floodplain managers, Public Works Administrations, hydrologists and professionals from the United States Army Corps. of Engineers. The first round of recruitment focused on connecting with emergency managers and mitigation professionals that had contributed to the development of county-level HMPs. Through the survey process, it became evident that few emergency management professionals are familiar with PFF hazards and associated mitigation strategies. These professionals often redirected recruitment to floodplain managers, or Public Works administrators. Future researchers should begin by reaching out to hydrology, floodplain management, and Public Works offices to recruit PFF, hydrology, or planning specialists to participate in the survey.

By prioritizing connecting with professionals in these fields, the study can expand its breadth to further understand how PFF hazards are being considered and managed in regions across the western US. Further, these professionals may have more specialized experience with managing post-fire flood risk, which would be crucial to building stronger understandings of existing processes and measures addressing PFF risk. Additional recruitment could be expanded into counties that are experiencing PFF risk but do not have past experience nor inclusion of PFF mitigations in the county HMPs. Recruitment from these areas could provide insight on how PFF hazards are being considered without the influence of trigger events, or how mitigations may be considered beyond the development of HMPs. With an increased survey sample, researchers will be able to conduct correlative statistics tests. These tests will aim to determine how a number of surveys may influence levels of preparedness and the implementation of mitigation strategies across the western US. Future research on this project will also include case study projects with counties that have experienced recent PFF hazards.

Beyond expanding the extent of this study, measures for delivering PFF-mitigation funding to western states should also become a priority. With increasing wildfire risk, PFF risk grows as well. As such, jurisdictions across the western states are experiencing PFF risk with little to no knowledge or resources to manage these hazards. With appropriate funding, future steps in PFF mitigation research can expand to include the development of PFF-specific mitigation strategies, improved prediction models, and region-specific research on initiation conditions and mitigation strategies for PFF hazards. These steps have the potential to increase risk-awareness, improve mitigation strategy efficacy, improve warning and prediction systems, and to inform counties without prior PFF hazards of future risk.

Conclusion

As an emerging and intensifying issue throughout the western U.S., PFF hazards pose risks to human life and property. Emergency managers and professionals in hazard management are beginning to consider the reality and impending effects of PFF hazards in their jurisdictions. This study sought to determine how professionals are considering PFF hazards in their fields, and what resources and support are needed to improve PFF mitigation measures. Results from phone surveys with professionals revealed a lack of literature regarding PFF hazards in varying climates, effective mitigation strategies, and prediction models. Respondents found that additional research, and funding will be crucial to improving mitigation implementation and risk-awareness. This study emphasized the role professionals have in improving jurisdictional preparedness and what they need to better support the safety and resiliency of their jurisdictions in the event of future PFF hazards.

Appendix

Interview Protocol Script

Part 1: Participant background

1. **How long have you worked and/or lived in XXX County?**
    - *Prompt for both worked and lived if they only talk about one or the other*

2. **Please describe your current position to me (position title, agency/entity).**

3. **What are your current responsibilities related to post-fire flooding? (Planning, response, and rehabilitation/recovery)**

4. **How many years of experience do you have in positions related to planning, response, or recovery for post-fire flooding?**

5. **Which one of the following best describes your background or training?**
    A. Emergency management, law enforcement, or public safety
    B. Wildfire management
    C. Hydrology or water management
    D. Land management
    E. Engineering (civil, structural, geotechnical, etc.)
    F. GIS, remote sensing, or spatial analysis
    G. Meteorology or climate
    H. Other, please describe [Prompts: What is your field called? What kind of programs or training is typical for this field?]

Part 2: Risk perceptions

6. Does your county have a history of post-fire flooding? Yes or no.

1. Yes
    - Text entry box in case they give fire/flood names, years, details
2. No

- *If yes:* **7. How often does your county experience post-fire flood events?**
    1. More than once a year
    2. Once a year
    3. Once every 2-5 years
    4. Once every 6-10 years

5. Less than once every 10 years

8. Which of the following best describes the current level of <u>wildfire</u> risk in your county?

1. Very low
2. Low
3. Moderate
4. High
5. Very high

9. Which of the following best describes the current level of <u>post-fire flood</u> risk in your county?

1. Very low
2. Low
3. Moderate
4. High
5. Very high

10. Which of the following best describes the likelihood of a post-fire flood event somewhere in your county during the next 5 years?

1. Very unlikely
2. Somewhat unlikely
3. Neither likely nor unlikely
4. Somewhat likely
5. Very likely

11. How influential or uninfluential is <u>XXX</u> on the post-fire flood risk in your county?
[Respond for each factor on Likert Scale: 1. Very uninfluential, 2, moderately uninfluential, 3. Neither influential or uninfluential, 4. Moderately influential, and 5. Very influential.]

A. Wildfire risk
B. Non-fire related flood risk
C. Availability of water-related infrastructure, such as drainages, waterways, and irrigation ditches
D. Development patterns
E. Rainfall intensity
F. Rainfall duration
G. Topography
H. Are there any factors we didn't discuss that are influential on the post-fire flood risk in your county? (Yes, No)
    a. If "yes", please name and rate.

Part 3: Planning for post-fire flooding

12. Do you currently have access to XXX related to fire and post-fire risks? [For each factor, respond with: Yes, No, or I don't know]

A. A map of wildfire risk for you county (Yes/No/I don't know)
   i. **If "yes", what data or software were used to generate this map?** [text box]
B. A map of post-fire risk for your county (Yes/No/I don't know)
   i. **If "yes", what data or software were used to generate this map?** [text box]
C. A disaster recovery plan for your county (Yes/No/I don't know)
D. A hazard mitigation plan for your county (Yes/No/I don't know)
E. A protocol or plan for addressing flood risk for your county (Yes/No/I don't know)
F. A community wildfire protection plan (CWPP) for your county (Yes/No/I don't know)
   a. **Are there any additional documents or resources related to post-fire hazard planning in your county that we have not yet mentioned?**
      - If "yes," then *"What have we missed?"*
         - Enter responses in textbox(es)
      - *If "no" Proceed to next question*

13. Have you been involved in XXX during the past five years? [For each factor, respond with: Yes, or No]

A. Creating or updating a County Multi-Hazard Mitigation Plan (Yes/No)
B. Creating or updating a Community Wildfire Protection Plan (Yes/No)
C. Creating or updating a State Mitigation Plan (Yes/No)
D. Grant writing for post-fire flood risk reduction (Yes/No)
E. Community or public meetings related to post-fire flooding (Yes/No)
F. Training, conferences, or other education related to post-fire flooding (Yes/No)
G. Working groups related to post-fire flooding (Yes/No)
H. Are there other activities related to post-fire flood mitigation that you've been involved in during the past 5 years that we did not mention? (Yes/No)
   - **If yes, Please describe relevant planning activity or event [text box**]

14. When working on post-fire flood related issues, which of the following collaborators do you work with? [For each factor, espond with: Yes, or No]

A. Federal land management agencies *(e.g., USDA Forest Service, BIA, BLM, NPS, NRCS)* (Yes/No)
B. State agencies *(e.g. State emergency management office, state forestry)* (Yes/No)
C. Tribal governments (Yes/No)
D. County-level governments (Yes/No)
E. City or Town governments (Yes/No)
F. Members of the public (Yes/No)
G. Local interest groups (Yes/No)
H. Are we missing any partners? (Yes/No)
    i. **If yes, "please describe the partners we've missed" [text box]**

15. In the last five years, has your county implemented <u>XXX mitigation</u>?
[For each factor, respond with: Yes, no, or I don't know]

A. **Post-fire flooding risk assessments, such as** Burned Area Emergency Response (BAER) Team post-fire assessments, economic or hydrologic modeling, flood prediction, or engineering analyses? (yes, no, I don't know)
B. **Slope stabilization measures**, such as mulching, seeding, wattles, or contour felling? (yes, no, I don't know)
C. **Sediment or debris control measures**, such as dam installation, dredging, or debris removal? (yes, no, I don't know)
D. **Public safety measures**, such as area or road closures, installation of warning signage, or installation of rain gauges (yes, no, I don't know)
E. **Wildfire risk reduction measures**, such as prescribed fire or thinning (yes, no, I don't know)
F. **In the last five years, has your county implemented any fire or post-fire risk mitigation strategies that we have not mentioned yet?** (yes, no, I don't know)
    a. **If "Yes",** please describe [text box]

16. How difficult or easy has it been to access XXX to advance post-fire flood risk reduction in your county?
[Respond fir each factor on Likert Scale: 1. Very difficult, 2. Somewhat difficult, 3.. Neither easy nor difficult, 4. Somewhat easy, or 5. Very easy)

A. Funding to support mitigation
B. Staffing capacity
C. Local expertise on post-fire flooding or related topics
D. Public support
E. Political support
F. Coordination of mitigation across jurisdictions
G. Contractors or skilled workers to execute mitigation activities

H. Others challenges or successes, please describe [text box]
I. Are there any other resources that we missed? (Yes/No)
    a. If yes, please describe the resources that we missed.
        i. How difficult or easy has it been to access XXX resources?

17. How prepared do you feel your county is for a future post-fire flood event?

1. Not at all prepared
2. Somewhat prepared
3. Moderately prepared
4. Very prepared

18. How helpful or unhelpful would XXX be for advancing post-fire flooding hazard management in your county?
[Respond for each factor on Likert Scale: 1. Unhelpful, 2. Helpful, or is already in place because you "3. I already have access to this."]

A. Collaborative response drills with cooperators
B. Collaborative tabletop or scenario-exercises
C. Shared training days
D. Memorandums of understanding (MOUs) for post-fire flood response
E. Mutual Aid Agreements for post-fire flood response
F. Proactive establishment of shared communication channels
G. Shared equipment for post-fire flood
H. Grants specifically to support post-fire flood mitigation
I. Cost shares specifically to support post-fire flood mitigation
J. Support or resources to accelerate mitigation activities
K. Are there any other resources that we didn't mention that influence post-fire flooding planning in your county?
    i. *If yes,* please describe the resources that we missed, and rate on the same scale [text entry]

Part 4: Navigating post-fire flood response
[Only ask if they've had previous floods/post-fire flood events in their jurisdiction.]

Earlier, you mentioned that your county has had recent experience(s) with post-fire flooding.

19. Did that event or events impact multiple jurisdictions (e.g. private or public land, city and federal land, etc.)? "Yes/No/I don't know"

20. How helpful or unhelpful were XXX when engaging in response and recovery? [Respond to each factor on Likert Scale: 1. Not at all helpful, 2. Somewhat helpful, 3. Moderately helpful, 4. Very helpful, 5. We didn't reference the plans, or NA: we didn't have plans]

A. Map(s) of wildfire risk in your county
B. Map(s) of post-fire risk in your county
C. County disaster recovery plan documents
D. County hazard mitigation plan documents
E. Community wildfire protection plan(s) document(s)
F. Are there other documents that factored into your post-fire flooding response and recovery that we missed?
    i. **If yes, please describe the documents and rate on the 1-6 scale. [text box]**

21. For the documents we just discussed, to what extent are revisions needed for better response and efficacy in the future?

1. Significant revisions are needed
2. Moderate revisions are needed
3. Some revisions are needed
4. No revisions are needed

22. Please briefly describe any revisions or improvements that are needed. [open ended, text box]

23. What lessons have you learned from your experience with post-fire flooding that you would share with others with similar roles to you in other western states? [open ended, text box, make sure to catch the name of the fire or flood event]

Part 5: Close out

24. Is there anything else related to post-fire flooding that we did not talk about today that you'd like to share? [text box]

25. Is there anyone else we should contact in your county and invite to participate in this study? [text box, try to get email or phone number]

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