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Research article

Water utility engagement in wildfire mitigation in watersheds in the western United States

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ABSTRACT

Scaling up climate-adaptation in wildfire-prone watersheds requires innovative partnerships and funding. Water utilities are one stakeholder group that could play a role in these efforts. The overarching purpose of this study was to understand water utility engagement in wildfire mitigation efforts in the western United States. We conducted an online survey of water utilities in nine states and received 173 useable responses. While most (68%) respondents were concerned or very concerned about future wildfire events and the impact of wildfire on their operations, only 39% perceived their organization as responsible for mitigating wildfire risk. Federal land ownership decreased feeling responsible for wildfire mitigation, while concern for and information on wildfire increased feeling responsible for mitigation. The perception of response efficacy of mitigation actions for the 68 water utilities engaged in wildfire risk mitigation activities was very high, with most agreeing that mitigation actions are effective. Self-efficacy to implement mitigation actions, however, was mixed, with most utilities wanting more information on wildfire risk and impacts to watershed services. The most reported wildfire mitigation actions were forest thinning and stream restoration. Water utilities engaging in these actions typically partnered with government agencies or other water utilities to complete the work and funded these activities through water user fees and grants. Our findings suggest that water utility engagement in wildfire mitigation for water security could be increased through providing more assessments of wildfire risk to water utilities and through more outreach and engagement with water utilities operating on federal lands.

1. Introduction

Forests play a critical role in the provision and regulation of water supplies to downstream populations in the United States (US) (Brown et al., 2008; Liu et al., 2021). Forested lands are especially important for surface water supplies, with almost 90% of public surface water intakes relying on some proportion of forested lands for their source water. In the western US, federally-owned forested lands provide about 52% of total water supply, whereas privately-owned forests are more important to water supply in other parts of the country (Liu et al., 2021). These forests, along with shrub and grassland vegetation types, increasingly face multiple threats, including wildfire, drought, and urban development (Sun and Vose, 2016).

Wildfires, while a natural part of many ecosystems in the western US, are becoming more frequent and intense due to climate change (Abatzoglou and Williams, 2016; Hagmann et al., 2021; Heidari et al., 2021). Past fire suppression policies in the US have contributed higher-than average fuel loads that combined with changing fire regimes, can result in significant impacts to watershed services (Bladon et al., 2014; Hallema et al., 2018; Rhoades et al., 2019; Robinne et al., 2020). These impacts are expected to be exacerbated by other climate changes like extreme rainfall in the western US (Touma et al., 2022). Hydrological effects include increases in harmful contaminants, increases in sedimentation and debris flows, and flooding (Williams et al., 2022). These changes incur direct costs to water utilities and the communities they serve through loss of reservoir storage capacity, damage to water infrastructure, increased water treatment costs, and the need to find alternative water sources (Jones et al., 2022). The vulnerability of a water utility's operations to fire depends on the geographical characteristics of where it is located, as well as water system characteristics and

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redundancies (Gannon et al., 2019, 2022).

Proactive wildfire mitigation can reduce wildfire risk (Calkin et al., 2014; Stephens et al., 2021). This includes prescribed burning and thinning, but to date, the pace and scale of these mitigation actions have constrained large-scale changes in fire frequency or intensity (Prichard et al., 2021). After a wildfire has occurred, post-fire rehabilitation efforts, such as mulching, stream restoration and rehabilitation, and native tree planting, can be used to restore ecological health and watershed function. Pre- and post-fire management actions have the potential to reduce the impacts of wildfire on drinking water supplies (Jones et al., 2017), but their placement and other water system characteristics influence the effectiveness of these efforts (Jones et al., 2022; Gannon et al., 2022; Dobre et al., 2022).

The US Forest Service recently estimated that to reduce the risk of high-severity wildfires in the US, about 50 million acres of forest across federal, state, tribal, and private lands need to be treated (Clavet et al., 2021). At an average cost of US$1000 per acre, this amounts to US$50 billion needed for initial treatments, with additional funding required to maintain treatments over time. The US federal government has invested resources in several landscape-scale forest restoration programs such as the Joint Chiefs Landscape Restoration Partnership, started in 2014, and the Collaborative Forest Landscape Restoration Program, started in 2009, to scale up forest restoration efforts (Schultz et al., 2018). In 2022, the US federal government started a 10-year Wildfire Crisis Strategy to further address the fuel treatment deficit. To date it has selected 21 high-risk landscapes to receive increased funding to scale up wildfire mitigation across multiple land ownership types (USDA, 2022). These government efforts need to be complemented by non-traditional funding sources and partnerships if the US is going to address the current wildfire crisis (Clavet et al., 2021).

One alternative source of funding and partnership could be water utilities that rely on surface water and are thus vulnerable to post-fire hydrological changes (Lee et al., 2022). Water utilities are involved in several source water protection programs across the US to enhance their water systems (Bennett et al., 2014). However, most of these programs rely on regulatory drivers to incentivize utilities to protect drinking water quality. When water utilities get involved with source water protection from wildfire their contributions are often voluntary and motivated by previous wildfire experiences (Bennett et al., 2014; Roberts et al., 2020). Denver Water (located in Colorado, US) exemplifies this type of utility engagement. Motivated by costly expenditures following wildfires, Denver Water now proactively invests in wildfire mitigation and watershed restoration through several partnerships and collaborations that prioritize, coordinate, and fund wildfire risk mitigation and post-fire recovery (Jones et al., 2022). Similarly, the Albuquerque Water Utility Authority (located in New Mexico, US) participates in the Rio Grande Water Fund, a collaborative effort started after a 2011 wildfire that coordinates work to protect storage, delivery, and quality water supplies through wildfire mitigation and forest restoration (Morgan et al., 2023).

Not all water utilities faced with wildfire risk will engage in wildfire mitigation behaviors like fuels reduction or post-fire rehabilitation. Like variation in individual and community responses to wildfire risk (e.g., Meldrum et al., 2018), water utilities faced with increasing threats to their source water will choose different responses. Previous studies have noted that water utility involvement in wildfire risk mitigation in the western US can be limited by land ownership and management policies (Sham et al., 2013). Additionally, utility response may vary based on whether there is an economic or business justification for their organization, which is related in part to their perceived risk of fire impacting their operations (Bennett et al., 2014; Roberts et al., 2020); the perceived efficacy of wildfire mitigation actions to protect watershed services (Hamilton et al., 2018); the perceived self-efficacy of their organization or partners in taking mitigation actions (Hamilton et al., 2018; van Valkengoed and Stag, 2019); the utility's feelings of whether they are responsible for wildfire mitigation versus other entities (Martin et al., 2009; Hamilton et al., 2018); and social interactions or pressures from constituents or other organizations (Dickinson et al., 2015; Hamilton et al., 2018).

The purpose of this study is to assess water utility engagement in mitigating wildfire risk in the western US. Specific research questions include: (1) What is the level of concern—or risk perceptions—about future wildfire events among water utilities in the western US and how does this vary? (2) How much functional redundancy do water utilities in the western US have to deal with wildfire and what operational plans and strategies do they have in place? (3) Do water utilities in the western US perceive personal responsibility for mitigating wildfire risk and restoring watershed function, and if so, what factors explain their feelings of responsibility? and (4) Does perceived efficacy of wildfire mitigation or perceived self-efficacy to implement mitigation act as barriers to engagement? We build on previous analyses examining water utility engagement in watershed protection from wildfires (Bennett et al., 2014; Roberts et al., 2020), but more explicitly examine some of the social and psychological drivers of engagement that are commonly considered in studies of individual and community engagement in wildfire mitigation (e.g., Meldrum et al., 2018; Hamilton et al., 2018). Our results allow us to provide recommendations for improving engagement, and potentially funding, from water utilities so the pace and scale of wildfire mitigation can increase in the western US.

2. Methods

2.1. Data collection

2.1.1. Water utility database

This study targeted water utilities located within the western US due to the frequency of wildfire events and the impact that wildfire can have on source water in these locations. We focused on: Washington, Oregon, Idaho, Montana, Wyoming, Utah, Nevada, Colorado, Arizona, and New Mexico. A comprehensive search for water utilities in these 10 states was conducted online. After identifying several state-specific websites, the Environmental Protection Agency's Safe Drinking Water Information System (SDWIS) Federal Reporting Services was used to find active water utilities that relied on surface water and served communities of any size. Contacts were compiled for nine of the 10 states; Nevada was not compiled due to missing contact information (Table 1).

2.1.2. Survey instrument

An online quantitative survey consisting of 22 questions was developed in Qualtrics. It took about 20 min to complete. This instrument built on work by Padowski (2020), which explored wildfire concerns and related strategies for mitigating fire by water utilities in the Pacific

Table 1
Number of water utilities by state contacted about and responding to the online survey.

State	Number of water utility contacts emailed online survey	Number of water utility contacts that completed online survey	Number of useable surveys
Arizona	35	7	6
Colorado	410	68	68
Idaho	55	9	9
Montana	39	4	4
Nevada	0	NA	NA
New Mexico	41	8	8
Oregon	212	46	44
Utah	102	18	16
Washington	30	6	6
Wyoming	90	12	12
No state listed		6	0
N	*1014*	*184*	*173*

Northwest. The survey instrument was submitted and declared exempt, indicating minimal risk to human subjects, through Colorado State University's Institutional Review Board (#3591).

The survey collected information on watershed and water utility characteristics, including the size and location of the utility as well as land ownership types within the watershed(s). Respondents were then asked about previous wildfire experiences and perceived risk of future wildfire impacts on their operations. A separate section asked respondents whether their organization had taken any of twelve different internal operational actions and strategies identified from the literature that could help mitigate wildfire risks (e.g., used fire resilient building materials or developed wildfire plans). Respondents were also asked whether they had the infrastructure in place to handle a significant wildfire event and whether they had alternative sources of water they could rely on if a fire occurred.

Most of the survey focused on pre- and post-wildfire and watershed risk mitigation actions. Respondents were asked what level of personal responsibility their organization had to mitigate wildfire risk. This question specified that risk mitigation included pre- or post-wildfire management actions. If a respondent answered that they had any level of responsibility to mitigate wildfire risk, they were asked about perceived efficacy of wildfire mitigation actions, perceived self-efficacy to take mitigation actions, and specific mitigation actions that had been taken by the water utility on their own or in partnership with another entity. This section also collected information on collaborations and funding sources to carry out mitigation actions and additional barriers to taking actions. Following the close-ended questions, a final open-ended question asked respondents if there was anything else they wanted us to know about their organization's experiences managing water in relation to wildfire risk.

2.1.3. Survey dissemination

The survey was sent to all water utility emails from a university email address in August 2022 (Table 1). Two rounds of reminder emails were sent out in two-week intervals. The survey instrument remained open for three months. The number of completed online surveys totaled 184. Eleven surveys were missing too much information to be useful and were dropped. The final sample used in this paper was 173 water utility responses (Table 1).

The overall response rate was 18% and this varied between 10% and 22% for individual states; we received responses from all states. This response rate is lower than a 44% average online response rate found in a recent meta-analysis of educational online surveys (Wu et al., 2022). Factors that may have contributed to a lower response rate include incorrect email addresses leading to bounced emails, emails being delivered to spam folders, incorrect contact information leading to the respondent not feeling qualified to respond, or the respondent not feeling they had the time to respond. We did not pre-contact participants nor did we use follow up phone calls to increase response rates.

2.2. Data analysis

2.2.1. Summary statistics and univariate correlations

For all four research questions, frequencies were used to describe binary, categorical, and five-point Likert-scale questions, and means were calculated to summarize continuous variables. A Wilcoxon rank-sum test was used to test for differences in median values of social and psychological factors and actions taken by utilities to address wildfire risk, by four group-level variables of interest. A Wilcoxon rank-sum test was chosen because it is a non-parametric test and does not require the assumption of normality, so it can be used with binary, categorical, and ordinal Likert-scale data (McCrum-Gardner, 2008). Rank-sum tests were intended to be exploratory to look for differences across variables of interest. Based on the response rate and survey design, we did not measure the relationship between social and psychological factors and implementation of mitigation actions by water utilities.

The social and psychological factors included in the rank-sum tests were risk perceptions of wildfire (question one), perceived responsibility for wildfire mitigation (question three), response efficacy of mitigation actions (question four), and self-efficacy to implement mitigation (question four). Perceived risk of wildfire was measured through a categorical variable asking how concerned their organization was about the impact of future wildfires on their operations. The four categories included not concerned, somewhat concerned, concerned, and very concerned. Perceived personal responsibility to mitigate wildfire risk was asked as a categorical variable of no responsibility, partial responsibility, or full responsibility. Response efficacy and self-efficacy were both measured as five-point Likert scale questions that ranged from Strongly Agree—coded as one—to Strongly Disagree—coded as five.

There were two types of actions taken to address wildfire risk analyzed using the rank-sum tests: the number of internal operational actions and strategies a utility had undertaken (question two) and the number of pre- and post-wildfire mitigation actions taken (question four). The sum of the total number of actions a utility had taken was used in the rank-sum tests.

The four group-level variables used to test for differences in the median values of the social and psychological factors and actions taken were water utility size, federal land ownership in the watershed, previous exposure to wildfire events, and having a vulnerability assessment. Larger water utilities may be more vulnerable to wildfire and may have more incentive to engage in mitigation actions due to the size of the downstream population (Lee et al., 2022). To explore differences across utility size, a binary variable was created based on the median size reported by water utilities, which was 2000 customers. Utilities with more than 2000 customers were considered large and assigned a "1". Related to land ownership, federal agencies own an average of 47% of land in the western US (Liu et al., 2021) and land ownership can influence feelings of who is responsible for mitigation actions (Hamilton et al., 2018). Federal land ownership was self-reported and we created a binary variable with "1" if the US Forest Service, Bureau of Land Management, or National Park Service was reported as owning land where the utility operated. Previous fire exposure is often correlated with mitigation behaviors (Hamilton et al., 2018). Exposure to a previous wildfire event was recorded as a binary variable and having had a fire was assigned a "1" for analysis. Vulnerability assessments can increase knowledge of wildfire risk and potentially lead to mitigation actions (Dickinson et al., 2015). Vulnerability assessments include any process-based assessment of wildfire risk and or impacts of fire on water sources. Having access to a vulnerability assessment for the watershed was coded as a "1" for analysis.

We had planned to explore differences in the survey responses across states but given the small response rate for some states (Table 1), we decided to group states based on US Forest Service defined regions. Idaho, however, falls within two US Forest Service regions and for this analysis we put it with Montana due to sample size. Thus, we used the following five regions for our analysis: Region 1 (Idaho and Montana), Region 2 (Wyoming and Colorado), Region 3 (New Mexico and Arizona), Region 4 (Utah), and Region 6 (Washington and Oregon). To explore regional differences in wildfire risk perceptions and preparedness we compared observed frequencies.

We also included quotes from the open-ended optional question to contextualize the quantitative findings. Specifically, we identified write-in responses related to research question one about wildfire concerns, research question three about feelings of responsibility, and research question four about perceived efficacy and self-efficacy.

2.2.2. Regression analysis

As part of research question three, we analyzed correlations between multiple factors that could influence a utility's perceived responsibility toward mitigating wildfire in their watershed. We converted the categorically-measured perceived responsibility variable described in

2.2.1 into a binary response variable where "0" represented no responsibility and "1" partial or full responsibility. A logistic regression model was used to assess which factors were correlated with feeling responsible for wildfire mitigation:

$$Prob(P_i = 1) = F(\alpha + \beta X_i) \quad (1)$$

where $P_i = 1$ when a water utility felt it was responsible, X_i are observable variables, and F is the logistic function. Based on our literature review and where we had enough responses to survey questions, we focused on the following independent variables in Equation (1): utility size, land ownership types, past exposure to wildfire, concern for future wildfire events, and if a vulnerability assessment had been conducted on wildfire impacts. Correlation tests confirmed the absence of multicollinearity across these independent variables.

We included utility size in Equation (1) expecting that larger utilities would feel more responsible because they have more resources to address wildfire risk and have more customers that rely on source water. Since utility size was heavily skewed in the data we log-transformed this variable for regression analysis. We hypothesized that feeling responsible for mitigating wildfire risk would be positively related to the utility owning land and negatively related to the federal government owning land. We included dummy variables for the water utility owning land and the federal government owning land in Equation (1), with the latter defined in Section 2.1.1.

We hypothesized that exposure to past fires would lead to feeling personally responsible for mitigating future wildfire risk. Past exposure to wildfire was measured as a binary response to whether the drinking water system, including the watershed, had been impacted by a wildfire in the last 20 years. A "1" indicated that they had been exposed. Concern for future wildfire events, or risk perceptions, was expected to be positively correlated with feeling personally responsible for wildfire mitigation; level of concern was measured categorically as described in section 2.2.1. We also expected that having information about wildfire risk, through a vulnerability assessment, would lead to more perceived risk and therefore feeling more responsibility to act. We included whether the utility, or some other organization, had conducted a vulnerability assessment in Equation (1) with "1" indicating presence of an assessment.

We estimated Equation (1) for the full 173 responses and as a robustness check used a reduced sample that only included Colorado and Oregon, given the high response rates in these two states (N = 112 or 65% of the responses). For both samples, we ran Equation (1) with US Forest Service regional dummy variables to further reduce unobservable bias in terms of wildfire and water conditions and region-level policies or programs on wildfire mitigation. We show results including all independent variables and for parsimonious models, omitting any variable not statistically significant at a confidence level of 95% or higher using backward stepwise selection. For all regression models, we report odds ratios and robust standard errors. An odds ratio greater than one indicates a positive relationship; an odds ratio less than one a negative relationship. A positive odds ratio can be interpreted as the odds of increasing the likelihood that a water utility feels responsible for wildfire mitigation actions. A negative odds ratio must be reversed by taking $1/\beta$ and interpreted for a water utility not feeling responsible for wildfire mitigation actions.

3. Results

3.1. Sample characteristics

The mean number of individuals served by the 173 water utilities in our sample was 40,000. However, size was very heterogenous and the median size was 2000 customers. This is slightly higher than the mean and median population sizes served by the full sample of water utilities that the survey was emailed to, at 16,000 and 1000 respectively. Of the water utilities that responded to the survey, most withdrew or managed surface water from just one watershed. About 76% of water utilities reported that the land where they operated was owned by at least one of the three US federal agencies included in the survey (US Forest Service, Bureau of Land Management, or National Park Service). The most common landowners were the US Forest Service (70% of respondents), private owners (55% of respondents), Bureau of Land Management (45% of respondents), and the water utility itself (39%).

Less than half of water utilities (41%) responded that their watershed had been impacted by a wildfire in the last 20 years. Across regions, water utilities in Region 1 had the lowest reported exposure to past wildfires (23%). The highest reported exposure was in Region 3, with 64% of utilities reporting exposure in the last 20 years.

A similar number of respondents replied that they, or another entity, had assessed the vulnerability of their watershed to wildfires (41%). Across regions, Region 1 was the least likely to have had a vulnerability assessment, with less than 30% of respondents reporting that there had been an assessment conducted in their watersheds. Region 4 was more likely than other regions to report having this type of assessment available, with about 65% of utilities reporting that a vulnerability assessment had been conducted.

3.2. Perceived risk of wildfire

Concern for future wildfire events was high, with 35% of respondents very concerned, 33% concerned, 27% somewhat concerned, and only 4% not concerned at all (Fig. 1). Across regions, utilities in Regions 1, 2, and 3 were more likely to state they were very concerned about the impacts of future wildfires, than the average utility, whereas Regions 4 and 6 were more likely to state they were concerned. Most water utilities also felt their customers were concerned about the impact of future wildfires on their operations, with 73% of respondents saying customers were concerned or very concerned.

Concern about future wildfire events did not vary by utility size, but it was higher amongst water utilities that operated in areas with federal land ownership, that had previous exposure to a wildfire event, and or that had a vulnerability assessment for the watershed, based on Wilcoxon rank-sum tests (Table 2).

If a water utility was at least slightly concerned about a future fire event, they were asked about the specific concerns they had. Water quality (turbidity, ash, nutrients, etc.) was chosen most frequently as the wildfire-related impact of concern (90%), with hydrological flows (timing and volume of runoff) and infrastructure impacts (reservoir sedimentation or damage to equipment) each selected by more than 60% of respondents. A few water utilities selected "other concern" and wrote in additional impacts of concern, including power failure and impacts to their local economy. A few respondents highlighted the concern about power or electrical failure post-fire in the open-ended optional question, with one respondent in Oregon stating: "Power failures as a result of wildfires will be as damaging to us as the actual fire."

3.3. Water utility preparedness

3.3.1. Redundancy in operations

The respondents to this survey were split in terms of having the infrastructure in place to handle a significant wildfire event or access to alternative water sources (Fig. 2). About 38% agreed or strongly agreed they had the infrastructure in place to deal with fire, and 41% that they had alternative sources of water they could use. About 42% disagreed or strongly disagreed they had the infrastructure in place and 47% disagreed they had access to an alternative source of water. There were no discernible patterns across US Forest Service regions in terms of access to infrastructure or water source redundancies.

3.3.2. Operational plans and strategies

Respondents had taken several different types of internal actions and

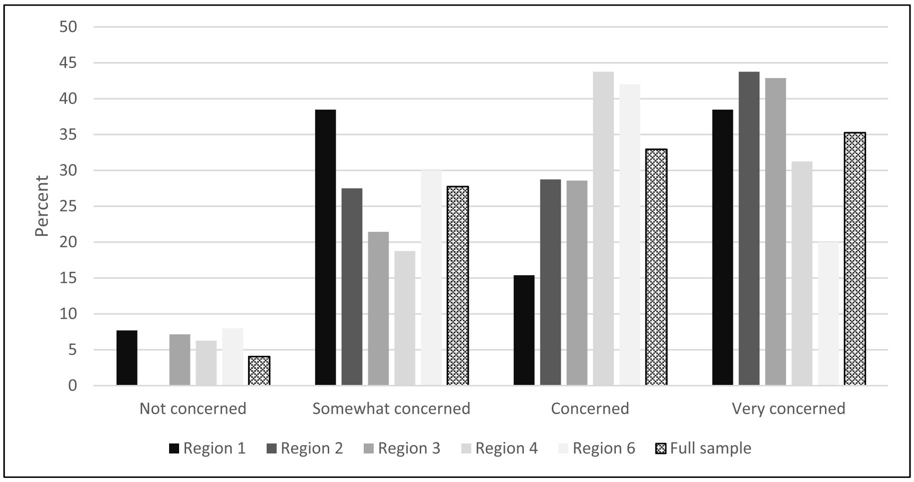

Fig. 1. Level of concern or risk perceptions for the impact of future wildfires on water utility operations by full sample and US Forest Service Region (N = 173).

Table 2
Wilcoxon rank-sum tests. Z-score and statistical significance reported at the **95% and ***99% levels. The interpretation of the sign depends on the coding of the variables and cannot be interpreted directly from this table of z-scores.

Independent Variable	By utility size	By federal government land ownership	By previous exposure to wildfire event	By having a vulnerability assessment
Risk perceptions of future wildfire	−0.03	−3.93***	−2.36**	−1.92**
Undertaken operational plans or strategies related to wildfire	−3.40***	−2.79***	−3.09***	−3.16***
Perceived responsibility for wildfire mitigation actions	0.47	−2.01**	0.52	1.59
N	*173*	*173*	*173*	*173*
Perceived response efficacy of wildlife mitigation actions	0.57	2.03**	1.11	0.75
Self-efficacy in terms of having all the data and information needed for wildfire mitigation	1.16	0.46	1.64	3.26***
Undertaken wildfire mitigation actions (pre- or post-wildfire mitigation)	−2.08**	−2.52**	−2.07**	−1.42
N	*68*	*68*	*68*	*68*

strategies to reduce wildfire risk (Fig. 3). The mean number of internal operational actions taken by a water utility was 2.4 with a maximum of 11 out of the 12 asked. The most common actions and strategies respondents said their organization had taken were installation of redundant/backup infrastructure, identification of new or additional water sources, installation of more fire resilient building materials, modification of their treatment process, and development of agreements with another water utility. Only about 20% of water utilities stated they had developed a formal wildfire plan for their organization, provided staff training about wildfire response, or conducted outreach to their customers about wildfire response. There was not much variation across US Forest Service regions in terms of the number of operational plans and strategies taken, with Regions 1 and 6 having a slightly lower mean score of actions taken compared to the other three regions. Having conducted these types of preparatory activities was more common for larger water utilities, for water utilities operating in a watershed with land owned by the federal government, if a water utility had a previous experience with wildfire, and if the utility had a vulnerability assessment, based on rank-sum tests (Table 2).

3.4. Perceived responsibility for wildfire mitigation

3.4.1. Level of responsibility for wildfire mitigation

About 61% (N = 105) of respondents to the survey indicated that they were not responsible for mitigating wildfire risk in their watershed. Of the 39% (N = 68) that felt they had some level of responsibility, 10 water utilities selected that they were completely responsible for these types of actions and 58 utilities selected that they were partially responsible. Across the five US Forest Service regions, water utilities in Region 1 were more likely to feel responsibility for wildfire mitigation and utilities in Regions 4 and 6 were the least likely to feel responsible (Fig. 4). There were few statistically significant differences between feeling responsibility and other variables using rank-sum tests. The one difference was that water utilities operating in places with federal land ownership felt less responsible for wildfire mitigation (Table 2).

A few water utilities left optional comments in the qualitative open-ended question about their feelings of responsibility and being located on federal lands. A water utility in Wyoming left the comment: "Unfortunately, the burden of this is in the hands of the US Forest Service who has yet to do proper job of forest management which has gotten us in the terrible situation we are already in when it comes to our forests risk's so that leaves very little hope that these concerns will ever be addressed prior to an incident."

3.4.2. Regression of factors that influence responsibility for wildfire mitigation

Summary statistics for the dependent variable and six independent variables included in the logistic regression can be found in Table 3. In the full regression model, for both the full sample and the Colorado and Oregon sample, we found that size of the water utility was not correlated with feeling responsible for wildfire mitigation actions (Table 4). Both land ownership variables were statistically significant at the 99%

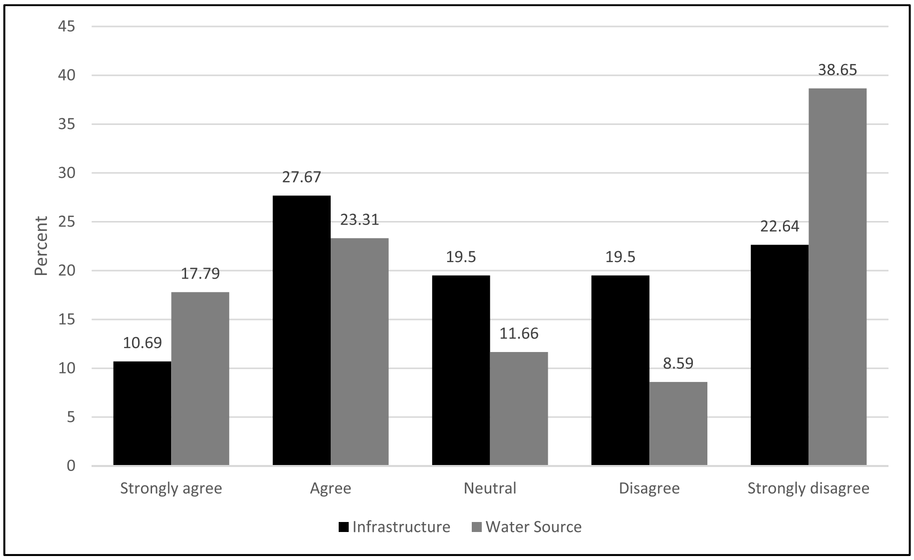

Fig. 2. Proportion of respondents agreeing or disagreeing with the statement that they have the infrastructure in place to handle a significant wildfire event and that they have access to an alternative source of water in case of a wildfire (N = 173).

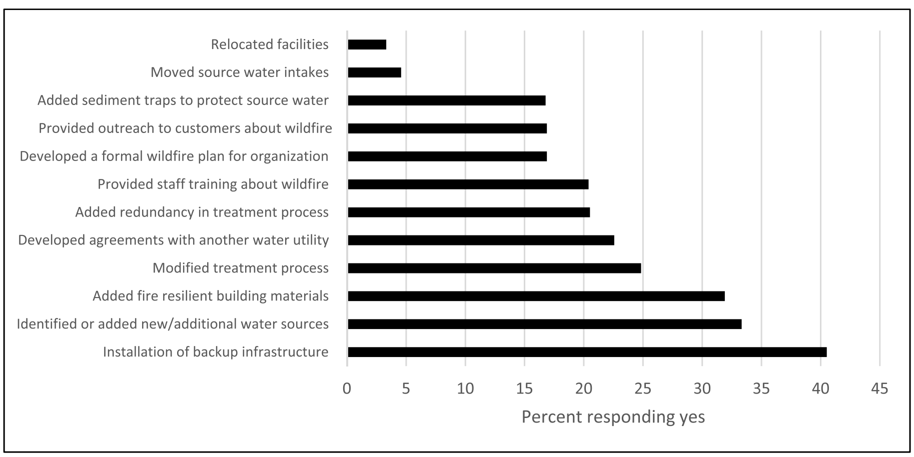

Fig. 3. Percent of respondents undergoing internal operational actions and strategies to mitigate wildfire and its impacts on water infrastructure (N = 173).

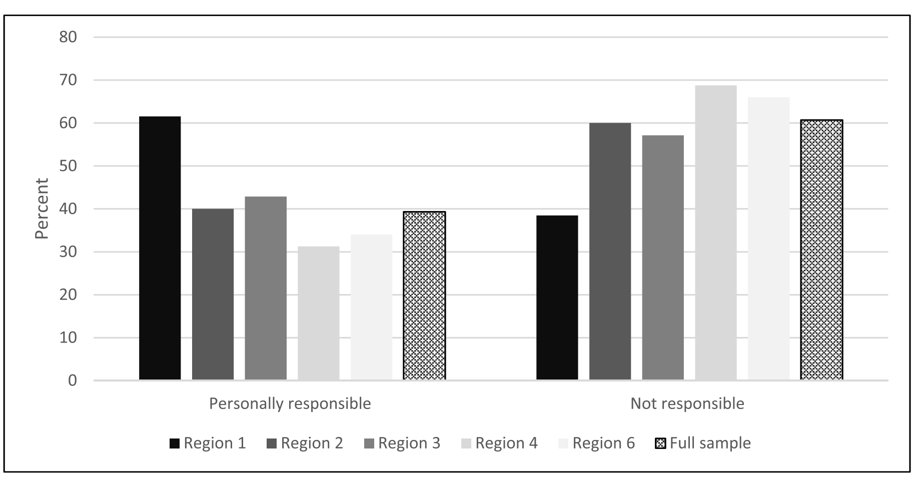

Fig. 4. Perceptions of personal responsibility for mitigating wildfire risk in their watersheds for full sample and by US Forest Service Regions (N = 173).

Table 3
Descriptive statistics for full sample and the Colorado and Oregon sample for variables included in regression analysis.

Variable	Full Sample	Colorado and Oregon Sample
	Mean (Std dev)	Mean (Std dev)
Personal responsibility (dependent variable)	0.39 (0.49)	0.40 (0.49)
Utility size	7.78 (2.56)	7.74 (2.43)
US federal agency land ownership	0.76 (0.43)	0.76 (0.43)
Water utility land ownership	0.39 (0.49)	0.42 (0.50)
Exposure to past wildfire	0.42 (0.50)	0.44 (0.50)
Risk perceptions of future wildfire	2.99 (0.89)	3.09 (0.85)
Vulnerability assessment conducted on wildfire impacts in watershed	0.42 (0.50)	0.43 (0.50)
N	*173*	*112*

Table 4
Logistic regression results for perceived personal responsibility to mitigate wildfire risk in their watershed(s). Odds ratios (>1 indicates positive and <1 indicates negative relationship) and robust standard errors presented. Statistically significant values reported at confidence levels of 95%** and 99%***.

Variable	Model 1 – Full model	Model 2 – Full model (only Colorado and Oregon)	Model 3 – Parsimonious model	Model 4 – Parsimonious model (only Colorado and Oregon)
	Odds Ratio (Robust std err)	Odds Ratio (Robust std err)	Odds Ratio (Robust std err)	Odds Ratio (Robust std err)
Utility size	1.14 (0.09)	1.16 (0.13)		
US federal agency land ownership	0.22*** (0.10)	0.07*** (0.05)	0.28*** (0.10)	0.09*** (0.06)
Water utility land ownership	3.72*** (1.46)	6.79*** (3.61)	3.44*** (1.46)	6.48*** (3.45)
Exposure to past wildfire	1.29 0.50	1.60 0.80		
Risk perceptions of future wildfire	1.72** (0.37)	2.23** (0.68)	1.68** (0.37)	2.28*** (0.63)
Vulnerability assessment conducted on wildfire impacts in watershed	2.26** (0.95)	4.27** (2.49)	2.65** (0.97)	5.63*** (3.15)
US Forest Service regional dummy variables included	YES	YES	YES	YES
N	*172*	*111*	*172*	*111*
Pseudo R^2	*0.15*	*0.24*	*0.13*	*0.22*
% Correctly predicted	*72%*	*76%*	*68%*	*72%*

confidence level in both samples. If the water utility owned land in the watershed it was more likely to feel responsible for wildfire mitigation, supporting our original hypothesis. The odds ratio suggests that for the full sample, water utilities that owned land in their watershed were almost four times more likely to feel responsible for wildfire mitigation, and in Colorado and Oregon, water utilities were almost seven times more likely to feel responsible if they owned land in the watershed. If a federal agency owned land in the watershed, the water utility was less likely to feel responsible for wildfire mitigation. The odds of not feeling responsible were about five times greater if a federal agency owned land in the watershed for the full sample and almost 14 times greater for the Colorado and Oregon sample.

Unlike our hypothesis, exposure to past wildfire events did not have a statistically significant influence on whether a water utility felt responsibility for wildfire mitigation actions in this study (Table 4). Risk perceptions, or concern about future wildfire events and their impacts on operations, however, was statistically significant and positively influenced feelings of responsibility. For both samples, the odds of feeling personal responsibility were about two times higher for a one level increase in concern for future wildfire events (e.g., going from somewhat concerned to concerned). The influence of having had a vulnerability assessment of the potential impacts of wildfire in the watershed were statistically significant at the 95% level and the odds ratio was larger than that for concern about future wildfire events. For the full sample, the odds of perceiving responsibility were about two times higher if a vulnerability assessment had been conducted for the watershed, and this increased to about four times higher in the Colorado and Oregon sample.

The parsimonious models were qualitatively like the full models for both samples, with some minor changes in the size of the odds ratios (Table 4). The variability explained by the two samples varies, with more variation explained when the sample is reduced to just Colorado and Oregon respondents.

3.5. *Wildfire mitigation actions*

3.5.1. *Perceived response efficacy*

There was a strong perceived effectiveness of wildfire and watershed mitigation actions across the utilities that felt responsible for wildfire mitigation (N = 68). Specifically, 92% of these water utilities stated they somewhat or strongly agreed that the evidence is clear that implementing watershed and wildfire risk mitigation actions reduces wildfire impacts. Only 7% of these respondents (four water utilities) were neutral and only one water utility disagreed with this statement. Perceived response efficacy was higher among water utilities that had a federal agency owning land in the watershed but did not vary by other variables tested using rank-sum tests (Table 2).

3.5.2. *Perceived self-efficacy*

Respondents that indicated they were at least somewhat responsible for wildfire risk mitigation had mixed perceptions on whether their organization had all the data and information needed to make decisions about these activities. The same proportion of utilities somewhat or strongly agreed they had all the information needed to make decisions about mitigation activities, as disagreed or strongly disagreed with the statement (39% for both). About 22% of the respondents were neutral on this question. Perceived self-efficacy did not vary by utility size, federal land ownership, or previous exposure to wildfire, but utilities that had a vulnerability assessment were more likely to report they had the data and information needed to make mitigation decisions (Table 2).

When asked specifically if more data and information would help improve their organization's decision-making, most water utilities agreed more information on wildfire risk, post-fire flooding, and post-fire water quality or sedimentation would be useful—90% of utilities responded yes to these questions. Many utilities also indicated that economic assessments such as return on investment analyses would be useful to have (88%).

3.5.3. *Actions taken to mitigate wildfire risk*

The most common wildfire and watershed mitigation activities undertaken in the sample of 68 water utilities that perceived responsibility for mitigation were thinning (69%) and stream or wetlands restoration (49%) (Fig. 5). Water utilities were less likely to have been involved in, independently or in partnership with other organizations, prescribed fire, clear cutting, mulching, or reforestation activities. The mean

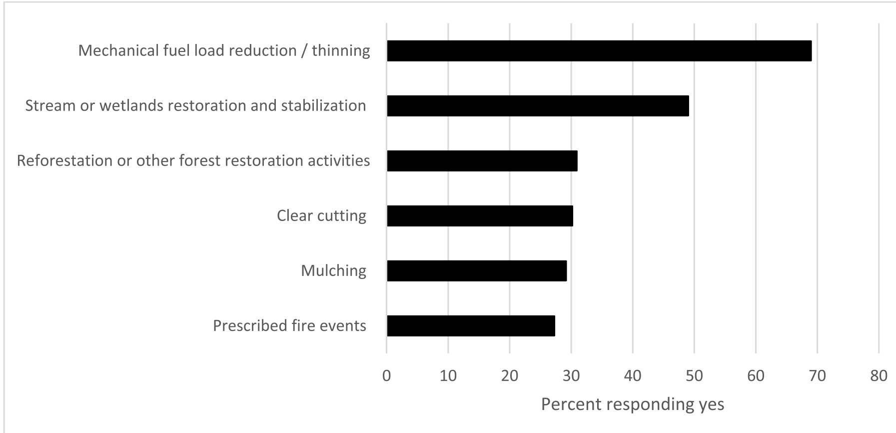

Fig. 5. Percent of respondents implementing pre- and post-wildfire mitigation activities on their own or with other entities (N = 68).

number of actions taken by a water utility was two.

There were differences across water utilities in the number of mitigation actions implemented (Fig. 5) by utility size, federal land ownership, and previous exposure to wildfire, based on Wilcoxon rank-sum tests (Table 2). Specifically, larger utilities, utilities located on federal lands, and utilities that had a previous exposure to wildfire implemented more of these wildfire mitigation actions. There was no difference in mitigation activity based on whether a water utility had a vulnerability assessment.

To implement these wildfire risk mitigation actions, water utilities indicated that they worked jointly with several types of organizations (Table 5). Most frequently, water utilities partnered with their local government, the US Forest Service, and non-governmental organizations or coalitions.

Wildfire mitigation actions were funded by water utilities using diverse sources (Table 6). The most stated sources were customer user fees, cost sharing with partner organizations, and grants.

3.5.4. *Additional barriers to mitigation actions*

Funding was indicated as the greatest barrier to implementing watershed and wildfire risk mitigation activities by water utilities that felt partially or completely responsible for risk mitigation (Table 7).

Several water utilities wrote in information in the optional open-ended response question about barriers to implementing wildfire and watershed mitigation actions. Related to funding and other resource constraints, a water utility in Colorado wrote: "There is very little funding available for non-disadvantaged communities to make infrastructure upgrades other than low interest loans and this makes it a massive hurdle in providing the necessary redundance." Another utility in Colorado noted: "We have only one employee, are financially strapped, and have an all-volunteer board. We just haven't had the capacity to do fire mitigation."

Table 5
Entities that water utilities worked most frequently with to mitigate wildfire risk (N = 68).

Entity	Frequency
Local Government	44%
US Forest Service	32%
Non-government organization or coalition	25%
Other water utility	24%
State Forestry Agency	19%
Other State Government Agency	15%
Private industry	12%
Other Federal Government Agency	10%
Other non-water utilities	7%
Tribal Organizations	4%

Table 6
Funding sources used to mitigate wildfire risk (N = 68).

Funding source	Frequency
User fees	49%
Cost share with partner	29%
State grants	25%
Grants from collaborations or partnerships	24%
Federal grants	23%
Loans (state or federal)	5%
Environmental impact bonds	1%

Table 7
Barriers related to wildfire risk mitigation for those water utilities engaging in wildfire risk mitigation actions (N = 68).

Barriers	Frequency responding yes
Funding	77%
Land ownership	55%
Permitting requirements	40%

Related to the theme of land ownership and working jointly with the federal government, several water utilities wrote in additional information. One in New Mexico stated: "We are extremely small and in domain in the [omitted] National Forest. We have little ability to control actions of the US Forest Service although we try to work with them. Frequent personnel changes there make relationship building difficult." A water utility in Colorado also noted obstacles of land ownership in taking mitigation actions: "Our water source is located on the edge of [omitted] National Park and the US Forest Service lands of [omitted] National Forest, so we have no jurisdiction to do wildland fire mitigation and we must rely on the efforts or not of these other entities. It is concerning because they take years to make any decisions to do any work and we are a very small water utility with few resources, physical or financial."

4. Discussion

This study explored wildfire risk perceptions and other social and psychological perceptions of water utilities toward wildfire mitigation, as well as their engagement with and barriers to wildfire mitigation, in the western US. In general, water utilities are concerned about future wildfire on source water operations, but their preparedness for wildfire events and their current engagement in wildfire mitigation activities appears low relative to this concern. Water utilities, like many stakeholders involved in wildfire mitigation, face several barriers including land ownership, funding, and access to information. Below we expand on our results and highlight their implications for enhancing water utilities' adaptive behaviors related to wildfire.

4.1. Risk perceptions

An individual's perceptions of wildfire risk, including both the intensity of fire and the impact on assets, has been shown to motivate adaptive wildfire behavior in various contexts (Martin et al., 2009; Fischer, 2011; McFarlane et al., 2011; Brenkert-Smith et al., 2012; Fischer et al., 2014). In our study, we found that water utilities expressed high levels of concern about future wildfire events and their impacts on water operations. These risk perceptions appear to be in line with wildfire risk assessments in the western US that predict more frequent and intense wildfires, with more negative impacts on source water (Abatzoglou and Williams, 2016; Rhoades et al., 2019; Robinne et al., 2020; Hagmann et al., 2021; Heidari et al., 2021; Williams et al., 2022). While there were slight variations in level of concern across US Forest Service regions, there were no discernible patterns indicating that some regions were less concerned than others.

The risk perceptions of future fire by water utilities did not vary by size of the utility, suggesting that large and small utilities feel equally vulnerable to wildfire. Risk perceptions were higher for utilities that had previously experienced a wildfire, which is similar to results from studies measuring individual risk perceptions (Fischer, 2011; Fischer et al., 2014). We also found that utilities operating in watersheds with federal land had higher risk perceptions. This could be because of access to information, which can play a mediating role in risk perceptions and mitigation behaviors (Dickinson et al., 2015). An alternative explanation is that utilities perceive higher likelihood of wildfires on federally-managed lands because they are more prone to burn, which is what is found in recent empirical studies that show higher fire probability on federally-managed forests compared to privately-owned forests in the western US (Starrs et al., 2018; Siegel et al., 2022). Having an assessment of wildfire risk was also related to higher risk perceptions. We cannot say whether the assessment led to increased risk perceptions or if having higher perception of risk led to having an assessment conducted, but there is a relationship between awareness of hazard conditions and risk perceptions in the wildfire literature (Fischer et al., 2014; Hamilton et al., 2018).

4.2. Operational redundancy and internal plans and strategies

Despite high levels of concern for future wildfire events, the vulnerability of water utilities to wildfire remains high in the western US. Close to two-thirds of utilities in our sample replied that they did not have the infrastructure in place to deal with a wildfire event or have access to alternative sources of water. In terms of operational actions and strategies, changes to operations, such as installing backup infrastructure, adding new water sources, or modifying water treatment processes, were the most reported actions. A relatively small number of utilities had provided training or information to staff or customers about wildfire impacts or developed a formal wildfire plan for their organization. Undertaking operational actions was more common for larger water utilities, utilities that experienced a past fire event, utilities that had an assessment of wildfire hazards, and those located in watersheds with federal ownership.

4.3. Perceived responsibility for wildfire mitigation

Individuals that perceive more personal responsibility for hazard reduction behaviors have been shown to engage in more adaptive behaviors (van Valkengoed and Stag, 2019). In the wildfire risk mitigation literature, this locus of responsibility has also been demonstrated to influence whether individuals take actions that protect themselves and their property (Martin et al., 2009; Hamilton et al., 2018). Overall, water utilities in this study perceived low responsibility for mitigating wildfire risk in the watersheds where they get their surface water. This was strongly associated with whether the water utility owned land in the watershed, in which case they perceived responsibility, versus whether a federal agency owned land in the watershed, in which case they were less likely to perceive their organization as responsible. This could be because they feel it is the federal agencies that should address this risk or that they do not have the legal license to act (McFarlane et al., 2011). Our qualitative responses suggest that both explanations are possible for why utilities do not perceive responsibility when located on federal lands.

Experience with a wildfire did not influence perceived responsibility to implement wildfire mitigation, nor did utility size. However, having higher perceived risk of future wildfires and access to information about hazards through an assessment, were both related to higher likelihood of perceiving utility responsibility for mitigation. Both variables had a large influence on feeling responsible, with a larger influence from having a vulnerability assessment. Since we only have cross-sectional data on perceived responsibility, perceived risk of fires, and having a vulnerability assessment, we cannot determine the order in which these three factors occur. That is, feeling personally responsible could lead to procuring information such as a wildfire vulnerability assessment, which in turn increases perceived risk of future wildfire events. However, we can say that these three variables are all positively related to one another. We also found variation in perceived responsibility across US Forest Service regions, with higher perceived responsibility in Region 1. This could be due to higher amounts of reported non-federal land ownership by respondents in this region.

4.4. Perceived response efficacy and self-efficacy for wildfire mitigation

Both perceived response efficacy and feelings of self-efficacy affect individual adoption of wildfire risk mitigation behaviors (Martin et al., 2009; McFarlane et al., 2011; Hamilton et al., 2018). These two variables have some of the largest effect sizes in a meta-analysis exploring factors associated with climate-adaptive behaviors, with both factors positively influencing behavior (van Valkengoed and Stag, 2019). In our study of water utilities, we found high response efficacy among water utilities that perceived some level of responsibility for wildfire mitigation. There was an association between utilities located in watersheds with federal land and higher perceptions of response efficacy. This could be because federal agencies are providing information or awareness about mitigation actions (Brenkert-Smith et al., 2012; Dickinson et al., 2015). Overall, the perceived benefits of mitigation do not appear to be a major concern or limitation to adaptive responses among water utilities that perceived themselves as responsible for mitigation actions.

Perceived self-efficacy to implement mitigation, however, was more mixed among water utilities in this study. The same proportion expressed that they had all the information and data they needed as stated they did not have the information and data they needed. We did not identify many factors that explain this variation in perceived self-efficacy using the rank-sum tests in this analysis. The only variable that showed some variation with self-efficacy was if a utility had a vulnerability assessment. While not a causal relationship, the vulnerability assessment could be providing the necessary information for a utility to feel confident in making risk mitigation decisions. Most utilities still reported that they would like additional information on wildfire risk, hydrological effects, or economic benefits, suggesting that even when a utility had some degree of self-efficacy, more information on wildfire-watershed relationships is still valuable for most utilities operating in the western US.

4.5. Adaptive wildfire behaviors and barriers

Of the wildfire mitigation behaviors being implemented by water utilities, on their own or in partnership with other entities, the majority were related to fuels reduction to proactively reduce wildfire risk. This suggests that water utilities are engaging in adaptive or transformative resilience practices that go beyond basic resilience of restoring ecosystem function after a fire occurs (McWethy et al., 2019). Another common adaptive behavior among water utilities was post-fire restoration practices aimed at restoring stream and wetland function, which reflects utility concern for source water protection.

Larger water utilities and those previously exposed to a wildfire had undertaken more wildfire mitigation actions than other utilities that also perceived some level of responsibility for wildfire mitigation. Operating in a watershed with federal land also led to more wildfire mitigation behaviors being reported. This might reflect the collaborations or partnerships that the federal government is engaging in (Schultz et al., 2018), and many utilities reported working with the US Forest Service on mitigation actions. However, many utilities also wrote in qualitative responses about the challenges they faced in working across land ownership types, specifically with federal agencies. These barriers of working across land ownership are commonly reported in the wildfire mitigation literature (Sham et al., 2013; Jones et al., 2022).

Lastly, the costs of mitigation appear to be a major concern for utilities given the number of respondents that selected financing as a barrier. Like individual decision-makers, water utilities weigh the benefits versus costs of mitigation, and the business case may be even more important for utilities that have to justify funding decisions to board members and customers (Bennett et al., 2014; Roberts et al., 2020). However, when water utilities can justify the expenditures, almost half were able to draw on user fees to help finance adaptive behaviors in this study, which could provide a new source of financing if more engagement occurred. Cost sharing was also an important way to fund wildfire mitigation in this study. Cost sharing of wildfire mitigation may be especially important given that several economic assessments of fuels treatments find that considering the benefit to watershed services alone does not necessarily justify the costs (e.g., Jones et al., 2022; Dobre et al., 2022). However, when the benefits of fuels treatments are considered more holistically, such that watershed services and other social and environmental benefits are measured, fuels treatments make economic sense (Jones et al., 2022; Hunter and Taylor, 2022).

4.6. Conclusion and recommendations

The high level of concern among water utilities about future wildfire in the western US suggests that there is scope to increase their engagement and scale up wildfire mitigation efforts. While there is no silver bullet for increasing utility engagement in wildfire mitigation due to variation in biophysical, economic, and other factors across utilities, we provide some guidance based on the results of this study. First, increasing the number of utilities with up-to-date vulnerability assessments of wildfire risk or fire impacts on operations could increase water utility engagement. Having a vulnerability assessment increases self-efficacy and may lead to more adaptive behaviors by providing the information needed to make risk management decisions. We also found connections between having a vulnerability assessment and several social and psychological factors, but we cannot determine the direction of these relationships using our data. Specifically, we found a relationship between water utilities that have an assessment and their perceived risk of future wildfire events and their perceptions of responsibility toward wildfire mitigation. Water utilities do not always have the capacity to develop assessments themselves. One suggestion is to have land management agencies or universities work with utilities to produce assessments. Having more wildfire assessments available to water utilities would help respond to the need expressed by utilities in this study that they want more information on wildfire risk, water quality impacts, and hydrological effects of fire.

Secondly, there is a need to change water utility perceptions of responsibility for wildfire mitigation in the western US that operate on federal lands. There is a direct relationship between perceived responsibility and engaging in adaptive behaviors, and these perceptions of responsibility are much lower due to federal land ownership in the western US. The role of government in mitigating wildfire is shifting and a larger view of wildfire governance is needed to address the current wildfire crisis (Morgan et al., 2023). Changing utility perceptions will require outreach and engagement about wildfire mitigation with water utilities operating on federal lands. This outreach and engagement should be aimed at providing information on the benefits of collaborative investments in wildfire mitigation, with an aim toward developing more partnerships. These partnerships or collaborations would have dual benefits. Water utilities would benefit by reducing their vulnerability to wildfire. Specifically, water utilities that were engaging in mitigation and were located on federal lands had taken more risk mitigation actions in our study. The federal government, and other partners, would benefit from diversifying funding sources since water utilities could bring user fees to the table. However, given the many negative opinions expressed about the relationship with federal land management agencies in this study, intermediary organizations, such as non-governmental organizations or universities, may need to be involved to make outreach efforts successful.

CRediT authorship contribution statement

Kelly W. Jones: Conceptualization, Formal analysis, Writing – original draft. **Julie Padowski:** Conceptualization, Writing – review & editing. **Melinda Morgan:** Conceptualization, Writing – review & editing. **Jaishri Srinivasan:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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