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Post-wildfire Drinking Water Crisis: Implications and Opportunities for the Insurance Industry

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Post-wildfire Drinking Water Crisis

Implications and Opportunities for the Insurance Industry

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Executive Summary

In recent years, there has been a rapid increase in wildfires across the United States, leading to mounting losses. The direct financial losses caused by wildfires have been well realized by the insurance industry, yet little is known about an emerging secondary hazard beyond the reach of the flames – wildfires can cause widespread drinking water system contamination. Depressurization of public and private water systems and heating of plastics can prompt harmful chemicals, like benzene, to contaminate the drinking water and infrastructure itself. Ash and debris from structure and vegetation burning can also enter drinking water. The problem is amplified as the contaminated water is spread throughout pipe networks and into buildings, chemicals penetrate certain plastic plumbing components, and then slowly leaching out over time, making "safe" drinking water and the plumbing unsafe. After a wildfire where drinking water has become contaminated, officials often assume insurance companies will resolve the property plumbing safety issue. However, the insurance industry lacks a fundamental understanding of the factors that influence the potential for plumbing components to be contaminated, in some cases irreparably damaged, how to conduct water testing, and remediate the damage.

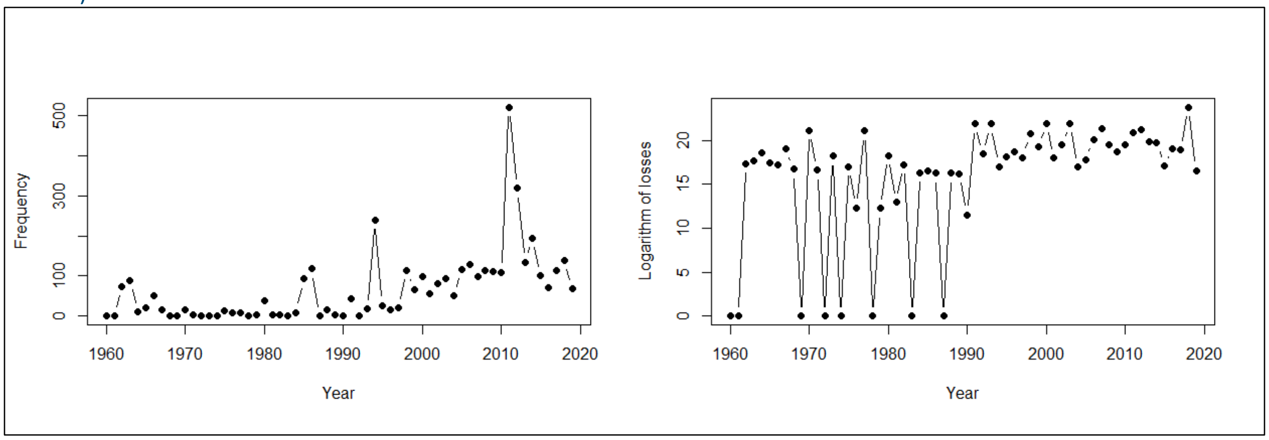
The purpose of this report is to provide the actuarial community with education about wildfire-caused contaminated plumbing and recovery associated phenomena, health, and financial impacts. From a practical perspective, this work can help raise awareness of this national emerging issue within the insurance industry and prepare the industry for confronting this issue. From an academic perspective, this report can serve as an important stepping-stone for promoting future in-depth investigation in related domains conducted by actuaries, advancing the actuarial community toward the research frontier of this national emerging issue.

Section 1: Introduction

In recent years, the western regions of the United States and regions across Canada have been the site of the most destructive, deadliest, and costliest wildfires in modern history. Exacerbating the problem is the continued expansion of human development into previously undeveloped wildland, leaving more people, properties, and critical infrastructure vulnerable to the impact of wildfires. Consequently, a noticeable rise in both the number of wildfires in the United States and wildfire losses can be seen from 1960 to 2020 (see, Figure 1). For more detailed information about the recent wildfire frequency and loss trends among different territories, we refer the readers to Chapter 2 of Li and Su, 2023.

FIGURE 1

HISTORICAL WILDFIRE FREQUENCY (LEFT PANEL) AND LOGARITHM TRANSFORMED WILDFIRE LOSS IN USD (RIGHT PANEL) IN THE UNITED STATES FROM 1960 TO 2020.



Insurance plays a critical role in wildfire risk management, providing crucial financial protection to property owners and promoting proactive risk reduction measures. The mounting frequency and severity of wildfire damages have, in turn, intensified the liability side of the balance sheet for insurance providers offering wildfire coverage. As a result, studies focused on statistical analysis of wildfire losses and the management of the tail risk associated with wildfire exposure have gained increasing prominence and significance within recent actuarial literature (e.g., Bairakdar et al., 2023; Brinkmann et al., 2022; Li and Su, 2023).

In contrast to well-documented actuarial knowledge pertaining to the direct financial damages caused by wildfires, there exists a less recognized but increasingly significant hazard - *the drinking water and infrastructure itself can be made contaminated and unsafe to use* (Draper et al., 2022; Jankowski, et al., 2023; OHA, 2020; Proctor et al., 2023; USEPA, 2021; Whelton et al., 2023). After some wildfires since 2017 in the United States, levels of some chemicals found in drinking water being delivered to buildings have exceeded U.S. Environmental Protection Agency regulated hazardous waste limits, not just drinking water exposure limits. Exposures to high concentrations of these post-fire related chemicals can lead to a series of health-related issues. Health officials often permit this contaminated water to be delivered to affected households and businesses for restricted use (and thus entry into plumbing) so there can be fire-fighting and basic sanitation abilities in the disaster impacted community.

Water system assets may be damaged and made unsafe to use in a variety of ways. The following damage scenarios are possible due to fire damage to water systems and structures:

1. **Physical damage**: Heat and flames can cause plastics in pipes, fittings, valves, tanks, etc. to expand, shrink, melt, or burn. This phenomenon can result in leaks, bursts, or asset failure altogether. Drastic pressure fluctuations due to rapid water loss (depressurization) and/or hydrant use due to firefighting operations

can put additional strain on the plumbing system prompting leaks, bursts. Physical strain and breaks can also occur when either structure debris impacts the plumbing or plumbing components are displaced.

2. **Chemical contamination due to plastic degradation**: Volatile organic compounds (VOC) and semi-volatile organic compounds (SVOC) are created when plastic water system materials are heated. These can remain in the plastic or leach out into water. The presence of VOCs and SVOCs in water can post immediate and long-term health risks to plumbing users.

3. **Chemical contamination due to depressurization**: VOCs, SVOCs, and possibly heavy metals may be drawn into the plumbing. VOCs are known to penetrate plastics, thereby making plastics like gaskets, pipes, and other components (i.e., faucet connectors, water softeners, etc.) a long-term source of contamination.

4. **Microbiological contamination due to depressurization:** Disease causing organisms like *E. Coli* have been thought to enter plumbing due to fires. Another possibility is the presence of other pathogens like Legionella, but neither these nor other microorganisms will be addressed in this report.

In addition to the original source of contamination, plumbing components that contact contaminated water may become a secondary source of contamination. These assets do not need to generate contamination themselves but can become subsequently contaminated and compromised. For example, VOCs are known to penetrate certain plastics used for a variety of applications. These include gaskets, fittings, valves, pressure tank expanders, polyethylene pipes, polyethylene and vinyl faucet connectors, water softeners, among other components. These materials can become a long-term source of contamination.

While the health risks associated with contaminated water are not the primary focus of this report, it is nevertheless pertinent to briefly address them herein. Population exposure to the contaminated water can occur due to ingestion, skin contact, and inhalation (i.e., vapors from showering, misting, boiling water, spraying the water, etc.). This happens during routine water use activities and also during plumbing decontamination (e.g., flushing). The health impacts will be influenced by the chemicals present, their concentration, duration of exposure, among other factors. Exposure can cause headaches, nausea, dizziness, rashes as well as irritated eyes, noses, and throats, vomiting, diarrhea, among other effects. Long-term exposure to certain chemicals can increase cancer risks, prompt organ damage, and neurological impairments. Children and immunocompromised populations are most at risk of adverse health impacts. Animals (i.e., pets, livestock, etc.) can also be negatively affected if exposed to contaminated water. Secondary exposure due to water use for contaminated foods and vegetables, etc. is also a concern. Other receptors for contamination water could be animals and pets.

A current challenge due to the rapid emergence of this serious health risk to households and businesses is an absence of a clear definition for the eligibility of wildfire-induced contaminated plumbing claims and diverse responses by insurance companies. These have led to substantial delays in disaster recovery and, at times, exacerbated contamination severity. These circumstances also pose a considerable reputation cost to the insurance industry. A primary challenge is that when property plumbing damage and contamination is suspected or occurs, it is often assumed that insurance companies will consistently address all of these issues for affected individuals. Discussions with insurance professionals in various roles indicate diverse perspectives on whether losses from wildfire-induced damaged and contaminated plumbing should be covered by standard home insurance policies. Consequently, after wildfires, some insurance companies have denied claims for contaminated plumbing issues, while others approved them, sometimes even for neighbors. Additionally, insurance companies sometimes hire water professionals for testing and treating building plumbing for this contamination that are not technically prepared to diagnose or address the problem. As some of these consultants have prepared to conduct investigations, they have contacted the authors for help. Others have shared their opinions and experiences, and many of their actions made clear they were incapable of finding contamination even if it existed.

The purpose of this project was to help educate the actuarial community about wildfire-caused contaminated drinking water, plumbing, recovery associated phenomena, as well as health and financial impacts. Information contained in this report can serve as an important stepping-stone for promoting future in-depth investigation in related domains conducted by actuaries, advancing the actuarial community toward the research frontier of this national emerging issue. The report contains the following information:

- Section 2: Description of the physical process causing plumbing contamination in the aftermath of wildfires
- Section 3: Introduction to intervention strategies to recover from wildfire-induced drinking water quality threats
- Section 4: Financial and insurance lessons learned from recent contamination disasters
- Section 5: Brainstorming potential toolkits from the existing actuarial knowledge tank for quantifying the financial risk associated with wildfire-caused contaminated plumbing, which can be further used to support recovery decision-making

Section 2. How Drinking Water and Plumbing are Chemically Contaminated by Wildfires

The focus of this project is on property drinking water systems, not regulated public water systems (PWS) though these systems will be mentioned due to their importance delivering contaminated water to properties, in some cases. A PWS is defined as an entity that serves drinking water to at least 15 service connections or an average of at least 25 people for at least 60 days a year. Drinking water produced by these systems must comply with the *Safe Drinking Water Act*. The responsibility for responding to the damage and contamination to a PWS is outside the property owner's responsibility. The focus of this project is on properties and the water systems on that property. For perspective, there are more than 44.5 million people in the U.S. relying on private wells as their primary water sources not relying on PWS.

Property plumbing designs and materials can vary property to property. Plumbing can include an array of different materials for pipes, tanks, water treatment devices, appurtenances, etc. (see, Table 1). Water lines responsible for conveying water from the public water system to the property water meter and into buildings, are also frequently made from plastic. Upon entering buildings, drinking water can further travel through additional plastic pipes designed to convey both cold and/or hot water. Notably, the length of piping in building water systems is typically 5 to 10 times greater than that in buried water distribution systems.

TABLE 1

LIST OF SOME MATERIALS COMMONLY FOUND IN PROPERTY PLUMBING.[1]

Plumbing Component	Type of Material
Service line	Polyvinyl chloride (PVC), high-density polyethylene (HDPE), cross-linked polyethylene (PEX), chlorinated PVC (CPVC), copper, lead, multilayer pipes (plastic layer–barrier layer–plastic layer; barrier layers could be aluminum, polvinyl alcohol)
Piping and tubing	PVC, HDPE, PEX, polypropylene (PP), CPVC, HDPE-raised temperature, copper, ductile iron, galvanized iron, concrete, lead, lead-lined steel, black steel, malleable iron, brass, stainless steel, multilayer pipes (plastic layer–barrier layer–plastic layer; barrier layers could be aluminum or ethylene vinyl alcohol)
Pipe and tank coatings	Epoxy, polyurethane, polyurea
Fixture fittings, valves, fittings	Synthetic rubber (o-rings), PVC, lead, stainless steel
Gaskets	Ethylene propylene diene monomer [sulfur and peroxide cross-linked], natural butyl rubber, styrene-butadiene rubber, neoprene
Water-heater specific	Polysulfone dip tubes, steel, glass, ceramic interior linings, magnesium, or aluminum sacrificial anode rod
Domestic storage and cistern	Fiberglass polymer composite, stainless steel, HDPE
In-building treatment	Filter material (membranes, paper micro filters), plastic housing for sorbent or filter storage, activated carbon, ion exchange resin, stainless steel
Small-diameter tubing for faucet connectors, humidifiers, dishwasher supply, washing machine supply, in-building water treatment systems	Linear low-density polyethylene, PEX, copper, PVC, HDPE, PP

All water system components are vulnerable to chemical contamination, though certain are more vulnerable than others. Water system components often have scale and biofilm, or a slime layer coating them. This can allow some chemicals to adsorb, or stick to the surface. Metal components would be resistant to permeation, or the penetration of the chemicals into the component. In contrast, certain plastics are vulnerable to this type of penetration such as polyethylene, elastomers like rubber, ethylene propylene diene monomer (EPDM), and unplasticized polyvinylchloride components, among others. These flexible materials allow for chemicals like VOCs to absorb into them. After the contaminated water is removed from the component (i.e., pipe) and replaced with clean water, these contaminated assets can then leach the VOCs into that clean water making it unsafe. The plastics mentioned above can be long-

[1] The table is expanded from Julien et al. (2020) and Casteloes et al (2015). Entire or part of the service lines may or may not be considered property plumbing. In some cases, this material may be owned by the drinking water provider.

term sources of the chemical contamination and these components are used in private property water systems, in and outside the buildings, and also regulated public water systems.

2.1 FACTORS THAT INFLUENCE DRINKING WATER AND PLUMBING CONTAMINATION RISK

The contamination risk to properties impacted by fire will be dependent upon the water system they are connected to. For example, **Figure 2** shows a building receiving drinking water from a public water system. In this scenario numerous buildings on multiple properties are connected to a single contaminated water system. Here, the contamination risk is highly interdependent. For example, a single building that's destroyed or depressurized may allow for its contamination to be drawn into the PWS and thus be delivered to a neighboring property, even when that property is not damaged by fire. **Figure 3** shows a different scenario where a building receives drinking water from a single drinking water well that only serves that property. Here, the property water system is not connected in any way to other surrounding properties or water systems. Therefore, the contamination if it exists, is isolated to this single property water system.

FIGURE 2

DRINKING WATER CAN BE PROVIDED VIA PUBLIC WATER SYSTEMS AND THE RELATED BASIC COMPONENTS ARE DESCRIBED.

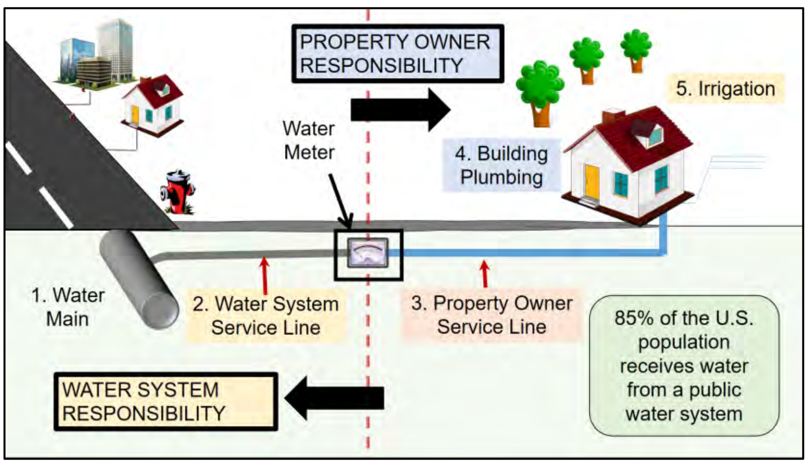
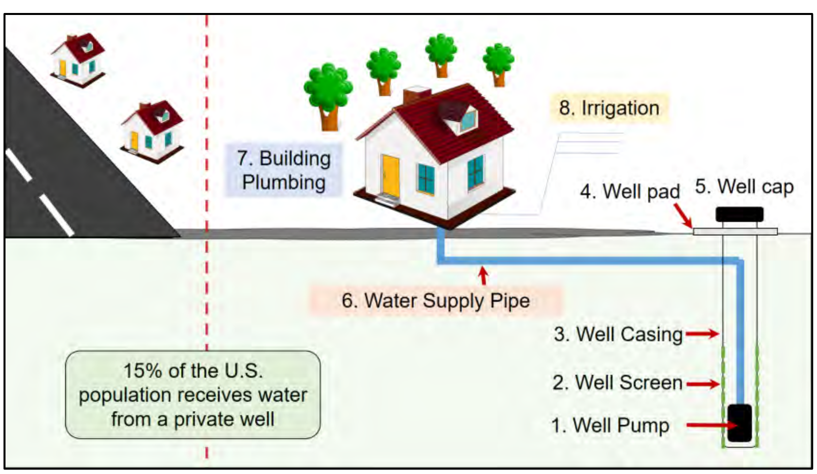


FIGURE 3

DRINKING WATER CAN BE PROVIDED VIA PRIVATE WELLS AND THE RELATED BASIC COMPONENTS ARE DESCRIBED.



2.2 THE SOURCES OF CHEMICAL CONTAMINATION OF DRINKING WATER AND PLUMBING

Wildfires and structure fires can cause physical damage to water system infrastructure as well as chemical contamination of drinking water and plumbing. Particulates and vapors are generated during burning of vegetation, structures, and even water system materials. These can be drawn into depressurized drinking water systems. Pressure loss can occur due to power outages and the loss of water production capacity, fire-suppression and fighting activities where water is being drawn out of the water system without being replenished, leaks in water distribution systems and buildings' plumbing components during and after fires.

Direct thermal degradation of plastic infrastructure used for water systems can be another contamination source. Figure 4 displays example water system components thermally damaged by the 2018 Camp Fire in and around Paradise, California. During wildfires, surface temperatures can range from 200 °C to 800 °C, and temperature is influenced by, including, but not limited to, the type and quantity of fuel, humidity, height above ground, and velocity. The temperatures that water system components experience depend on surface temperature, burial depth, or their locations within (the walls of) buildings, etc. At present, there are no standards that require the installation of backflow prevention devices on building service lines in wildfire prone areas. These chemicals can also enter water by deposition with ash and debris or by being drawn into water systems that are undergoing depressurization.

Thermal degradation of plastics *generates and releases* hazardous chemicals from the plastics themselves. These chemicals include VOCs[2] and SVOCs. In comparison to one another, VOCs are lighter compounds that more readily lead the drinking water and transfer into the air than SVOC. For example, boiling VOC contaminated drinking water would expose the person to the chemicals after they left the water and entered the air. SVOCs are heavier compounds which do not readily partition into the air. Another difference between VOCs and SVOCs is that VOCs can permeate certain plastics. This means they can travel into the plastic and out of the plastic (making drinking water unsafe). SVOCs are larger and cannot readily do this. Therefore, plastic plumbing contamination and health risks post-fire, to date, are primarily VOC issue. As more information becomes available this may change.

The source of the VOC and SVOC contamination may be on the affected property or, for properties connected to public water systems, those nearby damaged properties. For example, if a property is damaged and the plumbing becomes contaminated, the contaminated water can be drawn back into the public water system pipe network, travel down the street, and then be delivered to a non-fire damaged property. At present no studies have been conducted to assess how far away the contamination can move from the source. Predicting contamination fate is complicated due to many unknown phenomena and once in drinking water, VOCs and SVOCs interact with water pipe scales, biofilms, and intact plastic water system materials.

[2] VOCs found in drinking water systems after recent wildfire events include benzene, dichloromethane, naphthalene, styrene, tert-butyl alcohol, toluene, and vinyl chloride.

FIGURE 4

IMAGES OF FIRE-DAMAGED WATER SYSTEM COMPONENTS INCLUDING PIPES AND WATER METERS.

2.3 CONSIDERATIONS FOR A PROPERTY SERVED BY A PRIVATE DRINKING WATER WELL

Contamination stemming from wildfires can impact users of private drinking water wells, and in the United States, over 44.5 million people rely on these water resources (McCann et al., 2011; Maupin, 2014). Specifically, in the aftermath of wildfires, wells and their associated components may face contamination from debris[3], smoke, particulates, and vapors. Contaminants may infiltrate well systems through damaged well covers or caps. The heat generated by wildfires or structure fires can lead to the melting of plastic well casings and other underground plastic components, even when they are buried 2 to 5 feet below ground level. Thermally degraded plastic well casings, pipes, tanks, and other components can generate and leach VOCs and SVOCs into the water, rendering it unsafe for use. Additionally, if building owners leave home garden hoses and sprinklers running, resulting pressure fluctuations or pressure loss conditions can prompt the entry of VOCs and SVOCs into well systems. It is noteworthy that well system components and configuration can vary widely, as not all well systems have well caps, well pads, cisterns, yard hydrants, for example.

Section 3. Recovery From the Disasters

Plumbing inspection, testing, and remediation strategies have not been formally issued by regulatory agencies, and most current practice is based on this report's co-author Whelton's research team discoveries. It should be noted that

[3] In this context, debris contain broken down building materials, infrastructure, consumer items, and vegetation.

while consultants have conducted plumbing contamination investigations following fires, some conducted after wildfires were reviewed by Professor Whelton and found to be deficient. For example, some consultants collected samples improperly or requested laboratories analyze the samples in a way that was incapable of finding fire-related VOC drinking water contamination. Information described below and in the enclosed references is the most up to date best practice as of the date this report was finalized.

3.1 INSPECTION AND RISK FACTORS

There are a variety of actions that should be conducted in order to address the plumbing contamination concern after fires. An important action is the inspection and damage assessment activity. An inspection is important to understand the water system components are present on the property, document damage, and estimate the potential that any water being provided to the property is or could be contaminated rendering the plumbing unsafe. A summary of best practice inspection approaches can be found elsewhere:

- For properties served by a public water system: https://engineering.purdue.edu/PlumbingSafety/resources/After-a-Wildfire-Water-Safety-in-Buildings-2021-05-16.pdf

- For properties served by a private well system: https://engineering.purdue.edu/PlumbingSafety/resources/After-a-Wildfire-Private-Drinking-Water-Wells-2021-05-16.pdf

There are several risk factors associated with water contamination. These are summarized below.

- Risk Level 1: Plumbing NOT depressurized, NO structure damage, NO smoke in the area.

- Risk Level 2: Plumbing depressurized, NO structure damage, smoke in the area.

- Risk Level 3: Plumbing NOT depressurized, structure damage on or near the property, smoke in the area.

- Risk Level 4: Plumbing depressurized, structure damage on or near the property, smoke in the area.

If the property is served by a public water system or private water system and that system has been damaged or contaminated, the likelihood that the property plumbing is contaminated is greater. If the property is served by a cistern, these water systems can be contaminated due to debris on the rainfall runoff surfaces (i.e., roofs). Care must be taken to identify all potential sources of water contamination to the property.

3.2 REMEDIATION STRATEGIES

If water contamination is suspected or confirmed the following actions should be considered:

1. Isolate: In some circumstances, isolating contaminated plumbing sections/assets from the rest of the plumbing by shutting valves, physically disconnecting pipes, etc. can help stop contaminants from spreading to unaffected components. This approach can help minimize further damage and remediation costs.

2. Decontaminate by Water Flushing: For mild to moderate chemical contamination situations, repeated flushing of the plumbing can sometimes be successful. Though, flushing can be time-consuming and labor intensive, and will require follow-up chemical testing to validate whether contamination has been fully removed. Decontaminating plumbing components affected by VOCs and SVOCs can take weeks to months, contingent on factors such as the degree of contamination, plastic type, pipe diameter, temperature, and

flow rate, among others. Sometimes flushing has shown to be incapable of removing all pollutants. There are some conditions post-fire where, for example, a 1-inch diameter HDPE drinking water pipe could require more than 1 year of water flushing at 1 gallon per minute, 24 hours/day, to make it safe again (Whelton et al., 2019). The degree flushing may be effective would be measured by examining chemical drinking water testing data AFTER a 72-hour stagnation period.

3. Install Water Treatment: Contaminants in water can be removed or reduced using techniques like reverse osmosis, activated carbon filtration, or ultraviolet disinfection. However, the magnitude of contamination, the type of contamination (VOC vs. SVOC), and the site of treatment (point of use or point of entry) all affect how well water is treated. If the contamination is at a point following the point of entry (i.e., water heater vs. shower vs. kitchen sink) installing a water treatment technology at the point of entry would not make that water safe. Furthermore, given the high cost of each individual treatment, providing treatment at every point of use can be exceedingly expensive. In California, periodic water samples (once every 6 months) after the treatment system are required when building water treatment is installed to validate the system is working correctly and there is no breakthrough (=failure).

4. Remove and Replace: When certain plumbing fixtures or components are discovered to be contaminated and cannot be remediated in a timely manner or may be cost prohibitive, removing and replacing these assets is necessary. To remove sources of contamination, pipes, valves, fittings, connectors, faucets, fixtures, and devices are replaced with new ones. It may be less costly to remove and replace certain assets under certain conditions than to attempt to flush the contamination out of the plumbing.

3.3 RISK PREVENTION VIA BACKFLOW PREVENTION DEVICES

Backflow prevention devices are commonly used and required for industrial water service connections and public water systems. These devices prevent water from flowing in the reverse direction but allow for water to be delivered by pressure to the customer. When a pressure loss occurs in the public water system, the backflow prevention device can stop the movement of water from the industrial customer backwards into the public water system pipe network. There are a myriad of examples where backflows have caused drinking water pipe and plumbing contamination (Casteloes et al. 2015). Backflow prevention devices help prevent this.

There are rarely requirements for the installation of backflow prevention devices on residential water services. To reduce the risk of contaminated water from a single residential building being drawn back into the public water distribution system and being delivered to unaffected buildings, making those buildings unsafe, backflow prevention devices could be used. These devices could be installed at the water meter and be the responsibility of the public water supplier to install and service. The installation of such a device without proper routine inspection and maintenance would have little protective value. By encouraging or requiring backflow prevention device installation at many or all buildings in a community, the overall risk of contaminated water from one building affecting other buildings would be reduced markedly. Simply put, the contaminated water would remain isolated to the building that was damaged by the fire and not spread the contamination throughout multiple buildings and even public water system assets.

Section 4. Financial Considerations and Implications to the Insurance Industry

Understanding the financial costs needed for impacted individuals to recover plays an important role in disaster preparation and response. Lack of access to financial support and information ambiguity may cause delays in disaster recovery, thus intensifying the anxiety, stress, and depression faced by the impacted individuals. However, due to the emerging nature of post-fire plumbing contamination phenomena, there is very little study pertaining to the financial damages associated with contaminated plumbing. The only related study we are aware of is the experience survey this report's co-author Whelton's research team conducted to households impacted by the 2018 Camp Fire. Their findings are summarized in the following subsection.

4.1 LESSONS LEARNED FROM THE 2018 CAMP FIRE, CALIFORNIA

The 2018 Camp Fire in Butte County, California, was the state's most destructive wildfire in history. After the fire began, approximately 40,000 people were evacuated and relocated throughout California and the U.S. During the 17-day burning period, 18,793 buildings including more than 14,600 homes were destroyed. The 2018 Camp Fire was also one the first known wildfires where widespread chemical contamination was discovered in the drinking water network. The Camp Fire damaged critical drinking water system assets including water mains, reservoirs/tanks, hydrants, services lines, meters, and building plumbing. Plastic materials in water systems exposed to elevated temperatures leach VOCs and SVOCs into drinking water. Extensive chemical contamination was found in the water distribution systems. For instance, benzene contained in the water systems was greater than 2,217 ppb, whereas U.S. Environmental Protection Agency defines the associated hazardous threshold as 500 ppb. Even short-term exposure to 26 ppb of benzene in drinking water may cause adverse health effects for children. The toxic chemical propagates through pipe networks, enter into buildings, and permeate plumbing components in the standing homes. Further, an estimated number of 2,438 private drinking wells inside the fire zone were also impacted. A variety of water use restrictions were issued by multiple agencies.

Six months after the Camp Fire, a research team led by this report's co-author Whelton conducted an online survey concerning the attitudes and experiences of community members who lived in or owned homes in Butte County. Each survey was completed by the head of the household, who served as the sole respondent for all household members. Throughout the survey period, materials causing chemical contamination were still present in the water systems, and drinking water advisories issued by water agencies were still in effect. The survey addressed the impacts of contaminated water on employment, water use, and reallocation. Additionally, a significant number of questions were devoted to understanding the costs of installing treatment devices, conducting water testing for safety, and what costs are covered by home insurance.

The survey yielded 233 validated household responses, representing 607 current or past inhabitants in the impacted community. Among the survey responses, more than half of the households reported anxiety, stress, or depression directly related to the water contamination issue. Approximately 35% of employed households had at least one household member miss work specifically due to water-related issues (e.g., installing water treatment devices, plumbing testing). Seventy percent of respondents reported that at least some household members had returned to their homes, and among them, more than half reported that the drinking water contamination issue affected their decisions to move back. Among the households that were undecided or planned to never return, 95% stated that the possibility of drinking water contamination and the associated health risks were the greatest concerns.

The figures presented in the remainder of this section are derived from the 233 validated household responses. To address water contamination issues, most households sought alternative water sources, such as bottled water. The estimated spending on bottled water per household ranged from $140 to $310 over six months. Approximately 5% of households opted to install outdoor drinking water storage tanks, incurring an average cost of $3,545 per household, though some exceeded $10,000 per household. Nearly half of the households installed treatment devices equipped with activated carbon filters, which can remove certain VOCs present in contaminated water. Installing these treatment devices can be costly, ranging from $2,300 to $4,300 per household. It is also essential to note that the installation of outdoor water tanks or whole-house filters may not fully protect households from contaminated water if internal plumbing had accumulated contamination prior to installation. Additionally, if a filter device is installed, regular monthly water testing is recommended to ensure proper operation and determine whether the device requires filter replacement.

The above-mentioned in-home water treatment systems were covered by insurance in some cases, but not always. Approximately 40% of households that installed water tanks reported that the costs were covered by their home insurance. A few insurance companies covered the purchase and installation of activated carbon filter devices. Just under half of the households conducted in-home water testing, incurring an average cost of $400 per household. About 10% of these households had water testing expenses covered by insurance. *[Following prescribed guidance, many households only looked for the chemical benzene in drinking water at once location in their plumbing on time because it was about $50/sample, compared to the wider scan VOC analysis which ranged from $145-$250 per water sample. It has been proven however benzene is not the indicator chemical for contamination after wildfires, it may not be present when other VOCs are present and pose an immediate risk to human health.]*

Admittedly, the survey is limited in describing a more complete financial impact on individual households due to wildfire-caused contaminated plumbing. More than 40,000 people were impacted by the wildfire, and less than 300 households participated. Although, this represents the only post-wildfire study that has been conducted to date. Other relevant financial losses, which have not been taken into account yet can result from loss of employment, loss of rental incomes, additional living expenses, medical expenses due to concentrated exposures to contaminated water, etc. Sometimes, all or parts of the internal plumbing need to be replaced, and the associated costs can be substantial. It is also important to note the severity of financial impact in another wildfire-caused water contamination disaster can be very different from the one that occurred during the 2018 Camp Fire. Future research is urgently needed to develop a comprehensive understanding of the financial risks associated with different scenarios of wildfire-caused contaminated plumbing.

4.2 IMPLICATIONS TO THE INSURANCE INDUSTRY

During a post-wildfire plumbing contamination disaster, officials often assume insurance companies will resolve the issue. FEMA's restrictive individuals and households' program can sometimes provide financial help to those who cannot find support elsewhere but is often used only for physical/water/mold/structure repair and disaster debris. To the authors' knowledge, FEMA did not provide financial assistance to homeowners for plumbing contamination. Instead, FEMA has repeatedly told homeowners to look for financial support from their home insurance after wildfires. However, the insurance industry lacks a fundamental understanding of the factors that influence the potential for plumbing to be irreparably damaged and contaminated, how to conduct water testing, and remediate the damage. After wildfires, some insurance providers have denied claims for contaminated plumbing issues while other companies have approved those claims (sometimes the neighbor next door). Insurance companies sometimes hired unqualified water professionals to test water because insurance companies did not understand the issue.

The lack of understanding of plumbing contamination among the public and officials generally, and in the insurance industry particularly, has caused significant delays in wildfire disaster responses and intensification of disaster losses. Homeowners have been puzzled about what disaster costs are covered by their home insurance, and why their water treatment claims were denied. Sometimes neighbors have been supported in their water treatment claims while other policy holders for another company were denied. The induced ambiguity may cause a significant reputational cost to the insurance industry, and potentially hamper the purchase of private insurance by the public for managing disaster risks. Moreover, uninsured households who often represent vulnerable or marginalized groups (low-income, communities of color, elderly, disabled, those in rural and isolated communities, etc.), have to face even more significant financial hardships in the aftermath of the crisis. Through education and research, the actuarial community can contribute to promoting the efficient use of insurance in disaster response and recovery on this important national emerging issue.

Section 5. Potential Future Contributions from the Actuarial Community

The coverage of losses due to contaminated plumbing under existing standard home insurance or through future endorsements/riders is yet to be clarified by the industry. Nevertheless, this crisis presents both opportunities for the insurance sector to expand into this relatively unexplored domain.

If insurance coverage for contaminated plumbing is offered, insurance companies would require clear guidance to handle claims and effectively address policyholders' challenges. Current recovery guidance for contaminated plumbing is often based on subjective experience and lacks consideration for insurance and financial constraints. Mitigation decisions, such as the use of point-of-use devices, water tanks, or complete replacement, detached from financial and insurance considerations, may not be practically optimal and could be infeasible. Actuaries, with their toolkit of quantitative methods, can contribute to the development of effective and cost-efficient strategies to help impacted households recover from contaminated plumbing with minimal interruptions. Formally, within the set of all plausible recovery strategies, denoted as $A = (a_1, \dots, a_d)$, the goal is to identify the optimal intervention strategy that minimizes the objective function:

$$min_{a_i \in A} f\left(DC_{a_i} + IC_{a_i};\ p_{a_i}\right), \textit{ subject to } DC_{a_i} + IC_{a_i} \leq \textit{Insurance limit + Household available wealth.}$$

(Equation 1)

Here, "DC_{a_i}" and "IC_{a_i}" denote respectively the direct costs (e.g., testing, substitute products, water treatments, and plumbing component(s) removal and replacement) and indirect costs (e.g., additional living expenses, immediate medical costs). Moreover, p_{a_i} denotes the probability distribution of different financial cost endpoints. There are various meaningful choices for the function f in (Equation 1), including the expected value, mean-variance criterion, and the probability of default (i.e., the recovery cost exceeding the budget limit, dependent on the household's savings and insurance policy limits). Two crucial inputs for the decision framework are the recovery time and cost probability distributions, which can be constructed based on available empirical studies from the engineering field. To address model vulnerabilities due to data limitations, one can treat the uncertainties around the best-estimated probability distributions as a robust control problem, as described in the actuarial and economic literature (see, e.g., Li et al., 2022; Shen and Su, 2019).

One can delve into an advanced hybrid approach where various combinations of treatment strategies are permitted across different recovery phases. To achieve this, another switching time control variable will be introduced into the optimization framework (Equation 1) to delineate the decision process for selecting optimal treatment strategies during different recovery phases. By concurrently evaluating intervention combinations, the framework can enable decision-makers in the insurance industry and government to determine whether a particular strategy (or set of strategies) warrants priority consideration in a given disaster scenario.

Actuaries can also contribute to pricing the financial risks associated with wildfire-caused contaminated plumbing, though this can be a challenging task due to the absence of credible data. Typically, actuarial modeling assumes access to a large volume of historical claim records. For ratemaking purposes, loss estimations are linked to policyholders' profiles using statistical learning methods like generalized linear models and tree-based models. In the context of property insurance, separate frequency and severity modeling is commonly considered a best practice. Here, insurance loss L is modeled as $L = \sum_{j=1}^{N} X_j$, where N represents the number of disaster occurrences over a specific time window, and X_i denotes the amount of loss in each disaster. The financial survey discussed in Section 4, coupled with expert knowledge from the engineering area, can be utilized to estimate the claim severity X_i. However, there is no available data regarding the frequency of contamination occurrence. To address this challenge, a conservative pricing approach can be considered, approximating the contamination occurrence frequency by assuming that once a wildfire occurs within a reasonable spatial scale of the insured property, contamination is triggered. The occurrence of wildfires can be modeled using commercial catastrophe simulators or other insurance company in-house models.

At the expense of mildly over-estimated premiums, the proxy approach's merit, in the absence of credible data, is that the financial solvencies of insurance companies are secured. We believe that lack of contamination claim data is largely caused by the lack of plumbing contamination knowledge across the insurance industry. We sincerely hope that this report can acknowledge the importance of contaminated plumbing to the insurance industry, so companies will begin collecting the related data, and the data limitation will be resolved in the next future.

Risk reduction is key to disaster response and recovery. The insurance industry, known for its historical contributions in addressing root causes (e.g., founding the first fire department, establishing building codes, and implementing auto safety testing protocols), can extend this role to mitigate losses resulting from contaminated plumbing. Promoting plumbing designs that necessitate lower contamination repair costs is crucial. The statistical analysis outlined above can assist in advocating for risk-based premiums for plumbing contamination coverage. This approach ensures that premiums accurately reflect the implicit lower financial risk incurred by households implementing low-risk plumbing designs.

Section 6. Conclusion

In this report, we discuss the phenomena of plumbing contamination caused by wildfires and the associated recovery efforts. We examine the physical processes that lead to chemical contamination of drinking water systems in the aftermath of wildfires. Additionally, we outline necessary strategies to help affected properties recover from contaminated plumbing, including the use of backflow prevention devices to reduce systemic losses within disaster-affected communities. Despite the significance of this issue, there is limited available data on the financial losses incurred due to wildfire-related contaminated plumbing. Therefore, we revisit risk attitudes and experiences surveys conducted with households impacted by the 2018 Camp Fire to extract the costs incurred by affected households in addressing water contamination issues.

Throughout the research process, the author team struggled with challenges in elucidating details surrounding the decision-making processes behind the diverse responses to claims of plumbing contamination resulting from wildfires. Additionally, there was a lack of consensus on whether losses from private home plumbing contamination should be covered by existing standard home insurance policies, and if so, what portion of the losses should be covered. We attribute these limitations to the emerging nature of the issue and a lack of understanding within the industry.

Through this report, we aim to serve as a Call to Action, urging the insurance industry to raise awareness of this national emerging issue and prepare for its implications. From a practical standpoint, we hope this report will catalyze proactive measures to address the issue. From an academic perspective, we envision this report as a crucial starting point for further in-depth investigations in related domains by actuaries, pushing the actuarial community toward the forefront of research on this national emerging issue.

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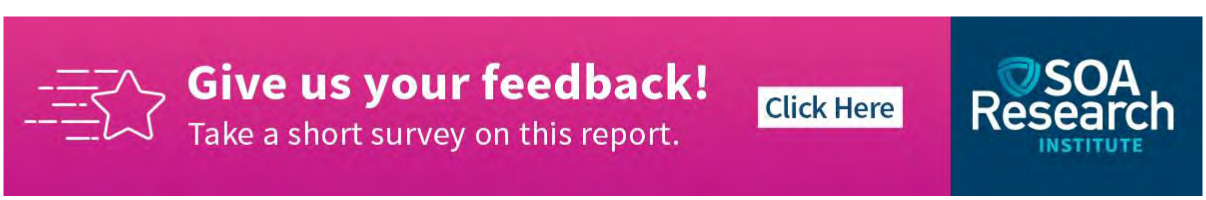
Feedback



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