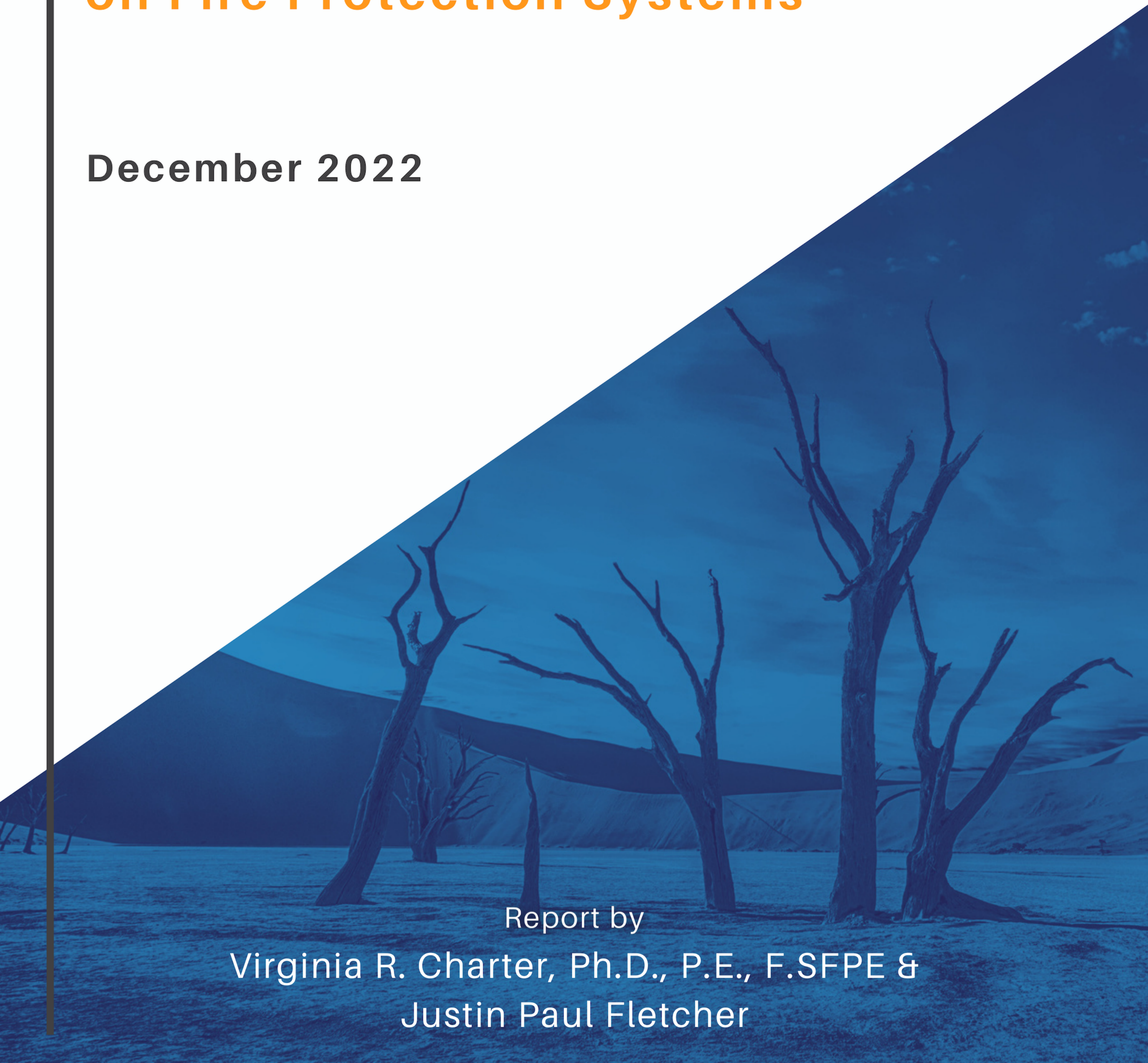
WATER SUPPLY & CLIMATE CHANGE:

The Impact of Water Stress on Fire Protection Systems

December 2022



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Water Supply & Climate Change

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Disclaimer

About the SFPE Foundation

The Society of Fire Protection Engineers (SFPE) established the SFPE Educational and Scientific Foundation in 1979. The Foundation is a charitable 501c(3) organization incorporated in the state of Massachusetts in the United States of America. It supports a variety of research and educational programs in service of its mission to enhance the scientific understanding of fire and its interaction with the natural and built environment.

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Executive Summary

Water-based fire protection systems rely almost entirely on having an adequate water supply to aid in control or suppression of fire. Furthermore, local fire departments also rely on the water supply as a part of their response. If water sources are somehow lost or the supply infrastructure is damaged, the protection system will not work as intended and thus the reliability of suppression systems heavily depends on adequate water supply. This project focuses on how fire protection system design and water supply system design must begin to include the concept of climate change, specifically water scarcity or stress, in the discussion of reliability of systems.

This project conducts a detailed literature review of current water supply practices, design of suppression systems that depend upon the use of water supplies, and the impacts of water stress or scarcity on water supply systems, as well as a gap analysis of what areas need to be researched more from the lens of fire protection systems and climate change. Additionally, the report will include four case studies of areas that have experienced water shortages: Winter Storm Uri 2021 in Texas; the 2018 Cape Town, South Africa 'Day Zero' water crisis; Spain's ongoing water crisis; and Australia's water challenges. By studying these scenarios, the project provides a vast look from rural to urban areas (including the wildland urban interface), as well as differing climates, and varying reasons leading to the water stress or scarcities in the regions. A final source of data is a stakeholder survey focused on plans for and experiences with water shortages.

It is determined that various stakeholders should be involved when communities plan for a water supply shortage, policies should be developed to help upgrade infrastructure to combat possible shortages, and alternative means of water supply should be considered such as the use of desalination plants to help supplement existing water supplies.

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Introduction

Climate change is defined as a change in global or regional climate patterns over the long-term (National Aeronautics and Space Administration [NASA], n.d.). According to NASA, climate change indicators have included land and ocean temperature increases, ice melt from glaciers, rising sea levels, and the frequency and severity of extreme weather. Extreme weather can include heatwaves, wildfires, droughts, hurricanes, and polar vortexes. These extreme weather events can lead to water supply issues for domestic, agricultural, industrial, and fire protection use.

In the coming years, climate models predict that pressures placed on the ecosystem from human population growth and climate change are set to exacerbate existent water scarcity (Gosling & Arnell, 2016). Climate change especially will likely have a significant impact on global water resources, increasing water scarcity and drought risk in some areas and decreasing it in others. Cook et al.'s (2020) analysis of climate models identified six global regions – western North America, Europe and the Mediterranean, Central America, South America (outside of Argentina), Southern Africa, and southwestern and southeastern Australia – likely to experience consistent warming and drying, even if carbon emission mitigation efforts are undertaken.

Complicating matters is climate change's potential to increase wildfire activity and severity. As with water, the effects of climate change will be uneven across varying landscapes (Keeley & Syphard, 2016). For instance, Zhuang et al. (2021), in a study funded by the National Oceanic and Atmospheric Administration (NOAA), concluded that anthropogenic climate change is the main cause of the increase in wildfires in the Western U.S. over the last several decades. In the Pacific Northwest, warmer and drier conditions due to climate change will increase the duration and intensity of the forest fire season, creating more frequent fires that burn longer (Halofsky et al., 2020). Likewise, hotter and drier conditions in Australia have already contributed to more intense wildfires and will continue to do so (van Oldenburgh et al., 2021).

Many fire protection systems rely almost entirely on having an adequate water supply to aid in control or suppression of fire. Furthermore, local fire departments also rely on the water supply as a part of their response. These water supply systems are vast underground networks of pipes connected to a source of water. If that source of water is somehow lost or those pipes are damaged, the protection system will not work as intended. Typically, in rural areas, there will only be one source of water in small communities, and they may not have the resources available to quickly fix any supply issues. If these areas experience some effect of climate change, such as a drought, they may not have adequate water supply for their fire protection systems to function. Fire protection systems are not usually an area of consideration in the context of climate change. As such, this research is an important area to explore to ensure that codes, standards, and public policy begin to adapt.

Fire protection systems are typically designed based on the available water supply of an area. Generally, the first thing done on any fire protection project that involves an active fire protection system is getting the water supply information. This information can be gathered by hand (physically performing a flow test) or if in a sufficiently urbanized area, a computer model is used to determine average supply. After gathering the supply information, the system is designed to work based on that water supply and National Fire Protection Association (NFPA, 2022a) 13 Standard for the Installation of Sprinkler Systems (in most cases). This water supply and NFPA 13 are then used to determine exactly how much pressure and how many gallons per minute a single sprinkler needs to suppress a fire. If that water supply is incorrect, the system may not be adequate to perform its intended function. If that water supply changes over time, be it for any reason (the source has changed, the piping array has been reconfigured, or if the area is experiencing a water shortage), then this supply information is invalid, and the fire protection system will not work as designed, either performing inadequately or failing completely

Climate science is complicated, involving uncertainties, multiple models, and disciplines, but current evidence points to more extreme fires as climate change proceeds. Combined with changes in water supply, it follows that fire protection/safety engineers and designers should consider the impact of climate change in their plans for the built environment. Many times, fire protection systems are designed based upon a single location and point in time from a water supply test. Meaning, on a given day at a certain time, the water flow test provided this much flow and pressure at a location. Fire protection design may not always consider the nuances of weather events' impact on fire protection systems (O'Connor, 2020). Fire protection design, water supply, and climate change all need to be considered in the design of systems for the built environment as well as tactical decisions for responding firefighters. If the construction on a large project lasts multiple years or if there is a modification to the building that requires a change to the fire protection system after construction has finished, there may be changes in the water supply. Furthermore, communities, from rural to urban, need to keep up with the growth and water needs of the community to ensure the infrastructure can continue to support the demands. The water supply information the system was originally designed upon may have changed radically since the building was built. This can significantly impact the performance of said system and in some cases the system may not even be adequate for the building based solely on a new water supply.

This research seeks to explore what literature exists on water supply systems, particularly in relation to climate change and its impact on fire protection systems. Following the literature review, a gap analysis was done to determine new opportunities for research. As a result of the gap analysis, a survey was conducted to understand perspectives of identified stakeholders, primarily people working in fire protection roles, regarding water supply systems, climate change, and fire protection systems.

Literature Review

Water supply systems are a crucial component of most fire protection systems. This review will cover the importance of water supply systems, the various types of these systems, and how these systems interact with fire protection systems. The effect of climate change on water supply systems will also be reviewed. Studying climate change's effect on water supply systems and subsequent impact on fire protection systems offers a new perspective on how to factor these changes into the design of infrastructure.

Water-Based Fire Protection Systems

Water-based fire protection systems, as the name implies, use water to suppress or extinguish a fire. The means of delivering water will depend on the specific system. The use of a sprinkler system is the most basic of the water-based fire protection systems. *NFPA 13, the Standard for the Installation of Sprinkler Systems*, states that the "purpose of this standard shall be to provide a reasonable degree of protection for life and property from fire" (NFPA, 2022b). Sprinkler systems work by a configuration of piping connected to a water supply with outlets consisting of sprinkler heads and elements that are activated by heat. Once these elements have been activated, water flows through the outlet and discharges by hitting the sprinkler head deflector to disperse and suppress the fire. These systems are used in a variety of applications, ranging from commercial and industrial systems to those used in residential use.

While the design of the sprinkler systems may vary vastly in different occupancies, the purpose and the need for water will remain the same. Regardless of use, the system will require access to water. Residential occupancies can have slightly different systems. The use of sprinkler systems in domestic occupancies, i.e., one- and two-family dwelling units, is covered in *NFPA 13D* (NFPA, 2022b). These are systems designed for use in homes, and while they still require water to function, they can slightly divert from the need for a constant water supply using water tanks. These tanks still need to be filled at the inception of the system and when/if the system discharges the tank will need to be refilled. Use of sprinkler systems in residential occupancies, hotels, and apartments, four stories or less, is governed by *NFPA 13R* (NFPA, 2022c). Automatic sprinkler systems pressure and flow requirements are typically determined by the hazard class of the building the systems are installed in. Sprinkler systems are designed to *NFPA 13* standards which give modifiers based on square footage and design density, so at the lowest possible requirement, a system will need at least 150 gallons per minute (GPM, 568 liters per minute, LPM) of water pressure to function effectively. The pressure requirements as stated above are at the minimum of 7 pounds per square inch (PSI, 48 kilopascals, kPa) per head (NFPA, 2022a). As such, systems vary widely in pressure and flow requirements.

There are a variety of other fire protection systems besides sprinkler systems that actively use and require a water supply system. Standpipes and hose systems, typically used in tandem with another fire protection system like sprinklers, are governed by the *NFPA 14 Standard for the Installation of Standpipe and Hose Systems* (NFPA, 2019). Standpipes and hose systems are generally used as a supplement to help firefighters with water suppression and extinguishment. They are connected to the fire department connection on the side of a building and can be used for additional water supply in tandem with fire trucks. This means they usually require an active water supply which, if not available, would make firefighting much more difficult for firefighters.

Another fire protection system that requires the use of water is a water spray system (NFPA, 2022d). Water spray systems are similar to sprinkler systems with some key differences. The pressure in these systems is much higher and the discharge of a fire spray system is usually much larger than a typical sprinkler system due to multiple discharge outlets in place of the singular sprinkler discharging. Per *NFPA 15: Standard for Water Spray Fixed Systems for Fire Protection*, these systems are typically used for much higher hazard areas, including hazards such as: gaseous and liquid flammable materials, electrical hazards, and vapor mitigation (NFPA, 2022d). A basic sprinkler system would only make something like an electrical fire worse. Water spray systems are more effective in higher hazard areas but require much more water than other fire protection systems. According to *NFPA 15*, the most hydraulically remote nozzle shall not be allowed to drop below 50 PSI/345 kPa during nozzle operation (NFPA, 2022d).

Limitations of Water-Based Fire Protection Systems

One of the major limitations of water-based fire protection systems is that they require a large amount of water. For example, the range of flow required for a sprinkler system can be from 150 GPM/58 LPM (light hazard occupancy at 1,500 square foot (ft^2, 139 square meters, m^2, design area) to 1,000 GPM/3785 LPM (extra hazard group 2 occupancy at 2500 ft^2/232 m^2 design area). Hazard groups are defined in *NFPA 13* (NFPA, 2022a). Light hazard occupancies are where the quantity and combustibility of content is low and fires with relatively low heat release rate are expected. Ordinary hazard groups 1 and 2 are occupancies where quantities of combustibles are moderate, and stockpiles of contents are limited with moderate to high heat release rates. Extra hazard groups are areas where there are a large number of combustibles and high heat release rates are expected. Water-based fire protection systems commonly require anywhere from 30-120 minutes of water supply.

Water-based fire protection systems also require a large amount of water pressure for the system to work, typically set forth by a minimum of 7 PSI/48 kPa per sprinkler head as required by *NFPA 13* (NFPA, 2022a). Sometimes the existing water supply for a fire protection system does not have adequate pressure to supply the system. Additional pressure is needed to supplement the existing water pressure, which is usually achieved by using a fire pump (NFPA, 2022e). There are a multitude of different styles of pumps, but they all achieve the same outcome, usually intaking water flow with a certain pressure and raising that pressure by churning the water inside the pump. Pumps can make fire protection systems supplied by water systems with a low amount of pressure still reach the required pressure level for the fire protection system.

Another limitation of fire protection systems is the cost. The cost of a residential fire sprinkler system is around \$1.35 per ft^2 (\$14.35 per m^2), with the cost of commercial systems increasing to about \$2.00 per ft^2 (\$21.53 per m^2) and higher depending on the size and scope of the system (National Fire Spinkler Association, 2020). This cost is also upfront since the fire protection system is usually installed during the construction phase of the building. If done retroactively to add a system to an existing building, the cost can sometimes be more, as the installers may have to demolish portions of the existing structure to install the system. More intricate fire protection systems such as those requiring pumps, or a more advanced system such as a water spray or foam system, will also typically involve more upfront costs. Once the system is installed, there are also costs that will ensue to keep the system maintained. Usually referred to as Inspections, Testing, & Maintenance (ITM), these costs will be on a yearly basis to keep the system maintained and may also be required if the system discharges.

Water Supply Systems

Water supply is a complex system involving several smaller systems working in combination. Early in the history of water supply, aqueducts were utilized to bring water from faraway locations to communities (Angelakis et al., 2020; Chanson, 2008). These aqueducts were typically large concrete structures using gravity to move water across large distances. Nowadays, while aqueducts are still used to some extent, they are typically more in the form of pipelines, tunnels or canals. These systems can also still use the concept of gravity to more easily deliver water. Where gravity is not a feasible means of transporting water, pumping stations are typically used (Guyer, 2012). These pumping stations use a vast amount of energy to increase water pressure. This water pressure forces enough water through these pipelines to maintain a continuous and reliable source of water to the people or systems this supply serves. Where pipelines are not used, container shipping or towing is used (Wang et al., 2020). This shipping can consist of tank trucks, tank ships, or other large manmade vehicles used for the shipping of water. As water is consistently very heavy at large amounts, this is a very energy intensive process.

Treatment Process

Water treatment is a necessary step in the water supply process. Government agencies typically require surface and groundwater to be treated before it is allowed to be introduced into a municipal supply. This treatment process usually consists of nine steps including; collection, screening, chemical addition, coagulation and flocculation, sedimentation, filtration, disinfection, storage, and distribution (Combest, 2017). The collection process is the method of collecting the water from either a nearby surface water source, groundwater taps, by transportation, or a combination of the three. Once the water has arrived at the treatment facility, the water will first need to be screened and strained. Typically, water collected straight from the source will have large particles, and these will need to be screened out before the rest of the process can be completed. Once the water has been strained and the large materials are removed, chemicals are added. Some of the chemicals are used to clean the water and some are used to help the suspended particles remaining in the water clump together. Then the water is screened multiple times again to remove any small materials that are left in the water.

After the water has been strained and screened multiple times to filtrate the unnecessary materials out, the water can finally be disinfected (Combest, 2017). Chlorine is most often used to ensure all the bacteria and microorganisms that live in the water are killed. This is a careful process for adding too much chlorine will make the water unusable. After disinfection, the water is stored. This is usually in either an underground or elevated storage tank to ensure that there will always be water supply in the case of an emergency. Then the water is distributed through underground pipelines that are served by large water pumps to ensure the water has enough pressure to reach its destination. This is the usual process in an urban setting, but rural water districts function similarly, albeit on a much smaller volume but over a larger area to be served.

Another recent innovation for water supply systems is the presence of desalination plants. These plants take ocean water and remove the salt, hence the term desalination (Robbins, 2019). These plants can take ocean or sea water that is typically unfit for human consumption and bolster existing water supply systems by drawing from some of the largest bodies of water on earth. Desalination plants work by separating water molecules from seawater, filtering and then discharging the excess saltwater, and then treated through traditional wastewater treatment processes to ensure that the water is fit for human consumption (San Diego County Water Authority, n.d.). Using these plants can ensure that an accessible and adequate water supply is available, even when typical water supply systems can experience shortages.

Rural Water Supplies

Rural areas, such as agricultural areas, present their own set of problems where water supply is concerned. Rural areas have a much lower population density than urban areas. Rural areas can also be spread over a much larger land area, which can present problems when trying to supply all areas with a sufficient and adequate water supply. Rural area water supply is generally used for agricultural use including farm and livestock grazing. However, it can also be used for industrial purposes when large industrial plants are located outside of urban areas. This low population density, combined with a much larger area to be served requires large lengths of piping to be dug out and installed to serve the inhabitants and their water supply requirements.

Pomogaeva and Vasilyeva (2019) found that rural water suppliers serving villages in Russia face a multitude of problems, such as maintaining the water supply quality at a drinkable level through various means, keeping the large distribution network reliable, and disposal of wastewater. Keeping the pipeline in an adequate state is proving to be the largest challenge for Russian organizations. Inspection, testing, and maintenance of the distribution system is listed as the largest concern, as this is the only way to ensure that the network is reliable and able to provide clean, high-quality water.

The network of small villages in Russia can be comparable to many other rural areas throughout the world. Water supply shortage infrastructure issues are a global issue and not just limited to a single region or country. Pundir et al. (2021) conducted a risk assessment for water supplies in rural sites in Uttarakhand state, India to look at the implementation of a water safety plan and how that plan reduces the risk to the water supply system. They took an in depth look at how rural communities can keep their water supplies safe from pathogens and keep the quality of water high enough to be considered potable. When organizations consider implementing a water safety plan, the risk to both the water supply and the distribution system is reduced considerably.

At present, some rural distribution systems use a hydraulic model to determine the network's reliability and adjust the system to provide demand where needed (Kepa, 2021). These systems are expensive and are not widely used in rural settings, but they present a very powerful tool for water supply providers to ensure the integrity of their respective systems. The use of hydraulic models, as described below, is much more prevalent in urban settings where the piping system typically serves a much smaller land area but is usually considerably more complex.

Urban Water Supplies

Urban regions are characterized by a large population density in a much smaller land area. Urban water supplies are used for many things, including but not limited to domestic use, industrial uses, and general commercial use throughout an urbanized area. This leads to the water supply and distribution networks being much more complex typically than those that serve rural areas. A common system used in this type of distribution network is a hydraulic modeling system, which uses automation and information technologies to help these systems maintain and efficiently supply water to the area's constituents (Kepa, 2021). Hydraulic modeling systems can automatically trigger pumps to divert water to different regions served by the system to account for highs and lows in the supply and demand. These systems are typically very complex and run in real time to account for the supply and demand.

Wildland Urban Interface Considerations

One of the largest issues currently facing water supplies is the abundance of Wildland Urban Interface (WUI) fires. According to the Federal Emergency Management Agency (FEMA, 2019), the WUI is defined as "the zone of transition between occupied land and human development." A main concern of WUI fires is the loss of water supply to the affected regions. If a fire removes the water supply in a region, this will inhibit both the residents in the region by lack of water, as well as the ability to fight the fire. Fires can remove water supplies by damaging the infrastructure of the water source, such as damaging reservoirs or tanks crucial to the water supply system. Using Monte Carlo simulations, a study simulated the WUI fires in the watershed regions in Colorado to determine the actual effect of these fires (Gannon et al., 2021). It was determined that small watershed regions would not be drastically affected by these fires. Large watershed regions, however, such as the one in the Rocky Mountains that supply the majority of Colorado, could be impaired by a WUI fire. This is somewhat alarming, as this watershed provides the majority of the water used in the state of Colorado (Gannon et al., 2021). If a WUI fire were to effectively wipe out the watershed used by this state, there would be no water supply available to millions of people. The need for a secondary water source in case of incidents like a large WUI fire is becoming more necessary.

Climate Change Impact on Water Supply Systems

Climate change is the "long-term shifts in temperatures and weather patterns" either natural or anthropogenic due to burning of fossil fuels for energy (United Nations, n.d.). The increase in levels of carbon dioxide in the atmosphere leads to an increase in temperature. The phenomenon of climate change can have a large impact on various water supply systems/regions through various means, such as drought or other weather patterns that a region has not experienced and is not prepared for. There is evidence in the literature that water supply systems across the globe are vulnerable to the effects of climate change.

A study of the Illinois watershed, located in the Midwest of the United States, was completed to understand effects of different scenarios on the water supply (Zhang et al., 2021). This study looked comprehensively at the Kankakee watershed which supplies the Kankakee, Iroquois, and Ford counties in the state of Illinois. By using a hydrological model known as the Soil and Water Assessment Tool (SWAT), the researchers developed six different water demand scenarios based on sets of different socioeconomic scenarios, using three different sets of climate change scenarios, each based on high, medium and low carbon emissions (Zhang et al., 2021). This model found that climate change would increase the total surface runoff of the watershed. The streamflow would reduce, but the total amount of precipitation would increase. Zhang et al. (2021) conclude that the watershed region would not be greatly impacted by climate change, unless the demand for water supply was greatly increased. While there may be a lower flow in the rivers, the increase in precipitation would increase the total amount of water available to the region.

When looking at how climate change affects this watershed, an important distinction should be made between land used by humans and land that is still in its "natural" state. The impact of land use by humans is significant, especially in areas that have major urban development or areas cleared for farmland. Khan et al. (2021) also studied the Illinois Watershed. A statistical analysis approach was taken to determine how both climate change and human activities have affected stream flows in the Illinois Watershed. Much of the land in this watershed is used for farming of corn, which has drastically changed the landscape from its natural state. Khan et al. (2021) compared three regions that are primarily used for farmland and three regions which are still forested. Using statistical analysis, the researchers determined that the runoff from streamflow was majorly reduced once the land had been converted to farmland and that nearly no change was found in the region that was still in the forested natural state. The importance of this should be highlighted as while farming is not typically thought of as a major reason for reduction in water supply of a region, it can be reasonably determined that the conversion of this land to farmland by clearing the forest has resulted in a reduction in the water available in the streamflow. This could have a domino effect if this region was hit by a water supply incident, such as a drought, as the available amount of water would be majorly reduced even past what it has been already by the conversion of forest to farmland.

Huang et al. (2021) studied the water availability in central Taiwan, focusing on how climate change will affect the water supply when compared to the industrial and agricultural side. Using a mathematical water supply model to understand how the water supply facilities will be affected by a worst-case scenario of a dry climate and how bad the issue will be, they determined that the use of water in both industrial and agricultural industries will have a direct impact on the cost of tap water, or water used by people as opposed to businesses. This study shows how fragile the water supply system will be in a worst-case climate change scenario i.e., a drought. The government of Taiwan is involved in managing the water supply systems, as the Taiwanese government wants to achieve a water supply of 20 billion cubic meters (706 billion cubic feet) by 2031 (Huang et al., 2021).

As part of their study, Huang and Lee (2019) developed specific criteria that are necessary to ensure that the water supply in Taiwan will be able to counter the effects of climate change (Huang & Lee, 2019). The authors describe five principles: "(1) reliability of the water supply system; (2) economic feasibility—commercialized water supply technology and stable supply costs; (3) affordability of water for the public; (4) environmental friendliness—low wastewater and carbon emissions; (5) social acceptability—biodiversity conservation (provision of environmental flow)." The reliability of the water supply is the main principle. Being able to consistently rely on and use a water supply is of the utmost importance. If the water supply is unreliable to either humans or commercial activity, this will have a drastic effect on the region. These five principles can be used to analyze a region's water supply and determine the degree to which the region will be affected by possible water supply incidents/interruptions.

Case Studies

Supplementing the literature review, the following four case studies were conducted to determine how various regions deal with water supply shortages that are exacerbated by climate change. The cases were spread across four continents, with a wide variety of climate conditions and water supply sources. By examining multiple regions of the world and their similarities and differences when reacting to water supply issues, we can determine the leading causes and effects of those shortages and the implications that such shortages have on fire protection systems.

2018 South Africa Day Zero

By early 2018, Cape Town, South Africa came very close to what was dubbed as "Day Zero," where the water supply was predicted to be shut down and residents of Cape Town would need to be rationed water daily. During a span of 3 years (2015-2017), the winters in Cape Town were extremely dry, resulting in the water storage system falling to between 15-30% of its capacity (LaVanchy et al., 2019; Pascale et al., 2020). The severe drought was conjectured to be caused by the El Nino weather pattern occurring in the region, which is where warmer ocean waters result in reduced rainfall. A combination of reductions in water usage by Cape Town residents, water restrictions by the government, and increased rainfall the winter of 2018, beginning in June, allowed the water supply to recover to stored capacities back to 70% and the city to avert Day Zero (LaVanchy et al, 2019; Ziervogel, 2019). Though this event is considered by some to have been "severe and rare," understanding the geography, population, water supply configuration and usage, leading factors of shortages, and mitigation efforts will enable others to understand the impact on a region as well as what that means for those areas' fire protection systems protecting the buildings and infrastructure.

Geography and Population

Situated within the Western Cape province, Cape Town is the legislative capital of South Africa (Axelson, 2022). Cape Town was founded in the 1650's as a port to resupply ships. However, the location was also attractive to settlers as the farmland was fertile and well-watered. The region sits in the middle of a Mediterranean climate, where the summers are warm and dry, and the winters are wet. Over the course of a year, the average rainfall in Cape Town is approximately 20–20.5" (50.8–52.1 centimeters [cm]) (World Weather & Climate Information, n.d.) The dry period is from November to March. June is typically the wettest month.

From 1996 to 2016, Cape Town experienced a 56.8% increase in population from 2.5 million to 4 million (City of Cape Town, 2017). Cape Town has an estimated population of 4.7 million people living in the city limits in 2022 (Gitahu, 2022). The population steadily increased in the years leading up to and during the 2015-2017 drought.

Water Supply Configuration and Usage

The City of Cape Town (CoCT) and the South Africa National Department of Water and Sanitation (DWS) oversee the Western Cape Water Supply System (WCWSS) (Ziervogel, 2019). At the time of the extended drought, the water supply in Cape Town was mainly dependent on annual rainfall filling the reservoirs. Six dams filled from the mountain streams and rivers that are supplied from the annual rainfall provide 95% of Cape Town water (LaVanchy, et al., 2019; Ziervogel, 2019). The water then is sent through pipelines through pumping stations and one of the city's 12 treatment plants and then stored in reservoirs. Approximately 26% of the WCWSS is used for agriculture, Cape Town uses 58%, other smaller towns use 6%, and 10% is lost to evaporation or other means of loss (Ziervogel, 2019).

Leading Causes of Water Depletion

There are several factors that are believed to have led to the Cape Town water shortage. From 2015 to 2017, Cape Town saw a lower-than-average rainfall. In 2015, the rainfall was 80% of what is typical in the area (Wolski, August 2017). Additionally, the annual rainfall in 2017 set record lows since monitoring of rainfall began in 1933. Scientists have provided multiple estimates of the effects of anthropogenic climate change on the drought. Otto et al. (2018) concluded that it made the drought three time more likely to occur, while Pascale et al. (2020) projected that it made the drought five to six times more likely to occur, and that the likelihood of such an event happening again is not only possible but highly likely. Furthermore, there has been a temperature increase in Cape Town of approximately 1° C (1.8° F) in the last 100 years (World Weather & Climate Information, n.d.). Although that may not seem significant, more water can evaporate at higher temperatures, further reducing the water supply.

While the drought was the primary cause of the water deficit, other factors contributed to the problem. For instance, invasive plants that use more groundwater contributed to reduced runoff in the dams (Ziervogel, 2019). Political and government decisions could also be included in causes of the water depletion, or moreover, support and solutions to provide adequate infrastructure (LaVanchy, et al., 2019). For example, leading up to the drought, the government did not diversify the WCWSS or expand infrastructure, which would have been far more expensive than merely reducing demand. As indicated previously, the population in the Cape Town region has been exploding (CoCT, 2017). There was an increase in population from 1995 to 2015 of about 70%, however, the water storage dam capacities only increased by 17% in that time period. As the drought began, the agricultural sector, including vineyards and fruit farms, was initially not expected to conserve water like CoCT residents (LaVanchy et al., 2019). Eventually, agricultural allotments were also reduced, and the water diverted to domestic use.

Ziervogel (2019) also attributes reduced water supply to system failures such as nonoperational pumps and silted canals.

Mitigation Efforts

The City of Cape Town enacted water restrictions throughout the crisis, increasing restrictions as dam water levels decreased (LaVanchy et al., 2019; Ziervogel, 2019). The level of water restrictions ranged from 1-7, where Level 7 indicated the dam levels being less than 13.5% resulting in most of the water supply being shut off and water rationing. The restrictions consisted of varying approaches to reduce the overall amount of water used. It included limiting water for some urban and agricultural uses, banning non-essential use of water outdoors, encouraging the use of grey water where possible, reducing pressure in the system, and limiting the number of liters allowed per person per day.

There were other efforts to help push back the Day Zero date (Ziervogel, 2019). These included plans for buying water from other reservoirs outside of the CoCT system, temporary desalination plants, which were ultimately cancelled due to the cost, and water recycling. Individuals and businesses also took things into their own hands by purchasing rainwater collection tanks and drilling private boreholes to collect groundwater.

Ultimately, Cape Town residents reduced their water usage enough that the water supply was not shut off. After the crisis, the City of Cape Town developed a Water Strategy to strive towards a more resilient water future for the region (Ziervogel, 2019). The five components include: safe access to water and sanitation, wise use, sufficient, reliable water from diverse sources, shared benefits from regional water resources, and a water sensitive city. The strategy will require commitment and involvement from multiple departments and stakeholders in order to be successful.

Impact to Fire Protection and Fire Protection Systems

During restrictions, water pressure was decreased in the system, which could lead to inadequate pressure in a water-based fire protection system. Due to the invasion of alien plant species, the region has been at higher risk of wildland fires. In an already dry area, if fire protection systems are ineffective, a structure or wildland fire could easily be very destructive. Cape Town regularly experiences fire, particularly on Table Mountain, where a 2021 arson fire killed five firefighters, damaged over 600 hectares (ha, 1483 acres [ac]) of national park land, and destroyed parts of Stellenbosch University (Palm, 2022). Future droughts and fire suppression are inextricably linked in the Western Cape.

2021 Texas, USA Arctic Blast Water Crisis

In February 2021, the central United States was hit by a massive winter storm over the course of two weeks, causing large scale infrastructure failures across the region and in particular, Texas (Helsel & Talmazan, 2021). This winter storm, besides causing large scale power failures, also damaged water supply systems, leaving more than 12 million people without access to water due to pipes freezing and bursting. These water supply shortages also caused some water-based fire protection systems to be rendered inoperable, due to their reliance on a steady flow of water, amidst a steady increase in fires caused by residents unsafely attempting to heat their homes during the storm (Nguyen, 2022; Helsel & Talmazan, 2021; Kilbey-Smith, 2021; Owens, 2021; Torres, 2021). The winter storm was one of the worst in recent history. The City of Austin and Travis County (2021) after-action report highlights over 130 recommendations to improve infrastructure and better prepare for future weather events. The report also highlighted significant gaps in planning, response coordination, and staffing. It took months to repair the damage to the infrastructure that was damaged by the storm. This crisis highlighted how unprepared the state of Texas was for a natural disaster event. Understanding the geography, population, water supply configuration and usage, and mitigation efforts will help to understand how this area could be impacted by a water supply shortage.

Geography and Population

The state of Texas is located at the southern border of the United States with Mexico (Wooster, 2022). Texas has quite a storied history as it was first an area held by Spain, then France, then Mexico, then it stood as an independent nation until it joined the U.S. in 1845. As it is the second largest state in the nation it is home to a variety of climate zones (WeatherSTEM, n.d.). Typically, the climate in Texas is warm arid in the west and warm humid in the east near the Gulf of Mexico. Texas has an average rainfall of 27” (69 cm) but this varies wildly across the state, from 14” (36 cm) in the west to over 54” (137 cm) in eastern areas.

Texas has a population of more than 29 million per the 2020 Census (United States Census Bureau, 2020). The winter storm did not hit every corner of Texas, but its impact was felt by more than half of the current population, many of which were in the largest cities, including Houston, San Antonio, and Dallas and various outlying suburbs (Donald, 2021; National Weather Service, n.d.). The largest cities experienced weeks long water shortages along with not having access to other essential services, such as electricity and food supplies.

Water Supply Configuration and Usage

The state of Texas water supply is managed by the Texas Water Development board (Houston Advanced Research Center [HARC], 2021). Texas water supply is split about 50 percent groundwater and 50 percent surface water, with some various percentage points from the reuse of treated wastewater (Grubbs et al., 2019). That surface water, as reported by Grubbs et al. (2019), is sourced from “188 major reservoirs, 15 major river basins and eight coastal basins.” This water is then piped to various agricultural land or cities and redistributed through pumping stations. Based on a 2016 report, it was found that Texas used nearly all its available water supply, with the majority of that supply going towards agricultural use or municipal use (Grubbs et al., 2019).

Leading Causes of Water Depletion

The main cause of water shortage was caused by the winter storm freezing pipes and shutting down most of the infrastructure in place in the state (HARC, 2021). Homes and other buildings in Texas are not typically insulated for weather like that seen with Winter Storm Uri. Texans allowed their faucets to drip in order to prevent pipes from freezing, which then reduced system flow. Additionally, Texas is on a separate power grid from the rest of the U.S. and the power grid was also partially shut down during the storm. This grid, run by the Texas Energy Reliability Council (TERC), was less than five minutes away from a complete failure across the state before partial shutdowns were implemented. Due to the interdependency of Texas's water and energy systems, the shutdown of the power grid also affected water treatment facilities and pumping stations that would have supplied water, had the pipes not been frozen (Glazer et al., 2021; HARC, 2021).

These combined conditions contributed to a lengthy lack of water availability to much of the population, including emergency response (HARC, 2021). Firefighters struggled to suppress fires with the water system pressure so low. When fires occurred while and where pipes were completely frozen, the only water available was from fire fighter's tanker trucks, which can only supply a limited amount of water, and which also were at risk of freezing (Owens, 2021).

Extreme winter temperatures and weather events like Uri are becoming less frequent in Texas due to climate change (Glazer et al., 2021). While climate change did not directly contribute to the development of Winter Storm Uri, it does contribute to and increase other extreme weather events like droughts and floods in Texas. The cascading system and infrastructure failures that caused water shortages in Texas during Uri could plausibly happen again during other extreme weather events.

Mitigation Efforts

In 2021, the 87th Texas Legislative Session passed Senate Bill (SB 3), legislation that was a direct response to Winter Storm Uri (Gray Reed, 2022). SB 3, among other changes, increased and improved the governance of TERC and required water and wastewater utilities to adopt emergency preparedness plan approved by the Texas Commission on Environmental Quality (Gray Reed, 2022; Grubbs, 2021). Time will tell if mitigation efforts such as these will be enough to prevent future water supply shortages incurred by extreme weather events.

Impact to Fire Protection and Fire Protection Systems

During the crisis, water supplies were very limited to all Texans and house fires increased. As discussed previously, lack of water and low water system pressure affected the entirety of the fire protection systems that were dependent on that water supply. Without these systems in operation, the risk of not being able to control and suppress a fire was greatly increased across the state.

Spain Freshwater Crisis

Spain is currently experiencing a freshwater crisis from both water scarcity and pollution (Albiac et al., 2012). Recurrent droughts and extreme heat have reduced the available amount of water in the country, the latter via evaporation (Hervás-Gámez & Delgado-Ramos, 2019). This follows an overall trend in Europe where, exacerbated by climate change, droughts are increasing in frequency and severity. July 2022 was the hottest recorded month in Spain in over 60 years, conditions that have led to intense wildfires, and reservoirs fell to 40% capacity (West, 2022). In 2022, fall rainfall was 26% lower than normal (Piquer, 2022). Due to high nitrate concentration in the water in some areas from agricultural runoff, entire villages in Spain lack drinking water and residents must survive on bottled water (de Cuéllar, 2021). Most of Spain's water supply (67%) is used for agricultural purposes (Organization for Economic Co-operation and Development [OECD], 2015). Farmers and others have resorted to illegal methods of obtaining water, such as drilling hundreds of thousands of wells into the groundwater sources (Piquer, 2022; Bosque, 2020). This depletes the groundwater sources at an unsustainable rate and, if continued, will deplete them beyond their capacity to be refilled naturally. Without action, the crisis will continue; the water levels of Spain's river basins are projected to drop by 20% over the next several decades (Lewis, 2022). Southeastern Spain, where it is already dry, specifically will see a 40% reduction in water resources by 2050 (DeAndreis, 2021).

Geography and Population

Spain is located on the southwestern side of Europe, inhabiting the Iberian Peninsula, with coastline along the Mediterranean Sea (Raymond et al., 2022). The country has a diverse geography and climate including rainy mountains in the northwest, a large central plateau, plains leading to the coast on the east, and a desert region to the south. The northern, mountainous region is typically humid with high rainfall due to the presence of the sea and the mountains, with a moderate annual temperature (40s–50s °F, 4–10 °C) and an average rainfall of around 38" (97 cm). The rest of the country has a Mediterranean climate with warmer average temperature and lower annual rainfall. The 2022 population of Spain is estimated to be 47.32 million.

Water Supply Configuration and Usage

Water supply governance in Spain is decentralized, with national, state, regional, and local authorities all playing a role in management (European Committee of the Regions [COR], n.d.). Water resources are concentrated in the North and Galicia (OECD, 2015). Spain is served by 15 river basins that are managed independently of one another by regional River Basin Authorities (Rodríguez-Alarcón & Lozano, 2019; COR, n.d.). The central government has long transferred water resources from the wetter Northern regions to the drier Southern regions, despite political and social opposition (Rodríguez-Alarcón & Lozano, 2019). The European Union (EU) has sanctioned Spain for non-compliant water management for over three decades and for a combined 50+ million euros in fines (We are Water Foundation, 2022). However, Spain is also a world leader in desalination (Zarza, 2022). They built the first desalination plant in the world and currently produce over 5 million cubic meters of desalinated water per day for domestic, agricultural, and industrial usage. However, desalination plants are energy intensive and expensive to build and operate (Lewis, 2022).

Leading Causes of Water Depletion

Water depletion in Spain has several interdependent causes. A growing population has contributed to the demand outstripping supply (Center for Climate Adaptation, n.d.). Climate change is expected to continue to decrease annual precipitation in the northern region where most of the water supply is located, leading to persistent droughts, and to increase annual precipitation in the drier regions, causing damaging floods (Sumner et al., 2003). Glaciers in the Pyrenees mountains, which feed some of Spain's rivers, have been steadily melting due to warming temperatures (Center for Climate Adaptation, n.d.). Water resource mismanagement is also a factor. In one example, the EU has fined Spain repeatedly for not treating wastewater, inaction that has rendered drinking water unpotable in some areas due to the presence of nitrates from agricultural fertilizer and untreated arsenic (We are Water Foundation, 2022; de Cuéllar, 2021). The droughts worsen the potability crisis by decreasing the supply, thereby increasing the proportion of harmful substances.

Adding to water depletion and contamination are the thousands of illegal boreholes drilled into groundwater aquifers (Piquer, 2022; Martín-Arroyo, 2021; Bosque, 2020). Farmers are the primary users of illegal wells for crop irrigation, but use has also been documented in the tourism industry (Martín-Arroyo, 2021). Central and regional governments have only recently begun to act. Previously, the EU also fined Spain for their inaction on this issue. Aquifers in areas like Doñana National Park in Andalucia may never recover.

Mitigation Efforts

Desalination is helping to meet water demand (Lewis, 2022; Center for Climate Adaptation, 2021). However, desalination alone cannot solve the crisis. In 2021, the national government published *Spain 2050*, their strategy for the next quarter century which presents recommendations for how to mitigate the crisis, such as reducing water consumption by 15% by 2050 (Global Water Intelligence, 2021). In 2022, the central government approved a Water Cycle Strategic Project that aims to improve water management through digitization and automation of services with an investment of over 3 billion euros (Council of Ministers, 2022; Gobierno de España, 2022). One outcome of this strategic plan may be increased irrigation efficiency, reducing water waste in agriculture. National police have arrested illegal well users (Govan, 2022). However, total arrests pale in comparison to the number of illegal wells in use in Spain. The national government has not recently released any additional plans addressing the illegal borehole issue.

Impact To Fire Protection Systems

Wildland-Urban Interface (WUI) fires are a concern in Spain, where over 4% of forested land (1.1 million ha/2.7 millions ac) are WUI areas and over 12,000 forest fires occurred between 2010 and 2020 (Pastor et al., 2020). Droughts (and thereby climate change) dry out trees and vegetation, putting wildlands at higher risk for fires (Merzdorf, 2019). In 2022, Spain experienced a large spike in wildfires, hitting new records for number of wildfires and acres burned (Associated Press, 2022). Many of the areas affected by the water supply issues do not have active fire protection features, such as fire sprinkler systems. Water shortages could inhibit firefighters trying to combat active fire scenarios. Without enough water, firefighters will not be able to efficiently fight fires, which could lead to out-of-control fires and spreading. One example of this is an August 14, 2022 wildfire that broke out in Zaragoza province and required evacuations of 2500 people from nearby towns (Associated Press, 2022). By the time firefighters got the fire under control the next morning, it had burned 6,000 ha (14.8k ac). The situation has spurred some proactive fire protection innovation. At least two towns, Ribarroja and Paterna, have built giant outdoor sprinkler towers that surround the towns and spray the vegetation on the town borders with recycled water to keep them hydrated and slow down (but not stop) any approaching wildfires (Keeley, 2022). Going forward, fire protection engineers and designers can expect droughts and wildfires to persist in Spain.

Australia Water Crisis

Australia is experiencing its own water supply crisis. Despite above average rainfall in 2021, Australia regularly experiences droughts due to high climate variability, particularly variability in annual rainfall (Australian Bureau of Meteorology [BOM], 2022, Australia Bureau of Agricultural and Resource Economics and Sciences [ABARES], n.d.). Severity of droughts like the Millennium Drought is at least partially attributable to anthropogenic climate change (Cai et al., 2014). The droughts cause widespread drinking water shortages and lead to increased costs of water (Barrett, 2019). Even when dams are full, the water can be too polluted to be efficiently treated, straining water supply systems (9 News Australia, 2022). Population growth in cities like Sydney may eventually lead to water supply shortfalls if mitigation is unsuccessful (Davies, 2021).

Geography and Climate

Australia is a small continent of approximately 25.8 million people located in the southern hemisphere (Rickard et al., 2022). The country consists of mostly arid desert in the west but is large enough to possess a wide range of climates including temperate regions in the south and east, and tropics in the north (World Bank Group, n.d.). As much of the area is desert, the annual rainfall tends to be on the lighter side, averaging only about 20” (51 cm) throughout much of the outback region, with coastal cities receiving upwards of 45” (114 cm) of rain per year (Rickard et al., 2022). Droughts in Australia are a regular occurrence (Sousa Júnior et al., 2016). There is also significant desertification happening due to unsustainable agricultural practices (Minchin, 2019).

Water Supply Configuration and Usage

Water resources were primarily managed by individual Australian states until the 2000s when multiple laws allowed the national government to take more control over management and policy (Sousa Júnior et al., 2016). However, the National Water Act of 2004 was repealed in 2014, thereby reducing the national government’s authority with regards to water management. It still plays a role in coordination, but states are the primary managers for their local water resources.

Water supply in Australia is primarily driven by rivers, large freshwater reservoirs, and groundwater basins, as there is not enough water in each source to reliably depend on a single one (Elmahdi, 2015). Many towns in Australia, particularly in the outback, are heavily reliant on groundwater (BOM, 2021). Groundwater levels vary across the continent, again due to the climate variability. In 2019-2020, the levels in some aquifers were below average while others were above. Residents of rural, outback areas also face unique challenges accessing water. Water infrastructure may be poor, or they may not have a water supply at all and must purchase or catch and treat it themselves (Willis et al., 2015).

In recent years because of the water shortage and the droughts in Australia becoming more severe, desalination plants have been built in many of the coastal cities. Desalinated water made up 4% of the urban water supply in 2019-2020 (BOM, 2021). Australia also practices water recycling in which wastewater is treated and reused for non-potable purposes. In 2019-2020, recycled water was 8% of the urban water supply. In total, 70% of desalinated and recycled water goes to urban use and another 17% goes to agriculture (Elmahdi, 2015).

Leading Causes of Water Depletion

As mentioned previously, droughts are the leading cause of water depletion in Australia, and climate change is making them worse (BOM, 2022; Cai et al., 2014; ABARES, n.d.). Additionally, population growth will continue to put strain on existing water supply (Davies, 2021). Agriculture is by far the largest user of water available for human use, using 60% of that water supply (Australian Department of Climate Change, Energy, the Environment and Water [DCCEEW], n.d.). During droughts, farmers decrease their water usage, but will then increase it in wetter years when more water is available (Australian Bureau of Statistics [ABS], 2022). In 2020-2021, there was a 37% increase in the amount of water used for irrigation from the previous year.

Mitigation Efforts

Despite a relatively week central governance, Australia is taking an active stance in fostering a sustainable water supply. Water desalination and recycling are augmenting urban water supply and the country has invested billions of dollars in these climate resilient water sources (BOM, 2021; Almahdi, 2015). The people of Australia conserve water during droughts

(ABS, 2022). The government actively monitors the water supply, makes the data publicly available, and acknowledges the role of climate change in water shortages (BOM, 2021). Water restrictions are implemented when necessary (9 News Australia, 2021). Australia may be able to prevent a complete water crisis if they continue to mitigate the problem.

Impact To Fire Protection Systems

As with the droughts, climate change is also increasing the risk of bushfires (van Oldenburgh et al., 2021). In 2019, Australia's warmest and driest year on record, wildfires caused unprecedented destruction including burning 19 million ha (47 million ac) and killing one billion animals (Akter & Grafton, 2021). As in Spain, non-urban areas affected by water supply issues often do not have active fire protection features, such as fire sprinkler systems. The areas in the Outback are typically served only by fire and emergency personnel, which would be affected by the drought because they need water to fight the WUI fires that can accompany droughts. Disparities exist in wildfire hazard, with socioeconomic disadvantage correlating with wildfire hazard (Akter & Grafton, 2021). As such, it's possible that poorer areas that have seen less investment in fire protection systems will be hit worse by wildfires.

In the urban coastal cities, many buildings are served by active fire protection systems that require water. These cities do not have the same water supply issues as the agricultural regions, so they are less affected by the droughts. The cities can also use the water supply from the desalination plants to serve their active fire protection systems.

Gap Analysis

Water supply systems are frequently studied and discussed in climate change research, with a focus on ensuring that people will have access to clean and reliable water supplies for domestic use (He et al., 2021; Abedin et al., 2019; DeNicola et al., 2015) and agricultural use (Zobeidi et al., 2022; Nikolau et al., 2020; Dinar et al., 2019). As water supply systems pertain to fire protection systems, there is no research available on the implications of water shortages on fire protection systems, whether those protection systems are devices such as sprinklers or a more active role in suppression due to fire fighting. This gap in the research is concerning, because unreliable water supply systems will drastically decrease the effectiveness of fire protection systems in buildings and hinder the active suppression efforts of firefighters when they do not have the required water to combat a fire emergency.

There are various requirements/policies in place regarding fire protection systems in differing regions. The vast number of different requirements should also be examined when trying to determine how a water supply shortage will affect various fire protection systems and/or fire department suppression and response efforts. In the U.S, many buildings are sprinklered and therefore require an adequate and reliable water supply. These sprinklered buildings are used in conjunction with fire department response and suppression efforts to ensure that a fire emergency is combated effectively. Other regions rely more heavily on fire department response and suppression efforts, which also rely upon an adequate and accessible water supply. Understanding how differing regions heavily depend on water supplies for their various fire protection systems, whether it be through sprinkler systems or through fire department response and suppression, is key to understanding how to develop policies and plans to help to combat water supply shortage issues.

Survey of Stakeholders

The gap in the literature is clear when it comes to the impact of water supply stress related to water-based fire protection systems as well as manual fire department suppression efforts. Fire protection engineers and designers are not typically included in the conversation when discussing water supply stress in areas. Concerns are typically focused on domestic and agricultural use. To advance the conversation on fire protection systems and water supply stress with the fire protection engineering community, a brief survey was developed to begin to understand perspectives on water supply stress and the impacts to fire protection systems.

Survey Participants

The survey participants were varied across the world and across various occupations that have experience with water supplies. Respondents were asked to provide their location and occupation. Most respondents were from the United States of America (USA), with others being worldwide. Asia, Europe, Africa, and South America were represented as well. As water supplies shortages are a global issue, opinions and responses from across the globe were welcome and appreciated. Responses from all sorts of workers who could be involved with water supplies were also represented. Most of the responses were from Fire Protection engineers, but Authorities Having Jurisdiction (AHJs), fire protections systems designers, installers, and technicians, and insurance workers were also represented. The electronic survey was sent out through various sources, including SFPE and other outlets using purposive sampling and snowball sampling of those within the industry.

Survey

The survey was developed to gauge various regions' attitudes and respective plans regarding their water supplies. As stated before, the responders were first asked where they were from or the location of their work and their occupations. Then a question was asked to determine where/how they received the majority of the water, be it from rural or city water supplies and where that water came from, such as lakes, groundwater, or desalination plants. Once the where and the how of the water supply was asked, respondents were then asked if the communities they worked with had a plan in place for water shortages. If their community did have a plan in place, respondents were asked if the fire department was involved and what proposed solutions the plans offered. Next, a question of whether they had worked on a project that was subject to a water supply shortage and how that affected the project was asked. Questions were also asked about the possible causes of a project's water shortages. The survey then also posed questions regarding who should be involved in a community planning effort to prevent a water supply shortage and how such a shortage could impact fire departments. There were also free response portions for all questions allowing respondents to answer accordingly. See Appendix A for the complete survey questionnaire.

Data Analysis

Question 1 was to provide country of residence or global region. There were 230 responses to this question, with 79% of respondents located in the USA. The remaining 21% of respondents hailed from countries in Africa, Asia, Europe, Central America, North America and Oceania. Figure 1a displays the countries represented other than the United States. Figure 1b displays the represented global regions.

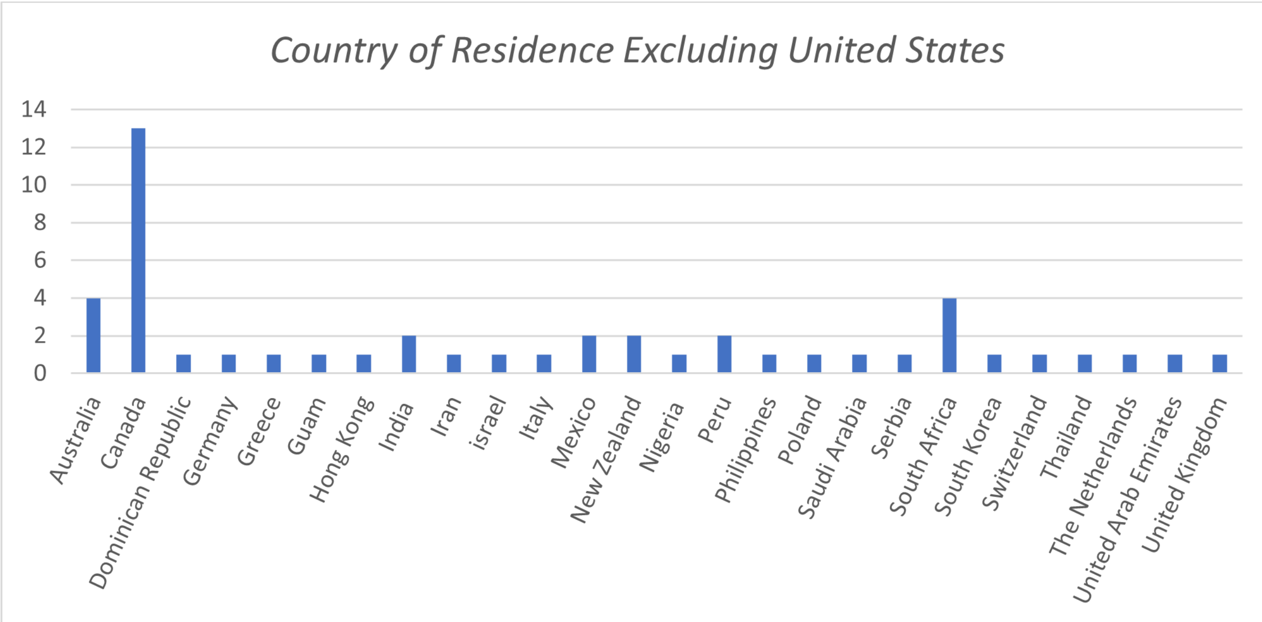

Figure 1a. Country of residence of respondent, excluding United States.

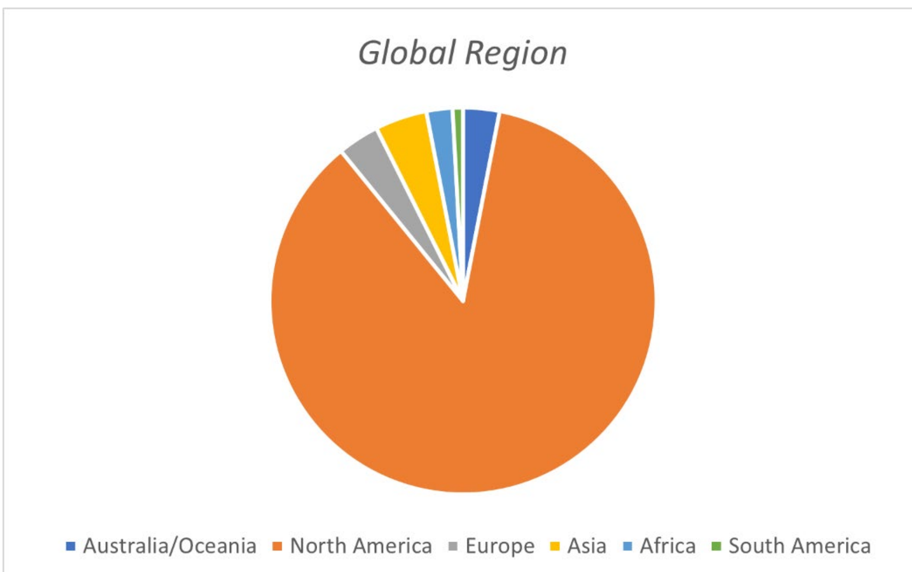

Figure 1b. Global region of respondent.

Question 2 asked respondents to provide their position or industry. There were 237 responses to this question. Over 50% of all respondents were fire engineers. Respondents that indicated "other" typically fell into fire service categories or fire protection engineers serving in a different capacity (owner/representative, etc.). Figure 2 displays percentages of all occupations represented.

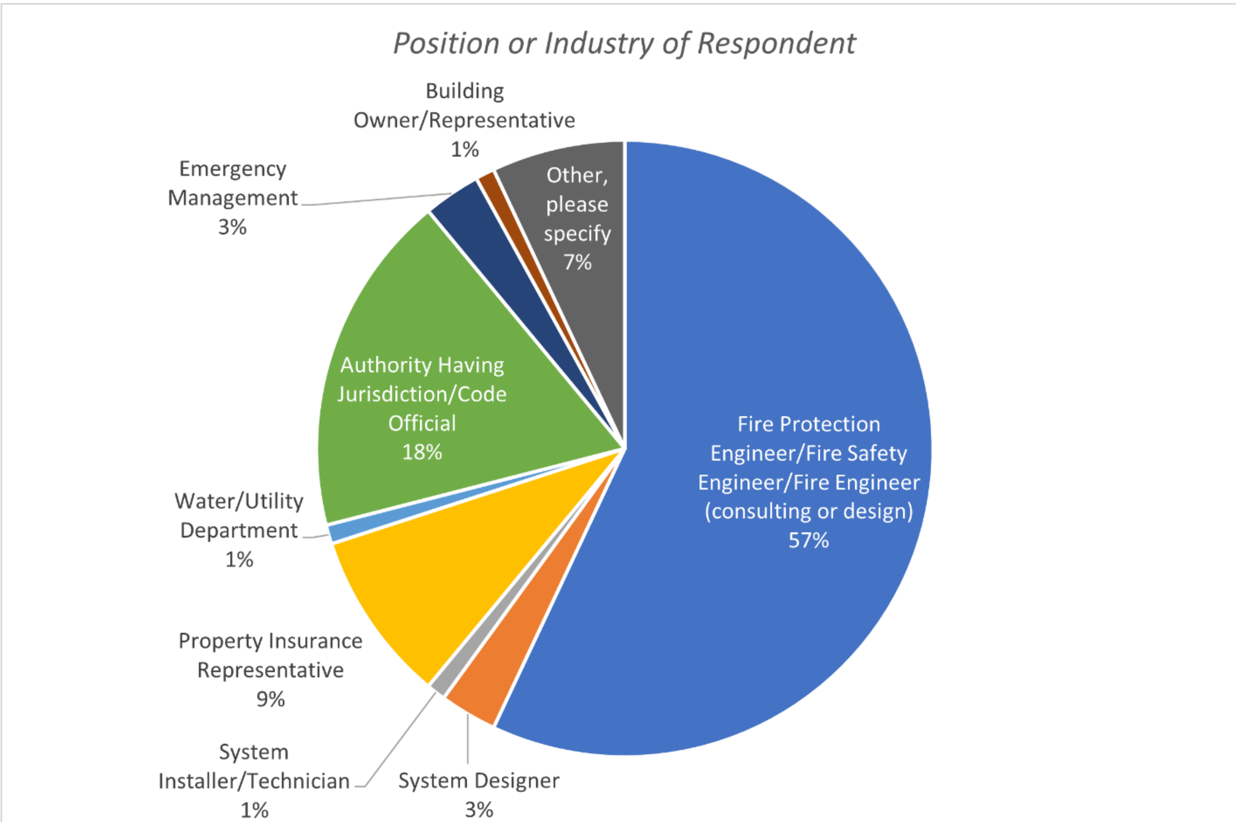

Figure 2. Position or industry of respondent.

Question 3 asked respondents to provide the type of water supply they dealt with primarily on projects. The answers are displayed in Figure 3. This question included a “select all that apply” option. Of the 468 responses, they were split primarily between city water supply with 46%, private water supplies with 29%, and rural water supplies with 24%. The other responses indicated the use of wells, tanks, and reservoirs.

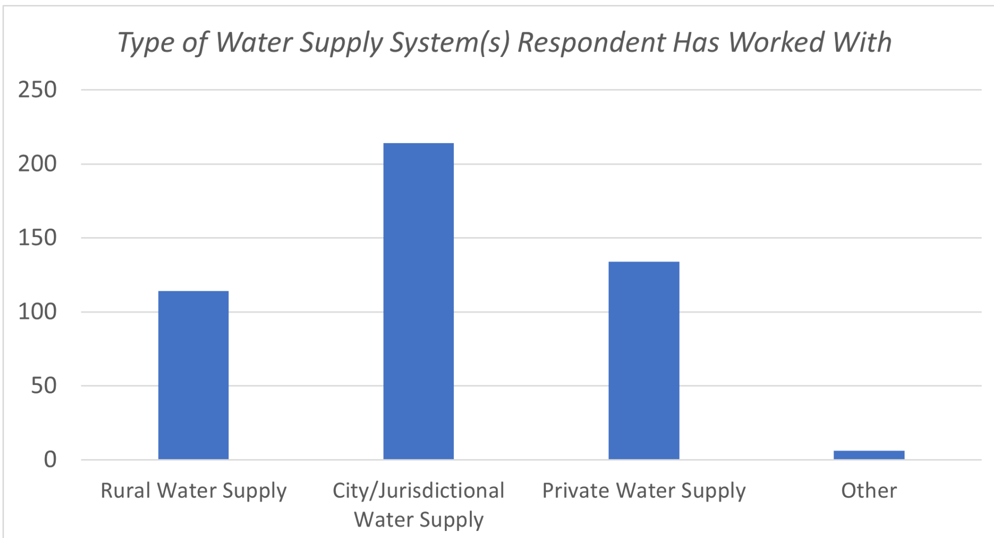

Figure 3. Type of water supply system(s) respondent has worked with.

Question 4 posed the question of where the water supply indicated in question 3 primarily came from (see Figure 4). There was also a “select all that apply” option. The overwhelming majority of the 354 responses stated that their water supply systems were primarily fed by lakes, rivers, and streams with over 50% of responses, followed closely by groundwater sources at 38%.

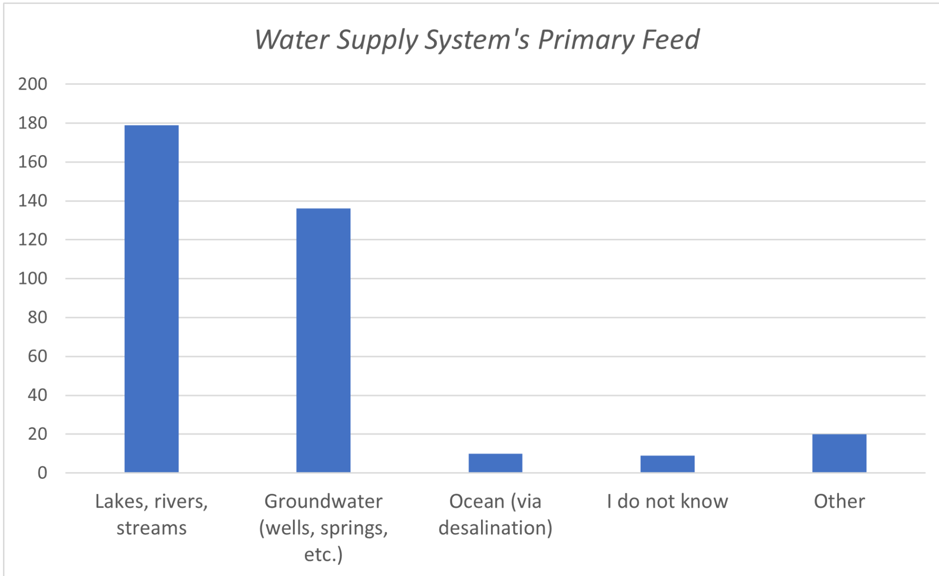

Figure 4. Water supply system's primary feed.

Question 5 asks if communities had a plan in place for a water supply shortage (see Figure 5). Roughly an equal number of responses indicated that yes, there is a plan in place (39%) or they did not know or were not aware of a plan in place (38%). Another 17% of respondents said they did not have a plan in place. Other responses indicated that respondents worked in multiple areas and it varied by location.

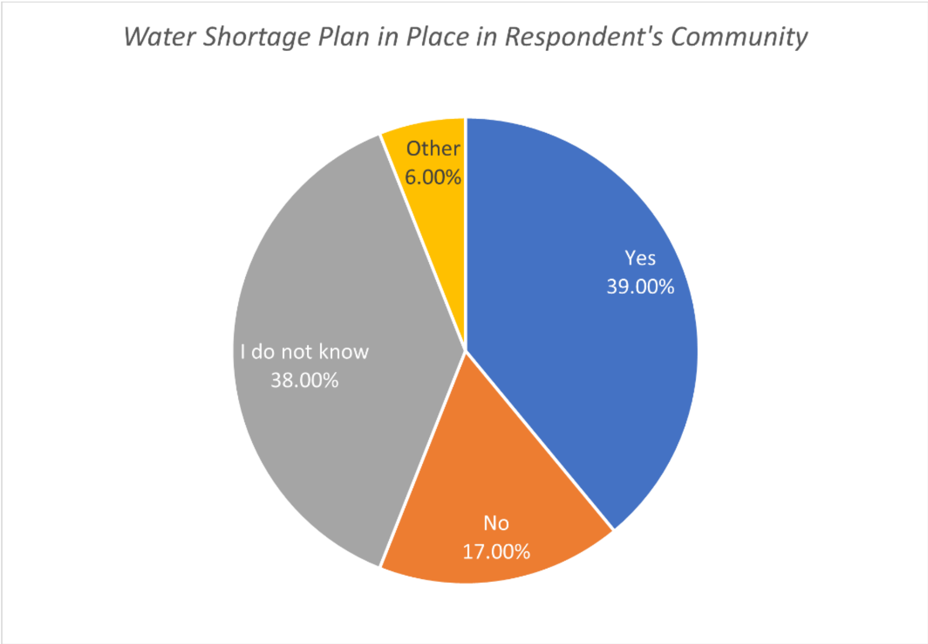

Figure 5. Water shortage plan in place in respondent's community.

A continuation of the previous question, Question 6 asked if fire protection systems or fire department response efforts were discussed in the plan for water supply shortage (see Figure 6). Of the 220 responses, the majority, 57%, answered they were not aware if suppression efforts were considered. Over a quarter of respondents, 26%, answered that these efforts were considered when planning for water shortages.

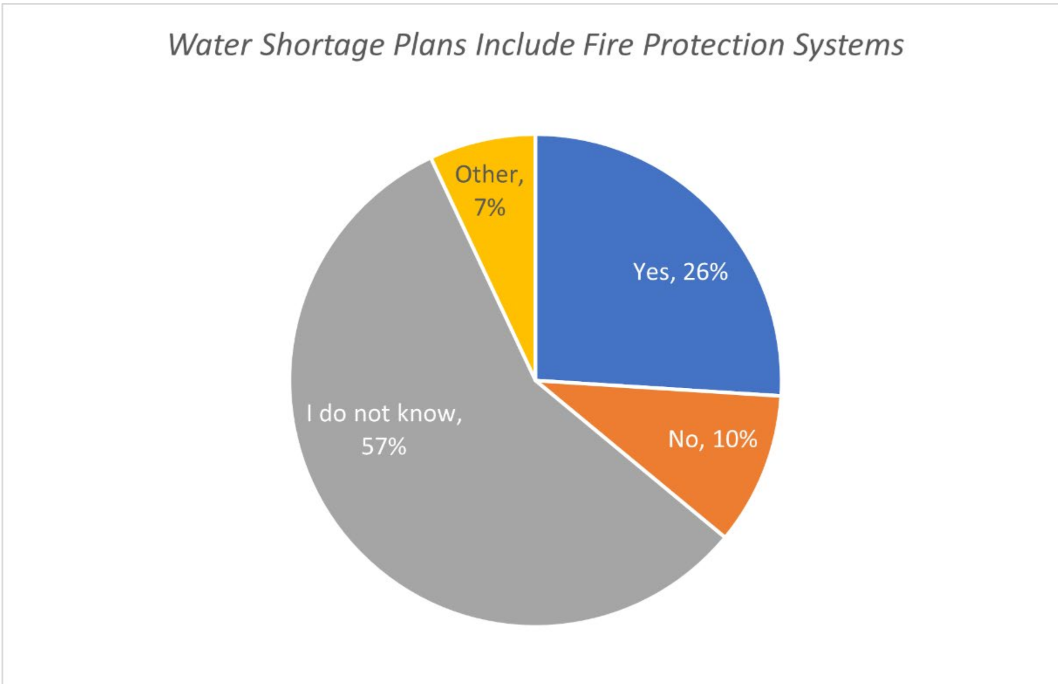

Figure 6. Water shortage plans include fire protection systems.

Question 7 continued the previous line of questioning, asking if a plan was in place, what were the proposed solutions, with a "select all that apply" option (see Figure 7). Of the 298 responses, most respondents indicated they did not know. Of proposed solutions the majority indicated that supplemental water supply, reduction of water pressure in system, and rationing of public water supplies were the planned for solutions.

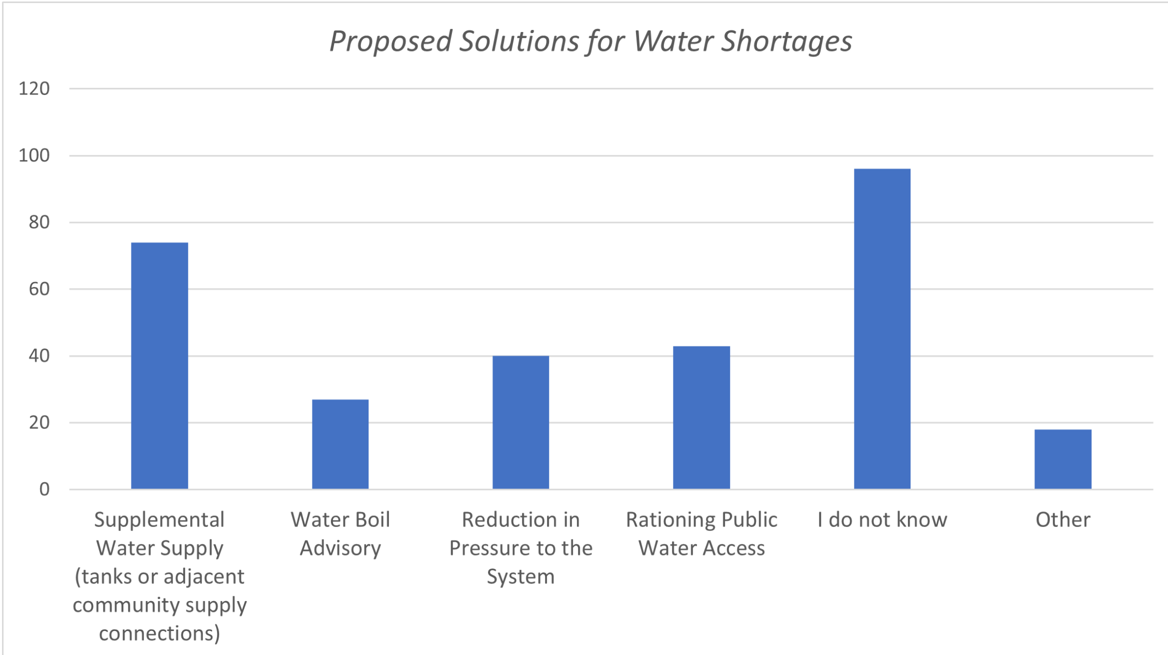

Figure 7. Proposed solutions for water shortages in plans.

Question 8 asked if respondents worked on a project or in a jurisdiction that was subject to water supply shortages (see Figure 8). Over 75% of the 237 responses were yes, they had worked in such an area. Of the other responses, one such answer was that in hindsight, they had worked in a region that had insufficient capacity for droughts.

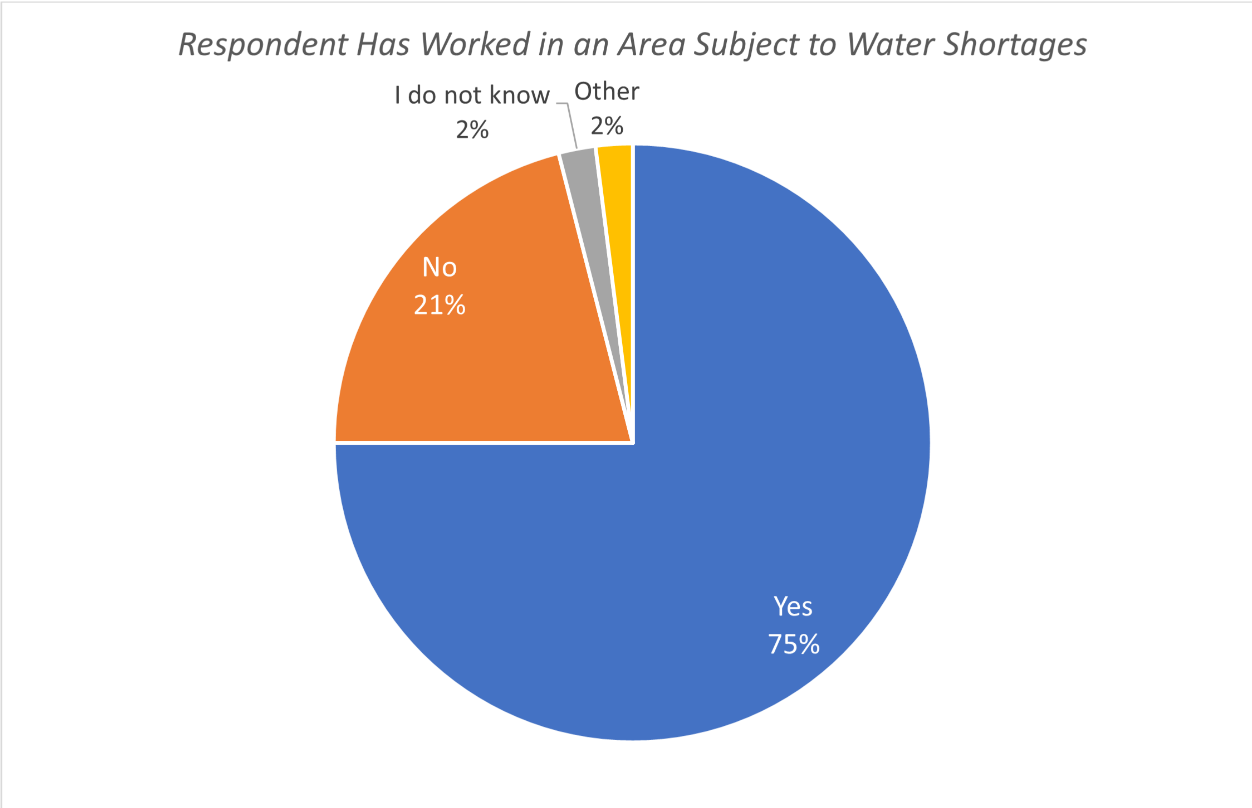

Figure 8. Respondent has worked in an area subject to water shortages.

Question 9, a continuation of the prior question, asked what sort of water supplies were present in the project/jurisdiction that were subject to water supply shortages (see Figure 9). Of the 203 responses, 60% were city/jurisdictional water supplies, with rural and private water supplies sitting at 17% and 16% respectively.

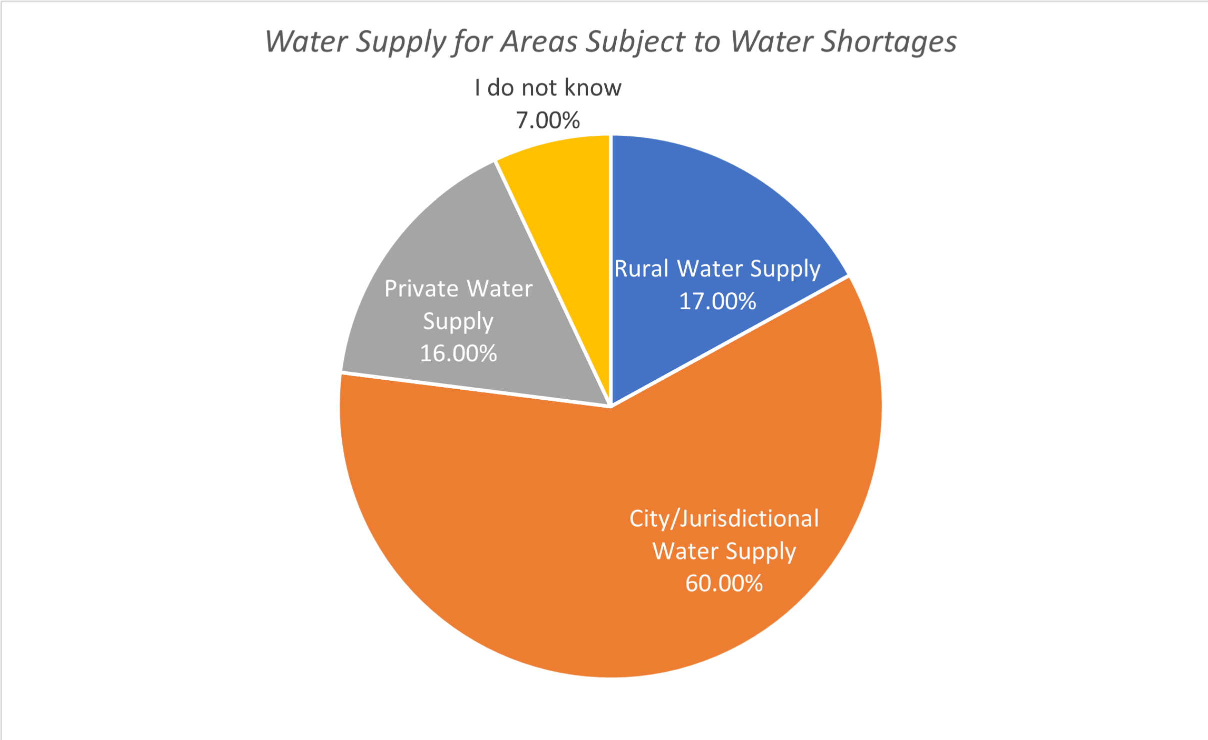

Figure 9. Water supply for areas subject to water shortages.

Question 10, continues the line of questioning from the previous question, asking what sort of water supply was feeding the water supply systems (see Figure 10). There was also a "select all that applies" option. Of the 245 responses, 42.86% were lakes, rivers, and streams. Groundwater was the second most prevalent with 38.37%. The other responses also indicated that rainfall was an additional source of water supply.

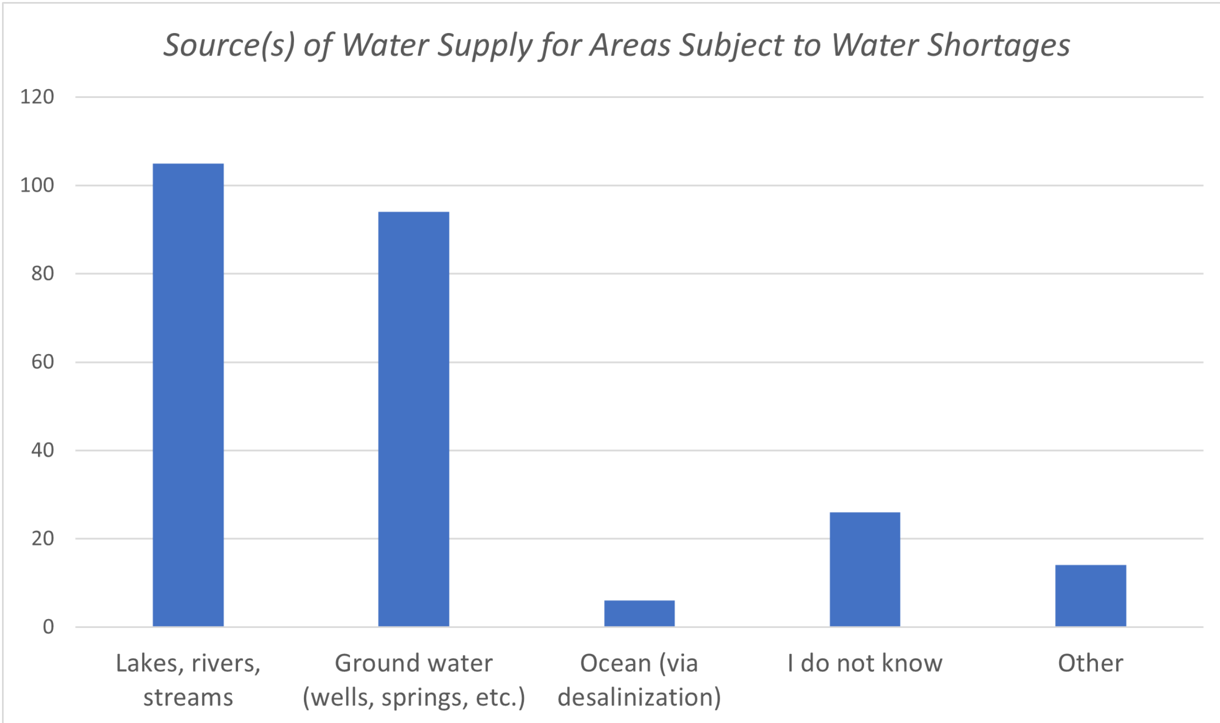

Figure 10. Source(s) of water supply to areas subject to water shortages.

Question 11 asked what the specific cause of the water supply shortage was (see Figure 11). There was also a "select all that apply" option. Of the 332 responses, the largest issue was found to be inadequate infrastructure at 40.06%. Other leading causes were lack of rainfall, population growth, and mechanical failure of water supply. There was a significant amount of free responses to this question, but the majority of them can be attributed to inadequate infrastructure.

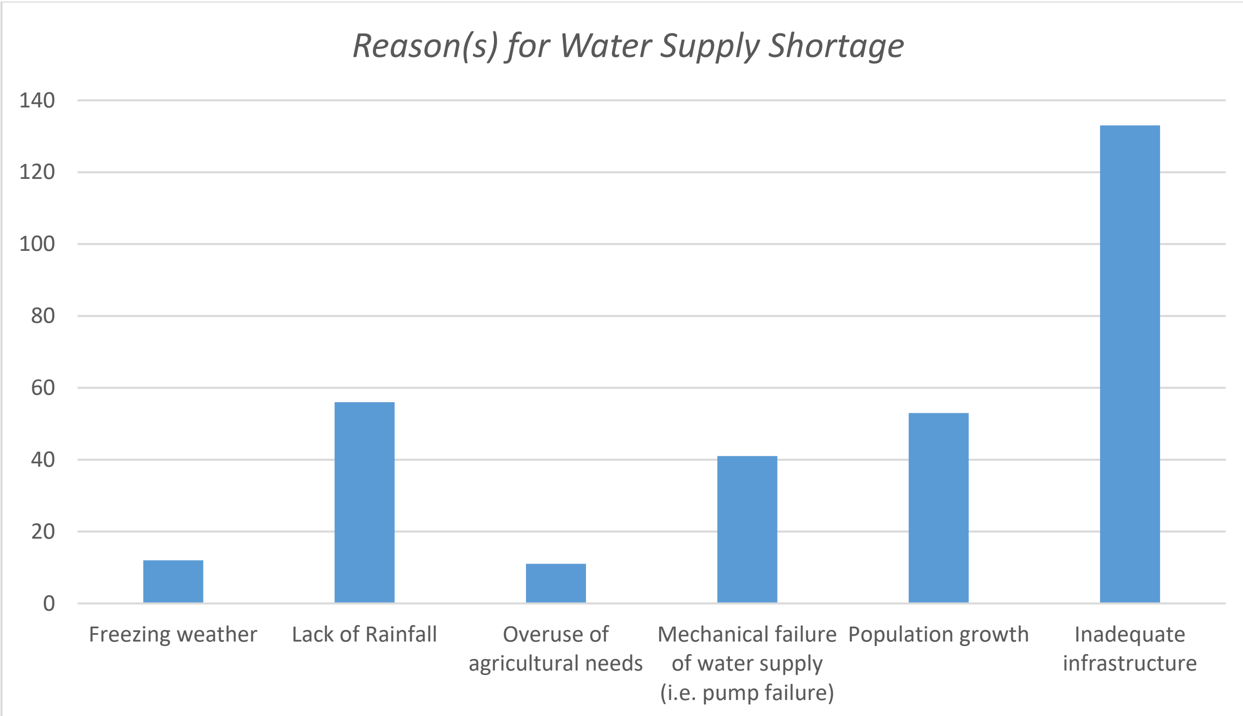

Figure 11. Reason(s) for water supply shortage.

Question 12 posed the question of what fire protection systems were impacted by a water supply shortage (see Figure 12). There was also a “select all that apply” option. Of the 294 responses, 34.69% indicated a sprinkler system inadequacy, followed by respondents not being aware of an event at 30.61%. The majority of free response questions can be attributed to sprinkler system inadequacy, although one response also noted that they were lucky a fire event had not occurred simultaneously with a water supply shortage.

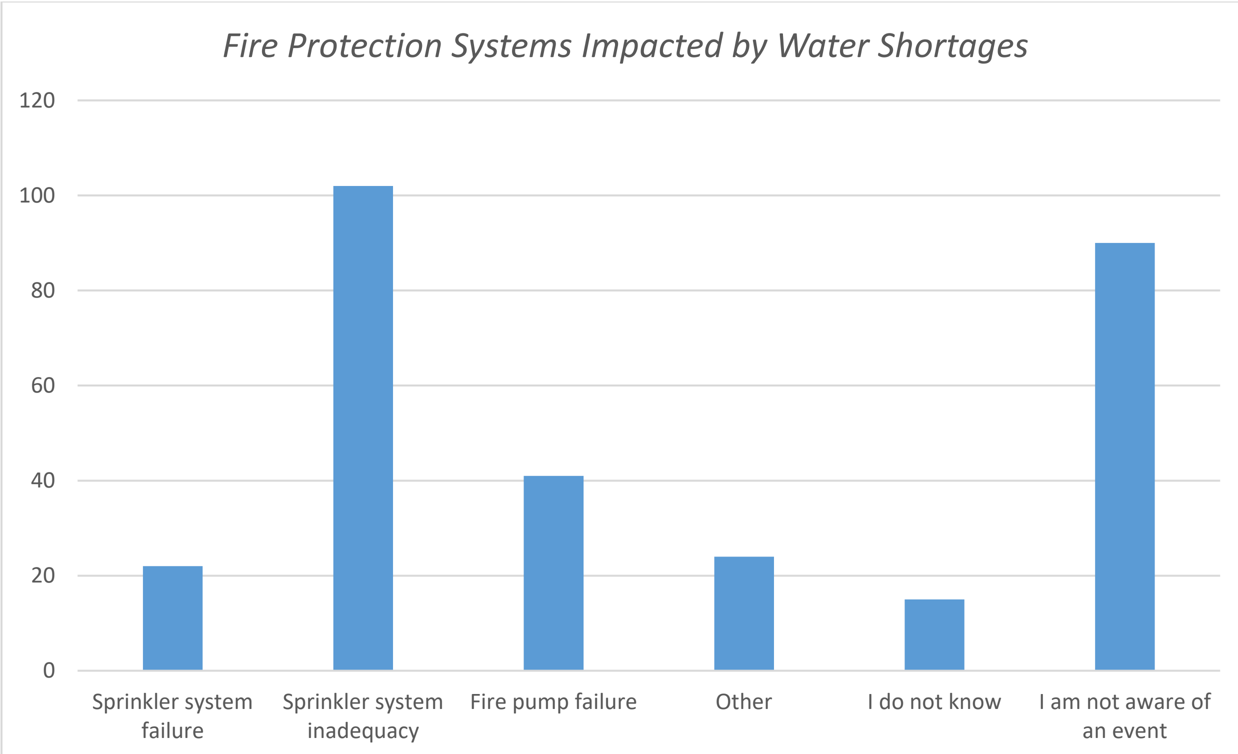

Figure 12. Fire protection systems impacted by water shortages.

Question 13 asked if a water shortage event had impacted fire department response and suppression efforts (see Figure 13). There was also a "select all that apply" option. With a total of 284 responses, the main answers were not aware of an event at 36.62%, suppression efforts unsustainable due to water shortage at 22.54%, and unable to provide suppression effort at 14.44%.

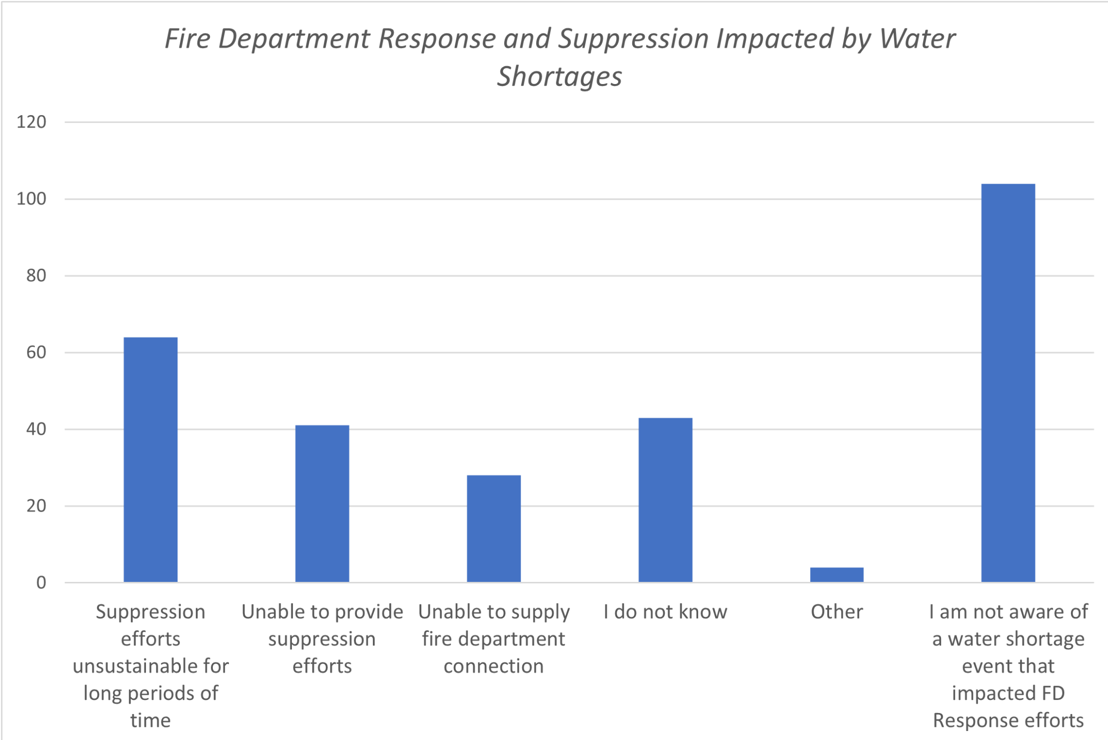

Figure 13. Fire department response and suppression impacted by water shortages.

Question 14 (see Figure 14) asked, in areas that have not experienced water shortages, how could a water supply shortage impact fire protection systems? There was also a “select all that apply” option. With 473 responses, the most common answers were sprinkler system inadequacies at 40.17%, fire pump failures at 27.27%, and sprinkler system failures at 24.52%.

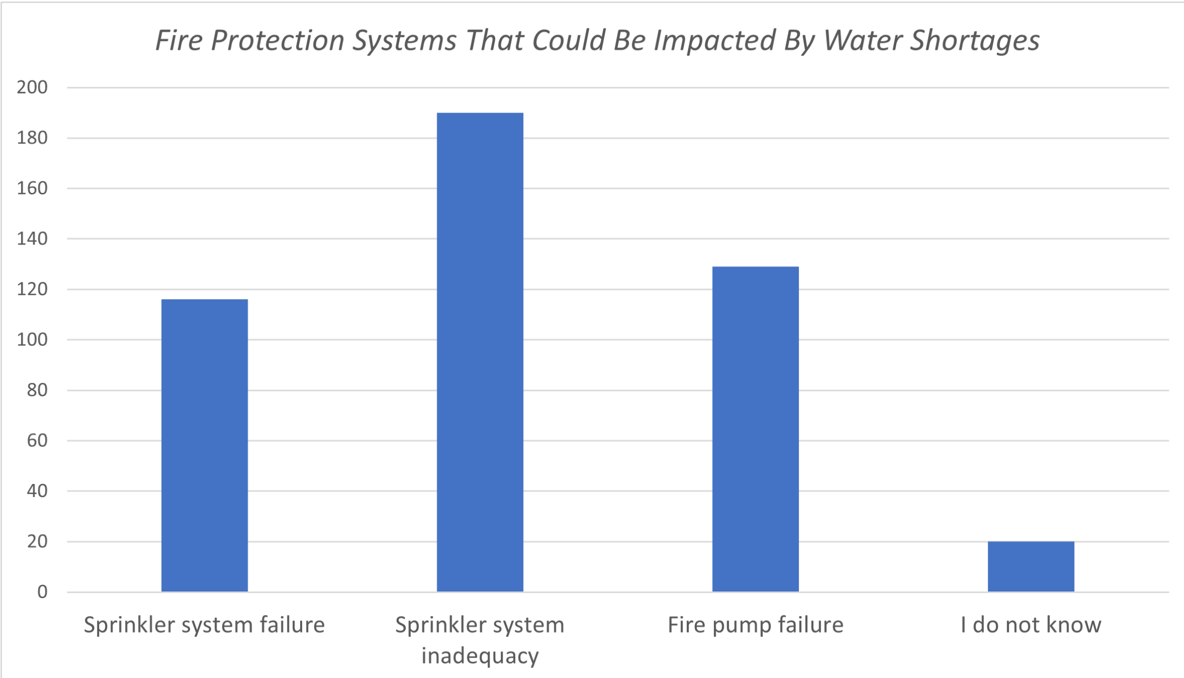

Figure 14. Fire protection systems that could be impacted in the event of a water shortage.

Question 15 (see Figure 15) asked in areas that have not experienced water shortage, how could a water supply shortage impact fire department response and suppression? There was also a "select all that apply" option. With 452 responses, the answers were about evenly split between suppression efforts unsustainable at 38.05%, unable to provide suppression efforts at 30.75%, and unable to supply fire department connections at 27.65%.

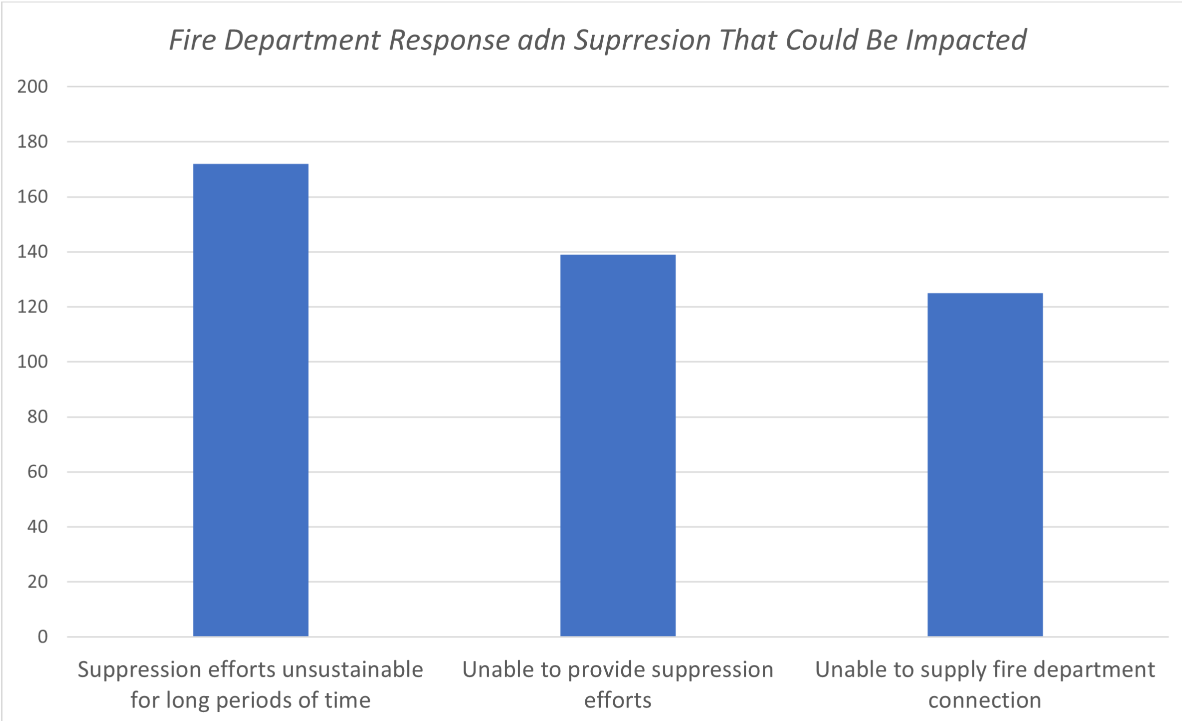

Figure 15. Fire department response and suppression that could be impacted in the event of a water shortage.

Question 16 asked for responders to include all stakeholders that should be involved in planning for a water shortage (see Figure 16). This question also included a "select all that apply" option. There were 1505 responses to this question, receiving the most feedback of all questions. The largest stakeholders were indicated as being water supply/utilities representatives at 14.35%, fire department/fire marshal at 14.09%, and fire protection engineers at 12.43%, with various other stakeholders that should be involved as indicated below. Of the other responses, codes and standards companies, the health department, and departments of natural resources were also mentioned as possible stakeholders that should be involved.

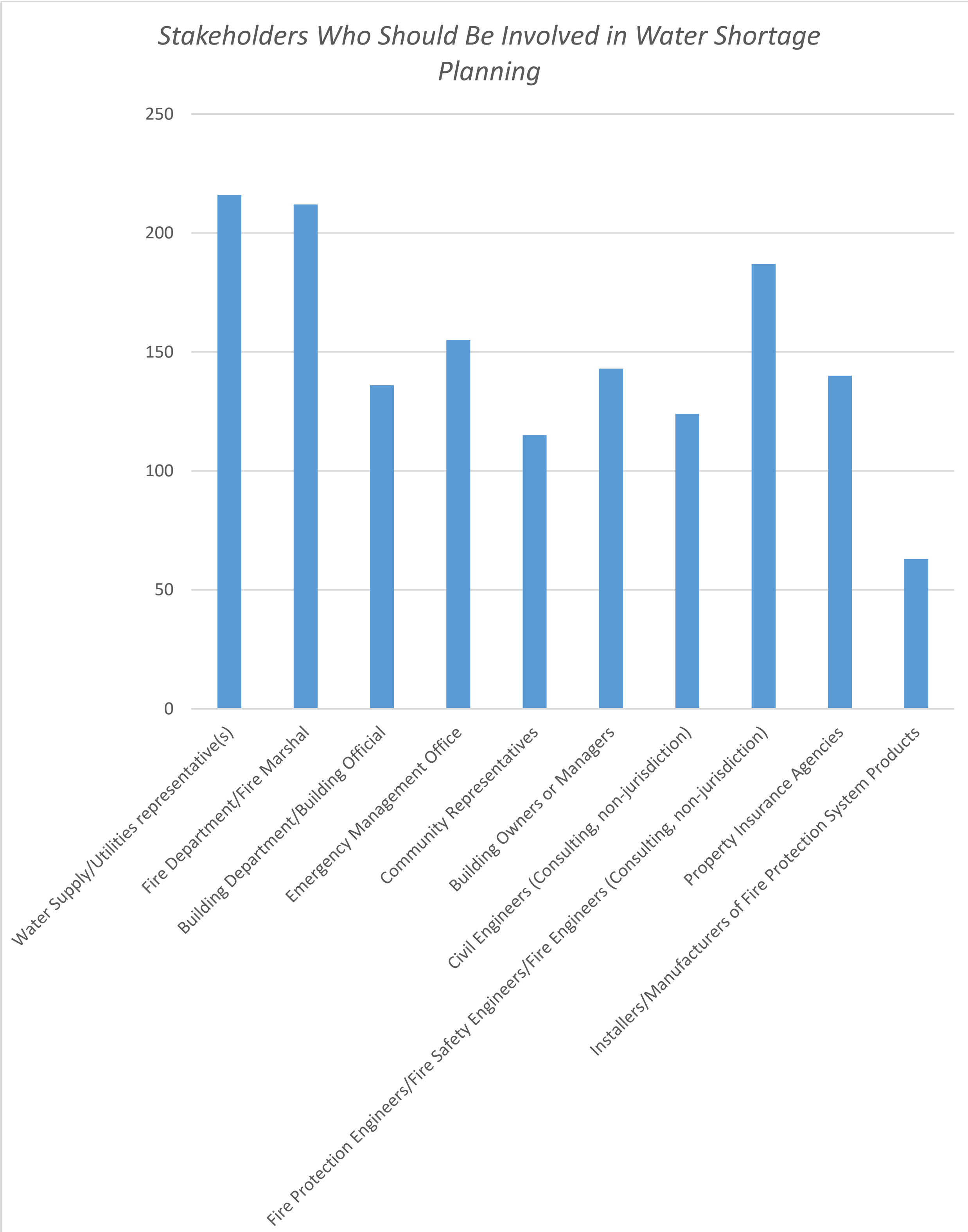

Figure 16. Stakeholders who should be involved in water shortage planning.

Question 17 was a free response question asking for additional comments and feedback on water supply systems dealt with and other issues with water supplies. The majority of free response answers can be attributed to there being inadequate infrastructure for water supply systems. Contamination of water supplies was also a large contributing factor for water supply issues. Some respondents also pointed out that politics in their local region also affect water supplies by way of not providing proper funding for adequate infrastructure. For more information on these free responses, see Appendix B.

Recommendations of Best Practices

In accordance with the results of the survey, a few things are made clear. In areas that were subject to water shortages, plans to account for the water shortage typically did not include water-based fire protection systems. Exclusion of such systems in the plans could cause issues if a fire event happens in tandem with a water shortage.

There were also a large number of responses that indicated respondents were either not aware of a water shortage plan or were not aware of the inclusion of water-based fire protection systems within said plan. As noted, water-based fire protection systems will be affected negatively by a lack of water or a water shortage. Another typical theme was the inadequacies of water supply infrastructure. Areas that do not have available or reliable water supply infrastructure in place will also have limited availability of water for fire protection systems.

Creating and developing policies that provide for means to upgrade current water supply infrastructure to alleviate water shortages will also help to improve fire protection systems performance when water shortages occur. Based on the case studies, different countries seem to understand that water shortages are a major problem, and they are (sometimes slowly) coming around to determining how to ensure their citizens have access to water. However, countries still are not recognizing the implications of losing their access to fire protection systems when experiencing a water shortage. This will need to change, so that countries are adequately prepared when fire events occur simultaneously with a water shortage events. As indicated by the results of the survey, one of the major problems with maintaining an adequate and reliable water supply is inadequate infrastructure. Upgrading and maintaining existing infrastructure when it becomes outdated or obsolete is one of the key provisions when accounting for water supply shortages.

In tandem with the development of policies to upgrade water supply infrastructure, the development of a plan to account for water shortage should also be developed in areas that have not already developed plans. These water shortage plans should include various stakeholders, as indicated above, and should be adapted to fit each area's specific landscape and water supply configuration. The development of such plans should be tailor-made to fit each community's needs. Including all the various stakeholders that may have an interest or possible solutions to problems will help to ensure that the water shortage plan will be as thorough and robust as it can be. Figure 17 below shows the stakeholders that should be involved when planning for and responding to water supply stress or scarcity.

In countries with easy access to oceans or seas, desalination plants would provide a reliable though costly water supply. Many countries have access to a large body of water such as an ocean or a large saltwater sea. Countries like Spain and Australia already have desalination plants in place. Ramping up production at these plants will lead to a reliable and easily accessible water supply in these areas. Creating such a reliable water supply will also ensure that fire protection systems will have the necessary water and pressure to work as intended.

Inspection, testing, and maintenance protocols should be developed to confirm water supply systems are still adequate for the system design. Water supply systems change over time, and with them the availability and reliability of these systems also change. Typically, water-based fire protection systems are designed to function from a specific water supply system and that information is used for the life of the system. By developing new practices to ensure that the water supply for water-based fire protection systems is still adequate to ensure functionality of the designed system, the system can continue to be reliable and adequate.

Public messaging for water supply shortages often notes water saving methods in the domestic and commercial industries. Lawn watering regulations and similar water saving requirements are typically distributed to the public in times of water shortages. Water usage restrictions such as this are common in areas where drought conditions occur, such as Texas, California, and New Zealand. The addition of including messaging regarding water-based fire protection systems to these announcements would be helpful in informing the average citizen of the vast implications of water supply shortages and how it can relate to public safety.

Water supply shortages can be supplemented with other solutions for fire protection systems that involve non-water-based fire protection systems. Other types of systems should be further explored to determine if they can provide appropriate protection to the building or hazard if water supplies are deemed inadequate. Fire protection engineers can work with AHJs to use these systems as primary or secondary for the facility.

Figure 17. Stakeholders who should be consulted when planning for water shortages

Discussion

Based upon the literature review and gap analysis, the effect of water shortages on fire protection systems is apparent, but not well studied. There are a variety of possible ways to combat this lack of knowledge. Implementing policy changes at all levels of government to ensure that water supply infrastructure is adequate will be key to maintaining a reliable water supply. Education of key stakeholders about how a water shortage can happen, and the key effects of that shortage will help to keep stakeholders aware of such situations. There is also much research to be done in this field that will be discussed.

Policy changes

At the current time, there is very little information on policy changes as it impacts fire protection systems use of water supplies. Countries are beginning to feel the impact of climate change on water supply systems in general and some are beginning to enact legislature to help to prevent and prolong their current water supply systems to ensure availability. Some countries are also beginning to supplement their current water supplies with various other means to ensure that there will not be shortages in the future. The countries that are enacting these policies will have a much easier time when trying to protect their fire protection systems from a water supply shortage simply by means of protecting and growing their current water supply system infrastructure. This report has looked at a very limited sample size of countries that are actively preparing and protecting their water supply systems. The vast majority of communities across the world do not have any legislation to protect water supply systems in the event of climate changes or other natural disasters.

Education

Members of the fire protection community will have to begin to accommodate for possible water shortages in the design of their systems. This will have to be a twofold approach. Firstly, education is needed on how to identify areas that may be subject to water shortages in the future. Specialists will have to learn to recognize areas that may be subject to future water shortages. This can involve stakeholders, such as those referenced above, that may be better familiar with the area and its climate. The second portion is implementing solutions/alternatives on how to supplement fire protection systems when designing said systems. Adding elements of safety to ensure that the systems, whether they be sprinkler systems or fire department suppression teams, will be able to operate effectively even in the instance of a water shortage, will help to maintain these systems capability in combatting a fire emergency. The development of an education policy to verify that fire protection specialists have accounted for water supply shortages in the design and commissions of their systems should be implemented. Fire departments should also be educated about the possibilities of water shortages, even in areas where shortages may be considered unlikely, to ensure they have the proper controls in place to ensure an adequate and reliable water supply to combat fire emergencies.

Future Research

There are many avenues for future research in regards to water supply shortages. Discovering the true impact of climate change on water supply systems is not fully known yet, but there are trends pointing to the fact that climate change is hurting the water supplies across the world. This in turn will reduce the amount of available water for fire protection systems, fire department response, and fire suppression.

Research into other options for fire protection systems outside of water-based systems is already being conducted, but special consideration should be given to furthering this research as the amount of water supply shortages grows yearly. Researching system level technology and the use of lower flow or pressure systems should be explored. Alternative solutions to upgrading water supply infrastructure would also be a reasonable avenue of research. There are many countries with desalination facilities in place, so including these facilities in the water supply systems of regions, especially regions with easy access to ocean water, would be a major improvement on the availability and reliability of water supplies.

Working with urban planners on the process of developing policies around water shortages and including local fire protection engineers and other stakeholders in the policy is necessary. An easily understandable methodology to determine which regions are at risk for a water supply shortage should be developed for use by urban planners as well as the design and engineering community. Being able to determine quickly and relatively easily if a region may be subject to a water supply shortage will help fire protection engineers and other stakeholders when developing/designing their fire protection systems. This will ensure reliability and effectiveness of fire protection systems in a fire emergency during a water supply shortage scenario. This methodology can be developed similarly to earthquake zones. Using a risk-informed design methodology to determine water shortage zones and implementing control measures and/or redundancies into the water supply system would help in maintaining a reliable and adequate water supply system.

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Appendix A

Questionnaire

1. Please provide your country of residence or global region.
2. How would you describe your position/industry?
    1. Fire Protection Engineer/Fire Safety Engineer/Fire Engineer (consulting)
    2. System Installer/technician
    3. Property Insurance Representative
    4. Water/Utility Department
    5. Authority Having Jurisdiction/code official
    6. Emergency Management
    7. Building Owner/Representative
    8. Other, please specify
3. How would you describe the water supply system(s) you have dealt with on projects or primarily deal with in your profession (select all that apply)?
    1. Rural Water Supply
    2. City/Jurisdictional Water Supply
    3. Private Water Supply
    4. I don't know
    5. Other, please specify
4. Where does the water supply in the previous question primarily come from (select all that apply)?
    1. Lakes, rivers, streams
    2. Groundwater (wells, springs, etc.)
    3. Ocean (via desalinization)
    4. I don't know
    5. Other, please specify
5. Does the community you primarily work with have a plan in place for water supply shortages?
    1. Yes
    2. No
    3. I don't know
    4. Other, please specify
6. If a plan is in place, were fire protection systems or fire department suppression response efforts discussed as a part of the plan?
    1. Yes
    2. No
    3. I don't know
    4. Other, please specify
7. If a plan is in place, what are the proposed solutions? (select all that apply)

    1. Supplemental Water Supply (tanks or adjacent community supply connections)
    2. Water Boil Advisory
    3. Reduction in Pressure to the System
    4. Rationing Public Water Access
    5. Other, Please Specify
    6. I don't know
8. Have you ever worked on a project or jurisdiction that was subject (either during the design process or after the system was in place) to water supply issues related to having enough water coming from the supply system?
    1. Yes
    2. No
    3. I don't know
    4. Other, please specify
9. If yes, how would you describe the water supply systems that had a water supply shortage?
    1. Rural Water Supply
    2. City/Jurisdictional Water Supply
    3. Private Water Supply
    4. I don't know
    5. Other, please specify
10. Where does the water supply in the previous question primarily come from (select all that apply)?
    1. Lakes, rivers, streams
    2. Groundwater (wells, springs, etc.)
    3. Ocean (via desalinization)
    4. I don't know
    5. Other, please specify
11. If yes, what led to water shortage? Select all that apply
    1. Freezing weather
    2. Lack of Rainfall
    3. Overuse of agricultural needs
    4. Mechanical failure of water supply (pump failure)
    5. Population Growth
    6. Inadequate infrastructure
    7. Other, please specify
12. How has a water shortage event impacted local fire protection systems in buildings? (select all that apply)
    1. Sprinkler System Failure
    2. Sprinkler System Inadequacy
    3. Fire Pump Failure

4. Other, please specify
5. I don't know
6. I am not aware of an event

13. How has a water shortage event impacted Fire Department response and suppression efforts?
    1. Suppression efforts unsustainable for long periods of time
    2. Unable to provide suppression efforts
    3. Unable to supply fire department connection
    4. I don't know
    5. Other, please specify
    6. I am not aware of a water shortage (event that impacted FD response efforts
14. In areas that have not experienced water shortage, how could a water shortage event like this impact local fire protection systems in buildings? (select all that apply)
    1. Sprinkler System Failure
    2. Sprinkler System Inadequacy
    3. Fire Pump Failure
    4. I don't know
    5. Other, please specify
15. In areas that have not experienced water shortage, how could an event like this impact Fire Department response and suppression efforts? (select all that apply)
    1. Suppression efforts unsustainable for long periods of time
    2. Unable to provide suppression efforts
    3. Unable to supply fire department connection
    4. Other, please specify
16. If a community is to plan for water supply shortages, who would be the appropriate stakeholders to have in the planning process? (Select all that apply)
    1. Water Supply/Utilities representative(s)
    2. Fire Department/Fire Marshal
    3. Building Department/Building Official
    4. Emergency Management Office
    5. Community Representatives
    6. Building Owners or Managers
    7. Civil Engineers (Consulting, non-jurisdiction)
    8. Fire Protection Engineers/Fire Safety Engineers/Fire Engineers (Consulting, non-jurisdiction)
    9. Property Insurance Agencies
    10. Installers/Manufacturers of Fire Protection System Products
    11. Other, please specify
17. Provide Additional Comments and Feedback Here (other water supplies you have dealt with, other issues you have seen with water supplies, etc.)

PARTICIPANT INFORMATION FORM

Water Supplies and Climate Change: The Impact of Water Stress on Fire Protection Systems

You are invited to be in a research study about fire protection/fire safety/utility professionals perspectives on water supply shortages related to fire protection systems. This research study is being conducted by Virginia Charter, PhD, PE, FSFPE, Oklahoma State University and Justin Fletcher, Oklahoma State University, FSEP MS Student. Your participation in this research is voluntary. There is no penalty for refusal to participate, and you are free to withdraw your consent and participation in this project at any time. This project is funded by the SFPE Foundation.

If you agree to be in this study, we would ask you to do the following things: Complete an online survey that will take 10 minutes.

Compensation: You will receive no payment for participating in this study.

Confidentiality: The information you give in the study will be anonymous. This means that your name will not be collected or linked to the data in any way. The researchers will not be able to remove your data from the dataset once your participation is complete. This data will be stored in a password protected computer indefinitely. The research team will ensure anonymity to the degree permitted by technology. Your participation in this online survey involves risks similar to a person's everyday use of the internet. If you have concerns, you should consult the survey provider privacy policy at https://www.qualtrics.com/privacy-statement/.

Contacts and Questions: If you have questions about the research study itself, please contact the Principal Investigator at 405-744-3237, virginia.charter@okstate.edu. If you have questions about your rights as a research volunteer, please contact the OSU IRB at (405) 744-3377 or irb@okstate.edu.

If you agree to participate in this research, please click "I Agree" to continue.

Approved: 03/17/2022
Protocol #: IRB-22-122

Appendix B

Question 17 Free Response Answers:

- Water Utilities are denying they are required to supply fire water efforts to the community networks they operate. Policy and poltical interfernce involved at all levles as no one wants to pay for upgrading 100 year old water syste,s yet 1.2 billion is spent on private fire water systems. Crazy.
- Our central water system work well 1000-1400 gpm hydrants. Ponds & river along with central water system location.
- Pleasae contacxt me for copies of bulletins I have written on these issues. Solutions to water supply issues vary from project to project.
- water standards or problems working from one set of standards for compatability of products
- In the Netherlands we use a lot of watertanks for sprinkler systems etc. We found these tanks to have a lot of corrosion after some years. The need to revise a tank or to replace it leeds to periods where the watersupply for the fireprotection systems in inadequate. We also sometimes use the citywaterpipes for sprinkler systems and these pipes are becoming smaller and smaller in diameter for a number of reasons so a supply that was sufficient years ago is in danger of becoming insufficient.
- lack of towns water for farm industries such as chicken farms and on-site industrial processes poses a challenge for fire fighting water supplies
- underwriters should have a great deal of information regarding utilities and failure rates.
- Designs taking suction from water retention ponds in regions that have subsequently experienced drought. Failure of Municipalities to maintain water systems - out of sight out of mind - until water fails to come out of a tap or a pipe break inconveniences people. This is much more wide spread than is indicated. Water quality well monitored. The absence of oversight on water authorities concerning pressure/volume testing issues as well as pro-actively communicating of those test results to stakeholders is rampant. Failure of Planning & Building oversight function to consider fire protection demands. The unrecognized or unmonitored impact of pressure/volume variations to the adequacy of hydraulically designed systems leads to a failure mode waiting to be revealed by a crisis. The sometimes over reliance of the capability of ESFR systems predicated upon water systems with variability in pressure/volume as a function of the system operation or area development.
- Move towards water misting and water treatment with surfactants noted to be increasing in popularity.
- I am a Consultant Electrical , Mechanical , Civel Engineer . I work with witness expertise engineering, I do not work with water supply system
- Water supplies in the WUI have become a point of focus in the FPE community. As people are building further into rural areas, the infrastructure design is not keeping up.
- Lack of internal inspection of underground pipe per NFPA 25

- Also look at no running live hydrant flow test, but allowing computer models and modelling to determine fire flows and design perimeters
- In South Africa a new sprinkler systems will have its own private water storage and pump. Going back 30 years sprinkler system were municipal fed. Private hydrants typically still rely on municipal water supply and frequently encounter issues with supply
- The water utility providers immediately go to a reduction is pressure to prevent failing water piping ruptures and to decrease irrigation usage. They do not recognize the fire department or fire protection a one of their customer service obligations. This is a difficult mindset to change.
- None
- I have also been consulted on the flip side of this issue where a community expansion led to new/larger water mains and higher pressures which then exposed existing buildings with sprinkler systems to pressures in excess of the 175psi rating of many of the system components, invalidating the fire pump designs, and a long discussion on the pros/cons of pressure reducing valves.
- Drought and overbuilding in undersupplied locations in our state.
- N/A
- I work with water utilities across the US to meet building sprinkler system demand. The trend is decreasing flows and pressures resulting in an increased reliance on fire booster pumps and water storage tanks.
- I have not had experiences with climate issues causing fire water supply shortages. The issues I have had deal with increase development in an area causing once adequate flows and pressures to now be reduced to inadequate levels; this shows the importance of including a safety factor in all sprinkler system designs.
- TANKS AND PUMP FOR D SYSTEMS, WELLS AND RESIVOIRS FOR COMERCIL, SCHOOLS, MANUFATURING AND STORAGE
- none
- Perhaps the largest issue I have come to realize is that of folks correctly testing water supplies. The industry utilizes water supply testing procedures that are often misunderstood, arbitrarily modified (without technical understanding of key hydraulic principles), and flat-out misused. I have encountered or been made aware of numerous examples of projects that have fallen into big problems due to inadequate water supply identified late in a projects' development or construction. Current test methods fail to account for a myriad of unknowns and make unsupported 'assumptions' regarding hydraulic conditions and/or out-of-sight infrastructure.
- The individual responsible for providing the water supply & not having the resources to fund the adequate water supply & nercessary pressures.
- Contaminated ground water destroying fire protection equipment.
- None.
- water department requirements to retrofit existing sprinkler systems with reduced pressure or other backflow prevention devices. Typically the water supply cannot provide sufficient pressure to make those changes.

- On Long Island, NY, chemical contamination of the aquifer is more likely, causing wells to be shutdown or filtration systems installed.
- Insufficient private water storage.
- Unable to use the "Other, please specify" answer on the "How has a water shortage event impacted Fire Department response and suppression efforts (select all that apply)?" question.
- MAINTENANCE ISSUES
- In the Dominican Republic all fixed water based fire suppression system's water supplies are private water tanks or reservoirs due to the city water supply be considered as unreliable. On most buildings/facilities the water supply is sized to the expected most demanding hazard, but no always. Water shortages can lead to water supplies' quantity be below minimum required.
- I have never had a water supply issue. Plenty of water here. Not an issue.
- Some of these H2O issues are already common with many rural / volunteer departments so water transfer and hauling techniques are being utilized. Interesting study on the NFPA water supply time basis and a possible revisit / revalidation - Grad student project?. Can the results of this study be provided to at lest the alumni network? Great and timely study issue.
- Part of our jurisdiction has a municipal water supply that is not adequate for even a 13D system. Through testing for a proposed development we learned that the current supply for the area that has two large mercantile occupancies and a 3 story hotel is inadequate to provide sprinkler and hose demand so we are requiring alternative water supplies for new construction to meet fire flow but still working through the hazard with the existing occupancies.
- I have designed FP systems for industry for 30 years and never had a water shortage problem.
- Texas has a minimum required pressure of 35 psi to be supplied by the municipality but the FP systems have been designed to the normal system pressure of 65 psi. Utility suppliers think the 35 is all they have to provide. Not true.
- In the worst case I have seen, Old abandoned wells had to be put back into service to provide water for tankers/tenders and possibly engines.
- I work in >10 states, I see more infrastructure issues than anything.
- Have observed water wasted on fires that could not be extinguished and water was not needed for cooling. It only resulted in environmental impacts / contamination and water issues for the community. Water should only be used where it is beneficial and not just to spray on a fire that is not going anywhere. Let it burn. Talking about very large total loss warehouse type fires where it would have been beter to let it burn and protect exposures vs contaminating adjacent ground waters.
- Water supply deterioration is a potentially big problem that goes broadly ignored outside of providing a safety cushion. As an example, my company has had an increasing set of issues with a certain large client when it comes to available water supply. As the years have gone by the water supply on their property has become increasingly over-stressed.

There is significant safety factor around water supplies and system requirements, but just as system density curves were revisited recently it could be reasonable to revisit flow test standards to consider if the standard practice needs updating.