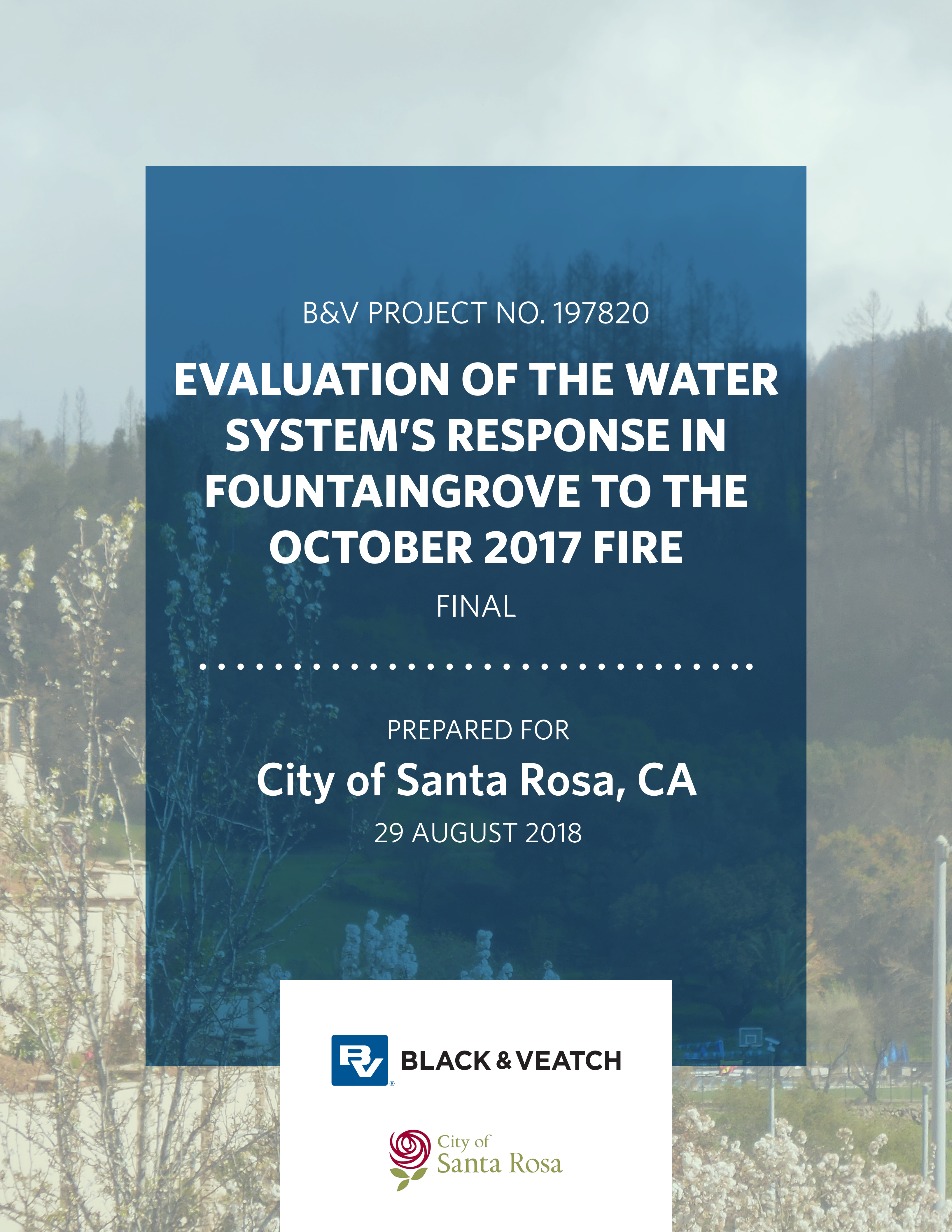

B&V PROJECT NO. 197820

EVALUATION OF THE WATER SYSTEM'S RESPONSE IN FOUNTAINGROVE TO THE OCTOBER 2017 FIRE

FINAL

PREPARED FOR

City of Santa Rosa, CA

29 AUGUST 2018

BLACK & VEATCH

City of Santa Rosa

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1.0 Executive Summary

The Tubbs Fire ignited at approximately 9:45 p.m. Sunday, October 8, 2017. Named for the location of its origin near Tubbs Lane just north of Calistoga, California, the fire spread rapidly through Sonoma County. By the time it was considered 100 percent contained on October 31, it had burned approximately 36,800 acres and more than 5,600 structures. In the City of Santa Rosa (City), more than 3,100 homes and businesses were destroyed. This report presents the results of a focused evaluation of the City's water system within the Fountaingrove area during the Tubbs Fire.

1.1 GOALS AND SOURCES

Goals of the evaluation were to determine the condition and operations of the City's water system before the Tubbs Fire, and to understand the system response in the Fountaingrove area during the fire. Another goal was to identify next steps to improve the water system's reliability and resilience as it relates to fire protection.

Toward this end, interviews were conducted with Santa Rosa Water operations, engineering, and water resources staff members as well as with individuals representing the Santa Rosa Fire Department. In addition, data generated by the City's water system for the Fountaingrove area was evaluated to understand tank and pumping operations before and during the fire.

1.2 EVALUATION FINDINGS

1.2.1 System Reliability and Resiliency

As part of the Santa Rosa 2014 Water Master Plan, fire flow availability for existing and future conditions was evaluated, and the resulting recommendations were followed and implemented prior to the Tubbs fire. Other improvements were being undertaken prior to, and during, the Tubbs Fire to mitigate seismic risks to the distribution system. Santa Rosa Water is more than halfway through a 20-year process of implementing seismic upgrades to all storage tanks in its service area. In the case of fire or other emergencies, all pump stations in the Fountaingrove area have on-site emergency generator power. There are emergency valves between pressure zones to prevent depressurization and to continue supplying water where it is needed in the case of a fire or other emergency.

1.2.2 System Operation Prior to and During Fire

Evaluation of the system operations prior to the fire showed that most of the storage tanks were operated, on average, at approximately 75 percent of their individual capacities. Tank R3 was out-of-service for seismic upgrades. Tank R5 was operated in the bottom third of its volume because of seismic concerns. Two tanks, R16 and R17, were operating near half-full to manage water quality due to low customer demand and high storage volume in the area. Maintaining some storage facilities at lower operating levels is a common practice by U.S. utilities that operate water systems with a high storage-volume to customer-demand ratio. This practice protects water quality by limiting water aging in the tanks, sustaining higher chlorine residuals, and reducing formation of harmful disinfection by-products (DBPs) that are regulated by the U.S. Environmental Protection Agency (EPA).

As the fire spread through the Fountaingrove area, operation of the water system was most impacted by four major factors:

- Extreme water demand due to the destructive effects of the fire which were many times higher than typical conditions
- Partial loss of real-time information provided by the Supervisory Control and Data Acquisition (SCADA) system. This system provides operators the ability to monitor the system and to understand the water levels within tanks, system pressures, and the flow rates at pump stations.
- The loss of full operation of some facilities because of fire damage and power outages in conjunction with back-up power issues.
- The inability to immediately access openly flowing appurtenances to close them and to gather operating information for facilities which had frozen or were being unreported in SCADA due to safety concerns (Staff was allowed to enter the burned areas on the morning of the 10th).

1.3 CONCLUSIONS AND RECOMMENDATIONS

Evaluations showed that the distribution system serving the Fountaingrove area could provide sufficient and reliable fire protection under typical conditions. However, the timing, intensity, rapid spread, and destruction of the Tubbs Fire created atypical conditions and overwhelmed the system. Fires or emergencies of this magnitude are typically beyond the emergency planning criteria used by U.S. water agencies.

1.3.1 Recommendations

Based on the interviews and evaluation of the system, the following are recommendations for improvements and for additional study by the City:

- Investigate ways to increase pumping reliability in upper pressure zones in the case of an outage or major line break
- Examine installing additional interconnections and pressure regulating valves to improve pressure between zones and system reliability
- Study technology, equipment, and software that can be incorporated with Advanced Metering Infrastructure (AMI), such as high flow detectors, and automatic shut-off valves, that offer the ability to prevent openly flowing appurtenances, with a focus on large customers or lines for fire suppression systems.
- Study the feasibility, cost, and impact of providing off-line storage to mitigate the damage of widespread fire events such as the Tubbs fire
- Review and conduct additional system modeling to analyze the feasibility of replacing small diameter dead-end pipes with larger diameter pipes, or provide looping in such areas, to bolster fire flow availability in those areas
- Study the potential for SCADA system reliability and redundancy improvements in the case of an emergency event
- Perform an evaluation similar to this study for the Coffey Park area of the system which is not exclusively controlled by City pumping and storage facilities
- Migrate from natural gas to diesel generators to increase generator reliability during fire or other emergency events such as an earthquake

- Update relevant sections of the City's Water Master Plan by incorporating the lessons learned from this study of the Tubbs fire, and implement all recommendations
- Include resiliency planning tasks in future master planning efforts and associated projects
- Differentiate fire flow goals based on land-use, zoning, structure-type, and Fire Codes and develop system improvements based on results of evaluations using these goals
- Formalize and document the communication structure between the Water Department and Fire Department during red flag conditions to adequately prepare for large spread fire events

Additionally, the Water Department, in coordination with the Fire Department, should investigate developing defined procedures that identify:

- Available flows and pressures in various areas of the city
- Emergency operating plans for critical facilities
- Communication protocols
- A mobilization plan during fire events to turn off openly flowing appurtenances to minimize water loss and stabilize the water system

2.0 Introduction

This report documents an evaluation of the water system serving the City of Santa Rosa (City) following the Tubbs Fire of October 2017. The City ordered the evaluation to assess the system's performance in response to the blaze, to determine lessons learned, and to provide recommendations for improved system performance in the event of future fires in the area.

Toward this end, interviews were conducted with Santa Rosa Water operations, engineering, and water resources staff members as well as with individuals representing the Santa Rosa Fire Department. In addition, data generated by the City's telemetry system was analyzed to understand water pumping and storage tank operations before and during the fire.

The evaluation focused particularly on the part of the system serving Santa Rosa's Fountaingrove area. System conditions for Fountaingrove are exclusively controlled by the Santa Rosa water system and facilities because the area is supplied by pump stations and storage reservoirs. When the Tubbs Fire spread into Santa Rosa, it hit Fountaingrove first and caused devastating damage area-wide.

Fountaingrove is in a wildland-urban interface. That is, the area's homes and businesses are spread across a semi-rural terrain cut by creeks and canyons with highly combustible natural fuel. Fire in the area is a perennial worry. A precedent to the Tubbs Fire was the Hanly Fire of September 1964. Ignited by a hunter's discarded cigarette, it spread rapidly across Santa Rosa's eastern hills. The terrain makes it difficult for officials and residents alike to respond to wildfires.

Black & Veatch was selected to conduct the evaluation of the water system's response to the Tubbs Fire. Major tasks for the Fountaingrove evaluation include:

- Conducting interviews with water department operations, engineering, and water resources staff and Fire Department representatives
- Comparing the development of the system and setting of water distribution system fire flow goals with Fire Code requirements
- Determining the state of the system immediately prior to the start of the Tubbs Fire, including utilizing a hydraulic model to provide a baseline understanding of system operations
- Documenting what occurred during the fire
- Holding a System Response Workshop to present findings
- Evaluating potential changes to increase system reliability and resilience

The following sections summarize the activities and results of these tasks.

3.0 Water System Overview

3.1 RELEVANT FEATURES

The City has adopted the State of California's Fire Code, which in turn follows the *International Fire Code® (IFC)*standards (*City Code Chapter 18-44, California Fire Code adopted by Ordinance 4079).* The City's Fire Code requires the water flow to meet a certain level of fire protection for properties and structures. The City has amended sections of the adopted California Fire Code and raised the minimum fire flow for all properties to 1,500 gpm for a duration of 2 hours. This is more conservative than the California Fire Code. The fire flow goals for the water distribution system are based on this minimum City Fire Code of a fire flow of 1,500 gallons per minute (gpm) over a duration of two hours while maintaining a minimum pressure of 20 pounds per square inch (psi). This is in the upper range of typical fire flow for fires in residential structures and is discussed more in detail in a following section.

To meet the City's fire flow goals across Fountaingrove's hilly topography, Santa Rosa Water operates a system that is divided into seven major pressure zones, which are areas that maintain system operating pressures (generally between 40 and 100 psi). Figure 1 shows a schematic of how the pressure zones are hydraulically connected. Fountaingrove has nine pump stations that maintain water in ten above-ground storage tanks (water towers) and supply the system to meet daily water needs. The tanks and pump stations operate in concert to provide flow and pressure to the distribution system for both normal and emergency conditions. During high-demand periods of the day, in the morning and evening, water drains from the tanks to help meet system needs. At off-peak usage times, during the late-night and early-morning hours, water depleted from the tanks is replenished. This is typical of U.S. water systems and allows Santa Rosa Water to supply water over the course of the day when hourly water uses fluctuates, as well as maintain water quality. Additionally, Santa Rosa Water uses Supervisory Control and Data Acquisition (SCADA) technology, an automation tool long used in various industries. The technology allows remote and intelligent monitoring and control of performance across Santa Rosa's water system, including its pump stations and storage tanks.

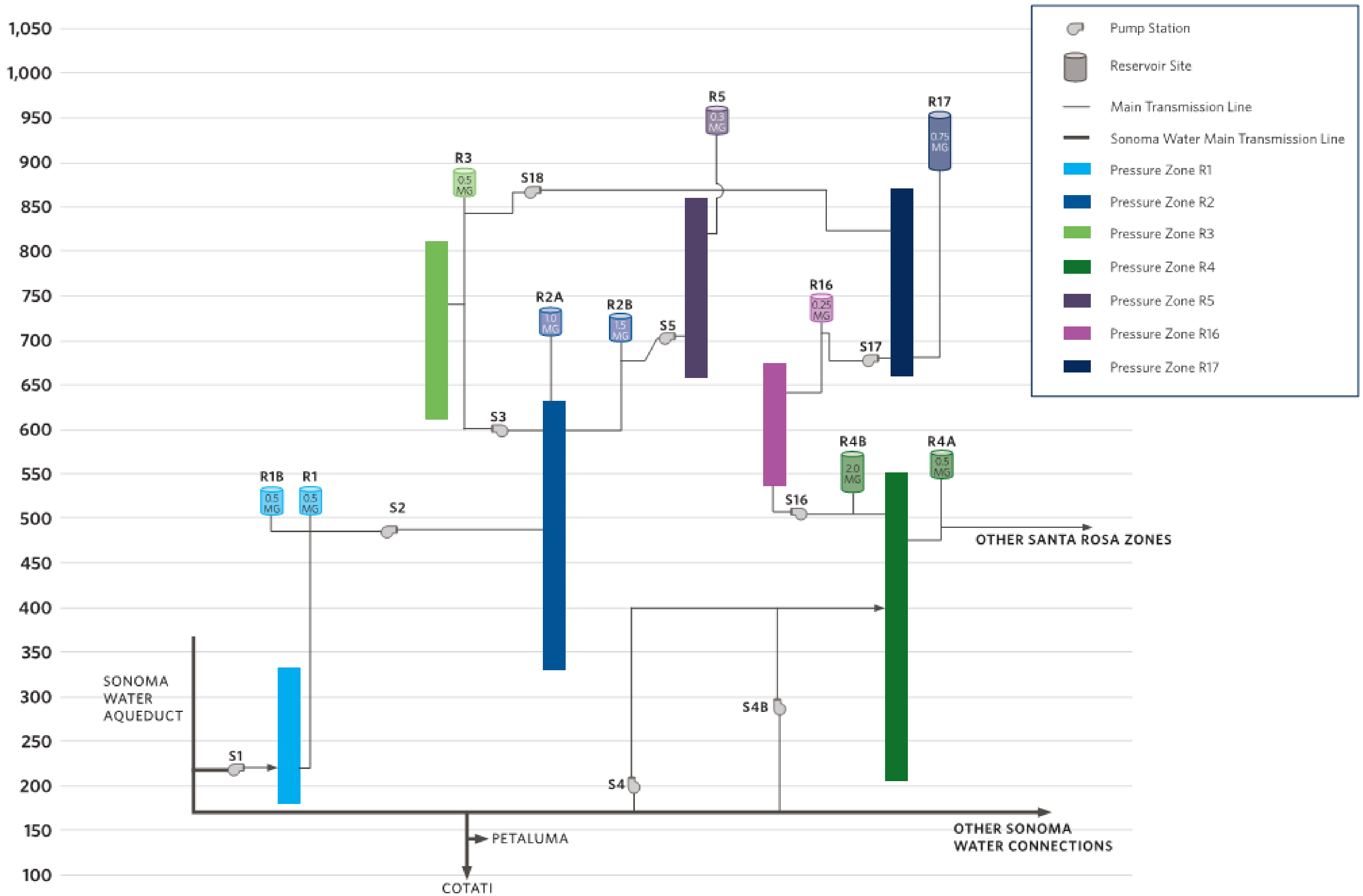

Figure 1. Fountaingrove Distribution System Schematic

3.2 SYSTEM RESILIENCE

As part of the Santa Rosa 2014 Water Master Plan, fire flow availability for existing and future conditions was evaluated, leading to the following recommendations:

1) Increase the capacity of Station S3 to 3,000 gpm
2) Upgrade Station S5 with a high-flow pump for fire protection
3) Provide back-up power generation at all pump stations for emergency conditions
4) Increase the size of the pipe along Fountaingrove Pkwy. from 10 inches to 12 inches for better conveyance of water into the pressure zone

All recommendations were implemented between 2014 and 2017, prior to the Tubbs Fire. The 2014 Water Master Plan noted that all other pressure zones had sufficient storage and/or pumping capacity to provide fire protection based on the fire flow goals for the water distribution system.

Steps were taken prior to, and ongoing during, the Tubbs Fire to protect the water system from the threat of seismic activity. To mitigate seismic risks to Fountaingrove's water supply, the City is more than halfway through a 20-year process of implementing seismic upgrades to all storage tanks in its service area. During the Tubbs Fire, one tank (R3) was out of service as part of the planned retrofit project. Before this tank was taken out of service, the City evaluated the impact and determined the upgrades necessary to meet the fire flow goals in the area with the tank offline. These upgrades included capacity improvements to Station S3 and replacement of a section of pipe with a larger diameter pipe. These improvements provided surplus pumping capacity into the area which offset the need for the storage volume. Thus, the water system fire flow goals are met through surplus pumping capacity when there is limited or no storage. The Fire Department was aware that this tank was out of service during the Tubbs Fire, as it is standard practice for the Water Department to notify the Fire Department when a tank is taken out of service for retrofitting or other maintenance.

Another tank, R5, also was operated at less than half-full because of seismic limitations. The Fire Department was aware of the typical operation of this tank.

Additionally, in the case of fire or other emergencies, all pump stations in the Fountaingrove area have on-site emergency generator power. Emergency use valves are located between pressure zones in case of pressure loss in a lower zone. These valves will automatically open to prevent depressurization and continue supplying water where it is needed. Furthermore, Pressure Zone R17 is served by two pump stations, Station S17 and Station S18. This area is one of the highest elevation areas in the system, and the secondary pump station to supply this pressure zone provides a degree of reliability in the case of a facility or pipeline failure at one side of the system.

Altogether, the system is flexible and can be operated several different ways to provide water supply to meet the fire flow goals for a single- or few-structure fire.

4.0 Codes, Guidelines, and System Review for Fire-related Flows

4.1 OVERVIEW

Industry guidelines exist regarding the design and operation of water systems for firefighting. There are two factors involved with these guidelines: the ability to supply the firefighting flow (fire flow) through the system to a particular location, and the storage volume of fire reserve which is based on the fire flow over a designated duration. These are guidelines or goals, and not direct requirements. Regulatory requirements involving fire protection in terms of fire flow are applied to buildings and property but do not apply directly to the water system. There are no direct regulatory requirements for providing a certain fire flow that apply globally to the water system. Each water system generally sets goals for providing fire flow, using the locally adopted Fire Codes for the buildings and properties as one input in the selection of the fire flow goals. These fire flow goals aim to provide appropriate fire protection while also balancing the need to maintain required water quality and provide cost-effective service. When evaluating a water system's ability to provide fire flow, the fire flow goal set for a location is based on the ability to maintain a minimum pressure of 20 psi in the distribution system at the location and surrounding locations of the fire flow for a specified duration.

4.1.1 Single- or Few-Structure Fire Event

Commonly used industry guidelines for designing a water distribution system to develop and meet fire flow goals are found in the American Water Works Association (AWWA) Manual - *M31 Distribution System Requirements for Fire Protection.* The manual presents several methods that are used to calculate fire flow requirements of individual structures and properties. The Insurance Services Office (ISO), Iowa State University (ISU), the National Fire Academy, and Illinois Institute of Technology Research Institute (IITRI) are among the methods presented in this manual.

The City of Santa Rosa has adopted the California Fire Code which has, in turn, been adopted from the *International Fire Code® (IFC)*. The *IFC* presents prescribed fire flow requirements for buildings and properties rather than detailing several methods of determining fire flow requirements like the *AWWA M31* does. The *IFC* also provides requirements for many other factors beyond required fire flow for structures, such as road access regulations, regulations for hazardous materials, explosion control, and other related items.

Both the *AWWA M31* and the *IFC* provide guidelines for calculating the requirements for fire flow for individual buildings and properties but, as noted above, they do *not* include explicit requirements for the design of the water system. Using either of these sources, the required fire flow for one- and two-family dwellings generally ranges between 500 and 1,500 gpm with a fire duration of one hour. For larger commercial properties, fire flow requirements generally fall between 1,500 and 2,500 gpm, with a fire duration of two hours. Larger industrial type buildings, institutional high-occupancy structures, high-occupancy residential housing, and other buildings can require up to 3,500 gpm and higher at a fire duration of three hours, but the required flows can vary. Santa Rosa's Fire Code stipulates a minimum requirement of 1,500 gpm for a duration of two hours for all properties, and larger non-residential property fire flow requirements can exceed this. The City has incorporated the California Fire Code in setting the fire flow goals for the City's water distribution system, and maintains a fire flow goal of 1,500 gpm for a duration of two hours for all locations in the distribution system (*City Code Chapter 18-44, California Fire Code adopted by Ordinance 4079).*

4.1.2 Wildland Widespread Fire Event

No Fire Codes exist dictating a water system to provide a certain fire flow for wildland-urban interface areas. Guidelines are aimed at construction and development methods for specific structure types instead of the water distribution system.

4.2 CITY DESIGN FOR FIRE FLOW AVAILABILITY

The City currently applies the fire flow goal of 1,500 for a duration of two hours to evaluate the entire system. As part of the City's 2014 Water Master Plan, the system was evaluated against land-use goals and designations within each individual pressure zone, as well as the fire flow goal of 1,500 gpm for a duration of two hours. Fire flow availability modeling was performed for the distribution system, and fire reserve storage adequacy was evaluated for the entire system. All recommendations from this effort for the area included in the burn zone were implemented prior to the Tubbs Fire.

4.3 WATER SYSTEM FIRE FLOW CAPACITY MODELING

As part of this study, fire-flow availability for the existing system was modeled based on operations the week before the Tubbs Fire. The goal of 1,500 gpm for a duration of two hours was applied to all areas within the Fountaingrove Area. The operations that were simulated in the modeling followed the same operations that the system actually experienced during the first week of October in 2017. Details are presented in Appendix A. A summary of the results follows:

- A small area with less than 1,500 gpm of fire flow availability occurred in the R17 Pressure Zone in the area around Tank R17. This deficiency was noted in the design, and the home builder was made aware prior to construction. In-situ booster pumping was required as part of the building design in conformance with the City Fire Code.
- All areas within Pressure Zones R16, R5, and R3 could provide fire flows of 1,500 gpm with a minimum distribution system pressure of 20 psi for a duration of two hours.
- A majority of Pressure Zone R2 could provide fire flows of 1,500 gpm for a duration of two hours at 20 psi with the exception of an isolated dead-end section near the boundary between R2 and R4.
- Small diameter dead-end pipes, mainly in the R4 Pressure Zone, resulted in several areas where the water system was not capable of delivering 1,500 gpm while maintaining a minimum pressure of 20 psi. However, the goal of 1,500 gpm applies to the water system at pipes along which hydrants are located. Pipes 4-inches or less do not have hydrants and some 6-inch dead-end mains will not have hydrants along them either. Therefore, this goal does not apply to the water system in these locations.

In summary, over the entire Fountaingrove Area, the system under existing operations could provide fire flow availability of 1,500 gpm for a duration of two hours at a minimum pressure of 20 psi except for a small area near Tank R17 and some of the dead-end small diameter pipes in the R4

Pressure Zone and one isolated section of pipe within the R2 Pressure Zone (in the sub-pressure Zone R2R1 which is fed from the R2 Pressure Zone).

Figure 2 shows the system pressures that would occur under a fire flow of 1,500 gpm for a duration of two hours. Junctions shown in red, less than 20 psi, indicate a *potential* deficiency in the distribution system to provide fire flow at 20 psi. These results are from the hydraulic model, where a junction can represent a fitting, valve, or a cap but does not represent a fire hydrant. These model junctions only represent a deficiency if there is a hydrant at or near the same location along the pipe, which is generally not the case with small diameter dead-end mains. Some of these smaller mains are in the process of being upgraded and are in the City's Capital Improvements Plan.

Figure 3 shows the same results excluding the junctions at the end of small diameter dead-end sections of pipes to highlight only areas where there is a potential deficiency. This uses the same information as Figure 2 but excludes the junctions that are on small diameter dead-end sections of the system to provide a more realistic representation of where potential deficiencies occur.

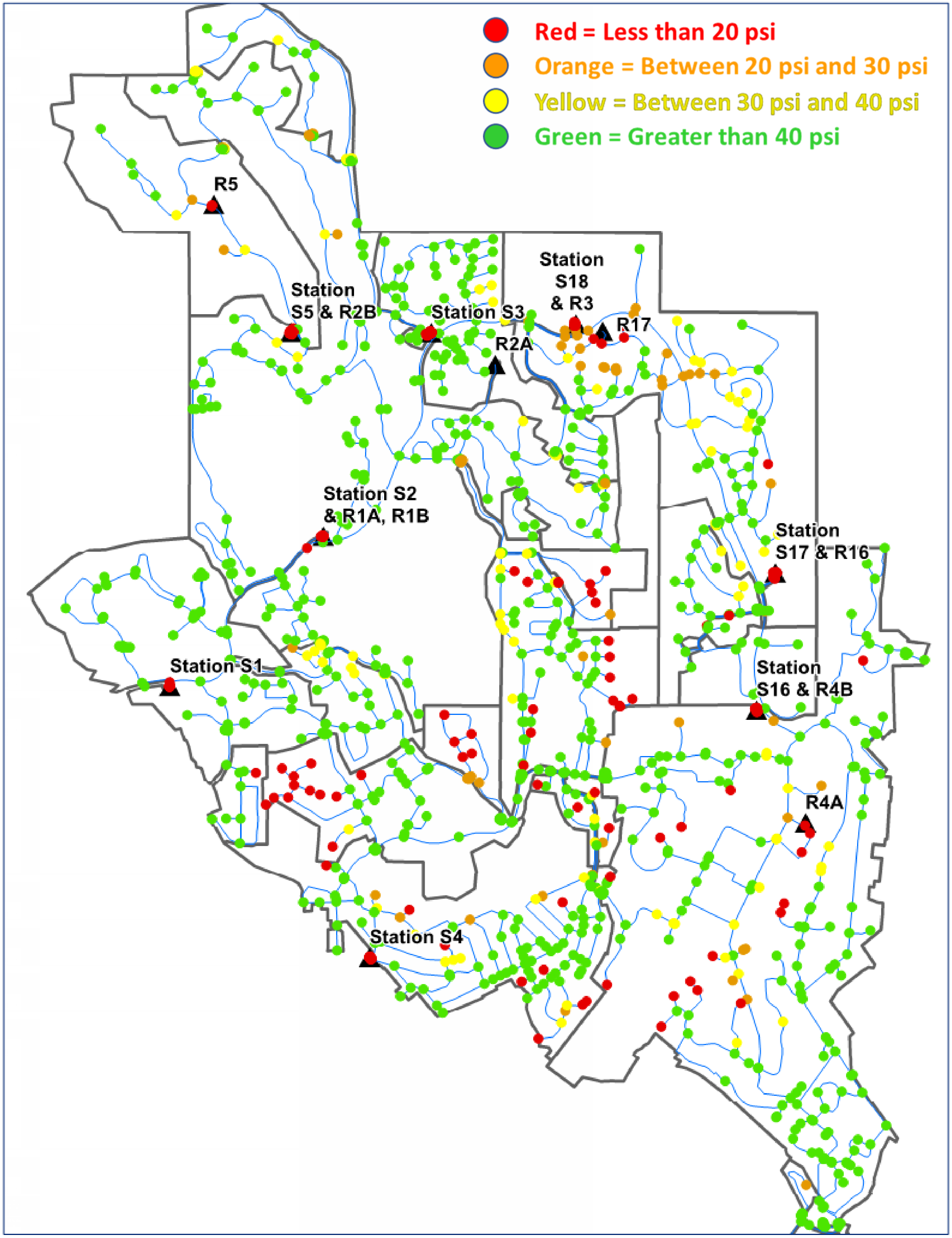

Figure 2. System Pressures for a 1,500 gpm Fire Flow at a Duration of two hours

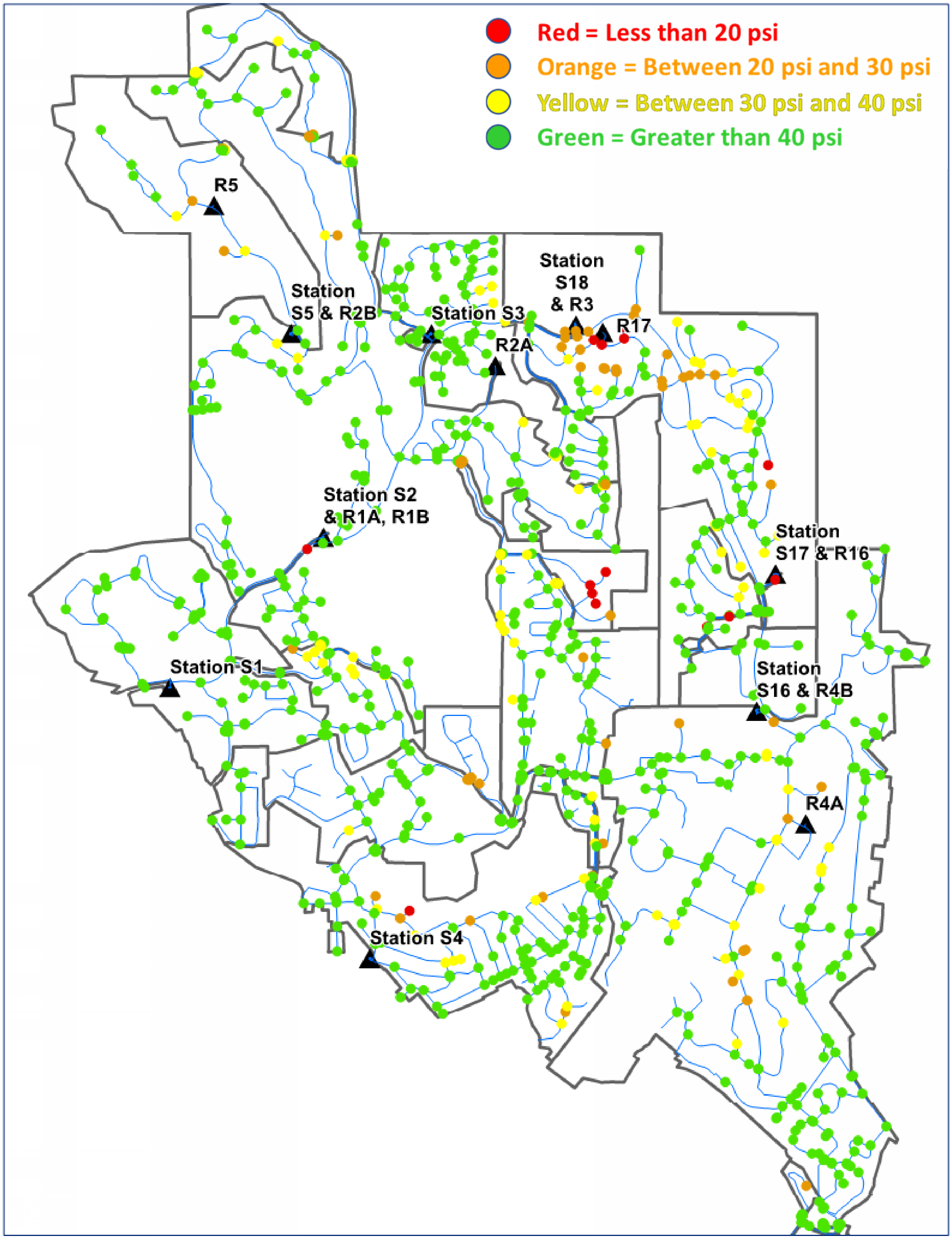

Figure 3. System Pressures for a 1,500 gpm Fire Flow at a Duration of two hours (Excluding Junctions in Small Diameter Pipe/Dead-End Areas)

4.4 FIRE RESERVE ADEQUACY EVALUATION

Additional modeling was performed to evaluate the adequacy of storage in each zone to meet fire flow demand within the Fountaingrove Area. These evaluations were performed in parallel with those presented in the previous section. They looked at the adequacy of the storage volume in each pressure zone, not the individual fire flow availability in the distribution system. Fire flows of 1,500 gpm for a duration of two hours were applied to the model to determine whether the storage volume was adequate to sustain these flows without emptying the system. The storage volume was based on the normal operating levels that occurred during the week prior to the Tubbs Fire.

Detailed results are presented in Appendix B. A summary of the findings follows:

- Tank R17 was sufficient to meet a fire flow of 1,500 gpm for two hours in the R17 Pressure Zone without emptying
- Tank R16 was sufficient to meet a fire flow of 1,500 gpm for two hours in the R16 Pressure Zone without emptying
- Tank R5 was sufficient to meet a fire flow of 1,500 gpm for two hours in the R5 Pressure Zone without emptying
- Tanks R4A and R4B were sufficient to meet a fire flow of 1,500 gpm for two hours in the R4 Pressure Zone without emptying
- Tank R3 was sufficient to meet a fire flow of 1,500 gpm for two hours in the R3 Pressure Zone without emptying
- Tanks R2A and R2B were sufficient to meet a fire flow of 1,500 gpm for two hours in the R2 Pressure Zone without emptying

In short, all storage facilities evaluated under this task could provide the needed storage for a fire flow of 1,500 gpm for two hours.

4.5 SYSTEM RESILIENCY

The City has increased the resiliency of its water system by providing emergency generator power at all pump stations in the Fountaingrove area. The emergency generators allowed the pump stations to operate despite the widespread electrical power outage during the start of the Tubbs Fire.

Other forms of system resiliency already employed by the City include providing pressure regulating valves between pressure zones, which allows water from one zone to flow to another in the case of pressure loss in a lower zone due to fire or emergency. These valves are found between Pressure Zones R17 and R3, between Pressure Zones R3 and R2, between Pressures Zone R5 and R2, between Pressures Zone R17 and R16, and between Pressure Zones R1 and R4. Additionally, there are two separate pump stations, Station S17 and Station S18, that can provide supply into Pressure Zone R17. This system is sufficiently robust to allow for multiple operational combinations to provide fire flow into specific areas in the case of a single structure or few-structure fire. It also allows for tanks to be taken out of service for repair and maintenance while still exceeding the Fire Code requirements.

Another analysis looked at the potential of the system to meet a fire flow demand in all locations up to 2,500 gpm while maintaining pressures of 20 psi. Note that because the area is primarily residential, only a few structures could reasonably have need for a 2,500 gpm fire flow. Figures for each pressure zone under the evaluation criteria of 2,500 gpm are presented in Appendix C. In summary, none of the pressure zones are capable of providing 2,500 gpm to *all* areas with a minimum pressure of 20 psi. That said, many areas within these pressure zones could be provided with a fire flow of 2,500 gpm while maintaining a minimum pressure of 20 psi for a duration of two hours.

In addition to the resiliency of the pumping and pipeline network, storage within the system provides extra capacity beyond what is required by the local Fire Ordinance. A fire reserve evaluation was performed using a higher rate of 2,500 gpm for a duration of two hours, 1,000 gpm above the Fire Ordinance. Detailed results are presented in Appendix D. This evaluation was performed using the typical operating water levels in storage facilities that occurred during the week prior to the fire (with the exception of Tank R3, which was offline and had no baseline data). Following is a summary of the findings:

- Tank R17 was sufficient to meet a fire flow of 2,500 gpm for two hours in the R17 Pressure Zone without emptying.
- Tank R16 was the only tank not sufficient to meet a fire flow of 2,500 gpm for two hours in the R16 Pressure Zone without emptying.
- Tank R5 was sufficient to meet a fire flow of 2,500 gpm for two hours in the R5 Pressure Zone without emptying.
- Tanks R4A and R4B were sufficient to meet a fire flow of 2,500 gpm for two hours in the R4 Pressure Zone without emptying.
- Tank R3 was sufficient to meet a fire flow of 2,500 gpm for two hours in the R3 Pressure Zone without emptying.
- Tanks R2A and R2B were sufficient to meet a fire flow of 2,500 gpm for two hours in the R2 Pressure Zone without emptying.

In summary, all storage facilities evaluated under this task except for R16 could provide the needed storage for a fire flow of 2,500 gpm for two hours. This fire flow is 1,000 gpm more than fire flow goals used in the design of the distribution system.

4.6 WATER QUALITY CONSIDERATIONS

Several tanks are operated at less-than-full levels to maintain acceptable water quality. This is a common industry practice as it reduces water aging, sustains a higher chlorine residual, and reduces formation of disinfection by-products (DBPs) in the water. The needs of the system for fire protection must be balanced with the City's water quality goals. These two concepts can be at odds with each other because greater fire protection requires more storage volume, but a higher volume of storage in the system has a detrimental effect on water quality. The City will need to continue to balance these needs as parts of the system destroyed by the fire are rebuilt. Although the temptation following a catastrophic event such as the Tubbs Fire is to prioritize adding significant storage volume for emergency conditions, over-sizing of system storage can lead to water quality concerns that would occur daily during normal operations as stored water sits unused during everyday operations. Practices employed by the City in the past instead emphasized balancing water quality with adequate storage for fire protection.

5.0 State of Fountaingrove Water System Prior to Fire

SCADA data were provided to support an evaluation of system conditions prior to the fire. Specifically, the data helped to determine system demand conditions and the operation of the system during the week before the fire occurred. Although this communication tool was damaged by the fire and much of the information was lost, Black & Veatch experts were able to use data from the week prior to the fire to analyze normal operating conditions.

5.1 SYSTEM DEMANDS

SCADA data indicating pumping and tank operations were used to determine normal water demand in the Fountaingrove area in the week prior to the fire. The SCADA data provides a method to calculate the actual water usage within the Fountaingrove area using the pumping rates and the water level within tanks over time. Understanding typical consumption as a baseline helps to quantify the effects that the fire had on the system regarding the additional water that was being demanded during the time of the fire. Figure 4 shows the daily demand in the Fountaingrove area for the week prior to the Tubbs Fire. Demand was relatively consistent during the week, averaging around 2,500 gpm.

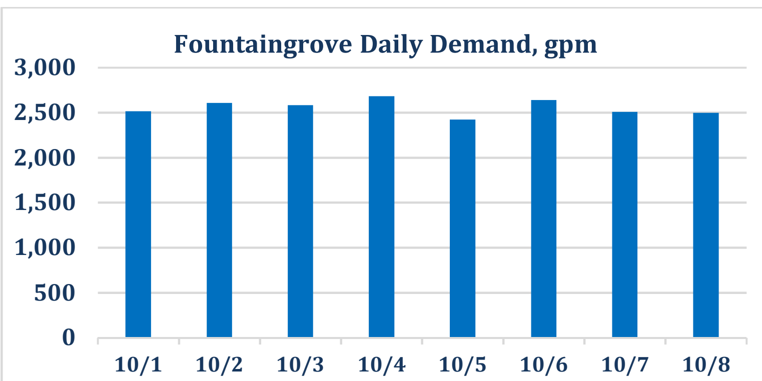

Figure 4. Fountaingove Daily Demand, Week Prior to Tubbs Fire

Figure 5 shows the average hourly usage in the Fountaingrove area for the week prior to the start of the Tubbs Fire. Demand in late-night and early-morning hours is generally the lowest. Usage peaks from around 4 to 9 a.m. Daily usage is highest during this timeframe. There is also a slight peak in usage from approximately 7 to 9 p.m.

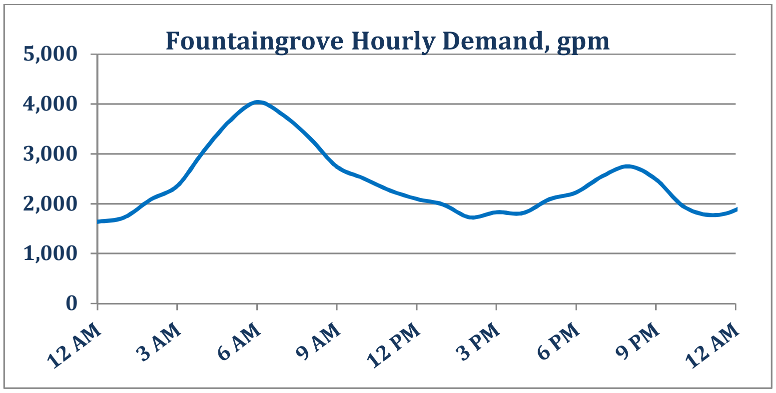

Figure 5. Fountaingrove Hourly Demand

5.2 SYSTEM OPERATIONS AND FACILITIES

The SCADA information was also used to evaluate system operations the week prior to the fire. This included a review of tank operating levels and the supply pumped into the Fountaingrove Area.

Figure 6 shows tank operations for the week prior to the Tubbs Fire. The red series shows the maximum percent full during the week, the blue series shows the average percent full over the week, and the green series shows the minimum percent full during the week.

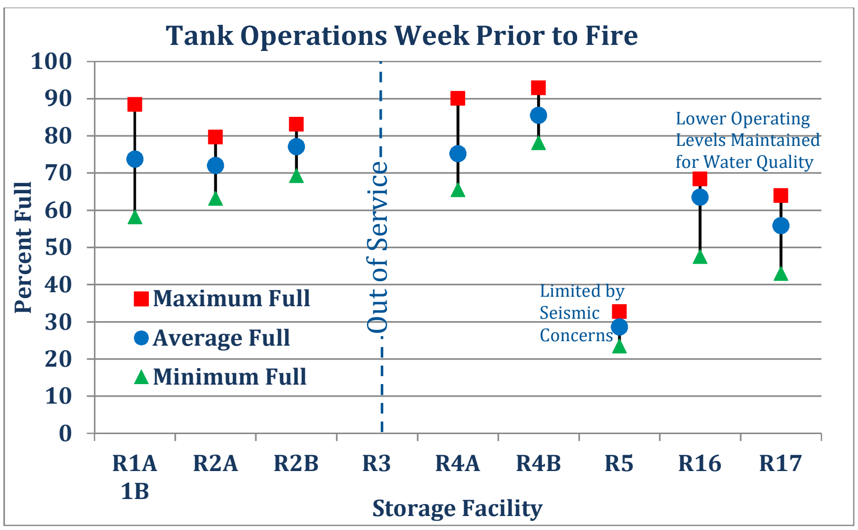

Figure 6. Tank Operations Week Prior to the Tubbs Fire

Most of the tanks operate in the top three-quarters of their volume. This is common practice by retail water agencies. A tank should not operate at 100% full all the time because, if it does, it loses usefulness for equalization of demand during high peaks and would contribute to water quality issues.

The evaluation found that:

- Tanks R1A, R1B, R2A, R2B, R4A, R4B were being operated in approximately the top three-quarters of their volume on average.
- Tank R3 was out of service for a previously scheduled seismic retrofit project. Improvements to the Station S3 and the distribution piping were made before removing this tank from service to meet fire flow goals in the area with the tank offline. The Fire Department was aware that the tank was offline for seismic retrofitting.
- Tank R5 is normally operated less than half full because of seismic concerns.
- Tank R16 and R17 are kept approximately half-full to maintain water quality.

Keeping tanks full raises concerns about aging water, especially because of the low demand in the Fountaingrove area. The low demand has resulted in part from water conservation efforts over the last 10 years. Low demand or excessive storage can lead to poor tank turnover and aging water, which creates low chlorine residuals and/or high DBP formation.

Meanwhile, maintaining tanks at less than full is a common practice among utilities nationwide for managing water quality. The City has employed the technique for years. It offsets the system's lower storage volumes by using large-volume pumps. The pumps provide above and beyond the volume needed for a single- or multiple-structure fire.

This approach was evaluated in the City's 2014 Water Master Plan. It included storage capacity and surplus pumping capacity. The evaluation determined that Fountaingrove's water distribution system met the fire flow goals to provide properties with their required fire flow as per Fire Code for a single- or few-structure fire event even when operating these tanks at less than full.

6.0 Overview of the Tubbs Fire

Named for its origin near Tubbs Lane just outside of Calistoga, the fire started around 9:45 p.m. on Sunday, October 8, 2017. While the cause of the fire remains under investigation, the conditions that fueled its devastation are clear. Single-digit humidity, strong and sustained winds from the north and east, and plentiful combustible grass stemming from years of drought followed by record rainfall in 2017 were key factors behind the fire's incredible speed, magnitude and intensity. The fire spread about 12 miles in the first three hours. By the time it was considered 100 percent contained on October 31, 2017, the Tubbs Fire had scorched approximately 36,800 acres. More than 5,600 structures were burned, including more than 3,100 homes and businesses in Santa Rosa.

6.1 OVERALL PROGRESSION OF FIRE

By 1 a.m. on October 9, the leading edge of the Tubbs Fire reached the City. A *New York Times* article used satellite imaging to display the extent and the timing of the Tubbs Fire (*New York Times*, October 21, 2017). This data was used to recreate a map showing the extent and timing of the Tubbs Fire (see Figure 7). During the first day of the fire, evacuations were the initial priority followed by firefighting. Strong winds drove the blaze across Highway 101 to the west, into the Coffey Park area. The southern and western extent of the fire did not change much after the morning of the 9th, as significant firefighting efforts were made to prevent the fire from spreading into the Town of Windsor. The northern extent of the fire, outside of Santa Rosa Water's service area, were battled from the 10th through the 13th. A strong effort was also made to prevent the fire from spreading northeast into the City of Calistoga. By October 12, the fire was approximately ten percent contained. The outer extent of the fire did not increase much after that day. Instead, fires within the area continued to occur. By October 14, the fire was estimated to be 50 percent contained. Full containment was achieved by October 31.

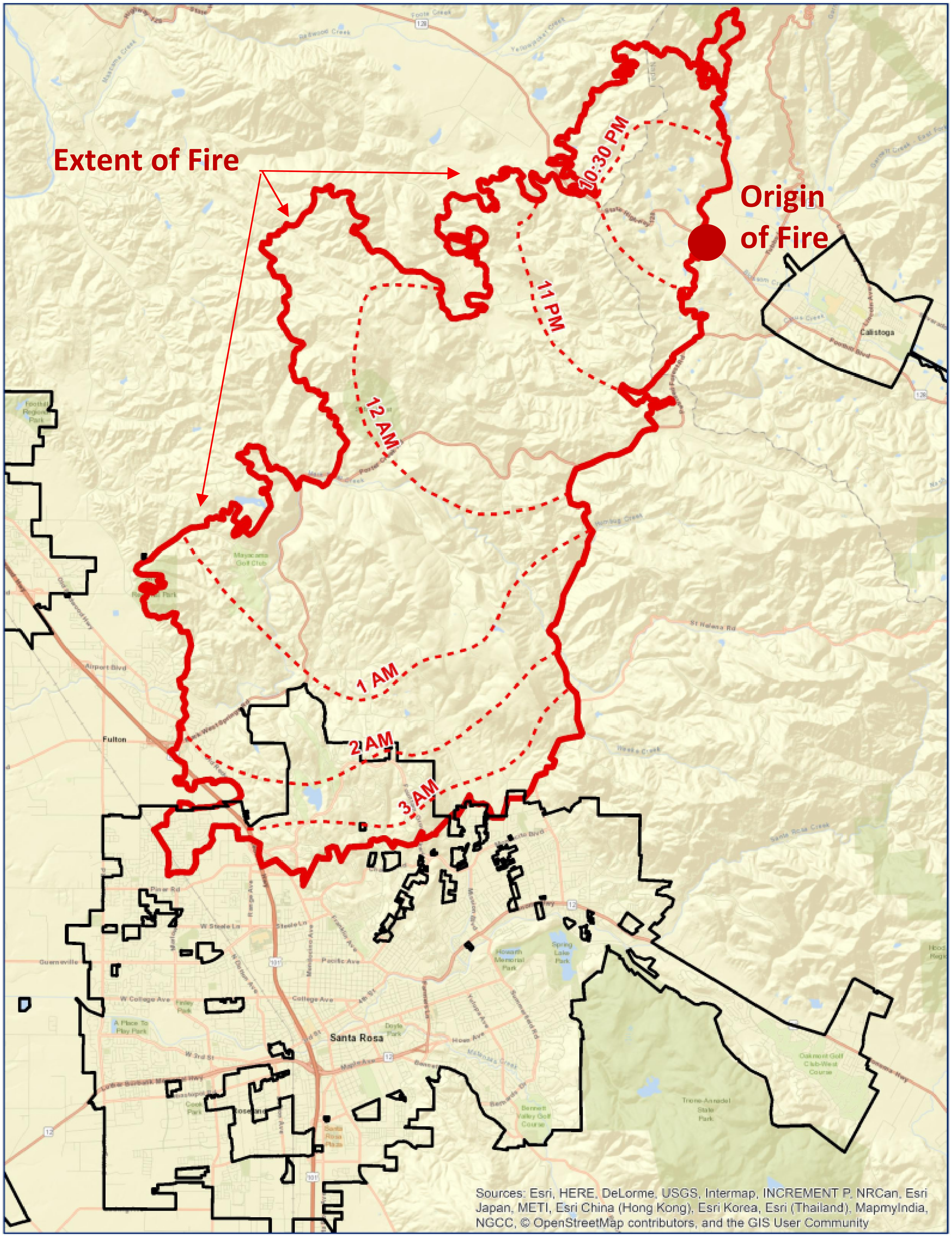

Figure 7. Overall progression and extent of Tubbs Fire (Data Source: *New York Times*, October 21, 2017)

6.2 FIRE IN FOUNTAINGROVE AREA

A closer look at the timing of the fire progression through the Fountaingrove area within the City is provided in Figure 8 below. This figure shows the various pressures zones, subzones, and facilities of the water system, and the timing of the fire's progression into these pressure zones. The subzones are fed from the major pressure zones by pressure regulating valves to manage the pressure but can be considered hydraulically related to the major pressure zone (e.g., R1 Subzone receives water through the R1 Pressure Zone). Between 1 and 2 a.m., the fire spread throughout the R5 Pressure Zone. It also entered the R3 Pressure Zone, the northern portion of R2 Pressure Zone and the R17 Pressure Zone. Between 2 and 3 a.m., the fire spread through all of the R3 Pressure Zone, and most of the R2 and R17 Pressure Zones. The southern extent of the fire after 3 a.m. and over the next two days included all of the R1, R2, and R3 Pressure Zones, and portions of the R16 Pressure Zones.

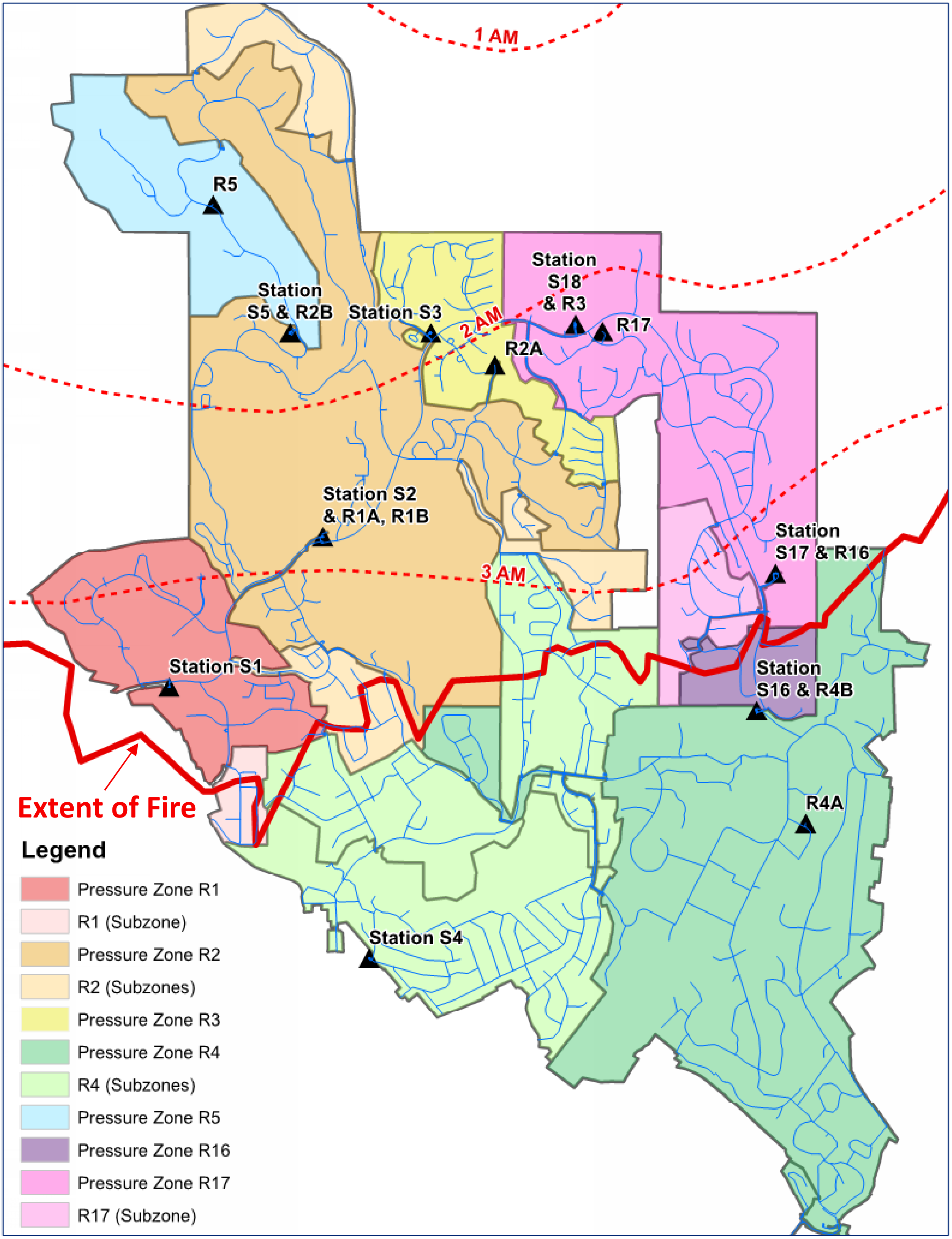

Figure 8. Progression of Tubbs Fire into the Fountaingrove Area of the City

7.0 Fountaingrove System Response

The response of the City's water system in the Fountaingrove area during the Tubb Fire was documented through interviews with individuals with the Water Operations, Engineering, and Water Resources Department and the Fire Department, and an evaluation of SCADA data.

7.1 OPERATIONS, ENGINEERING AND WATER RESOURCES, AND FIRE DEPARTMENT EXPERIENCE

Interviews with operations, engineering and water resources personnel and with Fire Department representatives were held March 26-27, 2018. The goal of these interviews was to gather information about the response to the Tubbs Fire from a water system perspective. Issues experienced by each department were documented. A summary of the interviews is provided in Appendix E.

Even before the fire entered the City, widespread electrical power outages from power lines downed by high winds created the need for several water facilities to rely on backup generator power. Station S2 had a known generator issue that was addressed by a Standard Operating Procedure (SOP) developed prior to the fire which required that a portable generator mobilize to the pump station upon receiving a power outage alert. As required, the water distribution supervisor delivered a portable generator to Station S2 shortly after receiving an alert around 1 a.m. that power was out at the location. Santa Rosa Water was unaware of the severity of the fire at that time, but staff followed the SOP when the power outage alarm was received. At around 2 a.m., however, the fire approached the pump station and staff had to flee with the backup generator.

When Station S3 was rebuilt/upgraded in 2016, a backup generator was added. The generator came on around 11 p.m. on the 8th due to power outage and was checked by a qualified operator at 12:45 when it was still operating. This generator also had a known issue – that when the high-flow pump was triggered and began to operate, at the same time as the other S3 pumps, it would trip the generator. The data shows that around the same time this high-flow pump would have been triggered to turn on, the suction pressure for this pump station, provided from the R2 Pressure Zone, had dropped considerably. Because these two conditions occurred at approximately the same time, it cannot be definitively stated whether the generator issue caused the pump station to shut down because of lack of power, or if the pump station stopped operating because of the lack of suction pressure. The opinion that was reached based on evaluation of all available data is that the pump station became inoperable because the water pressure in the R2 Pressure Zone became too low to provide the necessary suction pressure. This occurred around 3 a.m.

The electrical power outages and infrastructure burned by the fire caused the SCADA system to freeze for several facilities and report incorrect or no data for others. The operations staff uses the SCADA system as a guide to operate the system and to address issues as they arise. With incorrect or missing SCADA data, and unable to gain access to the fire zone until approximately mid-morning on the 10th due to the active fire and mandatory evacuations, operations staff members had to make decisions based on their experience, professional judgment, and requests from the field.

Because of the fire's magnitude and to protect the public, the focus in the first few hours of the fire (early morning October 9) was on safe evacuation for areas in the path of the fire. When mutual aid arrived and winds died down at about 6 a.m. on October 9, the Fire Department shifted its focus to fighting the fire.

Fire Department representatives interviewed had no recollection of the water supply completely running out in fire areas, only that the water system's pressure was low or that there was minimal fire-flow capacity. Sonoma Water, formally Sonoma County Water Agency, was contacted sometime in the morning and requested to increase the pressure in the aqueduct supply line to deliver more water to Fountaingrove and Coffey Park, specifically Station S1.

During the response to the fire, operations staff in the field discovered freely flowing appurtenances at fire lines and burned service connections, and at service connections where plumbing was destroyed. This resulted in a free flow of water pumped out of the open lines. This directly affected the City's ability to maintain water levels in the tanks. The following section presents the findings on the impact that these openly flowing services had on the system. A primary task through the first two days of the fire became identifying and closing open connections so that the system could recover and water could be redirected where it was needed. Nonetheless, while appurtenances were freely flowing and although Santa Rosa Water was pumping at maximum capacity in an attempt to fill the tanks, the storage volume in Fountaingrove system could not be recovered. Essentially, the same amount of water being pumped into the system was flowing out of it because of the open connections. More storage and/or pumping capacity would have resulted in just more water flowing freely out of the system at these open connections.

7.2 DISTRIBUTION SYSTEM HYDRAULIC IMPACT OF FIRE

A review of the SCADA data was performed to understand the operational system response during the fire. This involved a review of the demand placed on the system by the fire and the open appurtenances, as well as the impact of the fire to the infrastructure at storage and pumping facilities.

7.2.1 Water Utilization During Fire

Because some of the SCADA data was missing or incomplete/unavailable, the available SCADA data was used to develop estimates for water utilization during the fire for comparison to the baseline system demands experienced during normal conditions and documented in Section 5.0. Figure 9 presents the outcome of this evaluation.

The demand on the system by the effects of the fire was more than twice the normal system daily demand from typical customer consumption. The greater issue, however, is that in the first few hours of the fire the magnitude of the instantaneous demand, shown by the peak hourly demand, was almost twice the normal peak hourly demand. Plus, the peak demand lasted for several hours, rather than a single peak hour as is typical. This created an enormous drain on the system, causing storage to empty at high rates. Also, some areas were heavily taxed before the fire reached them because residents used hoses and taps to inundate their property, thinking it would help to save their properties from damage.

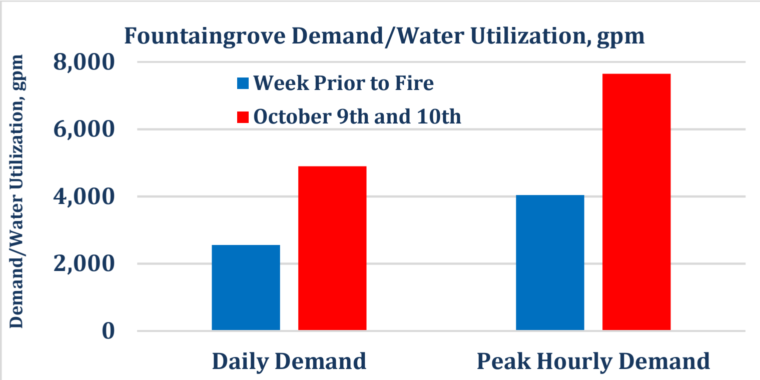

Figure 9. Water Utilization Before and During Fire

Services and fire lines at properties that had been burned acted as open taps, and the number of these services and fire lines grew as more structures burned. It should be noted that the flow through these openly flowing appurtenances has a dependent relationship to the system pressure. This means that the harder the pumping into the system from facilities or the higher the tank level in a pressure zone, the higher the rate that these open appurtenances will flow. Most of the demand on the system was caused by openly flowing appurtenances which were essentially allowing much of the water being pumped into the system to freely flow out. In addition to this there was water being used for firefighting and in other areas where the fire had not spread, general residential and commercial use of water continued. A post-fire review of burned structures provided the number of service connections and the sizes of these connections that would have been freely flowing.

The typical flow rates that would have occurred in the service lines were evaluated through modeling and are presented in Table 1. These numbers are conservative; with higher tank levels, these values would be greater because they are proportional to system pressure.

Table 1. Typical Free Flow Rate by Service Size

SERVICE LINE SIZE	FREE-FLOW RATE
⅝ inch	25 gpm
¾ inch	40 gpm
1 inch	80 gpm
1½ inch	180 gpm
2 inches	300 gpm
3 inches	700 gpm
4 inches	1,200 gpm
6 inches	2,500 gpm
8 inches	More than 2,500 gpm
10 inches	More than 2,500 gpm

Properties that were destroyed in the Tubbs fire were reviewed by geographic location to determine the services by size and the pressure zone in which they were located. This information is presented in Table 2. It should be noted that this is a theoretical evaluation, because not all services on properties that burned became freely flowing at the same time, and they were closed as they were discovered and as access allowed. However, the last column in this table provides an example of why it was so difficult to recover water storage in the system until the freely flowing services could be closed manually because the free-flow rates are generally much greater than the total pumping capacity into each area.

Table 2. Burned Structure – Meter/Service Line Information

PRESSURE ZONE	METER SIZE										POTENTIAL FREE FLOW RATE (1)
	⅝"	¾"	1"	1.5"	2"	3"	4"	6"	8"	10"	
R1	56	4			3		1			1	6,160 gpm
R2	379	7	104	1	8	2	1	3	2		35,755 gpm
R3	277	2	10		2						8,405 gpm
R4	131	8	10		1			1			7,195 gpm
R5	11	1	45								3,915 gpm
R16	1		3								265 gpm
R17	291	13	73	1	1				1		16,615 gpm
Total from all Services, System-wide (1)											**78,310 gpm**

(1) The potential free flow rate and the total from all services values are approximated based on the number of services multiplied by the rate at which they would flow freely. These numbers are hypothetical and assume simultaneous occurrence.

To put the value shown in Table 2 in context, the total pumping capacity into the Fountaingrove area is around 10,000 gpm. Therefore, if only 13 percent of these service lines were flowing freely, the loss out of the system through the openly flowing service lines would be greater than the capacity of the available supply pumping into the Fountaingrove area, meaning tanks would drain. If 25 percent of these service lines were flowing freely, it would be enough to overwhelm the system and drain all storage within 17 hours. This number is conservatively low because it ignores firefighting uses of water and any additional uses of water that were occurring at the same time in the Fountaingrove area due to residential and commercial water usage in areas that were not impacted by the fire but still in the Fountaingrove operational area.

In summary, it is clear that openly flowing service lines were the main cause of the tanks' inability to fill during the first few hours of the fire and were the primary reason why system pressures and tank levels dropped dramatically. Short of identifying and closing these openly flowing services, which the Water Department began to do as soon as they were allowed into the area on the morning of the 10th, the data indicates that there was nothing the City could have done to prevent some of the tanks from draining due to the excessive strain that openly flowing services created on the system.

Additional demand was put on the system when hydrants were used to provide water for firefighting purposes. The values shown in Figure 9 for the daily demand and peak hourly demand on the system during the fire are likely much lower than what would have occurred if all storage facilities were online and had been full. If this had been the case, a reasonable assumption can be made that the hourly demands placed on the system by the fire would have been higher because with higher system pressure, the corresponding water loss through openly flowing appurtenances would have been greater. This suggests that even with full system storage, the effects of the fire on the system would have exceeded the storage capacity within a similar timeframe, with only an extra hour or two before the tanks were drained.

A detailed review of the demand conditions, by individual pressure zone, is provided in Appendix F.

7.2.2 Impact to Storage and Pumping Facilities

As noted previously, one of the issues with pumping water into some areas was the widespread electrical power outage. The City has invested in back-up power, in the form of generators, which allows pump stations to continue pumping even when the main electrical power supply goes out. A portable generator had been brought to Station S2 due to the power outage and because the on-site generator was out of service. With the advancing fire and the evacuation efforts, staff was forced to flee from the pump station with the generator. The generator was brought back the same day when the threat had subsided, but analysis of the demands indicate that even maximum pumping would not have been able to keep up with the demand that firefighting and open service lines put upon the system.

As noted in the previous section, the resulting demand that the fire put on the system caused several tanks to drain within only a couple of hours. Although SCADA data related to the tanks is incomplete between October 9 and 11 because of the power outages, other SCADA data, such as pump pressure, provide an indication of the tank status, based on the suction or discharge pressure seen by the pump. A detailed, zone-by-zone evaluation of the SCADA data is provided in Appendix G and describes the impact that the fire had on each pressure zone. Below is a summary list of the tanks and their status during the fire. This summary is the best that could be discerned because of the somewhat-limited data:

- Tank R17, in the R17 Pressure Zone, appears to have completely drained sometime around 3 a.m. on October 9. Although the tank level began reading an error value at 3 a.m., discharge pressure from Station S17 indicates that the tank was nearly empty. Tank R17 went from 50 percent full to nearly empty in less than two hours. Although attempts started on the 9th to fill the tank, it began to recover in the morning of October 11 when a sufficient number of openly flowing service lines had been located and closed. Pressure data from Station S17 indicates that by 10 a.m. on October 11 the tank was beginning to refill, and by 4 p.m. it would have been 50 percent full or more.
- Tank R16, in the R16 Pressure Zone, maintained some level of water throughout the Tubbs Fire. Initially, the tank maintained water within the bottom 30 percent of its total volume, but by the morning of October 10 the tank had returned to normal operating levels after enough openly flowing service lines in the upper zone had been closed.
- Tank R5, in the R5 Pressure Zone, emptied completely around 3 a.m. The tank went from a quarter full to empty within one hour. This tank is normally maintained at a low level because of

seismic concerns. However, the rapid drain rate indicates that if it had been full at the start of the fire, it would have been empty by 6 a.m. This facility was not returned to service as quickly as the other zones since there were no longer homes threatened by the fire. Additionally, the ability to maintain water quality after recharging the system was a serious concern for the four remaining connections that would possibly need water service.

- Water was maintained in Tank R4A throughout the Tubbs Fire. However, normal levels could not be maintained, and from the afternoon of October 9 through the morning of October 10 the tank was operating within the bottom 25 percent of its volume. After around noon on October 10, the tank recovered a majority of its total volume and stayed in its normal operating range.
- Tank R4B emptied for a brief period around 2 p.m. on October 9. The tank began to recover around 6 a.m. on October 10 and filled to 75 percent of its total volume in the afternoon.
- Tank R3 was not online during the time of the fire, but high-flow pumping had been added at Station S3 before the tank was taken out of service to provide for emergency conditions. The normal peak demand in the R3 Pressure Zone was around 500 gpm. To meet the City's fire flow goals for the water system, an additional 1,500 gpm of pumping capacity had been added to Station S3 on top of the existing 1,200 gpm capacity. The demand that openly flowing services put upon the system in the zone was more than twice the total available pumping capacity, even with the addition of the high-flow pump. As a result, Tank R3 would have drained within a few hours if it had been in use. It would have had a similar recovery time as the tanks in the R2 Pressure Zone (described below) as it would have begun to fill on the morning of October 11.
- Tank R2A and Tank R2B drained between 5 a.m. and 7 a.m. on October 9, with Tank 2A emptying a little earlier than Tank 2B. Attempts to fill the tanks began on October 9; however, the demand on the system from the freely flowing service lines prevented the tank from filling. During the morning of October 11, after many of the open appurtenances had been located and were beginning to be closed, both tanks began to gain water. By the early morning of October 12, they were operating in their normal operating range.
- Tanks R1A and R1B likely emptied briefly sometime after 10 a.m. on October 9. The exact timing and status of these tanks is uncertain because the SCADA data froze before they were empty, and the levels do not track well with the pressures recorded, as is the case with tanks in other pressure zones. However, the data indicates that if they emptied, they recovered water within a few hours and probably maintained some water level from the evening of October 9 onward. Two facilities with large fire service lines, a 10-inch and a 4-inch fire line, suffered major damage and were among those that had openly flowing service lines.

8.0 Study Recommendations and Conclusions

8.1 DISTRIBUTION SYSTEM IMPROVEMENT PLANNING

A review of the evaluations performed under the previous task shows that the distribution system in the Fountaingrove area was designed to provide a degree of reliability in the case of an emergency and for a single- or few-structure fire. However, the timing, intensity, rapid spread, and magnitude of the Tubbs Fire created atypical conditions and overwhelmed the system. Further complicating the system response, in the first few hours of the fire, system operations were handicapped because of the loss of the SCADA system and the inability to "see" what was happening in real time.

As Santa Rosa redevelops the Fountaingrove area, the following are possible improvements to the distribution system or items for additional study. The practicality of the improvements, including their time, expense and benefits, should be used to inform the City's considerations.

- Investigate ways to increase pumping reliability in the upper pressure zones in the case of an outage or major line break
- Examine installing additional interconnections and pressure-regulating valves to improve pressure between zones and system reliability
- Study technology, equipment, and software that can be incorporated with Advanced Metering Infrastructure (AMI), such as high flow detectors, and automatic shut-off valves, that offer the ability to prevent openly flowing appurtenances, with a focus on large customers or lines for fire suppression systems
- Perform an evaluation similar to this study for the Coffey Park area of the system which is not exclusively controlled by City pumping and storage facilities
- Study the feasibility, cost, and impact of providing off-line storage to mitigate the damage of widespread fire events such as the Tubbs fire
- Review modeling and/or conduct additional modeling to analyze the feasibility of replacing small diameter dead-end pipes with larger diameter pipes, or provide looping in such areas, to bolster fire flow availability
- Study the potential for SCADA system reliability and redundancy improvements in the case of an emergency event
- Migrate from natural gas to diesel generators to increase generator reliability during fire or other emergency events
- Update relevant sections of the City's Water Master Plan, incorporating lessons learned, and follow recommendations identified
- Include resiliency planning tasks in future master planning efforts and associated projects

8.2 FIRE FLOW AVAILABILITY MODIFICATIONS

While currently requiring a minimum fire flow of 1,500 gpm, in its 2014 Water Master Plan, the City reviewed the possibility for higher fire flow requirements. As it rebuilds the Fountaingrove area, Santa Rosa should consider differentiating, and perhaps increasing, fire flow goals based on land-use, zoning or structure-type, as well as Fire Codes. As part of its considerations, the City will need to weigh the cost-effectiveness and potential water quality impacts of any modifications.

8.3 EMERGENCY RESPONSE CONSIDERATIONS

It is recommended that the City finalize efforts to formalize and document the communication structure between the Water Department and Fire Department during red flag conditions to adequately prepare for large spread fire events. Additionally, the Water Department, in coordination with the Fire Department, should investigate developing defined procedures that identify:

- Available flows and pressures in various areas of the City
- Emergency operating plans for critical facilities
- Communication protocols
- A mobilization plan during fire events to turn off openly flowing appurtenances to minimize water loss and stabilize the water system