San Francisco
Water Power Sewer
Services of the San Francisco Public Utilities Commission

January 17, 2018

Honorable Board of Supervisors
San Francisco City Hall
1 Dr. Carlton B Goodlett Place, Room #244
San Francisco, CA 94102

Dear Honorable Supervisors,

Following the March 15, 2017 Government and Audit Oversight Committee hearing on the status of the City's emergency water supply system, the San Francisco Public Utilities, working collaboratively with the San Francisco Fire Department, began working on a report analyzing options for fire suppression for the Richmond and Sunset Districts. The SFPUC employed AECOM as the lead consultant for the report. Professor Charles Scawthorn was enlisted to be an independent, third party, expert reviewer of the report.

The completed report, attached to this letter, analyzed twelve options for fire suppression. Options 1-7 analyzed the extension of the existing AWSS to the Richmond District. Options 8-12 analyzed the installation of a Potable AWSS system serving the Sunset and Richmond Districts. The options were hydraulically modeled for performance after a 7.8 earthquake. This modeling allows us to determine how each of the options will perform in the various Fire Response Areas in the Richmond and Sunset Districts after the earthquake. Professor Scawthorn's memo, also attached, confirms that, "the report and underlying analyses are reasonable and a valuable source of information by which to select one or a few options" for further, more detailed analysis.

The shared goal of our two agencies is to increase the firefighting capabilities of all areas of San Francisco, and we will continue to look for the best technologies and methodologies for doing so. Following our review of the report and Professor Scawthorn's memo, the preferred option of SFPUC and SFFD Senior Management is Option 12, a large Potable AWSS loop serving the Sunset and Richmond Districts. The SFPUC and SFFD propose to move forward with more detailed analysis and design for Option 12 to ensure that it is designed to meet the pressure and performance requirements of SFFD. Additionally, SFPUC and SFFD propose for Option 12 to be designed in a manner that allows for agility and the flexibility to add new technologies and water sources to the system in the future. Furthermore, the system shall be designed in a manner that allows the piping network to be extended in the future to serve additional areas.

We look forward to presenting our analysis and preferred option at the Government and Audit Oversight Committee meeting on February 7, and are happy to meet in advance, or after, the Committee meeting to further discuss.

Sincerely,

Harlan L. Kelly, Jr.	Joanne Hayes-White
General Manager	Chief of Department
San Francisco Public Utilities Commission	San Francisco Fire Department

AECOM

Westside Emergency Firefighting Water System Options Analysis

Prepared for the San Francisco Public Utilities Commission

January 5, 2018

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Abbreviations

AHP	Analytical Hierarchy Process
AWSS	Auxiliary Water Supply System
EFWS	Emergency Firefighting Water System
ERDIP	Earthquake Resistant Ductile Iron Pipe
ESER	Earthquake Safety and Emergency Response
FRA	Fire Response Area
GPM	Gallons per Minute
HPS	High Pressure System
LOS	Level of Service
NSF	National Sanitation Foundation
PWSS	Portable Water Supply System
PAWSS	Potable Auxiliary Water Supply System
SFFD	San Francisco Fire Department
SFPUC	San Francisco Public Utilities Commission

Executive Summary

San Francisco Public Utilities Commission (SFPUC) is actively improving and expanding its existing infrastructure for the Emergency Firefighting Water System (EFWS). The Auxiliary Water Supply System (AWSS) provides high pressure water supply for firefighting via independent supply and delivery networks to protect people and property from potential risk of fire following a major earthquake, but does not serve the entire city. CS-199 Planning Support Services for AWSS (CS-199 Study) and CS-229 EFWS Spending Plan (Spending Plan), and subsequent revisions identified and evaluated a set of future projects that enhance and expand the city-wide fire protection water supply reliability.

The Level of Service (LOS) objectives set in the CS-199 study are as follows:

> “AWSS will reliably provide water to supply the “probable fire demands” after a magnitude 7.8 San Andreas earthquake. Each FRA will have a minimum of 50% reliable water supply to meet probable fire demands. The Citywide average will be a minimum of 90% reliable water supply to meet probable fire demands.”

The system as it existed in 2010 had a citywide reliability score of 47%. The recommended ESER 2010 projects will increase the citywide reliability score to 68%. The recommended 2014 projects will increase the citywide reliability score to 86%. The recommended potential future projects would extend the emergency firefighting water system to all areas of the City and improve the citywide reliability score to 94%. This study addresses the Richmond District portion of those projects. Note that some included options also benefit the Sunset District, but the focus of this evaluation is on the Richmond District.

The Richmond District EFWS is currently supplied by a combination of SFPUC’s potable water system, some additional gravity water supply and cisterns and, to a limited extent (in the Inner Richmond), the AWSS. In aggregate these supplies do not meet the LOS goals for EFWS needs following a major earthquake. In order to increase the EFWS supply to the Outer Richmond District, this study compared two major alternatives: (1) extending the existing AWSS further into the Richmond District, and (2) “Potable AWSS” pipelines from the Sunset Reservoir (a potable supply) to the western part of the Richmond District. The Potable AWSS would serve on a daily basis as a potable transmission main (increasing potable water supply and quality to the Richmond) and in the event of an earthquake would automatically be isolated from the remainder of the potable distribution system and converted to a dedicated high pressure EFWS, similar to the AWSS. The Potable AWSS would be built to meet or exceed the current AWSS standards as well as meet the applicable potable water quality standards, would use Sunset Reservoir as its source and would provide EFWS to part of the Sunset as well as the Richmond District. It should be noted that these Alternatives are only one of several dozen projects being undertaken with Earthquake Safety and Emergency Response (ESER) 2010 and 2014 funds.

Between the two major alternatives, twelve options were considered, using reliability score, cost and other criteria (see **Table ES-1**). Four AWSS options and five Potable AWSS options meet the reliability criteria LOS goals set in the CS-199 study and any of them would improve the EFWS to the Richmond District. Of these nine options:

1. Four AWSS options serve the Richmond District.
2. Five Potable AWSS options serve the Richmond and Sunset Districts.
3. Pipe length, location and cost within the Districts vary according to the option.
4. The AWSS options have redundant water supply sources and looped pipeline networks, which afford increased reliability.
5. The AWSS options do not include AWSS for the remaining area of the Sunset District. A gravity-fed option for the Sunset District has been proposed, but is not evaluated in this study.
6. The Potable AWSS options have a single water supply source, Sunset Reservoir, and some pipeline options do not have looped networks. To achieve comparable reliability for source water redundancy, additional analysis and design are needed to evaluate options for emergency connection to AWSS or other supplies.

7. In addition to the EFWS benefits, the Potable AWSS provides daily reliability and water quality benefits as well as a post-earthquake potable water supply to the Richmond and Sunset Districts.

8. The Potable AWSS options are expected to be funded in part from water rate funds, reducing the amount of ESER bond funds needed, resulting in earlier project implementation.

Criteria for the evaluation of the options are presented in **Table ES-1** and include the need for a pump station, the total amount of installed pipe (an indicator of construction impact), LOS goals attainment, and single versus redundant water supply sources, potable water delivery, and estimated total cost. Costs were estimated using planning level data and are not based on detailed engineering design, so that their accuracy is correspondingly limited (and comparable to the differences between some options). The Potable AWSS options would replace a project that SFPUC is planning that would supply potable water to the Richmond District and is estimated to cost between $20 and $30 million.

In summary, several AWSS and Potable AWSS options provide a viable EFWS for the Richmond District and, in some cases, the Sunset District. The study identifies further analyses beyond the current planning level that would better inform the choice of the specific option. Integral to the selection of an implementation plan are non-technical factors such as meeting the citywide LOS goals, meeting LOS in the Sunset District as well as other districts, Fire Department operations, phasing, financing and future development.

Table ES-1 Options Evaluated

<table>
<tr><th>Option</th><th>Project Components</th><th>Number of AWSS Connections</th><th>Additional Pump Station</th><th>Pipe Length (LF)</th><th>Meets LOS Goals[1]</th><th>Redundant Supply[2]</th><th>Redundant Network[3]</th><th>Potable System Benefit and Funding[4]</th><th>Benefits to Sunset as well as Richmond District</th><th>Project Cost ($million)[5]</th><th>Comments</th></tr>
<tr><td>Base</td><td>AWSS Extension</td><td>2</td><td rowspan="6">No</td><td>22,800</td><td rowspan="4">No</td><td rowspan="8">Yes</td><td rowspan="8">Yes</td><td rowspan="8">No</td><td rowspan="8">No</td><td>$41</td><td></td></tr>
<tr><td>1</td><td>AWSS Loop with park crossover</td><td>3</td><td>28,000</td><td>$51</td><td></td></tr>
<tr><td>2</td><td>AWSS Loop with park crossover and additional pipe in Laurel Heights</td><td>10</td><td>43,500</td><td>$84</td><td></td></tr>
<tr><td>3</td><td>AWSS loop with park crossover and additional pipe on Geary</td><td>5</td><td>37,100</td><td>$68</td><td></td></tr>
<tr><td>4</td><td>AWSS loop with additional pipe in Laurel Heights (no crossover)</td><td>10</td><td>36,000</td><td rowspan="9">Yes</td><td>$75</td><td rowspan="2"></td></tr>
<tr><td>5</td><td>AWSS loop additional pipe on Geary (no crossover)</td><td>5</td><td>32,000</td><td>$60</td></tr>
<tr><td>6</td><td>AWSS loop with Lake Merced Pump Station</td><td>4</td><td>Yes (Lake Merced, 250 psi)</td><td>28,000</td><td>$87</td><td>Cost includes Ingleside Pipeline but developer funded pipelines also required</td></tr>
<tr><td>7</td><td>AWSS loop with Sunset Pump Station</td><td>4</td><td rowspan="6">Yes (Sunset Reservoir, 150 psi)</td><td>31,500</td><td>$67</td><td>Requires air gap facility</td></tr>
<tr><td>8</td><td>Potable AWSS with Pump Station</td><td>0</td><td>22,200</td><td rowspan="5">No</td><td rowspan="3">No</td><td rowspan="5">Yes</td><td rowspan="5">Yes</td><td>$58</td><td rowspan="5">Provides additional potable water distribution main to Richmond District</td></tr>
<tr><td>9</td><td>Potable AWSS with Pump Station and Richmond Loop</td><td>0</td><td>37,500</td><td>$85</td></tr>
<tr><td>10</td><td>Potable AWSS with Pump Station and extension to Lincoln Park</td><td>0</td><td>23,600</td><td>$61</td></tr>
<tr><td>11</td><td>Potable AWSS with Pump Station and One Loop</td><td>0</td><td>37,900</td><td rowspan="2">Yes</td><td>$85</td></tr>
<tr><td>12</td><td>Potable AWSS with Pump Station and Two Loops</td><td>0</td><td>51,500</td><td>$109</td></tr>
</table>

1. LOS Goal: Each FRA will have a minimum of 50% reliable water supply to meet probable fire demands.
2. The AWSS was constructed with multiple supplies (Twin Peaks, Pump Stations 1 and 2 as well as fireboat manifolds) while the Potable AWSS has one supply although future supplies are possible, particularly with Option 12. Design elements could increase the reliability of the supply through redundant pump units and inlet and outlet piping.
3. A looped or gridded supply provides redundancy in the pipe system. Option 11 provides a looped supply to the Richmond District and Option 12 provides a looped supply to both Richmond and Sunset Districts.
4. Options 8 through 12 provide daily benefit to the potable water supply system, could be funded in part by water rate funds and replace a planned new transmission main (estimated to cost $20 -$30 million)
5. Costs based on CS-199 and subsequent studies.

1. Introduction

In recognition of San Francisco's risk of earthquake and subsequent fire conflagration potential, the City has developed an Emergency Firefighting Water System (EFWS). The San Francisco Public Utilities Commission (SFPUC) is actively improving and expanding the existing infrastructure for the EFWS. The Auxiliary Water Supply System (AWSS) provides high pressure water supply for firefighting via independent supply and delivery networks to protect people and property from potential risk of fire following a major earthquake, but does not serve the entire city. CS-199 Planning Support Services for AWSS (CS-199 Study) and CS-229 EFWS Spending Plan (Spending Plan), and subsequent revisions identified and evaluated a set of projects that improve and expand the city-wide fire protection water supply and enhance its reliability. This study addresses the Richmond District portion of those projects.

The existing AWSS does not extend to the western part of the Richmond District. The furthest west existing pipeline is located east of Park Presidio Boulevard, resulting in no high pressure water supply system for fire protection west of this pipeline. The western areas do have cisterns, low pressure potable water supply and a gravity water system fed by Stow Lake on Fulton Street. In aggregate these supplies do not meet the Level of Service (LOS) goals determined for EFWS following a major earthquake.

In order to increase the EFWS supply to the Richmond, this study compared two major alternatives: (1) extending the existing AWSS further west into the Richmond District, and (2) "Potable AWSS" pipelines from the Sunset Reservoir (a potable supply) to the western part of the Richmond District. The Potable AWSS would serve potable water daily to the distribution system, increasing drinking water reliability and quality to the Richmond; following an earthquake, the Potable AWSS would be automatically isolated from the remainder of the potable distribution system and converted to a dedicated high pressure EFWS, similar to the AWSS.

The Potable AWSS would be built to meet or exceed the current AWSS standards as well as meet the applicable potable water quality standards, would use the North Basin of Sunset Reservoir as its source and would provide EFWS to part of the Sunset as well as the Richmond District. When the Potable AWSS is isolated for fire-fighting, even in non-earthquake scenarios, the potable water system will have adequate supply from the Sunset Reservoir, and adequate distribution system redundancy, to meet customer water demand continuously. Following an earthquake, when much of the potable distribution system is anticipated to fail, the Potable AWSS will provide reliable drinking water to the Richmond and Sunset districts after the fires are suppressed.

It should be noted that these Alternatives are only one of several dozen projects being undertaken with Earthquake Safety and Emergency Response (ESER) 2010 and 2014 funds.

1.1 Background

The AWSS is a stand-alone fire protection water supply and distribution system that was constructed following the 1906 earthquake. Construction of the original AWSS was completed in 1913 at a cost of $5.2 million. The AWSS has two above ground storage tanks, a reservoir and two saltwater pump stations for supply. The system is designed to provide water at higher pressures than the potable water system, allowing firefighters to use water from the AWSS hydrants without requiring a fire engine.

SFPUC is responsible for the operations and maintenance of the EFWS. The ESER Bonds approved by the voters in 2010 and 2014 provided SFPUC with funds to plan, design and construct projects to enhance the reliability of the EFWS in San Francisco.

The 2010 and 2014 ESER Bonds included funds for EFWS projects, including the CS-199 AWSS Planning Study. During the CS-199 Planning Support Services for EFWS study, 48 Fire Response Areas (FRAs) were delineated throughout San Francisco, and fire demands were developed in each FRA, to test the ability of the EFWS to reliably provide water supply to fight fires following a magnitude 7.8 earthquake. In such an emergency it is likely that the potable water distribution system would be compromised by pipe breaks and leaks.

The CS-199 Study developed an evaluation strategy and long term capital improvement recommendations for retrofit, improvement and expansion of the AWSS. Probability-based models were used to calculate the estimated performance of the AWSS. Reliability was defined, for the study, as the percentage of the estimated firefighting water demand met following a 7.8 magnitude earthquake on the San Andreas Fault.

The system as it existed in 2010 had a citywide reliability score of 47%. The recommended ESER 2010 projects will increase the citywide reliability score to 68%. The recommended potential future projects would extend the EFWS to all areas of the City and improve the citywide reliability score to 94%. The Level of Service (LOS) objectives set in the CS-199 study are as follows:

> AWSS will reliably provide water to supply the “probable fire demands” after a magnitude 7.8 San Andreas earthquake. Each FRA will have a minimum of 50% reliable water supply to meet probable fire demands. The Citywide average will be a minimum of 90% reliable water supply to meet probable fire demands.

1.2 Report Organization

This report is organized as follows:

- The two different water supply alternatives are described in Section 2
- The reliability score methodology and assumptions are described in Section 3
- The options developed for each alternative are described in Section 4
- The reliability score modeling results are described in Section 5
- The cost estimates developed for each option are described in Section 6
- The non-cost comparisons and conclusions are described in Section 7

2. Water Supply System Alternatives

This study looks at two methods to serve the western part of the Richmond District with EFWS, using an extension of the AWSS or using a Potable AWSS. This section describes the two water supply alternatives.

2.1 AWSS

The first method of supply extends the AWSS that is fed by Twin Peaks Reservoir, Ashbury and Jones Tanks with emergency supplies available from saltwater Pump Stations 1 and 2 and the three SFFD fireboats via water supply manifolds.

The AWSS pipeline standards have changed from the original heavy wall cast iron pipe with lead joints to take advantage of current earthquake resistant pipeline standards. SFPUC is in the process of formally adopting new standards that include material, design and testing requirements for the AWSS pipe, valves, hydrants and other system elements. Recent AWSS installations have used Earthquake Resistant Ductile Iron Pipe (ERDIP) that is described below (see **Figure 1** and **Figure 2**). This pipe as manufactured by Kubota has been deployed in Japan since 1974 and has had no documented failures in subsequent seismic events including the 1995 Kobe and the 2011 Great East Japan earthquakes.

Figure 1 Earthquake Resistant Ductile Iron Pipe (Source: Kubota Pipe)

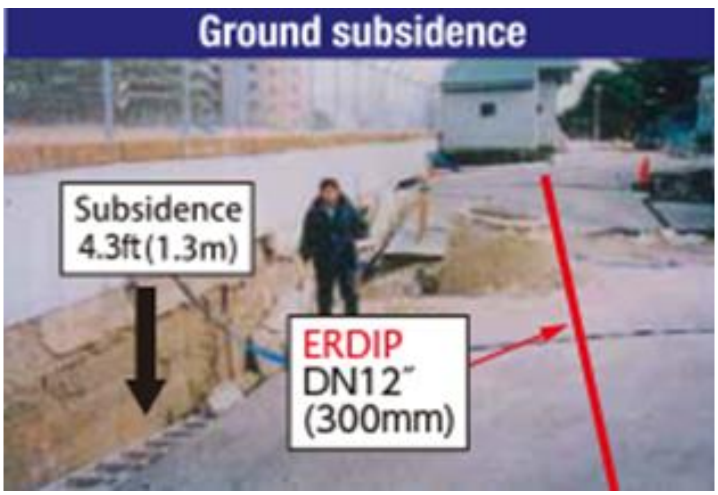


Figure 2 Earthquake Resistant Ductile Iron Pipe (Source: Kubota Pipe)

There are three AWSS pressure zones (Jones, Ashbury and Twin Peaks) that are defined by the tank/reservoir feeding the zone. The existing AWSS in the Richmond District operates normally on the Ashbury Tank pressure zone, providing a static pressure of 121 psi. The pressure can be increased by bypassing the Ashbury Tank and providing Twin Peaks Reservoir pressure of 236 psi static.

The AWSS has seismically actuated valves (see Figure 3) used to isolate areas that are likely to experience pipe breaks due to ground deformation or motions in an earthquake. These have been installed to control the supply to those areas defined as “infirm” based on historical experience and geotechnical data.

Figure 3 Seismic Actuated Valve and Battery System (Source: SFPUC)

2.2 Potable AWSS

The second water supply alternative explored is the Potable AWSS. The Potable AWSS approach utilizes a dual purpose pipeline that is independent from the existing AWSS network, which would be used as potable water transmission main in normal operations and would provide fire water supply for greater alarm fires in seismic and non-seismic conditions.

The existing potable supply to the Richmond District depends on two transmission mains that extend north from the Sunset District. One of those mains was constructed of steel in 1915. The other has been recently replaced with a ductile iron main. The Potable AWSS pipeline would provide a third main, built to modern earthquake resistant standards, to supply potable water to the Richmond District. Potable AWSS will use the same materials as the AWSS pipeline components (ERDIP) and NSF61 (NSF/ASNI 61 is a standard for products that come into contact with drinking water) Potable AWSS hydrants.

The water supply source for the second alternative is the Sunset Reservoir, with a total volume of 176.7 million gallons. The Sunset Reservoir is supplied by the regional supply mains that were seismically upgraded as part of the Water System Improvement Program (WSIP). The North Basin of the Sunset Reservoir (89.4 million gallons) was also seismically upgraded as part of WSIP. The LOS goal for the seismic upgrades of the regional water supply system is to resume supply of drinking water within 24 hours following an earthquake; thus with the combination of storage volume and restored supply it is anticipated that Sunset Reservoir will have a continuous supply of water.

The connections to the potable system would be limited in number (see schematic in **Figure 4**) to allow easier isolation from the potable system distribution pipe grid following an earthquake to preclude pressure loss due to breaks and leaks. The pipeline will utilize seismically actuated control valves (per AWSS standards) on the limited connections to the potable system allowing it to be automatically isolated following an earthquake. It is estimated that the planned connections south of Golden Gate Park would be normally closed and those in the Richmond District would be normally open. The connections to the potable system will be located in coordination with the SFPUC Divisions that provide potable water supply to ensure that sufficient water turnover occurs. Since the potable distribution system is also fed by other transmission mains, the potable water supply would not be cut off if the Potable AWSS is isolated from the potable system.

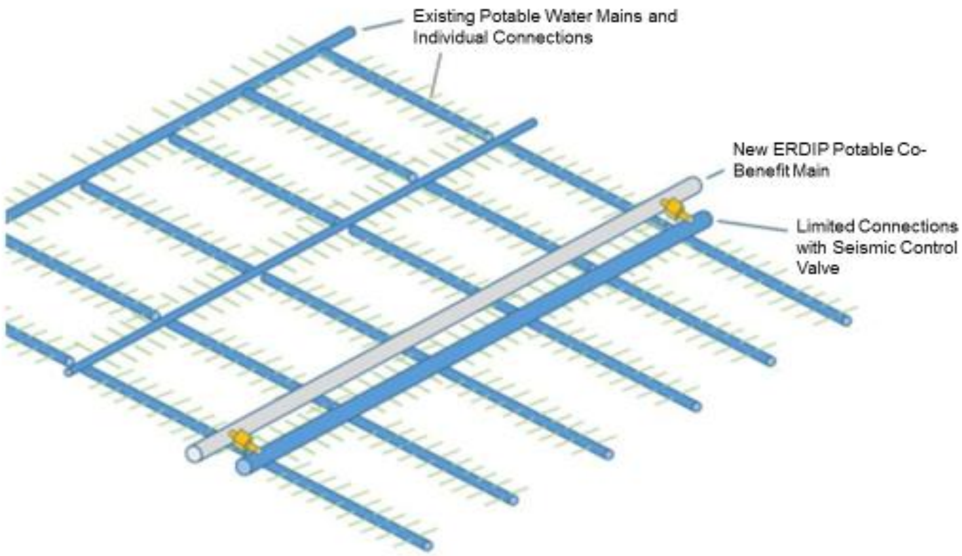


Figure 4 Potable AWSS Schematic (Source: Charles Scawthorn)

The isolated dual purpose pipeline would then be pressurized at a pressure similar to AWSS and as approved by SFFD. Project implementation will verify the system components needed to supply these pressures. Current planning efforts are evaluating the booster pump design criteria.

The booster pump station would include pumps that could be started remotely. With these operational changes, following an earthquake, the Potable AWSS pipeline will serve as a dedicated firefighting water supply with residual pressures equivalent to the AWSS. **Figure 5** shows a booster pump station schematic.

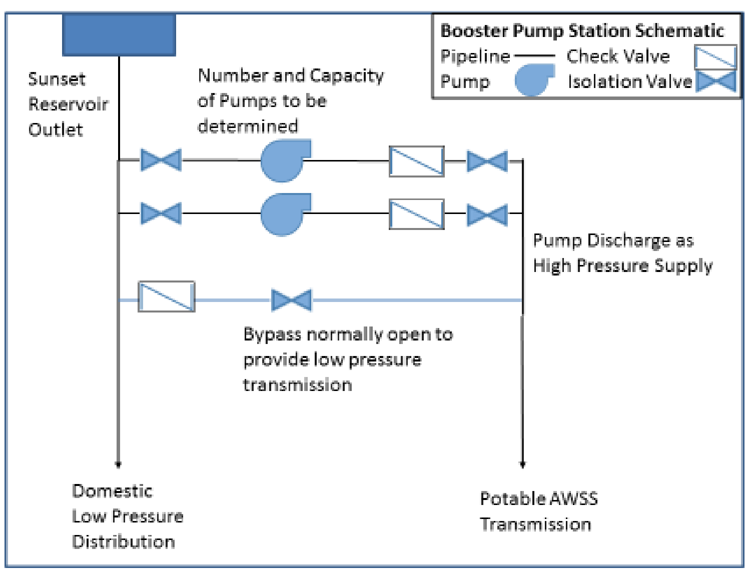


Figure 5 Booster Pump Station Schematic

Figure 6 shows a sequence "cartoon" of the planned operations for the Potable AWSS.

Following the firefighting, the Potable AWSS pipeline would become a water supply backbone for post-earthquake emergency potable water supply. The water supply volume of the North Basin of the Sunset Reservoir allows the projected fire demands for the Richmond and Sunset Districts (13,000 gpm) to be met for 57 hours with half of the water supply retained for domestic use (about 5 days of supply at normal consumption demand level). Note that the SFPUC Regional Water System is designed to provide continuous supply to refill Sunset Reservoir within 24 hours after an earthquake.

The Potable AWSS alternative provides daily reliability for the potable water system, and allows reliable water supply for post-earthquake fire protection and emergency drinking water. The seismically actuated valves would also be remotely controlled. There is an additional benefit of funding from water rates capital funds to support the potable water supply elements of the project.

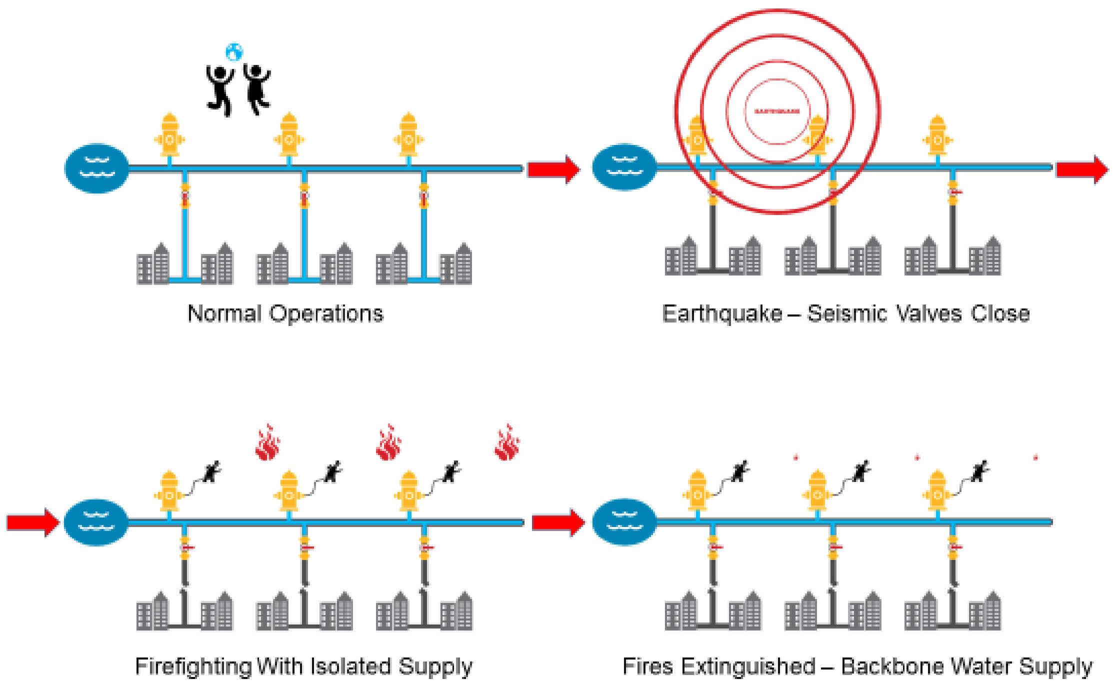


Figure 6 Potable AWSS Sequence (Source: SFPUC)

3. Performance Evaluation

The performance of these alternatives and the various options were evaluated with the same models used in the CS-199, Spending Plan and subsequent studies. The objective of this task was to evaluate the options for future EFWS supply in the Richmond district while minimizing impact to the existing AWSS.

3.1 Reliability Modeling Strategy

The seismic condition analysis uses the methodology developed from CS-199 and Spending Plan studies. The probabilistic approach assesses the hydraulic performance of EFWS after a major earthquake, accounting for pipe breakages and leaks due to ground motion and displacements. In order to more efficiently identify potential hydraulic deficiencies in the system, identify mitigating system improvements and analyze their benefits, the modeling is performed in two phases. The network is first analyzed in its undamaged state ("unbroken network") to identify preliminary deficiencies and optimize improvement project candidates.

Once a preliminary set of improvements have been developed, they are then analyzed in a seismic scenario in which the damaged networks from the CS-199 Study ("broken network") are utilized. These final runs on the broken network confirm whether the performance of proposed improvements meet the performance criteria of the system after the earthquake. Under the post-earthquake scenario, the system will experience earthquake damage. The LOS criteria must be achieved under the post-earthquake demands, while maintaining positive pressure (>0 psi) throughout the broken system.

3.2 Modeling Assumptions

3.2.1 Scenarios

The model includes the existing AWSS network with the addition of the projects identified from the current spending plan. These projects include those currently intended to be funded by ESER 2010 and 2014 and recommended projects that may be funded by future bonds as shown in **Table 1,** which summarizes the list of projects in the AWSS model for the "2014" and "Recommended" conditions. **Table 1** doesn't include the extensive list of projects already constructed using ESER 2010 funds. These projects were included in the modeling analysis.

The modeling was performed for both time frames to confirm the feasibility of each option for the near term and future conditions. Since the currently recommended project for the Sunset and Richmond Districts is the subject of this report it has been removed from the list shown below so that the projects are evaluated equally.

Table 1 Projects Included in the Models

Current EFWS Projects	ESER 2014 Bond Projects	Recommended Projects
19th Avenue Pipeline	X	
Clarendon Supply	X	
Pipeline – Diamond Street		X
Pipeline - Irving Street	X	
Pipeline – University Mound East	X	
Pipeline – University Mound West		X
Pump Station – University Mound Reservoir	X	
Pipeline – Ingleside Pipeline Phase 1	X	
Pipeline – Ingleside Pipeline Phase 2 and LMPS Modifications		X

3.2.2 Water Demands

The specific demands utilized for the Spending Plan were based on the median ground motions following a magnitude 7.8 earthquake on the San Andreas Fault. The reader should note that the use of the median ground motions was used for the CS-199 report. The use of median ground motions means that larger ground motions, therefore worse conditions and greater water demands, would be expected half of the time. While this was a reasonable assumption when made for CS-199, SFPUC and Department of Public Works staff have since developed a methodology to use higher or lower ground motions for system modeling. This new methodology was not used for this assessment but is being reviewed and adopted for use for future assessments.

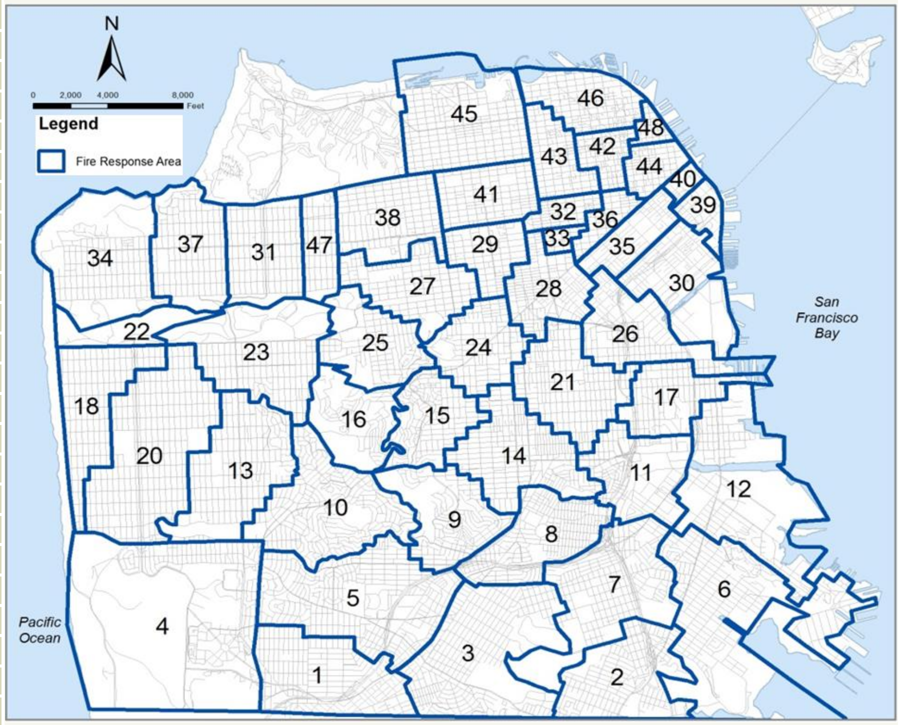
Figure 7 shows the new demand locations for the Richmond District (FRAs 34 and 37) as well as locations for key points used in evaluating the impact of new projects on the existing AWSS (FRAs 13 and 38). The FRA demands estimated in the CS-199 Study have been subsequently used as reference for any EFWS related studies, including the CS-229 EFWS Spending Plan. These key points are demand locations with higher elevations that demonstrate reduced water availability or pressure when the AWSS performance is stressed by high demands.

The following is a brief outline of the methodology utilized to estimate the FRA demands listed in **Table 2.**

- Determine the number of ignitions derived from a Monte Carlo analysis of possible number of ignitions given the median ground motions from a magnitude 7.8 San Andreas earthquake
- Determine the most probable locations of the set number of ignitions
- Estimate the representative fire demand and connection location for each FRA

Table 2 CS-199 FRA Demands (Averaged 60 Minute Aggregated Demands)

FRA ID	FRA Demand (gpm)	FRA ID	FRA Demand (gpm)
1	3122	25	1854
2	2230	26	521
3	3498	27	2348
4	1681	28	889
5	4994	29	924
6	1018	30	495
7	1907	31	3186
8	1999	32	1240
9	2675	33	195
10	4397	34	2271
11	645	35	463
12	449	36	830
13	3745	37	2944
14	3562	38	2695
15	1974	39	162
16	1107	40	144
17	859	41	2354
18	3125	42	1010
19	NA	43	1971
20	4720	44	491
21	2274	45	3937
22	NA	46	1553
23	2736	47	1469
24	2772	48	91



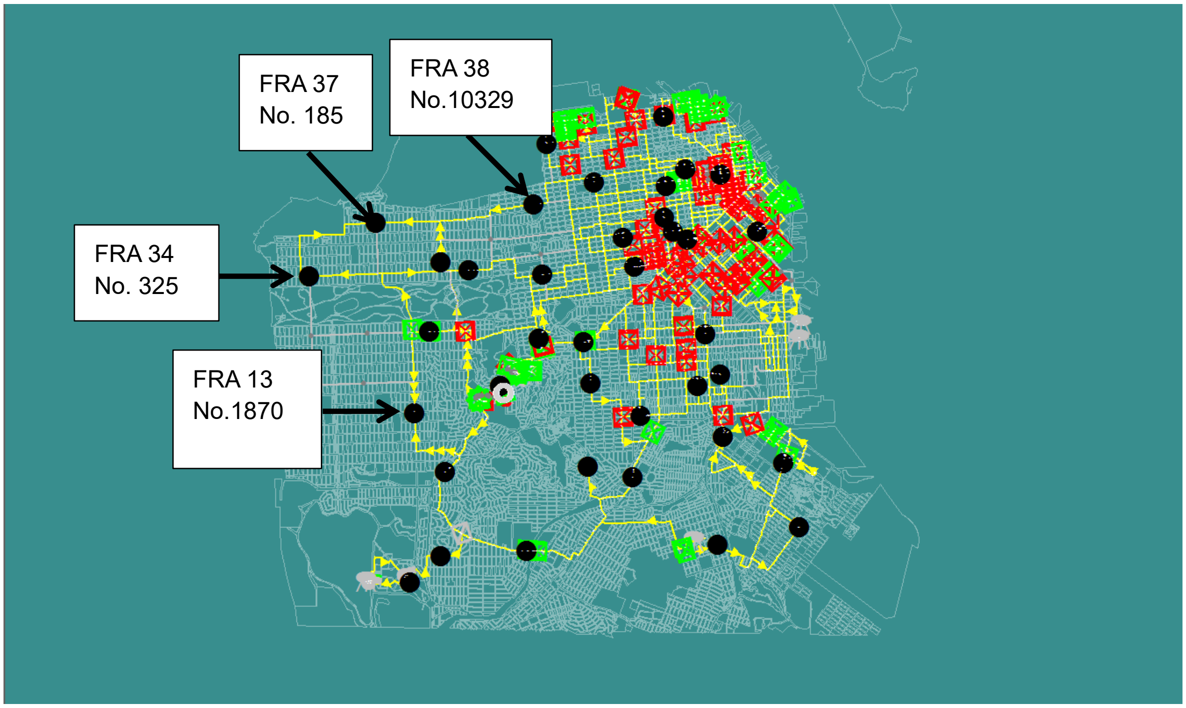


Figure 7 Demand Locations and Node IDs for FRA 13, FRA 34, FRA 37 and FRA 38

3.2.3 Operations and Boundary Conditions

Table 3 lists the operations and boundary conditions used for this analysis. All new pipes are assumed to be 20-inch diameter pipe meeting current AWSS standards.

Table 3 Operating Status of Existing and Planned Facilities for Seismic Condition

System Components	Status
Infirm Zone Valves	Closed
Ashbury and Lower Zone Tank Bypasses	Open
Division Gates at Market and Mission Street	Open
Pump Station 1 and 2	Operating

3.3 Performance Criteria

In the CS-199 and Spending Plan Studies, reliability score is defined as the percentage of the water demand met by the EFWS, including the High Pressure System (HPS) and other sources. This study uses the same methodology for evaluating the benefits of alternatives ability to provide water supply following an earthquake. This criterion, referred to in this study as reliability score, is defined for each FRA as the percentage of the water demand that is met by the seismically impacted EFWS. The LOS objectives, as described in Section 1, are to bring each FRA's reliability score above a threshold of 50% and to achieve a citywide reliability score of 90%.

The system before completion of the ESER 2010 projects was estimated to achieve a 47% citywide reliability score. Appendix A includes the maps showing reliablity scoring results for the various bonds and options. The recommended ESER 2010 and 2014 bond projects provided some water supply for the Richmond District (FRAs 34 and 37) and Sunset District (FRAs 18, 20) via new cisterns but did not include extension of the AWSS high pressure system to the Districts and therefore did not meet the LOS for those FRAs. Projects to extend EFWS to these areas were included in the recommended future projects.

The CS-199 Task 8 Technical Memorandum describes the modeling performed using hydraulic and reliability score modeling tools in detail.

The following EFWS components are included in the updated reliability scores calculation:

- AWSS
- Potable AWSS
- Cisterns (unchanged from CS-229)
- Suction Connections (unchanged from CS-229)
- Alternative Water Supplies, including Fulton Street emergency hydrants (unchanged from CS-229)

For each FRA, the reliability score is calculated as the sum of the available water sources contributions divided by the FRA demand. The citywide reliability score is calculated by averaging the FRA reliability scores. The method of calculation of the score is shown in Appendix B. The methodology used for option development is discussed in Appendix C. The hydraulic modelling results for each option are shown in Appendix D.

Other criteria used for evaluation of system modifications include the cost, benefits to other FRAs, benefits to the potable system and schedule.

4. Option Development

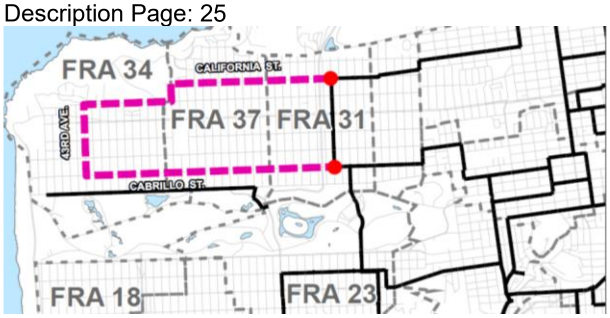
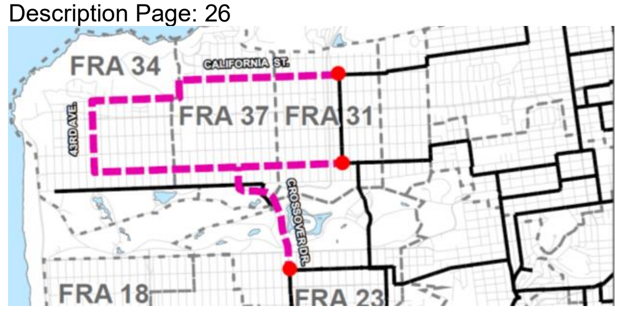
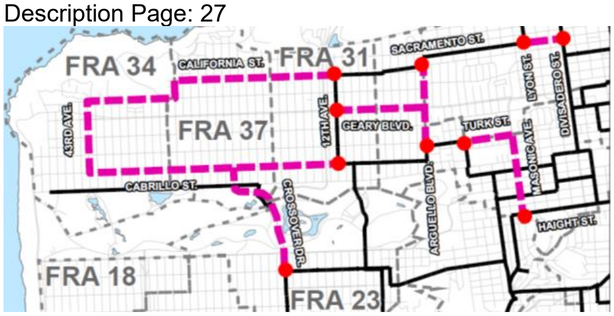
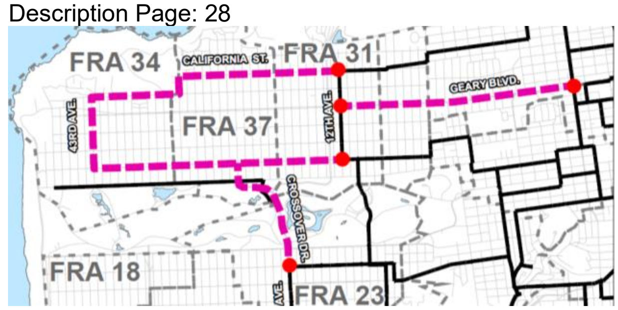
As described in Section 2, this study evaluates two alternatives to provide EFWS to the Richmond District. Potential AWSS pipe projects were developed in order to evaluate the extension of the AWSS to the Richmond District. Modeling results for the base option indicated that the addition of the Richmond District demands on the AWSS has negative impacts on the rest of the AWSS including FRAs 13 and 38 and the adjacent FRAs. The negative impacts (reduction in supply and pressure to other FRA demand locations) were addressed by adding new mains or supplies or a combination of both.

The general concepts developed and evaluated in this study include the options below:

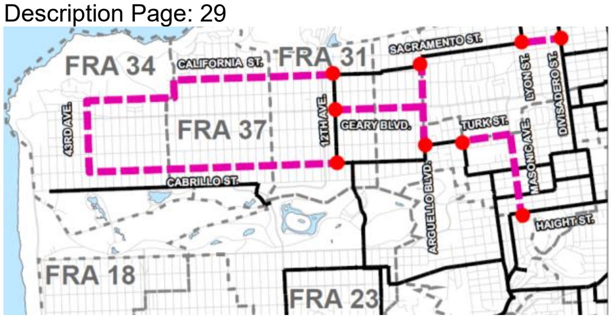
- Options 1 through 5 increase the hydraulic capacity in the Ashbury zone by adding AWSS connections through Golden Gate Park and Laurel Heights that provide additional capacity to deliver water from the Ashbury zone to the west.
- Options 6 and 7 bring additional water supply to the study area from Lake Merced and Sunset Reservoir, respectively.
- Options 8 through 12 utilize the Potable AWSS alternative to bring an additional potable water supply from the Sunset Reservoir via Potable AWSS pipelines to the Richmond District for EFWS.

The options evaluated are listed in **Table 4** and described in more detail in the next sections.

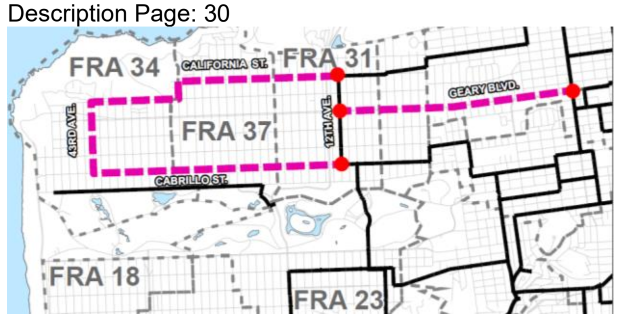
Table 4 Project Concept and Option Descriptions

Base Option. AWSS Extension AWSS connections: 2 Pipe Length: 22,900 LF Additional Pump Station: No Description Page: 25 	**Option 1. AWSS Extension** AWSS connections: 3 Pipe Length: 28,000 LF Additional Pump Station: No Description Page: 26 
Option 2. AWSS with crossover AWSS connections: 10 Pipe Length: 43,500 LF Additional Pump Station: No Description Page: 27 	**Option 3. AWSS with crossover** AWSS connections: 5 Pipe Length: 37,100 LF Additional Pump Station: No Description Page: 28 

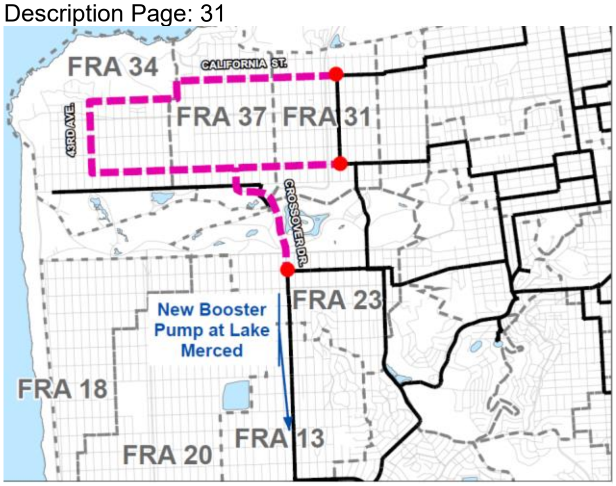
Option 4. AWSS without crossover
AWSS connections: 9
Pipe Length: 38,400 LF
Additional Pump Station: No
Description Page: 29



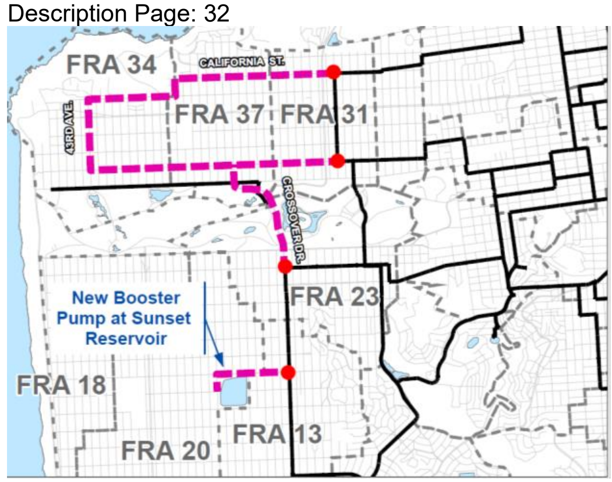
Option 5. AWSS without crossover
AWSS connections: 4
Pipe Length: 32,000 LF
Additional Pump Station: No
Description Page: 30



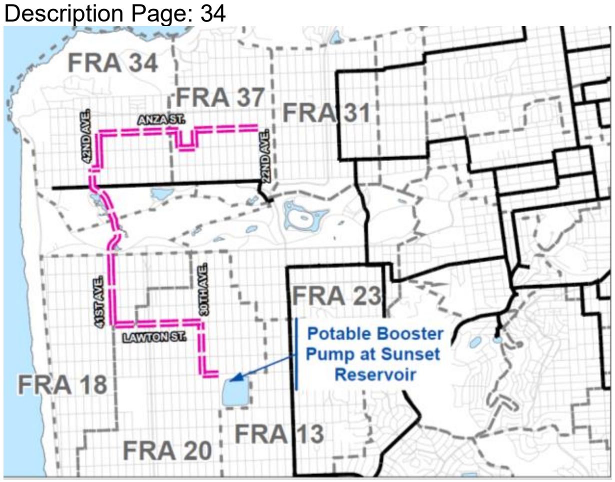
Option 6. AWSS with Additional Pump Station
AWSS connections: 4 (1 on Ocean Ave. not shown)
Pipe Length: 28,000 LF
Additional Pump Station: Lake Merced
Description Page: 31



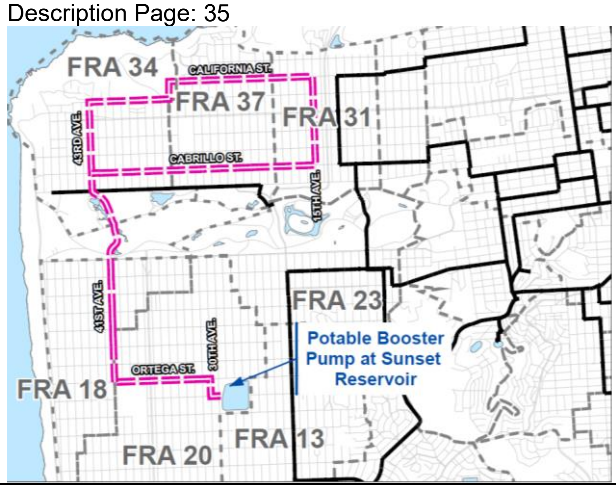
Option 7. AWSS with Additional Pump Station
AWSS connections: 4
Pipe Length: 31,500 LF
Additional Pump Station: Sunset Reservoir
Description Page: 32



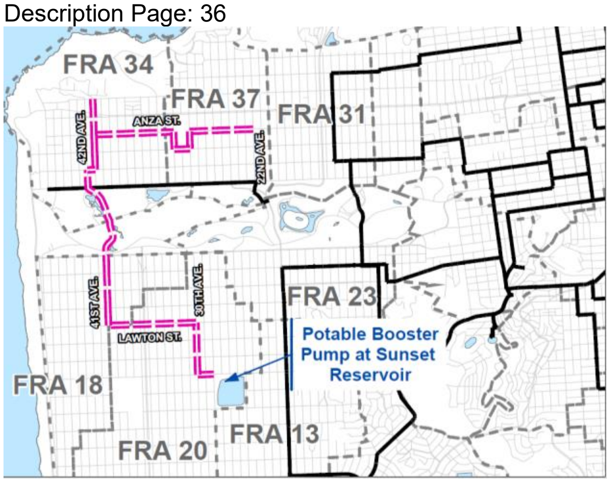
Option 8. Potable AWSS with Pump Station
Pipe Length: 22,200 LF
Additional Pump Station: Sunset Reservoir
Description Page: 34



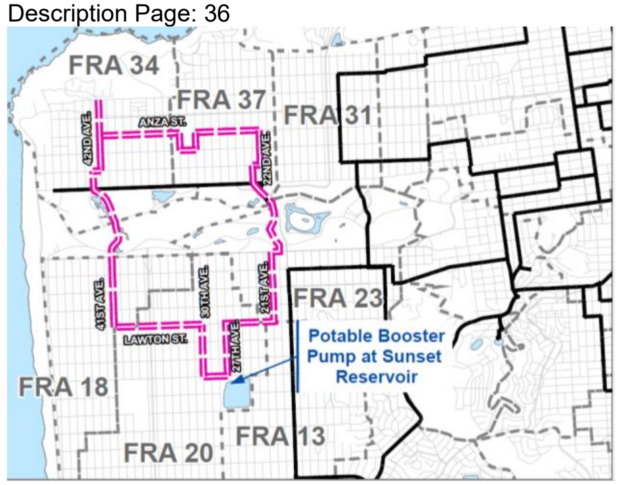
Option 9. Potable AWSS with Pump Station
Pipe Length: 37,500 LF
Additional Pump Station: Sunset Reservoir
Description Page: 35



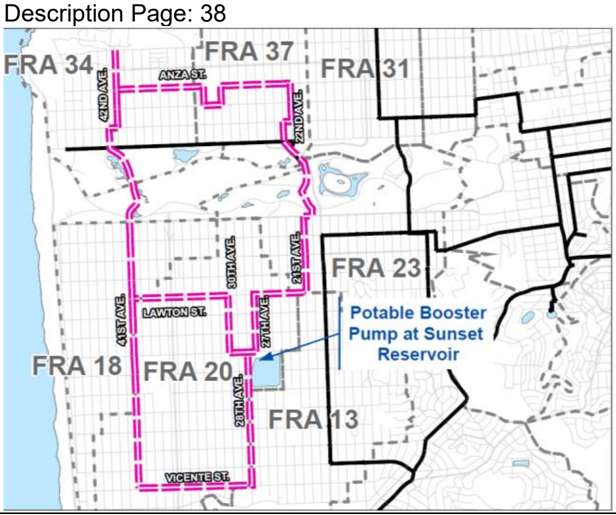
Option 10. Potable AWSS with Pump Station
Pipe Length: 23,600 LF
Additional Pump Station: Sunset Reservoir
Description Page: 36



Option 11. Potable AWSS with Pump Station
Pipe Length: 37,900 LF
Additional Pump Station: Sunset Reservoir
Description Page: 36



Option 12. Potable AWSS with Pump Station
Pipe Length: 51,500 LF
Additional Pump Station: Sunset Reservoir
Description Page: 38



4.1 Base Option – AWSS Loop with 2 Connections

The base option for AWSS extension to the Richmond District is shown in **Figure 8.**

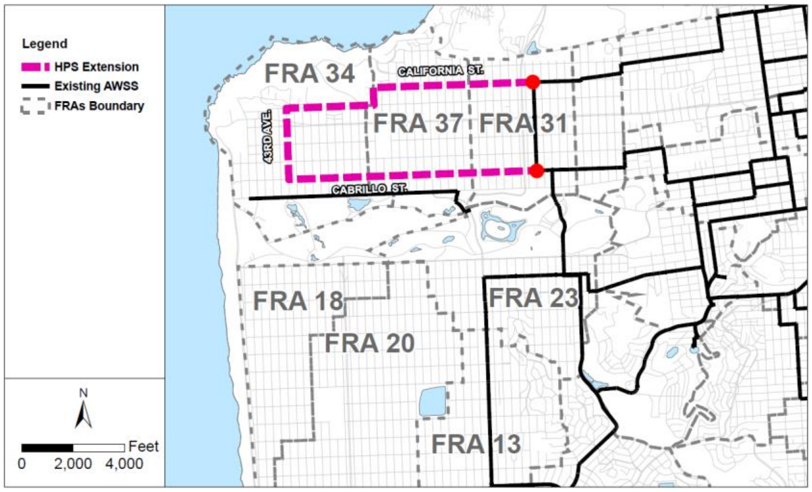


Figure 8 Richmond AWSS Loop Base Option Alignment

The reliability scores for the Base Option are shown in **Figure 9**. They show reduction in the reliability scores for FRAs 31 and 38 east of the new AWSS loop from post ESER 2014 conditions. The FRA 31 reliability score drops from 94% to 42% and FRA 38 score drops from 86% to 52%. The score for FRA 31 drops below the City's LOS objective of 50% per FRA.

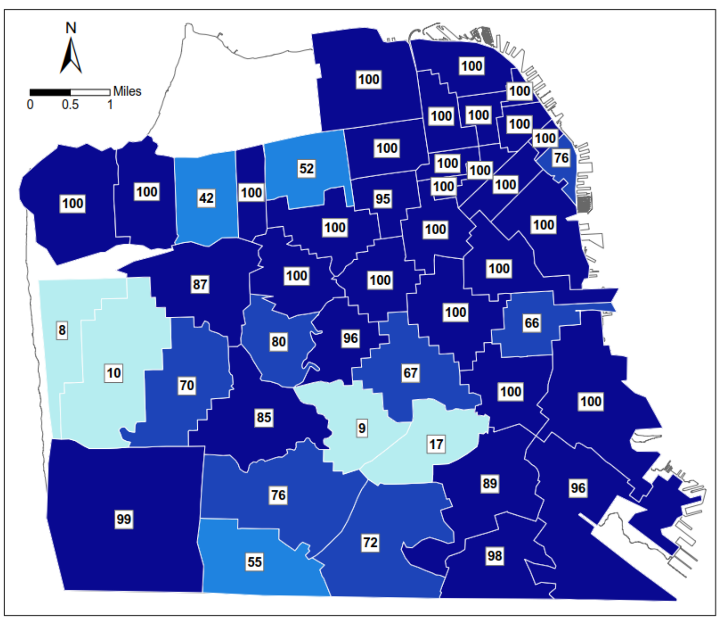


Figure 9 Reliability Scores for Base Option

4.2 Option 1 - AWSS Loop with Park Crossover and 3 Connections (28,500 LF Pipe)

Due to the low reliability achieved in the base option, a variety of potential system modifications were evaluated. **Figure 10** shows Option 1 that includes the addition of a connection from the south via a crossover from 19th Avenue in the Sunset District and the Twin Peaks zone.

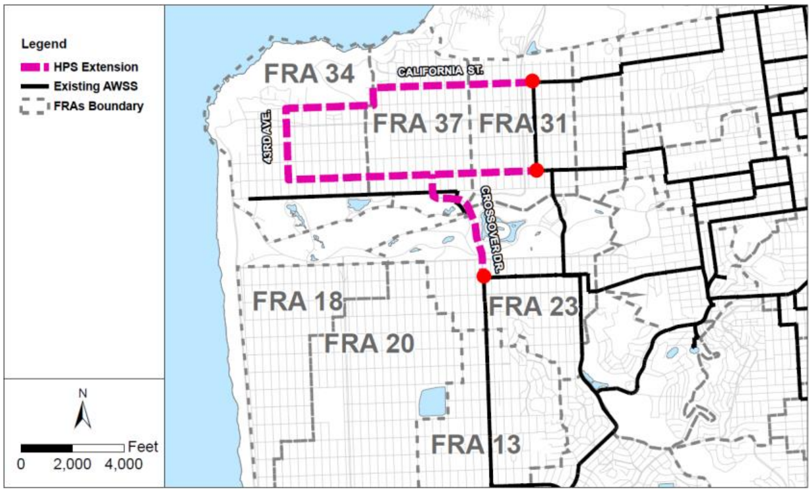


Figure 10 Option 1: AWSS Loop with Crossover and 3 Connections

The reliability scores for Option 1 shown in **Figure 11** show significant reduction in reliability scores for FRAs 1 and 13. The FRA 1 score is reduced from 55% to 26% and FRA 13 from 71% to 18%. Both FRAs scores are below the LOS objective of 50%.

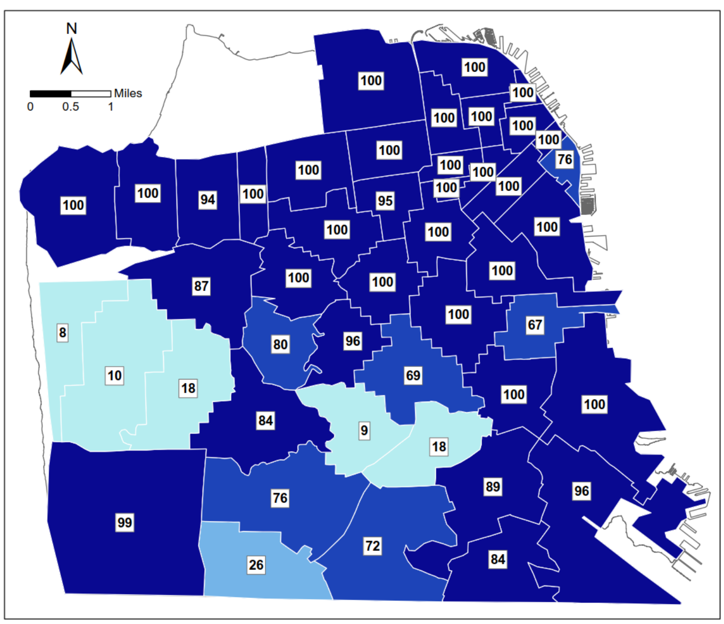


Figure 11 Reliability Scores for Option 1

4.3 Option 2 - AWSS Loop with Crossover, Additional Pipe in Laurel Heights and 10 Connections (43,500 LF Pipe)

Several different combinations of AWSS connections within Laurel Heights were tested while developing Option 2 to achieve the best possible performance in FRAs 13, 34, and 37 while limiting the new AWSS pipeline length along Geary Blvd, since it is a major thoroughfare for the area. Additional AWSS pipe is included around Laurel Heights **Figure 12** shows Option 2, each red circle indicates a connection point with the existing AWSS.

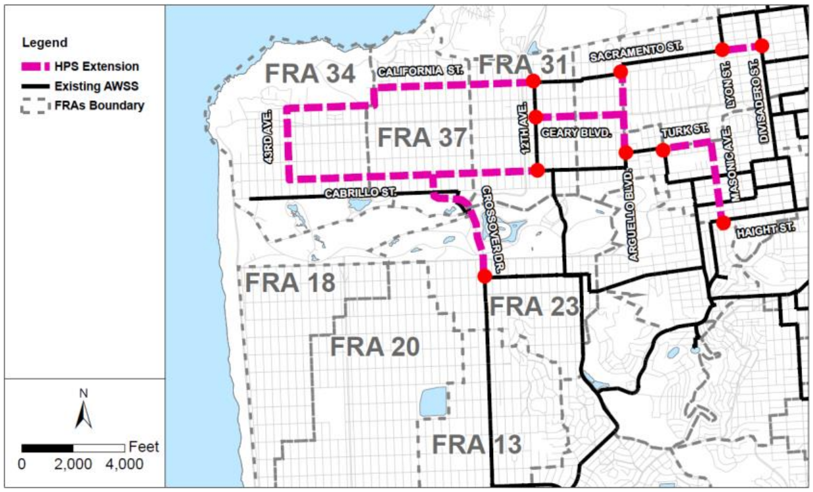


Figure 12. Option 2 - AWSS with 10 Connections

The reliability scores for Option 2 shown in **Figure 13** show reductions in reliability scores for FRAs 1 and 13. The FRA 1 score drops from 55% to 29% and FRA 13 drops from 71% to 25%. Both FRA's drop below the LOS objective of 50%.

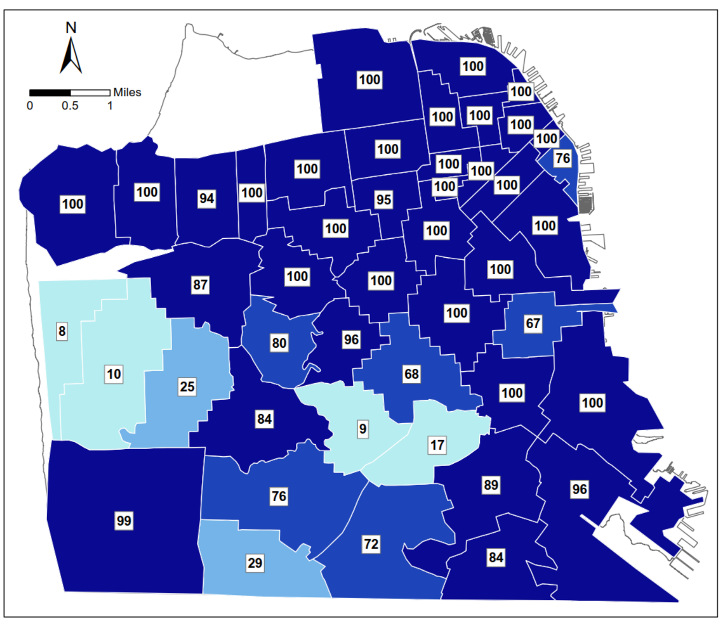


Figure 13 Reliability Scores for Option 2

4.4 Option 3 - AWSS Loop with Park Crossover, Additional Pipe on Geary and 5 Connections (37,100 LF Pipe)

Option 3 provides a similar expansion in hydraulic capacity through the Ashbury zone as Option 2, using a single connection through Geary Boulevard instead of multiple main connections. Though Geary Boulevard is a major street, the new connection improves the conveyance with a straight alignment and less new pipe length. **Figure 14** shows Option 3, each red circle indicates a connection point with the existing AWSS.

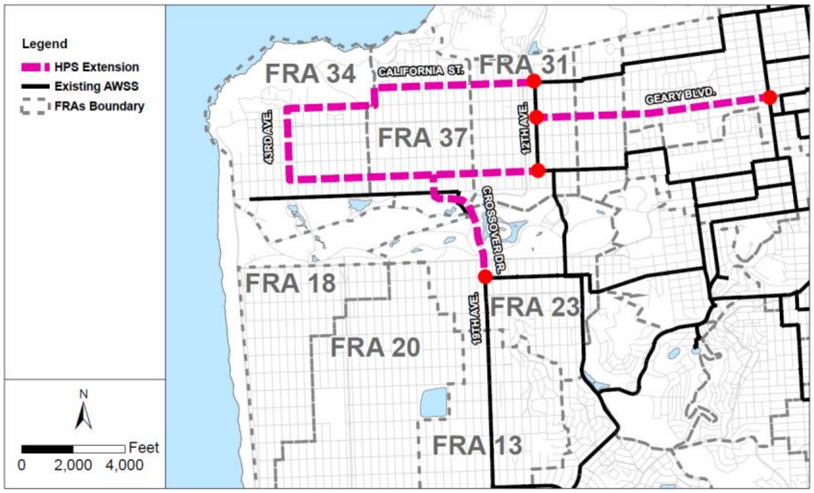


Figure 14 Option 3 - AWSS with 5 Connections with Crossover

The reliability scores for Option 3 shown in **Figure 15** show reductions for FRAs 1 and 13. The FRA 1 score is reduced from 55% to 28% and FRA 13 from 71% to 19%. Both are reduced below the LOS objective of 50%.

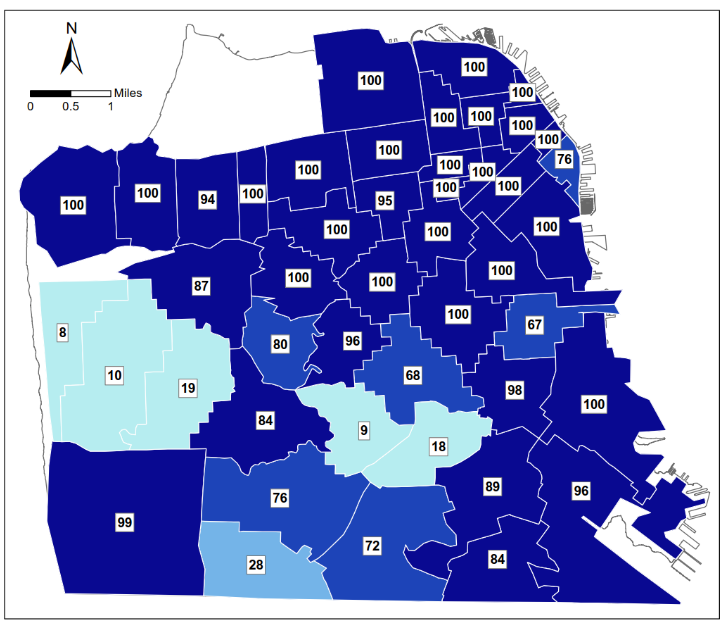


Figure 15 Reliability Scores for Option 3

4.5 Option 4 - AWSS Loop with Additional Pipe in Laurel Heights and 9 Connections (36,000 LF Pipe)

Option 4 includes the same layout as Option 2 with the removal of the crossover feed from the south. **Figure 16** shows the layout, each red circle indicates a connection point with the existing AWSS.

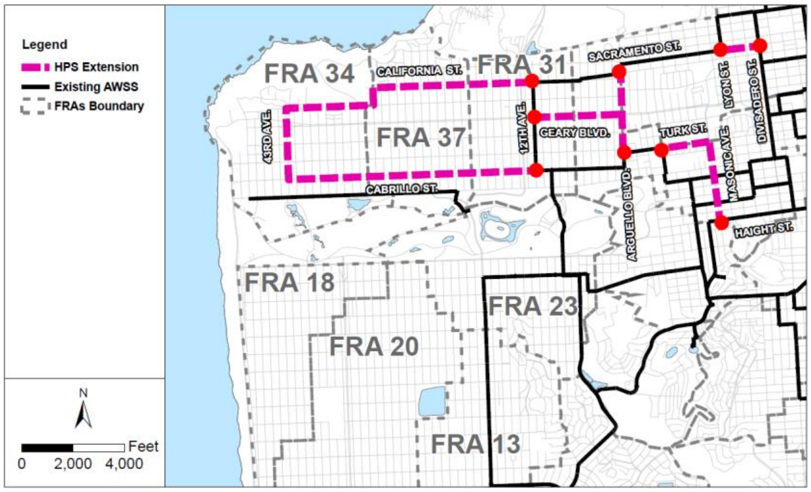


Figure 16 Option 4 AWSS with 9 Connections (Similar to Option 2 with Cross Over removed)

The reliability scores for Option 4 shown in **Figure 17** show slight reductions for FRAs 1 and 13. The FRA 1 score is reduced from 55% to 54% and FRA 13 from 71% to 70%. Both remain above the LOS objective of 50%. Option 4 meets the reliability criteria.

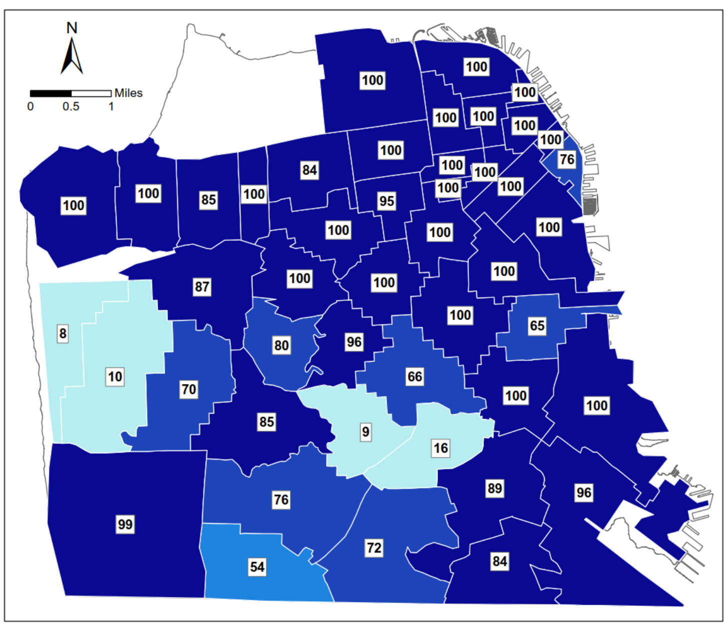


Figure 17 Residual Pressures for Option 4

4.6 Option 5 - AWSS Loop with Additional Pipe on Geary and 4 Connections (32,000 LF Pipe)

Option 5 includes all elements of Option 3 except with the crossover from the south removed. **Figure 18** shows the layout, each red circle indicates a connection point with the existing AWSS.

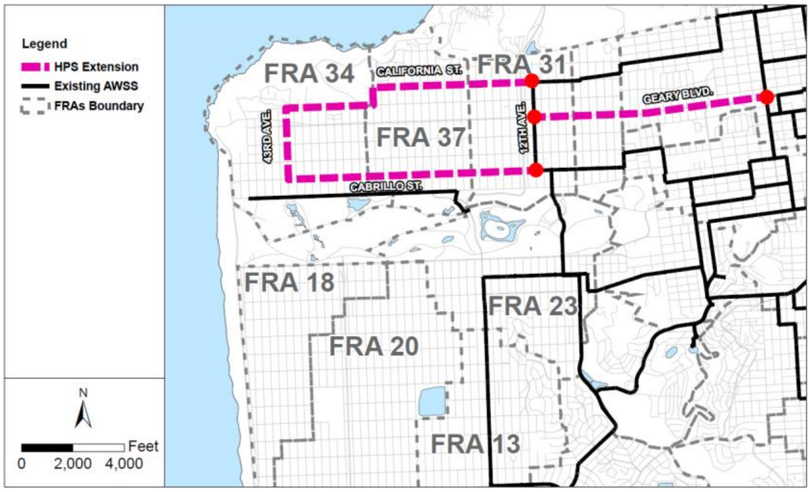


Figure 18 Option 5 AWSS with 4 Connections

The reliability scores for Option 5 shown in Figure 19 show a slight reduction for FRA 38 from 86% to 68%. The FRA score remains above the LOS objective of 50%. Option 5 meets the reliability criteria.

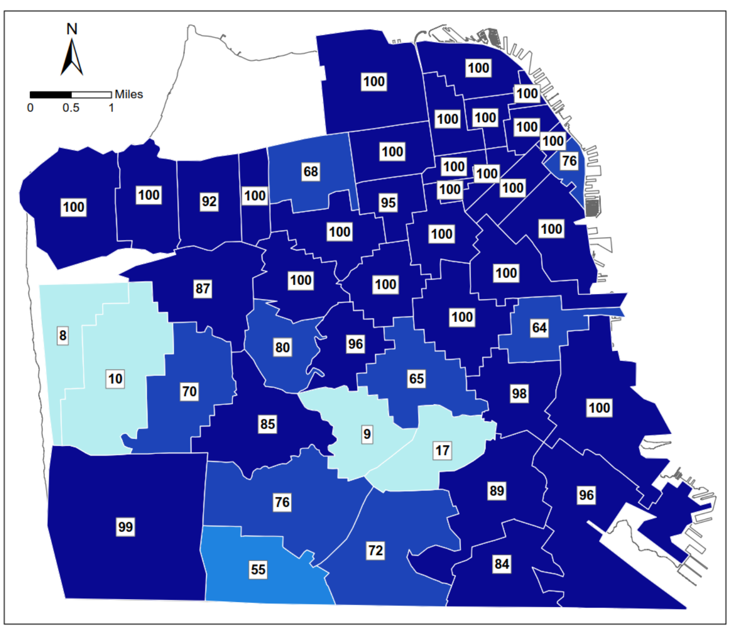


Figure 19 Reliability Scores for Option 5

4.7 Option 6 – AWSS Loop with Park Crossover and Lake Merced Pump Station with 4 Connections (28,000 LF Pipe)

Option 6 uses Lake Merced as a potential water source by installing an inline booster pump at the connection point between the Ingleside Pipeline project and Park Merced AWSS network. The pump output at this location is modeled at 15,000 gpm at 250 psi. At the same time, the division gate between Ingleside Pipeline and Ocean Avenue AWSS is opened to allow this booster pump to deliver water into the Twin Peaks zone. In order to take full advantage of this additional supply from Park Merced to the Twin Peaks zone, the division gates on both sides of I-280 are closed so that water from Lake Merced does not pass beyond I-280. **Figure 20** shows Option 6, each red circle indicates a connection point with the existing AWSS. The 4th connection from Lake Merced and Ocean Avenue AWSS is not shown.

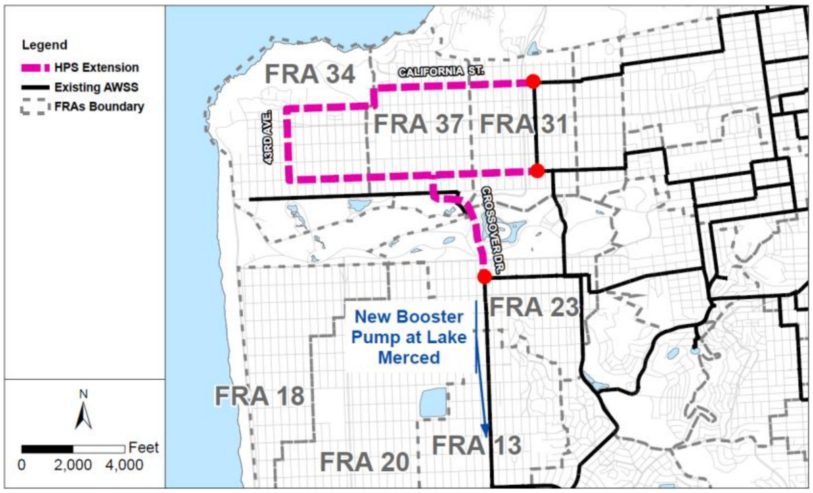


Figure 20 Option 6 – AWSS with Lake Merced Pump Station and 4 Connections

The reliability scores for Option 6 shown in **Figure 21** show slight increases for FRA 13 from 71% to 76% and for FRA 38 from 86% to 100%. The FRA scores are above the LOS objective of 50%. Option 6 meets the reliability criteria.

However, this option requires the construction of the Ingleside Project, the Lake Merced Pump Station improvements and the Park Merced AWSS mains that are currently planned to be constructed and funded by the Park Merced developer over the next 20 to 30 years. The Ingleside Project is currently planned to be constructed in at least two phases, the initial phase is recommended to be included in the ESER 2014 projects. Since construction of these projects would be dependent on the developer and potential future funding, the timing is unknown. If a method can be found to accelerate the construction the schedule uncertainty could be reduced or eliminated.

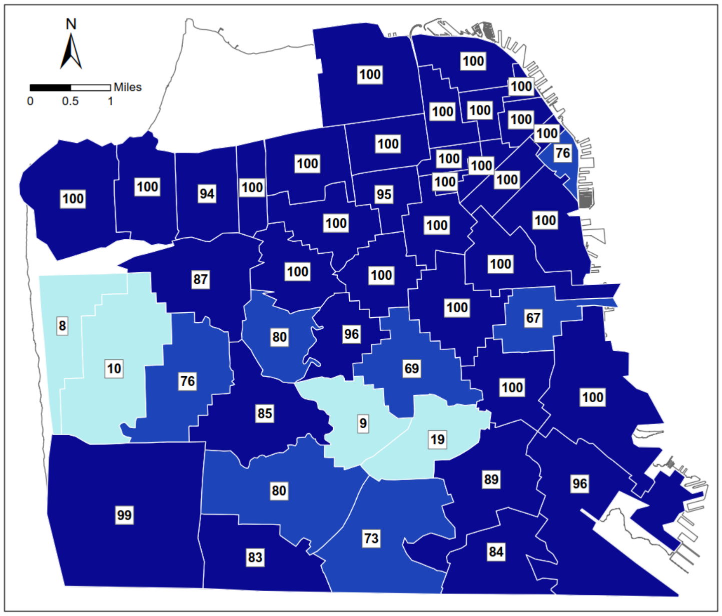


Figure 21 Reliability Scores for Option 6

4.8 Option 7 - AWSS Loop with Park Crossover, Sunset Pump Station, Air Gap Facility and 4 Connections (31,500 LF Pipe)

Sunset Reservoir provides another potential supply opportunity for future EFWS in the western part of San Francisco. Option 7 connects Sunset Reservoir to the non-potable AWSS with an inline booster pump. An “air gap” facility would need to be constructed to assure no AWSS water would be capable of entering the potable water system at Sunset Reservoir. **Figure 22** shows Option 7, each red circle indicates a connection point with the existing AWSS.

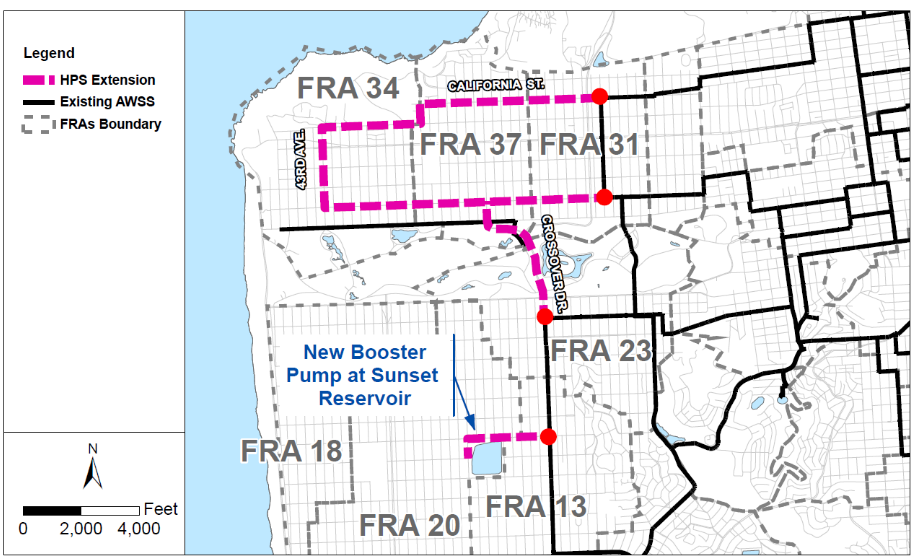


Figure 22 Option 7 - AWSS with Sunset Pump Station and 4 Connections

The reliability scores for Option 7 in **Figure 23** show that FRAs 13 and 38 were kept at post ESER 2014 levels (meeting the LOS criteria). Option 7 meets the reliability criteria.

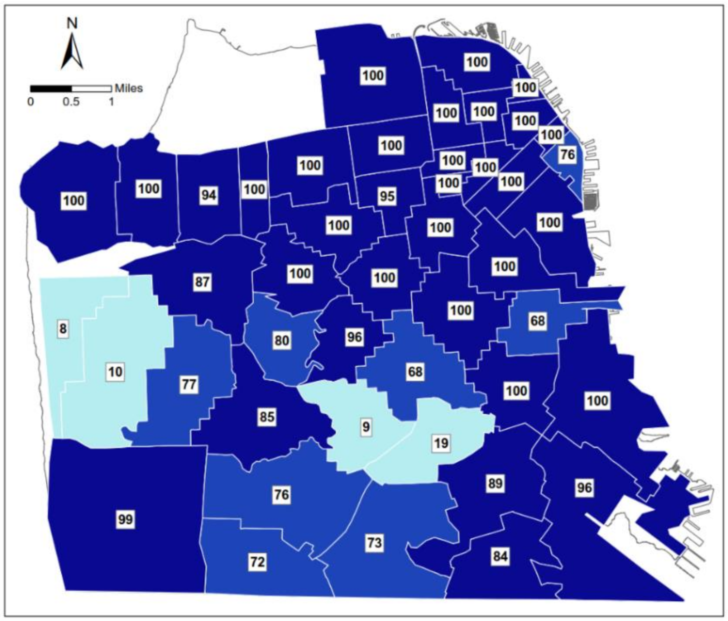


Figure 23 Reliability Scores for Option 7

4.9 Potable AWSS Option Development

Options 8 through 12 utilize the Potable AWSS alternative to supply water to the Richmond District as described in Section 2; the additional supply source eliminates the impact of the Richmond AWSS Extension on the existing AWSS. The Potable AWSS approach would be used as a potable water transmission line in normal daily operations, and provide firefighting water supply under emergency conditions. The dual purpose pipeline is to be designed to AWSS standards and have seismically actuated control valves (similar to existing AWSS valves) on the limited connections to the potable system, allowing it to be isolated following an earthquake. The isolated dual-purpose pipeline will be pressurized to a higher pressure with the booster pump system to provide high pressures for firefighting similar to the AWSS. Providing water to FRAs 34 and 37 with a Potable AWSS line does not rely on water supply from existing AWSS water sources so it does not impact the residual pressures in the AWSS.

4.10 Option 8 – Potable AWSS with Sunset Pump Station (22,200 LF Pipe)

Option 8 is a pipeline running west from Sunset Reservoir, north through Golden Gate Park and east through the outer Richmond District as shown in **Figure 24**, and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi.

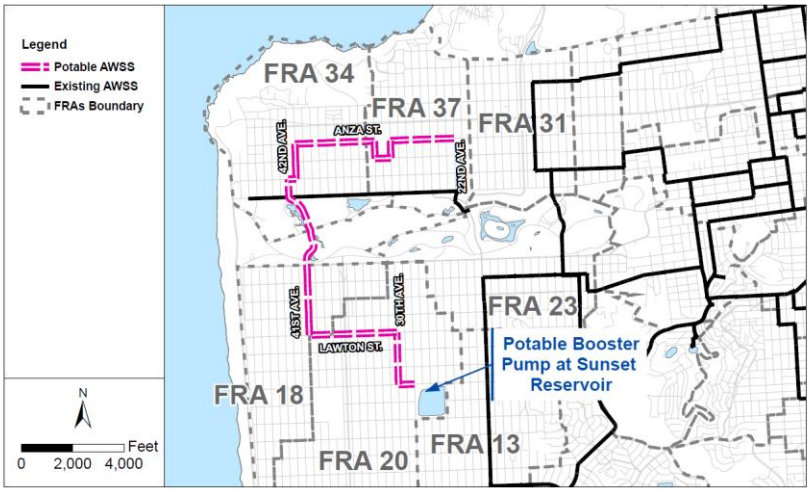


Figure 24 Option 8 – Potable AWSS with Sunset Pump Station

Options 8 through 12 meet the demands of FRAs 34 and 37 without compromising the AWSS. These options also meet the demands in FRAs 18 and 20 in the Sunset District that are also currently unserved by the AWSS high pressure system.

Options 11 and 12 provide a looped supply that provides additional benefits to the Richmond District by providing better area coverage and resilience to the FRAs. Option 12 provides a second loop through the Sunset District providing better area coverage and resilience to the FRAs. Option 12 would allow future connection to an additional water supply from Merced Manor or Lake Merced Pump Stations.

There was no methodology identified during CS-199 to assess the reliability scores for Potable AWSS. The pipeline reliability is assumed to be very high since it will be constructed to current AWSS standards. Because the source of supply and transmission pipes leading to Sunset Reservoir have been seismically upgraded, the supply reliability is also considered to be high. Other reliability factors could be applied to the other key system features such as the pumps and motorized valves. For this reason this report assumes 90% of the water supply demand is provided by Potable AWSS. Other water sources (cisterns etc.) are also available in certain FRAs and these are added to the Potable AWSS supply for calculation of the reliability score. Further refinements could be made to the reliability scoring.

This report also assumes equal reliability for each of the Potable AWSS options even though the options provide different area coverages. The options all include a booster pump station located at the Sunset Reservoir, which is sized to supply the full FRA demands for FRA's 18, 20, 34 and 37. The details of the booster pump station are under development in a separate work product. The reliability scores for the areas of the City served by AWSS for Options 8 through 12 are identical and are shown in **Figure 25**. Options 8 through 12 meet the LOS objectives.

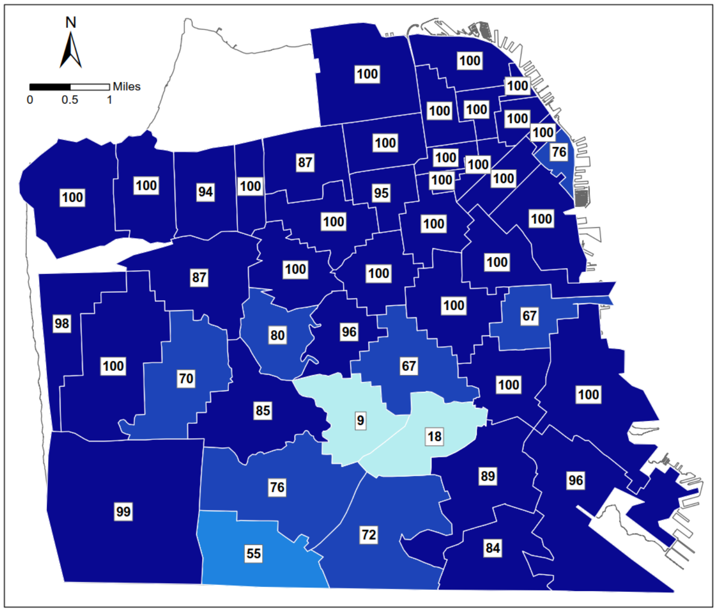


Figure 25 Reliability Scores for Options 8 through 12

4.11 Option 9 - Potable AWSS with Sunset Pump Station and Richmond Loop (37,500 LF Pipe)

Similar to Option 8, Option 9 connects a dual-use potable pipeline to the Sunset Reservoir in the western portion of San Francisco. Instead of building a single pipeline connecting in the Richmond District, this option includes a potable water system loop following an alignment similar to the Richmond AWSS Extension, and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi. **Figure 26** shows Option 9.

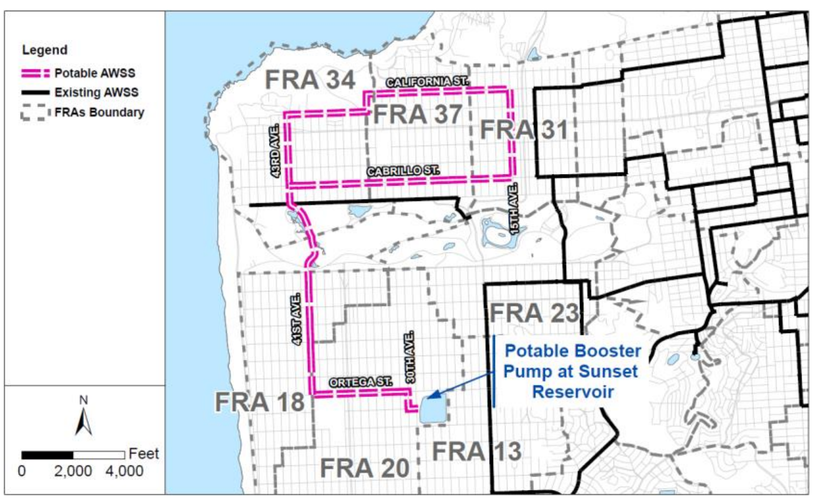


Figure 26 Option 9 - Potable AWSS with Sunset Pump Station and Richmond Loop

The additional loop provides larger conveyance capacity in the Richmond area. The extended pipeline provides additional benefits to the Richmond District than Option 8 by providing better area coverage to the FRAs.

4.12 Option 10 – Potable AWSS with Sunset Pump Station and Extension to Lincoln Park (23,600 LF Pipe)

Option 10 includes a similar route as Option 8 but includes a branch extended north towards the VA Hospital. The total length of Potable AWSS pipe is 23,600 LF and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi. **Figure 27** shows Option 10.

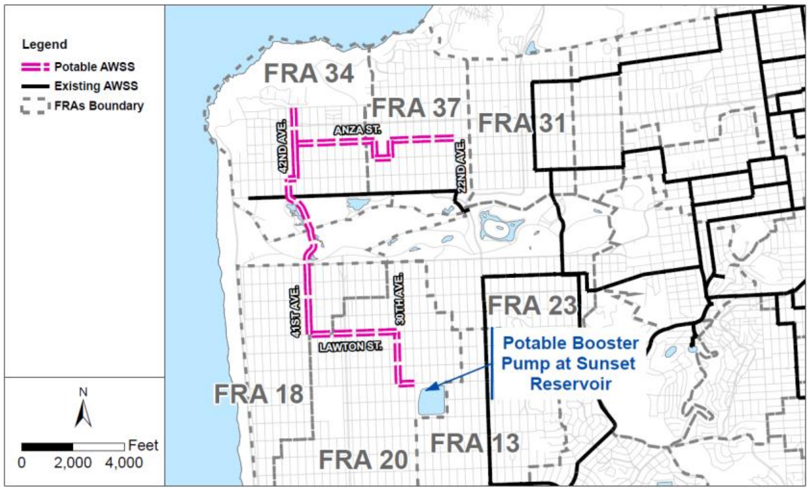


Figure 27 Option 10 – Potable AWSS with Sunset Pump Station and extension to Lincoln Park

The additional pipeline provides additional coverage into areas in the Richmond District. The extended pipeline provides additional benefits to the Richmond District, but less than Option 9, by providing better area coverage to the FRAs.

4.13 Option 11 – Potable AWSS with Sunset Pump Station and One Loop (37,900 LF Pipe)

Option 11 includes a route similar to Options 8 and 10 but includes a complete loop back to the supply point. The total length of Potable AWSS pipe is 37,900 LF and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi. **Figure 28** shows Option 11.

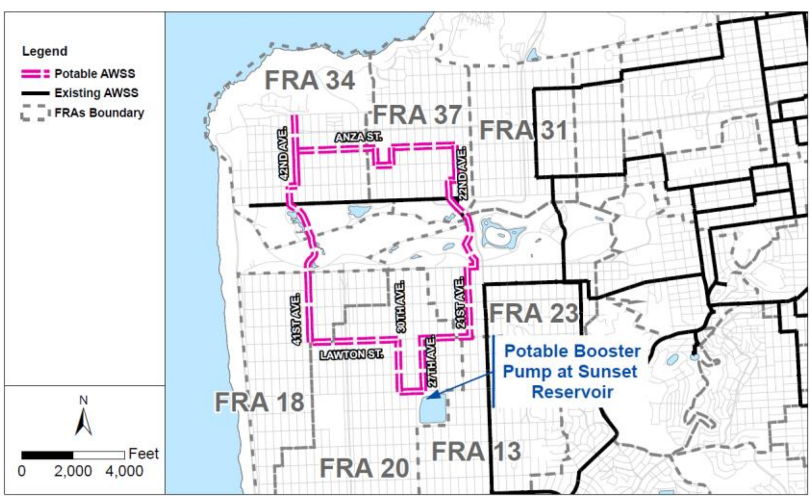


Figure 28 Option 11 – Potable AWSS with Sunset Pump Station and One Loop

The additional pipeline provides additional coverage into areas of the Richmond and Sunset Districts. The looped system pipeline provides additional benefits to the Richmond District by providing better area coverage and resilience to the FRAs.

4.14 Option 12 – Potable AWSS with Sunset Pump Station and Two Loops (51,500 LF)

Option 12 includes a route similar to Option 11 but includes a second loop back to the supply point. The total length of Potable AWSS pipe is 51,500 LF and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi. **Figure 29** shows Option 12.

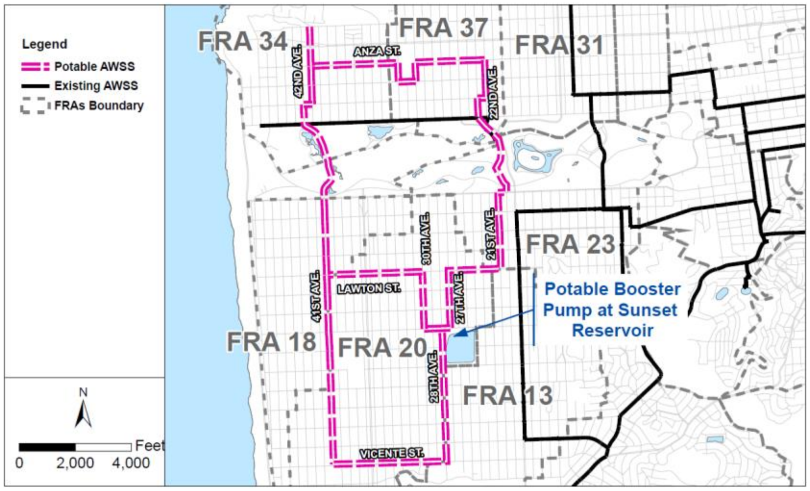


Figure 29 Option 12 – Potable AWSS with Sunset Pump Station and Two Loops

The additional pipeline provides additional coverage into areas of the Richmond and Sunset Districts. The looped system pipeline provides additional benefits to the Richmond District by providing better area coverage and resilience to the FRAs. The southern loop could allow a future connection to a second source of supply from the Merced Manor or Lake Merced Pump Stations.

5. FRA Reliability Scoring Results

The options to supply the Richmond District were evaluated using the methodology described in Section 3 and Appendix B. **Table 5** shows the reliability scores for the Sunset, Richmond and adjacent FRAs. The reliability score maps are included as **Figures 30** through **39** in Appendix A. Appendix B describes the method of reliability score calculation. The post ESER 2014 reliability scores shown in **Figure 31** have been modified by removing the previously recommended Sunset Pipeline project for equal comparison of the options.

The methodology used to locate the demand point is described in the CS-199 Task 8 TM. CS-199 and subsequent studies have located the FRA demand at an available pipeline connection point nearest to the largest or most repeated fire demands. For the purposes of this analysis the demand point has been set on the pipeline provided for each option as long as it enters the FRA (consistent with CS-199). Since the demand represents the water supply need for the entire FRA and the ignition locations are unknown, it is assumed that SFFD would utilize the Portable Water Supply System (PWSS) or engine relays to distribute the water supply within the FRA to the actual ignition locations. The options with more complete loops (more pipe) within the Richmond FRA's would most likely be able to supply SFFD with the available water at a closer location to the ignitions, but this benefit is not captured in the CS-199 methodology.

The AWSS was designed with redundant water supply and a gridded main system. This provides a more reliable water supply system, allowing potential pipe breaks to be bypassed. The parts of the AWSS that are not gridded (western and southern portions) have a higher risk of failure due to the lack of redundant pipelines. The non-redundant options for Potable AWSS would have a similar risk of failure. However the use of ERDIP significantly reduces the risk of pipeline failure (zero breaks on ERDIP pipelines in Japan following earthquakes since 1990). To provide water supply redundancy for the Potable AWSS, additional evaluations should be conducted to determine refinements of reliability scoring methodology, as well as to develop potential redundancy options (e.g. connection to other potable supplies, or emergency connection to AWSS).

The supply for the Potable AWSS utilizes the seismically upgraded North Sunset Reservoir basin. The Sunset Reservoirs are fed by the SFPUC's Regional Water System that has been seismically upgraded by the Water System Improvement Program (WSIP). Regional water supply lines include the San Andreas Pipelines 2 and 3, and the Sunset Supply Pipeline. The Lake Merced and Baden Pump Stations and San Pedro Valve Lots have also been improved to address seismic reliability. The LOS for the Regional Water System is to "Within 24 hours of seismic event, deliver average day demand to 4 out of 5 "terminal reservoirs" (Sunset, University Mound, Merced Manor and 2 large turn-outs at SF County Line)".

Sensitivity analyses were performed to evaluate the impact of some of the option development assumptions. These analyses included the impact of increasing the assumed pipe diameter as well as the review of potential changes over time in the pipe friction factor. The analyses compared the impact of the change on one of the 12 options. The detailed results are included in Appendix E. **Table 6** below summarizes the new model results from Option 3a and 5a. Specific conditions are described in the table notes.

Table 5 FRA Reliability Scores for Richmond, Sunset and Inner Parkside

Option ID		Post ESER 2010	Post ESER 2014	Base	1	2	3	4	5	6	7	8	9	10	11	12
FRA ID	**Location**		**Reliability Score %**													
13	Inner Parkside	27	70	70	18	25	19	70	70	76	77	70	70	70	70	70
18	Sunset	8	8	8	8	8	8	8	8	8	8	98	98	98	98	98
20		10	10	10	10	10	10	10	10	10	10	100	100	100	100	100
31	Inner Richmond	82	94	42	94	94	94	85	92	94	94	94	94	94	94	94
34	Outer Richmond	46	46	100	100	100	100	100	100	100	100	100	100	100	100	100
37		39	39	100	100	100	100	100	100	100	100	100	100	100	100	100
38	Presidio Heights	78	87	52	100	100	100	84	68	100	100	87	87	87	87	87

Blue highlight indicates a drop in reliability score from the previously recommended system but still above the FRA target of 50%
Pink highlight indicates a LOS score less than the FRA target of 50%

Table 6 Sensitivity Analysis Results

Option ID		3	3a[1]	5	5a[2]
FRA ID	**Location**	**Reliability Score %**			
13	Inner Parkside	19	18	70	72
18	Sunset	8	8	8	8
20		10	10	10	10
31	Inner Richmond	94	94	92	91
34	Outer Richmond	100	100	100	100
37		100	100	100	100
38	Presidio Heights	100	100	100	87

1. Sensitivity performed in Option 3a by utilizing 24-inch diameter Ductile Iron Pipe instead of the 20-inch diameter pipe used in the same layout for Option 3. No significant differences were noted in the reliability scores.
2. Sensitivity analysis performed in Option 5a by utilizing a Hazen-Williams C factor of 100 in Option 5a versus the factor of 130 used in Option 5. C=130 is typically used for new ductile iron pipe and C=100 would reflect aged ductile iron pipe. Even with the differences in the reliability scores the option still meets the LOS goal.

6. Cost Data

Relative cost data shown in **Table 7** has been prepared for use in comparing projects. The cost opinion assumptions are as follows:

- Costs used are from CS-199 and CS-229 AWSS Spending Plan
- Soft costs are 25% of construction costs
- Design costs are 10% of construction costs
- Contingencies are included as 30% of construction costs
- Potable AWSS projects are eligible to be funded by both water rates and ESER bonds
- The cost of the Ingleside Pipeline project was added to the project cost for Option 6 as the project is necessary for the option to function. This project would otherwise be part of the "All Recommended Projects"

The cost estimate detail is attached to this document as Appendix F.

Table 7 Project Cost for the Richmond EFWS Options

Option	Project Components	Pipe Length (LF)	Booster Pump Rating	Total Project Cost[1,2] ($million)
Base	AWSS Loop	22,800	N/A	$41
1	AWSS Loop with park crossover	28,000	N/A	$51
2	AWSS Loop with park crossover and additional pipe in Laurel Heights	43,500	N/A	$84
3	AWSS loop with park crossover and additional pipe on Geary	37,100	N/A	$68
4	AWSS loop with additional pipe in Laurel Heights (no crossover)	38,400	N/A	$75
5	AWSS loop additional pipe on Geary (no crossover)	32,000	N/A	$60
6	AWSS loop with Lake Merced Pump Station	28,000	15,000 gpm 250 psi	$87[3]
7	AWSS loop with Sunset Pump Station and Air Gap	31,500	7,500 gpm 150 psi	$67
8	Potable AWSS with Pump Station	22,200	13,500 gpm 150 psi	$58
9	Potable AWSS with Pump Station and Richmond Loop	37,500	13,500 gpm 150 psi	$85
10	Potable AWSS with Pump Station and extension to Lincoln Park	23,600	13,500 gpm 150 psi	$61
11	Potable AWSS with Pump Station and One Loop	37,900	13,500 gpm 150 psi	$85
12	Potable AWSS with Pump Station and Two Loops	51,500	13,500 gpm 150 psi	$109

1. Costs are based on CS-199 and subsequent studies. Potable AWSS Projects (Options 8 through 12) may be funded by both water rates and ESER bonds. Potable AWSS projects would replace the probable construction of a new potable transmission main (approximately $23.5 million).
2. Options 1 through 7 do not serve the Sunset District. A gravity feed potable pipeline to provide service could be provided (approximately $23.4 million) or AWSS extension pipelines (not evaluated in this study).
3. The full cost of the Ingleside Pipeline ($8.8 million) has been included in this project.

The total estimated project costs shown in **Table 7** are planning level estimates and reflect a relatively high contingency due to project uncertainties. These estimates are based on costs from the CS-199 study and have not been updated to 2017 costs. The level of uncertainty is approximately equivalent to an American Association of Cost Engineers (AACE) Class 5 estimate (data included in Appendix F) with a potential accuracy range of -20% to -50% and +30% to +100%. The differences in cost between some of the options is within the level of accuracy of the estimates. Costs are only one criteria used in the evaluation of the options.

A simple gravity-fed potable water pipeline has been described in Appendix C. The cost of this 13,000 foot pipeline is estimated as $23.4 million. This project could be added to alternatives 1 through 7 to provide gravity-fed EFWS to portions of the Sunset District. Additional costs for a pump station to boost the pressure, or a full AWSS extension pipeline, consistent with extending AWSS in the Richmond District, have not been evaluated, but would likely be higher than the gravity-fed potable pipeline option.

The cost of the minimum transmission pipeline that SFPUC would need to construct to supply the Richmond District as a third transmission main (12,600 feet of pipeline) is estimated, using the same pipeline, hydrant and valve costs as the above ERDIP pipeline, as $23.5 million. This pipeline would supplement the potable supply to the Richmond District by connecting via gravity the Sunset Reservoir to the 16-inch main in Cabrillo. This would not provide an equivalent ERDIP pipeline for distribution within the Richmond District but instead represents a planned investment for the potable system that could be off-set by the construction of Options 8 through 12.

7. Non-Cost Comparison and Conclusions

Options were developed to provide fire protection water supply to the Richmond District. The non-cost criteria used to evaluate options include the previously discussed reliability scores as well as cost, schedule and benefits to other FRAs. **Table 8** notes the non-cost criteria and relative comparisons.

Table 8 Non-Cost Evaluation

<table>
<tr><th>Option</th><th>Project Components</th><th>Meets LOS Goals[1]</th><th>Redundant Supply[2]</th><th>Redundant Network[3]</th><th>Potable System Benefit and Funding[4]</th><th>Benefits to Sunset as well as Richmond District[5]</th><th>Comments</th></tr>
<tr><td>Base</td><td>AWSS Extension</td><td rowspan="4">No</td><td rowspan="8">Yes</td><td rowspan="8">Yes</td><td rowspan="8">No</td><td rowspan="8">No</td><td></td></tr>
<tr><td>1</td><td>AWSS Loop with park crossover</td><td></td></tr>
<tr><td>2</td><td>AWSS Loop with park crossover and additional pipe in Laurel Heights</td><td></td></tr>
<tr><td>3</td><td>AWSS loop with park crossover and additional pipe on Geary</td><td></td></tr>
<tr><td>4</td><td>AWSS loop with additional pipe in Laurel Heights (no crossover)</td><td rowspan="9">Yes</td><td rowspan="2"></td></tr>
<tr><td>5</td><td>AWSS loop additional pipe on Geary (no crossover)</td></tr>
<tr><td>6</td><td>AWSS loop with Lake Merced Pump Station</td><td>Timing is uncertain since portion of pipelines to be built by developer</td></tr>
<tr><td>7</td><td>AWSS loop with Sunset Pump Station</td><td>Requires air gap facility</td></tr>
<tr><td>8</td><td>Potable AWSS with Pump Station</td><td rowspan="5">No</td><td rowspan="3">No</td><td rowspan="5">Yes</td><td rowspan="5">Yes</td><td rowspan="5">Provides additional potable water distribution main to Richmond District</td></tr>
<tr><td>9</td><td>Potable AWSS with Pump Station and Richmond Loop</td></tr>
<tr><td>10</td><td>Potable AWSS with Pump Station and extension to Lincoln Park</td></tr>
<tr><td>11</td><td>Potable AWSS with Pump Station and One Loop</td><td rowspan="2">Yes</td></tr>
<tr><td>12</td><td>Potable AWSS with Pump Station and Two Loops</td></tr>
<tr><td colspan="8">1. LOS Goal: Each FRA will have a minimum of 50% reliable water supply to meet probable fire demands.
2. The AWSS was constructed with multiple supplies (Twin Peaks, Pump Stations 1 and 2 as well as fireboat manifolds) while the Potable AWSS has one supply although future supplies are possible, particularly with Option 12. Design elements could increase the reliability of the supply through redundant pump units and inlet and outlet piping.
3. A looped or gridded supply provides redundancy in the pipe system. Option 11 provides a looped supply to the Richmond District and Option 12 provides a looped supply to both Richmond and Sunset Districts.
4. Options 8 through 12 provide daily benefit to the potable water supply system, could be funded in part by water rate funds and replace a planned new transmission main (estimated to cost $20 -$30 million)
5. Options 1 through 7 do not serve the Sunset District. AWSS for the Sunset District was not evaluated.</td></tr>
</table>

7.1 Reliability Scores

The reliability score results are summarized in Section 5. While all options improve the reliability scores for FRAs 34 and 37 in the Richmond District, the reliability scores for areas near the Richmond District are impaired in some cases. With the new connection through Crossover Drive, less water is available to the Twin Peaks Zone FRAs that results in reduced FRA scores in FRA 13 (Inner Parkside) for Options 1 through 3. The reliability scores are reduced below the LOS target of 50%.

Option 4 and Option 5 increase the reliability scores for FRAs 34 and 37 and cause reliability scores for FRA 38 to be reduced but still above the LOS target of 50%. Options 5 through 7 increase the reliability scores for FRAs 34 and 37, but do not increase the scores in the Sunset District in FRAs 18 and 20. Options 8 through 12 increase the reliability scores for FRAs 18, 20, 34 and 37 without impacting the other FRAs served by the AWSS.

7.2 Redundant Water Supply Source

One of the strengths of the AWSS is the redundancy designed into the initial system. This redundancy includes the gridded pipe in the initial pipe system as well as the multiple water supply sources. The redundancy increases the ability of the system to reliably supply water. The AWSS is designed to eliminate single points of failure that could cause failures of water supply.

The Potable AWSS as currently envisioned, depending on the option, would be less reliable due to single points of failure that could cause failures of water supply. For example, Options 8 through 10 have a single pipeline supplying the Richmond District from the Sunset Reservoir. Options 8 through 12 are dependent on a single supply from Sunset Reservoir, which includes a booster pump station. While a standby pump unit is planned, failure of the pump station would limit the water supply to a gravity system, reducing the pressure available to the system.

Options 11 and 12 provide a looped supply that provides additional benefits to the Richmond District by providing better area coverage and resilience to the FRAs. Option 12 provides a second loop through the Sunset District providing better area coverage and resilience to the FRAs. Option 12 would allow future connection to an additional water supply from Merced Manor or Lake Merced Pump Stations. Assessment of the potential failure points should be part of further analysis for both AWSS and Potable AWSS.

7.3 Benefits to the Potable System

Options 8 through 12 provide better reliability for the potable system on a daily basis, as well as a backbone post-earthquake drinking water supply to the Sunset and Richmond Districts. The Potable AWSS pipeline provides a third transmission main to supply potable water to the Richmond District, supplementing the existing infrastructure.

The Potable AWSS options would replace a project that SFPUC would need to construct to provide a third potable transmission main. This offset cost, as described in Section 6, is $23.5 million.

7.4 Benefits to Other FRAs

Options 8 through 12 provide EFWS to the Sunset District as well as the Richmond District. Addition of a gravity feed system (shown in **Figure 40** in Appendix D) to Options 1 through 7 can provide water supply to the lower elevation areas in the Sunset District with adequate pressure. Adequate pressure would not be achievable for the areas around the Sunset Reservoir and the eastern portions of FRA 20 without a pumped system as the elevation increases. The estimated cost of the system shown in **Figure 40** is approximately $23.4 million that has not been included in the cost for Options 1 through 7.

7.5 Schedule

Option 6 meets the LOS goal however is dependent on schedule of developer-funded pipeline construction. Since construction would be dependent on the developer, the timing is unknown. If a method can be found to accelerate the construction the schedule uncertainty could be reduced or eliminated.

For all options the implementation schedule will be impacted by the total bond contribution required as the future ESER Bond amounts and schedule are not known. Significant project bond amounts may not be funded in one bond cycle that could delay project implementation.

7.6 Conclusions

San Francisco Public Utilities Commission (SFPUC) is actively improving and expanding its existing infrastructure for the Emergency Firefighting Water System (EFWS). The Auxiliary Water Supply System (AWSS) provides high pressure water supply for firefighting via independent supply and delivery networks to protect people and property from potential risk of fire following a major earthquake, but does not serve the entire city. CS-199 Planning Support Services for AWSS (CS-199 Study) and CS-229 EFWS Spending Plan (Spending Plan), and subsequent revisions identified and evaluated a set of future projects that enhance and expand the city-wide fire protection water supply reliability.

The Level of Service (LOS) objectives set in the CS-199 study are as follows:

> "AWSS will reliably provide water to supply the "probable fire demands" after a magnitude 7.8 San Andreas earthquake. Each FRA will have a minimum of 50% reliable water supply to meet probable fire demands. The Citywide average will be a minimum of 90% reliable water supply to meet probable fire demands."

The system as it existed in 2010 had a citywide reliability score of 47%. The recommended ESER 2010 projects will increase the citywide reliability score to 68%. The recommended 2014 projects will increase the citywide reliability score to 86%. The recommended potential future projects would extend the emergency firefighting water system to all areas of the City and improve the citywide reliability score to 94%. This study addresses the Richmond District portion of those projects. Note that some included options also benefit the Sunset District, but the focus of this evaluation is on the Richmond District.

The Richmond District EFWS is currently supplied by a combination of SFPUC's potable water system, some additional gravity water supply and cisterns and, to a limited extent (in the Inner Richmond), the AWSS. In aggregate these supplies do not meet the LOS goals for EFWS needs following a major earthquake. In order to increase the EFWS supply to the Outer Richmond District, this study compared two major alternatives: (1) extending the existing AWSS further into the Richmond District, and (2) "Potable AWSS" pipelines from the Sunset Reservoir (a potable supply) to the western part of the Richmond District. The Potable AWSS would serve on a daily basis as a potable transmission main (increasing potable water supply and quality to the Richmond) and in the event of an earthquake would automatically be isolated from the remainder of the potable distribution system and converted to a dedicated high pressure EFWS, similar to the AWSS. The Potable AWSS would be built to meet or exceed the current AWSS standards as well as meet the applicable potable water quality standards, would use Sunset Reservoir as its source and would provide EFWS to part of the Sunset as well as the Richmond District. It should be noted that these Alternatives are only one of several dozen projects being undertaken with Earthquake Safety and Emergency Response (ESER) 2010 and 2014 funds.

Between the two major alternatives, twelve options were considered, using reliability score, cost and other criteria (see **Table ES-1**). Four AWSS options and five Potable AWSS options meet the reliability criteria LOS goals set in the CS-199 study and any of them would improve the EFWS to the Richmond District. Of these nine options:

1. Four AWSS options serve the Richmond District.
2. Five Potable AWSS options serve the Richmond and Sunset Districts.
3. Pipe length, location and cost within the Districts vary according to the option.
4. The AWSS options have redundant water supply sources and looped pipeline networks, which afford increased reliability.
5. The AWSS options do not include AWSS for the remaining area of the Sunset District. A gravity-fed option for the Sunset District has been proposed, but is not evaluated in this study.

6. The Potable AWSS options have a single water supply source, Sunset Reservoir, and some pipeline options do not have looped networks. To achieve comparable reliability for source water redundancy, additional analysis and design are needed to evaluate options for emergency connection to AWSS or other supplies.

7. In addition to the EFWS benefits, the Potable AWSS provides daily reliability and water quality benefits as well as a post-earthquake potable water supply to the Richmond and Sunset Districts.

8. The Potable AWSS options are expected to be funded in part from water rate funds, reducing the amount of ESER bond funds needed, resulting in earlier project implementation.

Criteria for the evaluation of the options are presented in **Table 9** and include the need for a pump station, the total amount of installed pipe (an indicator of construction impact), LOS goals attainment, and single versus redundant water supply sources, potable water delivery, and estimated total cost. Costs were estimated using planning level data and are not based on detailed engineering design, so that their accuracy is correspondingly limited (and comparable to the differences between some options). The Potable AWSS options would replace a project that SFPUC is planning that would supply potable water to the Richmond District and is estimated to cost between $20 and $30 million.

In summary, several AWSS and Potable AWSS options provide a viable EFWS for the Richmond District and, in some cases, the Sunset District. The study identifies further analyses beyond the current planning level that would better inform the choice of the specific option. Integral to the selection of an implementation plan are non-technical factors such as meeting the citywide LOS goals, meeting LOS in the Sunset District as well as other districts, Fire Department operations, phasing, financing and future development.

Table 9 Options Evaluated

<table>
<tr><th>Option</th><th>Project Components</th><th>Number of AWSS Connections</th><th>Additional Pump Station</th><th>Pipe Length (LF)</th><th>Meets LOS Goals[1]</th><th>Redundant Supply[2]</th><th>Redundant Network[3]</th><th>Potable System Benefit and Funding[4]</th><th>Benefits to Sunset as well as Richmond District</th><th>Project Cost ($million)[5]</th><th>Comments</th></tr>
<tr><td>Base</td><td>AWSS Extension</td><td>2</td><td rowspan="6">No</td><td>22,800</td><td rowspan="4">No</td><td rowspan="8">Yes</td><td rowspan="8">Yes</td><td rowspan="8">No</td><td rowspan="8">No</td><td>$41</td><td></td></tr>
<tr><td>1</td><td>AWSS Loop with park crossover</td><td>3</td><td>28,000</td><td>$51</td><td></td></tr>
<tr><td>2</td><td>AWSS Loop with park crossover and additional pipe in Laurel Heights</td><td>10</td><td>43,500</td><td>$84</td><td></td></tr>
<tr><td>3</td><td>AWSS loop with park crossover and additional pipe on Geary</td><td>5</td><td>37,100</td><td>$68</td><td></td></tr>
<tr><td>4</td><td>AWSS loop with additional pipe in Laurel Heights (no crossover)</td><td>10</td><td>36,000</td><td rowspan="9">Yes</td><td>$75</td><td rowspan="2"></td></tr>
<tr><td>5</td><td>AWSS loop additional pipe on Geary (no crossover)</td><td>5</td><td>32,000</td><td>$60</td></tr>
<tr><td>6</td><td>AWSS loop with Lake Merced Pump Station</td><td>4</td><td>Yes (Lake Merced, 250 psi)</td><td>28,000</td><td>$87</td><td>Cost includes Ingleside Pipeline but developer funded pipelines also required</td></tr>
<tr><td>7</td><td>AWSS loop with Sunset Pump Station</td><td>4</td><td rowspan="6">Yes (Sunset Reservoir, 150 psi)</td><td>31,500</td><td>$67</td><td>Requires air gap facility</td></tr>
<tr><td>8</td><td>Potable AWSS with Pump Station</td><td>0</td><td>22,200</td><td rowspan="5">No</td><td rowspan="3">No</td><td rowspan="5">Yes</td><td rowspan="5">Yes</td><td>$58</td><td rowspan="5">Provides additional potable water distribution main to Richmond District</td></tr>
<tr><td>9</td><td>Potable AWSS with Pump Station and Richmond Loop</td><td>0</td><td>37,500</td><td>$85</td></tr>
<tr><td>10</td><td>Potable AWSS with Pump Station and extension to Lincoln Park</td><td>0</td><td>23,600</td><td>$61</td></tr>
<tr><td>11</td><td>Potable AWSS with Pump Station and One Loop</td><td>0</td><td>37,900</td><td rowspan="2">Yes</td><td>$85</td></tr>
<tr><td>12</td><td>Potable AWSS with Pump Station and Two Loops</td><td>0</td><td>51,500</td><td>$109</td></tr>
</table>

1. LOS Goal: Each FRA will have a minimum of 50% reliable water supply to meet probable fire demands.
2. The AWSS was constructed with multiple supplies (Twin Peaks, Pump Stations 1 and 2 as well as fireboat manifolds) while the Potable AWSS has one supply although future supplies are possible, particularly with Option 12. Design elements could increase the reliability of the supply through redundant pump units and inlet and outlet piping.
3. A looped or gridded supply provides redundancy in the pipe system. Option 11 provides a looped supply to the Richmond District and Option 12 provides a looped supply to both Richmond and Sunset Districts.
4. Options 8 through 12 provide daily benefit to the potable water supply system, could be funded in part by water rate funds and replace a planned new transmission main (estimated to cost $20 -$30 million)
5. Costs based on CS-199 and subsequent studies.

7.7 Further Analysis

As discussed above, further analysis is recommended to assist in selecting the recommended option to better inform the choice of the specific option to provide EFWS to the Outer Richmond District. The further analysis should include the following:

- Pipe route evaluation (assessing Muni, traffic and utility impacts)
- Pipe sizing (further refinement of pressure loss versus pipe diameter options)
- Potable water transmission main connection locations and water quality requirements
- Sunset Reservoir and Lake Merced Pump Station connections and booster pump station details
- Refinement of reliability scoring methodology for Potable AWSS and AWSS
- Compare options using a method such as Analytic Hierarchy Process (AHP) (see Appendix G)
- Further assessment of Sunset District options (the focus of this memo has been the Richmond District)
- Implementation phasing of construction depending on fund availability
- Further assessment of water supply options on the west side of San Francisco

Appendix A - Reliability Score Maps

Reliability Score Maps

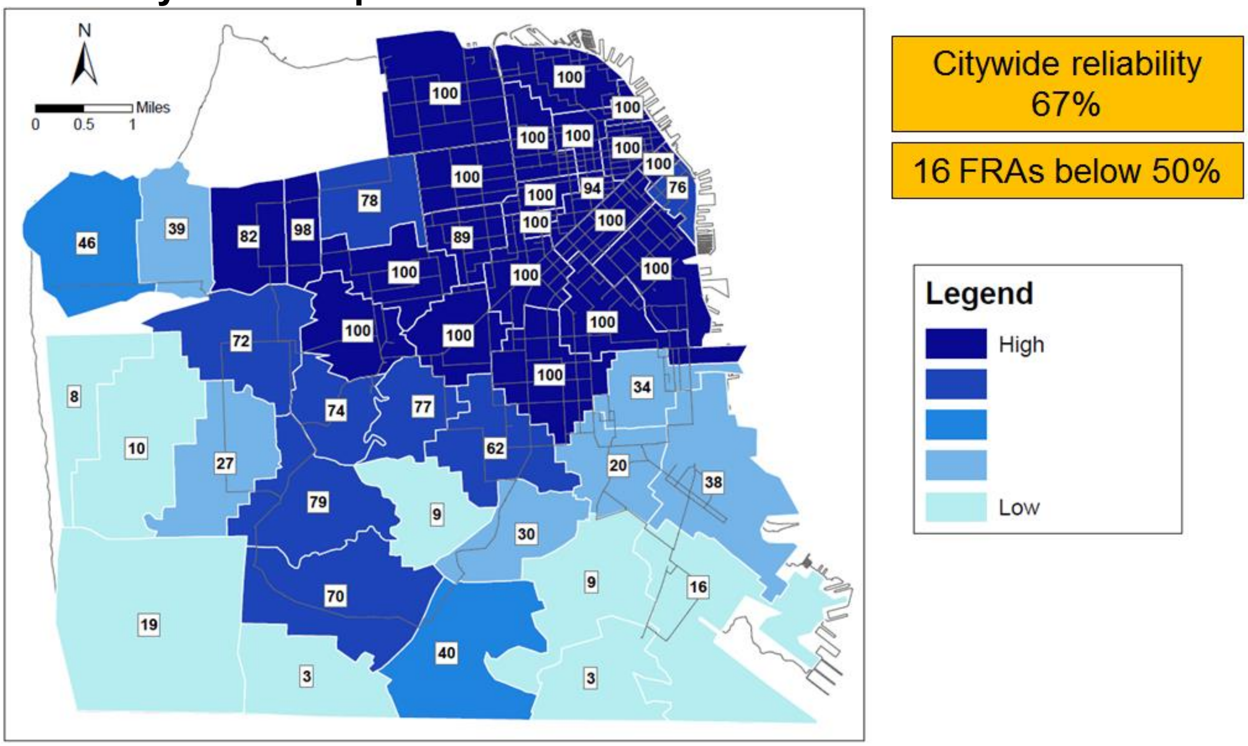


Figure 30 Reliability Scores after ESER 2010

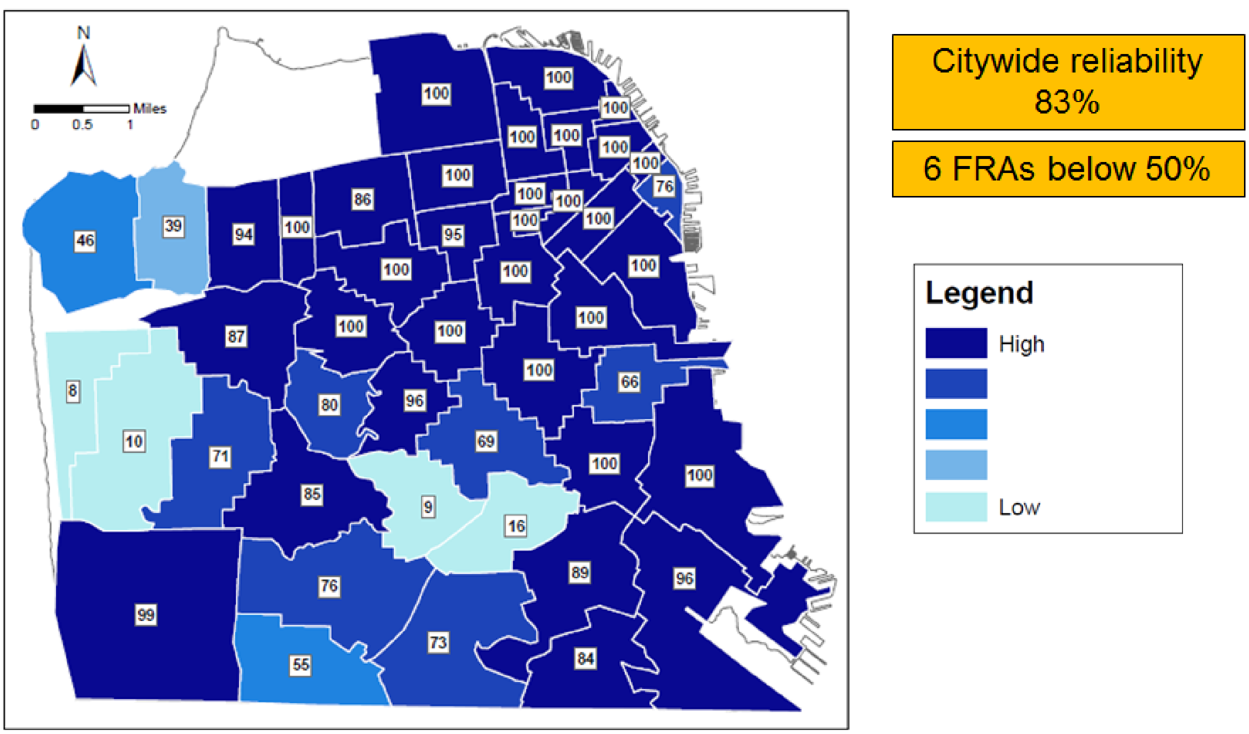


Figure 31 Reliability Scores after Current ESER 2014 Spending Plan without Sunset Pipeline

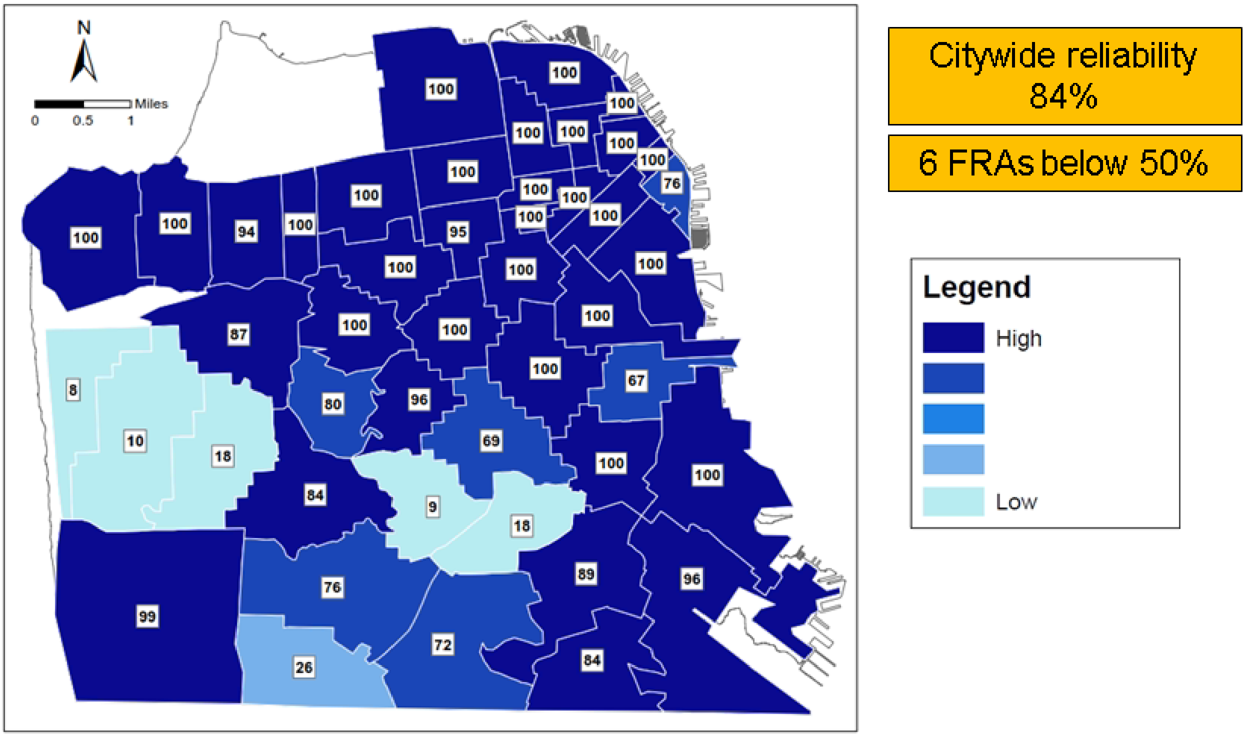


Figure 32 Reliability Scores after ESER 2014 with Richmond Extension Option 1

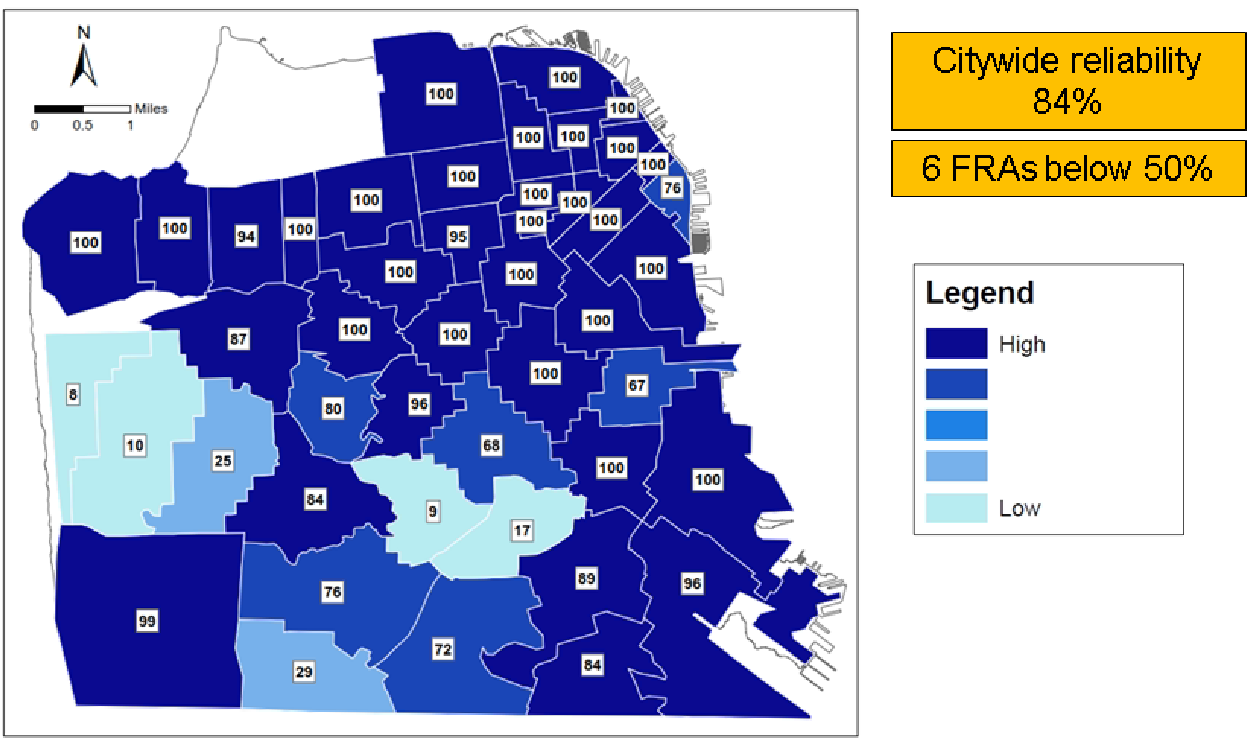


Figure 33 Reliability Scores after ESER 2014 with Richmond Extension Option 2

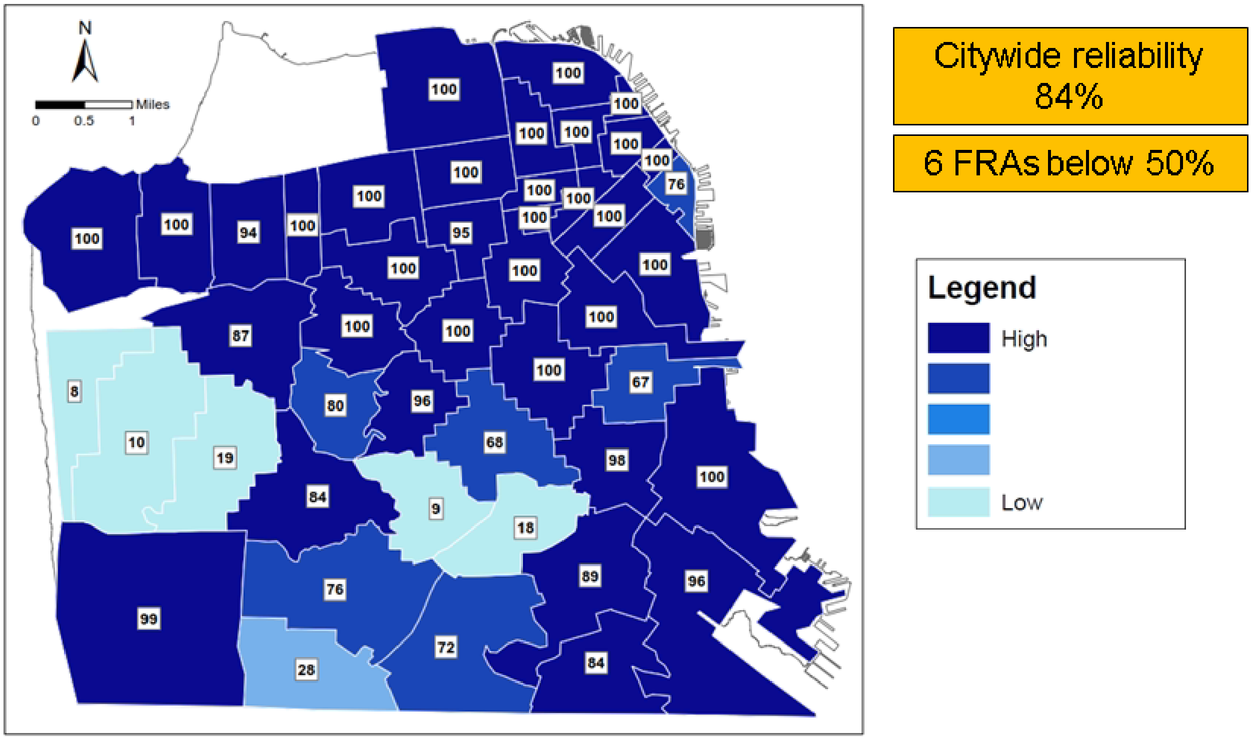


Figure 34 Reliability Scores after ESER 2014 with Richmond Extension Option 3

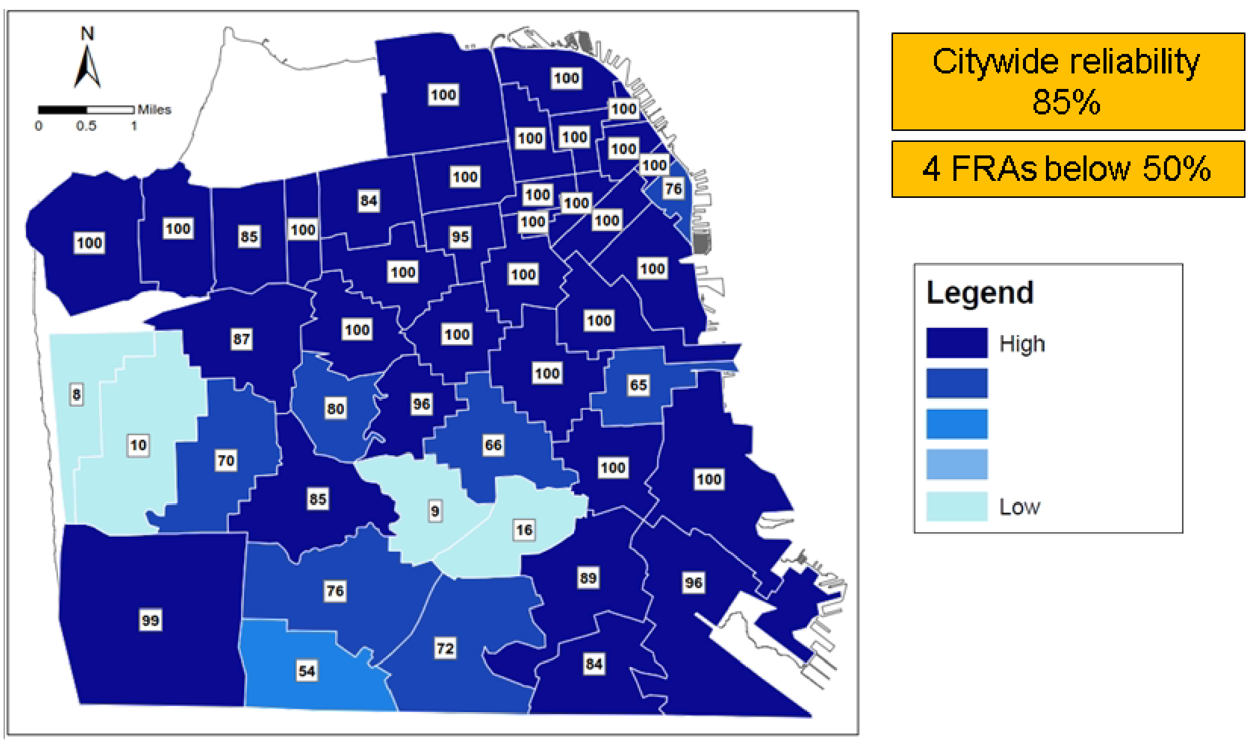


Figure 35 Reliability Scores after ESER 2014 with Richmond Extension Option 4

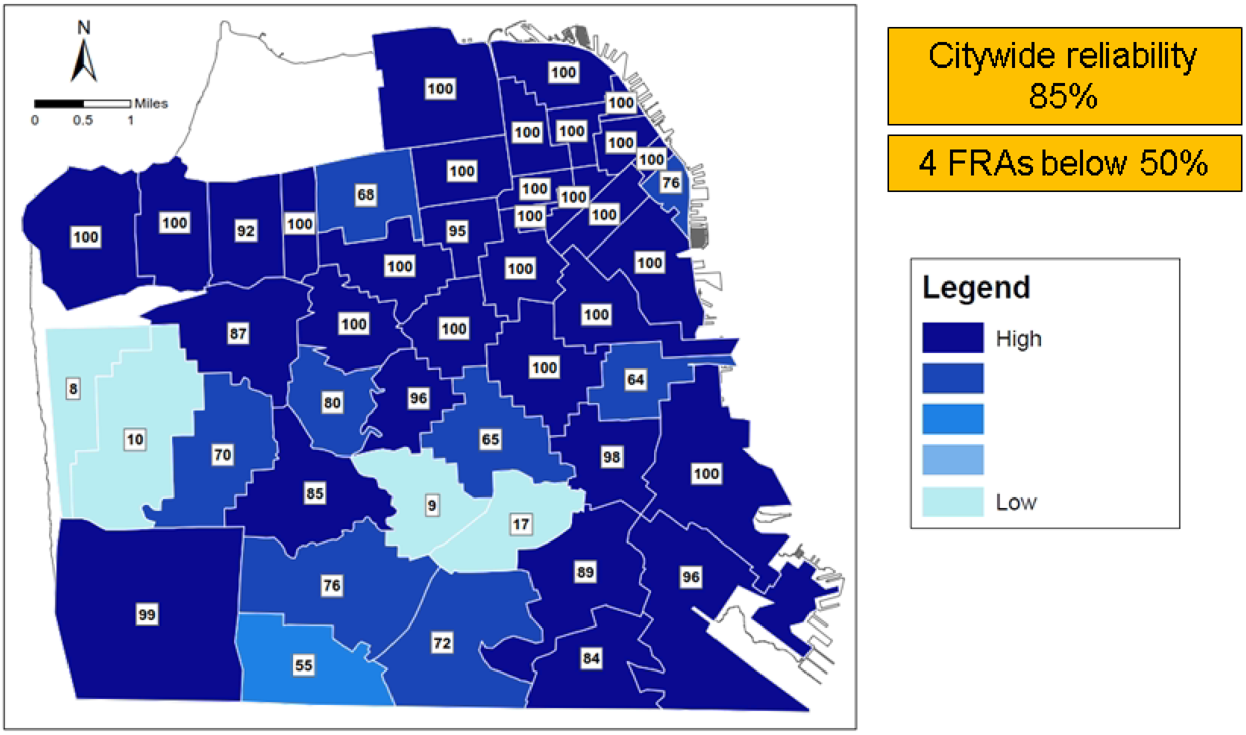


Figure 36 Reliability Scores after ESER 2014 with Richmond Extension Option 5

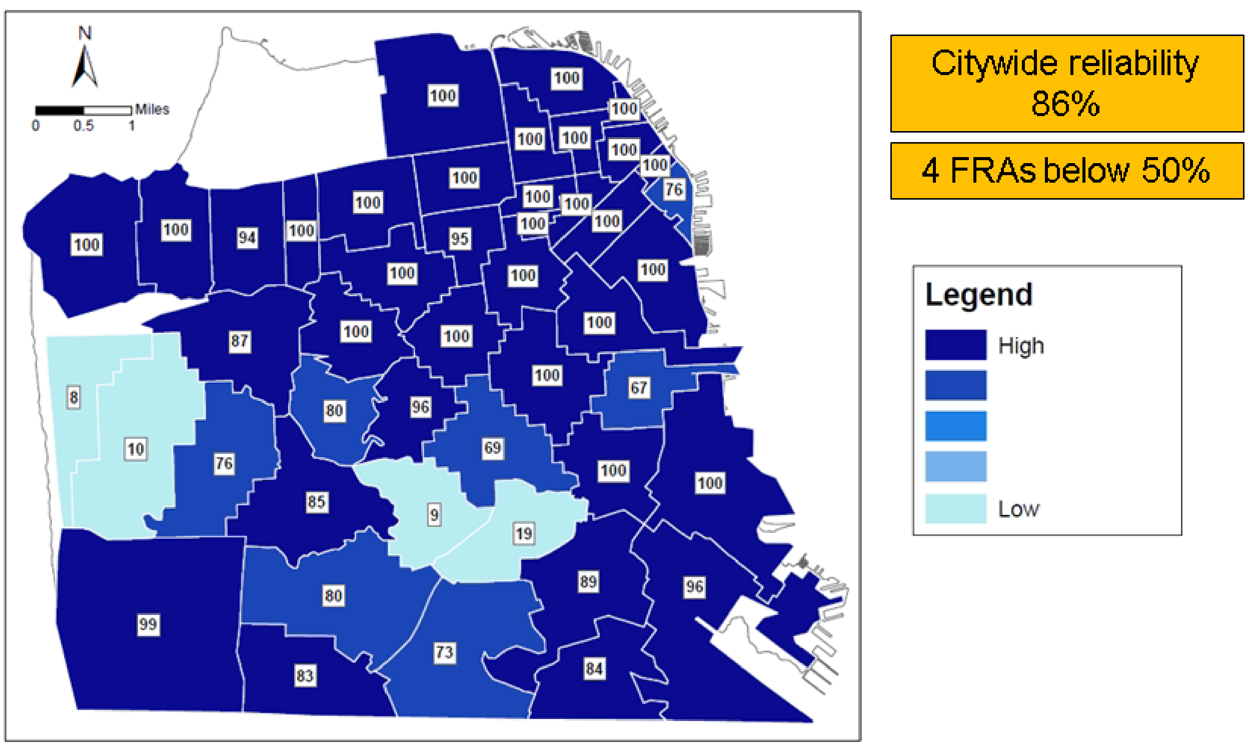


Figure 37 Reliability Scores after ESER 2014 with Richmond Extension Option 6

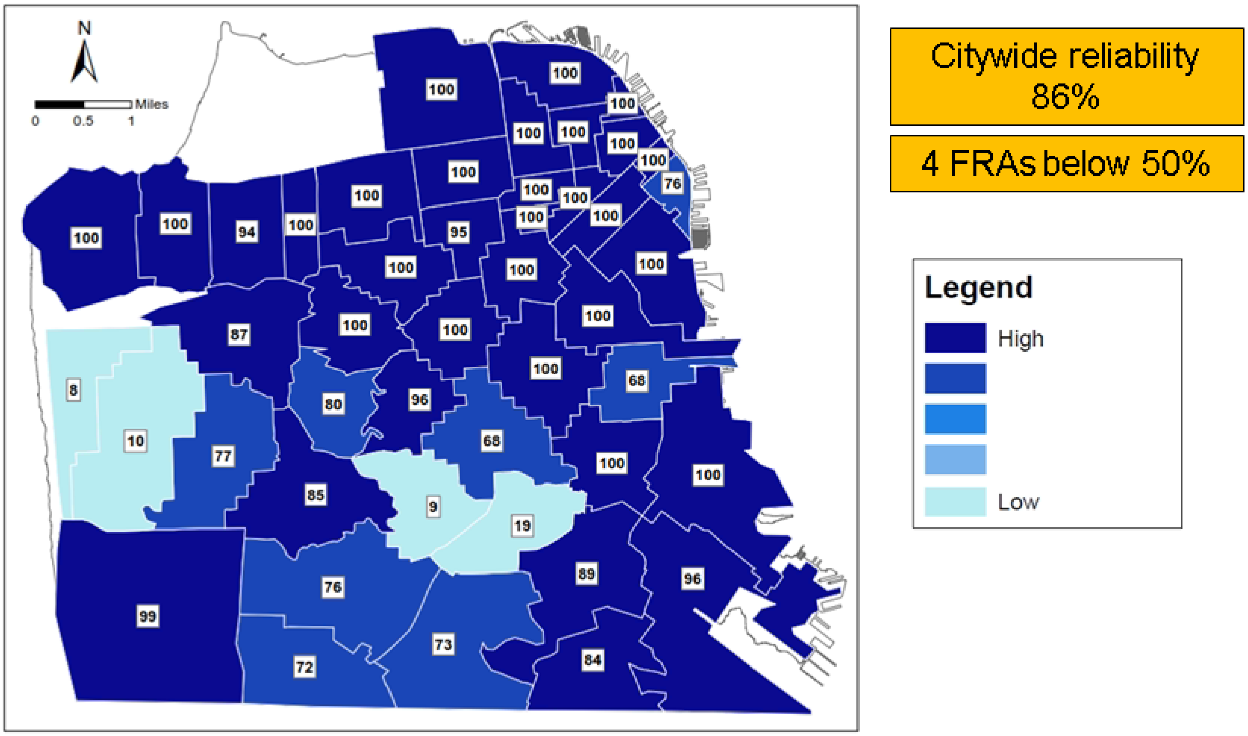


Figure 38 Reliability Scores after ESER 2014 with Richmond Extension Option 7

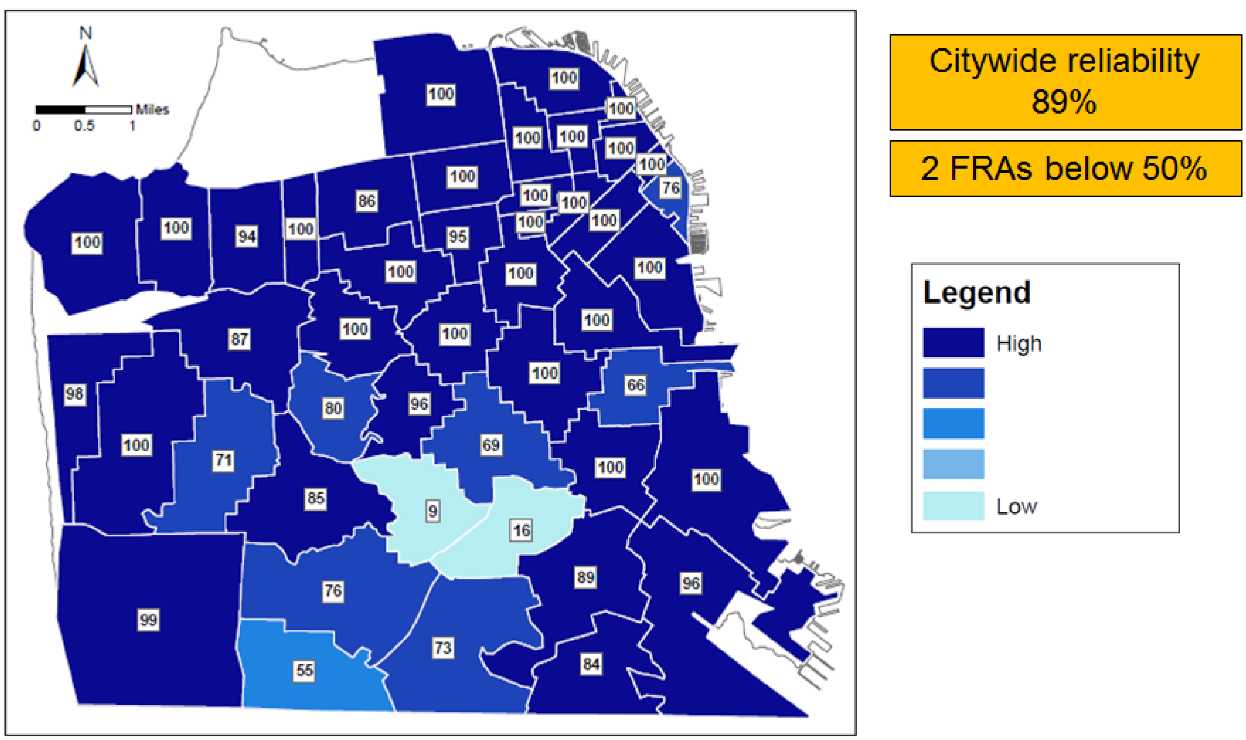


Figure 39 Reliability Scores after ESER 2014 with Richmond Extension Options 8 through 12

Appendix B – Reliability Score Methodology

4.0 Model Development

4.1 AWSS GIRAFFE Model

The original AWSS model was provided to AECOM/AGS JV by SFPUC in the SynerGEE platform. Details of the model calibration and conversion to EPANET are provided in Appendix A (Task 8a – Hydraulic Model Review and Calibration Plan) and Appendix B (Task 8b – Hydraulic Modeling Work Plan). Due to the nature of the result output from GIRAFFE, the scoring mechanism across the High Pressure System (HPS), cisterns, alternate water sources, and suction connections would be a mixture of connectivity and serviceability. This would result in a reliability score that is an index of AWSS performance. Therefore, the HPS was evaluated such that the serviceability could be determined, thereby making the HPS results compatible with those from the other water sources.

Because GIRAFFE generates an EPANET file that includes all of the damage before removing the pipe segments, the individual damage files were used to evaluate the performance of the HPS in EPANET. The same random seed was used for each model run to ensure a fair comparison between the damage states. However, some variation occurred when evaluating the alternatives because there are additional and different pipe segments in them. The following steps were taken to determine the available flow at each node.

1.) The damaged system was simulated in EPANET and all demand nodes that had negative pressures were identified.
2.) The demands at the negative pressure demand nodes were systematically decreased (by 10 – 20% each time) until either the demand node pressure was no longer negative or the demand had become zero.
3.) The damaged system was re-simulated with the updated demands and remaining negative pressures in the pipe system were identified.
4.) Every demand node was again systematically decreased until no negative pressures remained.[7]
5.) It was noted that in some cases, some small negative pressures still remained in the system and were not sensitive to the decreasing demands (either elevation issues or system end points with leaks nearby). These negative pressures were kept under the assumption that such a condition would cause that portion of the system to be isolated.

Following this iterative process, the amount of water the system was able to supply at each demand node with a positive pressure became the available supply. This was then used to

[7] For the Existing Condition, the nodes were decreased by zone, as the pressure zones were isolated. However, from 2010 Bond forward, the entire system was decreased together.

calculate the serviceability (i.e., amount of water available divided by the original nodal demand). This process was repeated for each case (Existing, 2010 Bond, Alternative A, Alternative B, and Alternative C) for each of the 15 damage scenarios.

The model was also run in SynerGEE and GIRAFFE with no damage to determine the consistency between the two platforms. Table 4-1 shows the results of the comparison. As can be seen, the connectivity in GIRAFFE is higher than that of SynerGEE. This is likely due to the nature of GIRAFFE removing the sections of pipe with negative pressure, resulting in a more reliable system. However, when comparing between SynerGEE and the unmodified system in EPANET, the connectivities are the same.

Table 4-1. SynerGEE and GIRAFFE Comparison

Model	Connectivity
SynerGEE	0.54
EPANET	0.54
GIRAFFE	0.59

4.2 Cistern, Suction Connection and Alternative Water Source Modules

The modules developed to analyze the reliability and benefits of the cisterns, suction connections, and alternative water sources in existing and future conditions are described in this section. The entire stochastic set of fire demands was used to evaluate the reliability of the cisterns, suction connections, and alternate water sources. GIS was first used to attribute to each city block the total number of cistern, suction connection, or alternate water sources available to it based on an assumed hose distance. A water source was assumed to be available to each block if it fell within reach of this hose distance from the actual location of the water source. In addition, for cisterns, the total cistern volume (i.e., the sum of the cistern volumes that are available to the particular block) for each city block was determined. Scripts were written using the R language to analyze the data.

For cisterns, the maximum capacity for each block (determined as the product of the number of available cisterns to that block and the capacity of a fire engine) was available only if both the total cistern volume divided by the smaller of the demand and the maximum capacity exceeded a selected time threshold, which was 30 minutes for this project. This criteria was determined by assuming that cisterns with too low of a volume would not be effectively used by the SFFD.

For suction connections and alternate water sources, the flow available to each block was the product of the number of water sources available to the block and the assumed engine capacity.

4.2.1 Module Assumptions

Table 4-2 shows the assumptions used in the cistern, suction connection, and alternate water sources modules.

Table 4-2. Cistern, Suction Connection, and Alternate Water Source Assumptions

Module	Assumptions
Cisterns	1. Assume need 60 minutes of flow to "handle" fire at demand 2. Use suppressed 60 minute demand 3. Use "Manhattan distance" for hose distance = 707 ft 4. Apply fragility rates for brick vs. concrete and firm soil vs. infirm area (see Table 3-10) 5. Assume each fire engine can pump 1500 gpm 6. Assign volume of cistern to hose distance buffer area. 7. Assume one cistern noted as concrete is the same as reinforced concrete for this analysis
Suction Connections	1. Assume unending volume at 1500 gpm per connection 2. Assume same buffer distance as cisterns (707 ft) 3. Use suppressed 60 minute demand
Alternative Water Sources	1. Assume unending supply 2. Assume engine at 1500 gpm each with radius of 707 ft from suction location 3. Assume locations as vetted with SFFD

Based on the material and whether or not a cistern was located in an infirm zone, a fragility factor was applied to the available volume of the cistern, as shown in Table 4-3. Although no records to date have shown a cistern failing after an earthquake, this approach was considered to be conservative and appropriate for this study.

Table 4-3. Cistern Fragility Factors

	In Infirm Area?	
Material	**Yes**	**No**
Reinforced Concrete	0.8	0.95
Brick	0.6	0.8

4.2.2 Module Demands

The block by block set of 1000 demands at the 60 minute time period were applied to these modules. These demands were adjusted for fire suppression.

4.2.3 Module Scoring

The amount of water supplied from each source was tabulated by taking the average water capacity from a water source over the 1000 demand iterations. These capacities were then added with the HPS capacity and divided by the average of the 3rd quintile demands for each FRA to determine the FRA serviceability. Serviceability for the HPS using EPANET, the cistern, suction connection, and alternative water sources were determined for each FRA and then averaged for a city-wide average with equal weight given to each FRA.

Table 4-4. Scoring Types

System Component	Scoring System	Description
HPS	Serviceability	Amount of water available to the demand node
Cisterns	Serviceability	Amount of water available to the block versus requested demand at that block aggregated to the FRA level
Suction Connections	Serviceability	
Alternate Water Sources	Serviceability	

4.3 PWSS

The PWSS was not explicitly modeled in this work and its impact on the AWSS has not been reflected in the reliability scores. However, some analysis was performed to determine the benefits of the PWSS to the overall capacity of the AWSS. The following potential PWSS contributions are as follows:

- Access to infirm zone demands: due to the isolation of the infirm zones, any fire within them would not normally be met through the HPS. By using the PWSS, these areas could potentially be served with water.
- Reaching fires far from the HPS: even with the pipeline extensions, the reach of the fire engines are still fairly restricted. Therefore, to reach any potential fires that are further from the pipeline, the PWSS can be employed.

2014 Alternative Source Water Supply Summary, gpm					
FRA	Cisterns	Flexible	Alternative	Suction	Total
1	90		18	0	108
2	78		0	0	78
3	267		0	0	267
4	237		86	0	323
5	50		0	0	50
6	158		0	0	158
7	179		0	0	179
8	71		0	0	71
9	254		0	0	254
10	288		0	0	288
11	132		0	0	132
12	11		0	162	173
13	264		0	0	264
14	806		0	0	806
15	317		0	0	317
16	0		0	0	0
17	137		0	0	137
18	236		21	0	257
20	450		36	0	486
21	1052		0	0	1052
23	200		0	0	200
24	915		0	0	915
25	495		0	0	495
26	299		0	0	299
27	756		0	0	756
28	800		0	0	800
29	141		0	0	141
30	491		0	317	808
31	434		8	0	442
32	422		0	0	422
33	111		0	0	111
34	399		635	0	1034
35	1169		0	0	1169
36	168		0	0	168
37	515		647	0	1162
38	734		0	0	734
39	6		0	117	123
40	585		0	9	594
41	932		0	0	932
42	941		0	0	941
43	614		0	0	614
44	1854		0	41	1895
45	887		81	107	1075
46	251		0	246	497
47	350		0	0	350
48	119		0	47	166

Appendix C – Hydraulic Modeling Methodology and Summary of Results

Hydraulic Modeling Methodology and Summary of Results

Due to the complexity of assessing the system reliability score used to evaluate adequate LOS performance, the planning work has used the unbroken hydraulic model for initial option screening and development due to the relative speed of the analysis and simplicity in making changes. This appendix describes the unbroken system hydraulic modeling methodology and results used in this initial screening.

The methodology used for option screening and development in the demand driven unbroken model is set as follows:

1. Full FRA demand is set at each node in the piped system
2. Hydraulic model is run
3. Residual pressure is reported for each demand node

The hydraulic model was run in a demand driven mode, applying the full FRA demand to each node and evaluating the residual pressure. A minimum residual pressure of 60 psi for each demand node was used for initial screening. In previous modeling results this residual pressure has been shown to reflect adequate performance in the subsequent reliability score modeling in the “broken” system. Project implementation will verify the system components needed to supply pressures similar to the existing AWSS and as approved by SFFD.

As the options are developed and the hydraulic system is modified, the changes may impact any node in the system. Providing service to new FRA’s can potentially compromise water supply to other FRA’s so the residual pressure at each demand node was monitored for adequate residual pressure.

The hydraulic model was also run in a pressure driven mode that allows the hydraulic model to determine how much supply can be provided at each demand node with a fixed node discharge pressure. This information has been provided for node discharge pressures of 60 psi and 0 psi. The 0 psi pressure residual was run to understand the behavior of the hydraulic system and show the maximum water supply available at each demand node.

Table 10 provides the residual pressure results for FRAs 13, 18, 20, 34, and 37 for all options and provides a comparison to the results from the post ESER 2010 and post ESER 2014 scenarios. **Table 11** provides the pressure driven model results at with the node pressure set at 60 psi and the maximum supply capped at the FRA demands. The pressure driven model has also been run at 0 psi node pressure with the water supply not capped. The water supply at each node for this condition is shown in **Table 12**. Appendix H includes a summary of the available flow and pressure from the uncapped pressure driven model for each FRA.

The unbroken hydraulic model results show that the residual pressures for the base option are less than zero for FRAs 34 and 37. The residual pressure for FRA 13 is less than 60 psi in Options 1 through 3 and the residual pressure for FRA 38 is less than 60 psi in Option 4.

An inline booster pump is provided for Options 6 and 7 to bring a new water source to the Twin Peaks zone. A higher dynamic head is required for the booster pump located at Lake Merced compared to Sunset Reservoir, because Lake Merced is both at a lower elevation and further away from the Richmond District. The pumping capacity required for these facilities depend on the number of FRAs served.

The Summit Reservoir was also considered initially as a potential new water supply booster to the Twin Peaks area to augment the Richmond AWSS Extension project. However, concerns were raised about a booster pump at this location due to its high elevation that could lead to potential pressure issues and pipe damage in downstream sections. This option was not modeled or considered further.

Based on the hydraulic modeling results from the demand driven unbroken model, Options 5 through 12 provide EFWS to the Richmond District (FRAs 34 and 37) without negatively impacting FRAs 13 or 38.

Since options 1 through 7 only expand the existing AWSS into FRAs 34 and 37 in the Richmond District, additional water supply still need to be introduced to FRAs 18 and 20 to improve the reliability scores to meet the city-wide LOS objective. **Figure 40** shows a potential pipeline alignment concept that provides a gravity feed potable water pipe from the Sunset Reservoir into the Sunset District. The concept alignment serves FRA 18 and the western part of FRA 20 where elevations are considerably lower than the Sunset Reservoir. With FRA demands modeled at these end points, preliminary modeling results indicate that the Sunset Reservoir is capable of providing the full FRA demands for FRAs 18 and 20 at the end points with residual pressures greater than 60 psi. It should be noted that 60 psi would not achievable within all parts of FRA 20, especially at the higher elevations closer to the reservoir with a gravity feed system.

The option shown in Figure 40 is consists of approximately 13,000 feet of pipe. Assuming construction using ERDIP and spacing of hydrants and valves similar to the AWSS pipeline the proposed pipeline would have an estimated capital cost of $23.4 million. This cost would be in addition to the AWSS costs for Options 1 through 7. Further evaluation would be required to compare the added reliability of this gravity-fed potable pipeline versus the pressure boosted options.

Sensitivity analyses were performed using the unbroken hydraulic model to evaluate the impact of two assumptions. The detailed results are included below. The evaluation reviewed the impact of increasing the pipe diameter on one of the options that did not have residual pressures above 60 psi, and the impact of modifications of the friction factor, as would be experience over time, from a Hazen-Williams factor of 130 (for new ductile iron pipe) to 100 (for older ductile iron pipe. The results for the residual pressures in the demand driven model are summarized in **Table 13**. The results for the pressure driven model are summarized in **Table 14**.

The results for the same cases in the reliability score model are described in Section 5 and shown in detail in Appendix E.

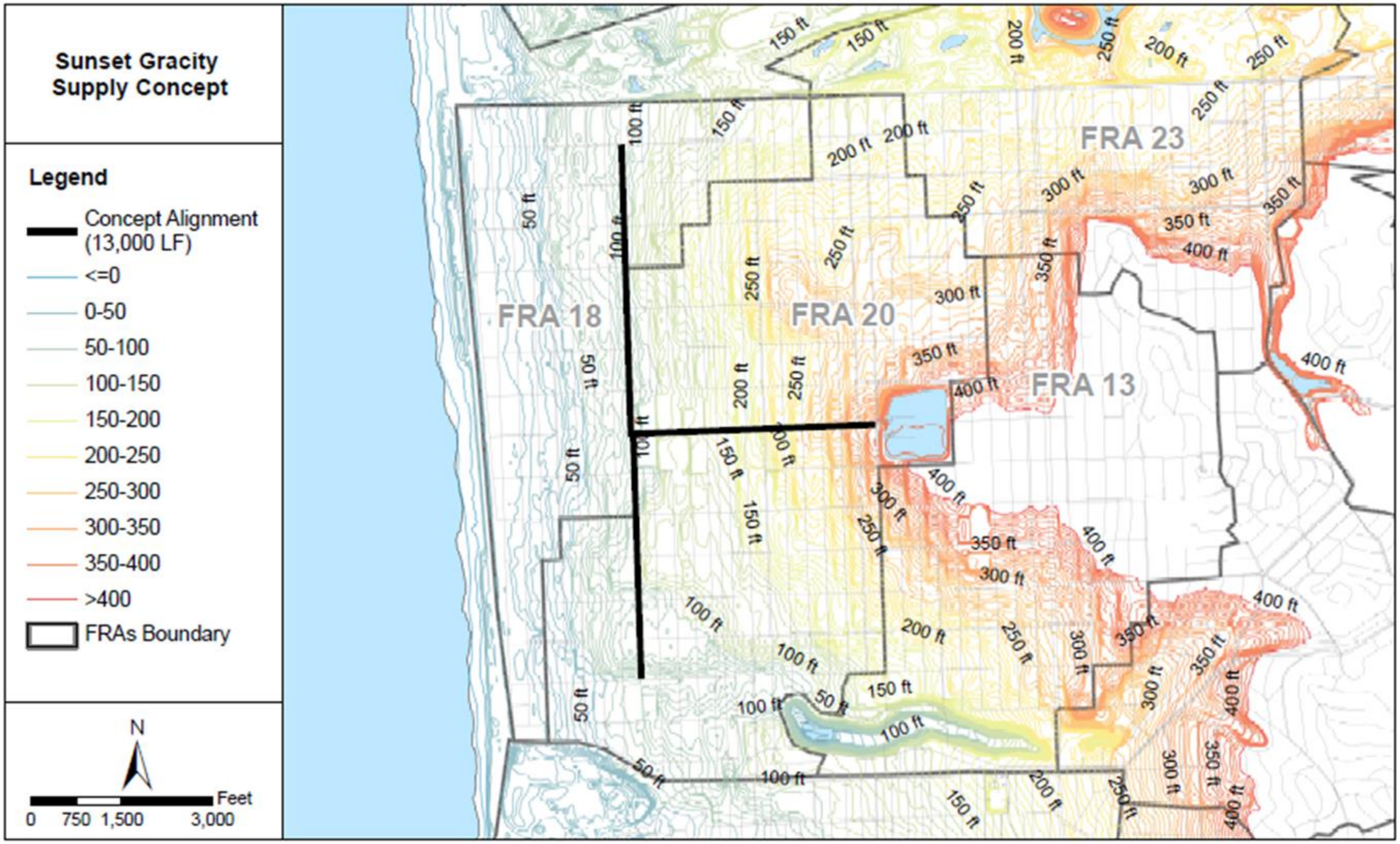


Figure 40 Concept of Sunset Gravity Supply to FRAs 18 and 20.

Table 10 Demand Driven Unbroken Hydraulic Model Results Showing Residual Pressure for all Options

Option ID		Post ESER 2010	Post ESER 2014	Base	1	2	3	4	5	6	7	8	9	10	11	12
FRA ID	**Location**	**Residual Pressure (psi)**														
13	Inner Parkside	-	91	91	24	45	51	91	91	67	94	91	91	91	91	91
18	Sunset	-	-	-	-	-	-	-	-	-	-	195	195	200	222	238
20		-	-	-	-	-	-	-	-	-	-	180	180	146	155	165
34	Outer Richmond	-	-	-44	128	162	168	79	138	174	191	137	175	85	123	137
37		-	-	-34	141	171	178	70	129	160	176	159	164	159	204	217
38	Presidio Heights	>60	>60	>60	72	93	102	30	72	105	116	79	79	79	79	77
Highlight indicates residual pressure is less than the 60 psi modeling goal																

Table 11 Pressure Driven Unbroken Model Results for 60 PSI Residual (capped at FRA demand)

Option ID		FRA Demand gpm	Post ESER 2010	Post ESER 2014	Base	1	2	3	4	5	6	7	8	9	10	11	12
FRA ID	**Location**		**Water Supplied (gpm) at 60 psi Pressure (Capped at FRA demand)**														
13	Inner Parkside	3745	0	1271	1271	0	0	0	1271	1271	2839	3551	1271	1271	1271	1271	1271
18	Sunset	3124	-	-	-	-	-	-	-	-	-	-	3124	3124	3124	3124	3124
20		4720	-	-	-	-	-	-	-	-	-	-	4720	4720	4720	4720	4720
34	Outer Richmond	2271	-	-	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271
37		2944	-	-	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944
38	Presidio Heights	2695	2401	2614	1568	2695	2695	2695	2695	2248	2695	2695	2614	2614	2614	2614	2614

Table 12 Pressure Driven Unbroken Model Results for 0 PSI Residual (not capped at FRA demand)

Option ID		FRA Demand gpm	Post ESER 2010	Post ESER 2014	Base	1	2	3	4	5	6	7	8	9	10	11	12
FRA ID	**Location**		**Water Supplied (gpm) at 60 psi Pressure**														
13	Inner Parkside	3745	0	1705	1706	0	0	0	1705	1706	1136	4798	1706	1706	1706	1706	1706
18	Sunset	3124	-	-	-	-	-	-	-	-	-	-	7653	7563	7653	7724	9243
20		4720	-	-	-	-	-	-	-	-	-	-	7547	7549	7547	8469	7923
34	Outer Richmond	2271	-	-	3034	8472	4513	5095	3681	8472	1345	1345	4199	4202	4199	7193	7650
37		2944	-	-	2400	4700	0	4653	3187	3997	1817	1817	4641	4635	4641	7670	8081
38	Presidio Heights	2695	0	1026	0	772	1866	973	0	0	873	1011	1026	1026	1026	1026	1026

Table 13 Sensitivity Analyses Results in Unbroken Demand Driven Model

Option ID		FRA Demand	3	3a[1]	5	5a[2]
FRA ID	Location	Residual Pressure (psi)				
13	Inner Parkside	3745	51	52	91	91
18	Sunset	3124	-		-	
20		4720	-		-	
34	Outer Richmond	2271	168	183	138	129
37		2944	178	174	129	120
38	Presidio Heights	2695	102	105	72	65

1. Sensitivity performed in Option 3a by utilizing 24-inch diameter Ductile Iron Pipe instead of the 20-inch diameter pipe used in the same layout for Option 3. No significant differences were noted in the residual pressures.
2. Sensitivity analysis performed in Option 5a by utilizing a Hazen-Williams C factor of 100 in Option 5a versus the factor of 130 used in Option 5. C=130 is typically used for new ductile iron pipe and C=100 would reflect aged ductile iron pipe. No significant differences were noted in the residual pressures.

Table 14 Sensitivity Analysis Results in Unbroken Pressure Driven Model at 0 psi (uncapped)

Option ID		FRA Demand gpm	3	3a[1]	5	5a[2]
FRA ID	Location		Water Supplied (gpm) at 60 psi Pressure			
13	Inner Parkside	3745	0	0	1706	1706
18	Sunset	3124	-	0	-	0
20		4720	-	0	-	0
34	Outer Richmond	2271	5095	5428	8472	3797
37		2944	4653	5022	3997	3344
38	Presidio Heights	2695	973	1300	0	0

1. Sensitivity performed in Option 3a by utilizing 24-inch diameter Ductile Iron Pipe instead of the 20-inch diameter pipe used in the same layout for Option 3. While differences were noted in the water supplied they did not change whether the option met or did not meet the FRA demand.
2. Sensitivity analysis performed in Option 5a by utilizing a Hazen-Williams C factor of 100 in Option 5a versus the factor of 130 used in Option 5. C=130 is typically used for new ductile iron pipe and C=100 would reflect aged ductile iron pipe. While differences were noted in the water supplied they did not change whether the option met or did not meet the FRA demand.

Appendix D – Option Hydraulic Modeling Results

D.Base Option – AWSS with 2 Connections

The base option for AWSS extension to the Richmond District is shown in **Figure 41**. Hydraulic modeling results indicate that the base option does not provide adequate water to satisfy the demands from FRAs 34 and 37 in the Richmond District with adequate residual pressures, see **Table 15 and Figure 42.** In the figure the pressure at each node is indicated by color. As shown, in the demand driven model, the demands in the Richmond District cause negative residual pressures for the new demands as well as demand nodes on the adjacent AWSS.

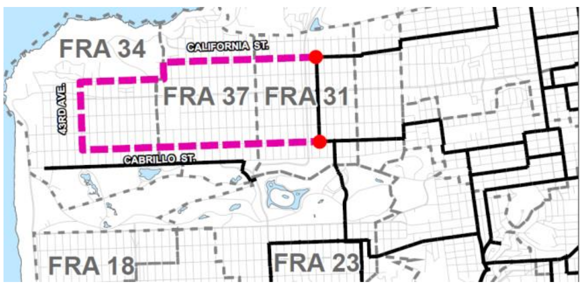


Figure 41 Richmond AWSS Extension Base Option Alignment

Table 15 Base Richmond Option Residual Pressures

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
34	325	Vista Del Mar (west of Outer Richmond)	-44
37	185	Outer Richmond	-34

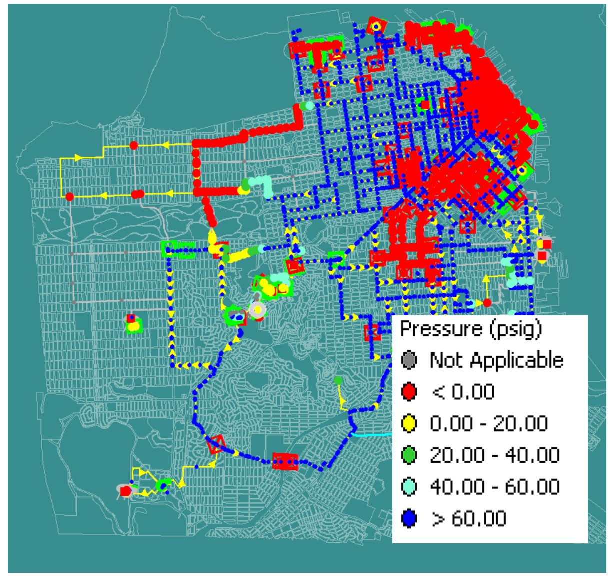


Figure 42 Residual Pressures for AWSS Richmond AWSS Loop

Table 16 shows that using a pressure driven model, with a 60 psi residual pressure, the system can meet the full system demands in FRAs 34 and 37 but in doing so reduces the supply to FRA 38. The performance at FRA 13 is unchanged from the Post 2014 condition (supplies 68% of demand in the unbroken system).

Table 16 Base Richmond Option Pressure Driven Model Results

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	1271
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	1568

The calculated reliability scores for the Base Option (see Appendix A) show significant reduction in reliability scores of FRAs 31 and 38 by half of their original reliability scores from post ESER 2014 conditions, below the City's LOS objective.

D.1 Option 1 - AWSS with 3 Connections

Due to the residual pressures achieved in the base option, a variety of potential system modifications were evaluated using the hydraulic model. **Figure 43** shows Option 1 that includes the addition of a connection from the south via a crossover from 19th Avenue in the Sunset District and the Twin Peaks zone.

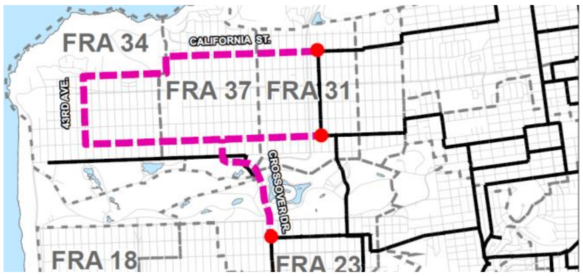


Figure 43 Option 1: AWSS Extension with Crossover Connection from Sunset District

The crossover provided sufficient flow to the Richmond District FRA demands but caused lower residual pressures within FRA 13. **Figure 44** and **Table 17** show the modeled impact on the existing AWSS pipeline in FRA 13 from an unbroken model run, where the residual pressure at Inner Parkside falls below the performance criteria of 60 psi.

Table 17 Richmond Loop with Crossover Residual Pressures

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	24.1
34	325	Vista Del Mar (west of Outer Richmond)	127.7
37	185	Outer Richmond	140.8
38	10329	Inner Richmond	72

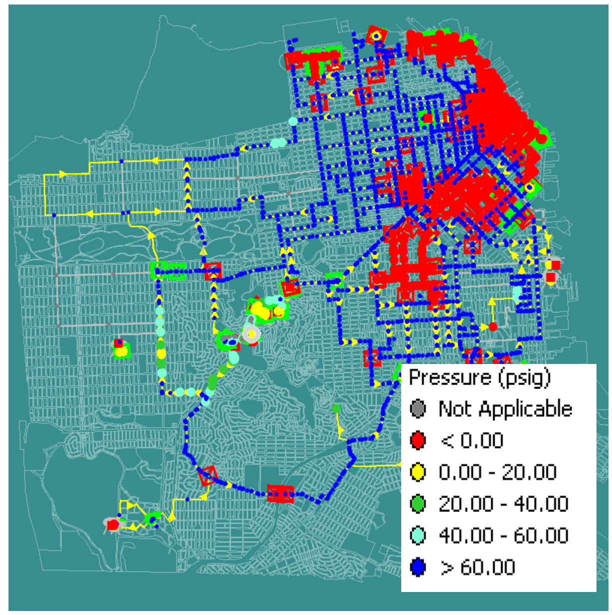


Figure 44 Residual Pressures for Option 1: Richmond AWSS Extension and Crossover

Option 1 with the crossover does not meet the hydraulic performance standards at all demand nodes.

Table 18 shows the water available at the nodes with a 60 psi residual.

The calculated reliability scores for Option 1 (see Appendix A) show significant reduction in reliability scores of FRAs 1 and 13 to levels below the LOS objective.

Table 18 Option 1 Pressure Driven Model Results

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	0
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	2695

D.2 Option 2 - AWSS with 10 Connections: Additional AWSS around Laurel Heights, Limited AWSS on Geary Blvd with Crossover

Several different combinations of AWSS connections within Laurel Heights were tested while developing Option 2 to achieve the best possible hydraulic performance in FRA 13, 34, and 37 while limiting the new AWSS pipeline length along Geary Blvd, considering that it is a major thoroughfare for the area. **Figure 45** shows Option 2, each red circle indicates a connection point with the existing AWSS.

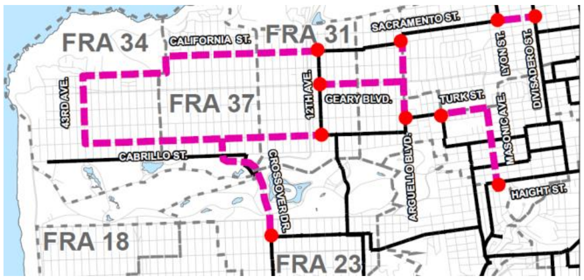


Figure 45. Option 2 - AWSS with 10 Connections

Figure 46 and **Table 19** show the residual pressure at FRAs 13, 34 and 37 with the Richmond AWSS Extension and additional AWSS connections across Laurel Heights. The additional AWSS connections provide a better gridded pipe system in the Ashbury zone. The residual pressure in FRA 13 dropped from 91 psi to 45 psi. Since Option 2 reduces the residual pressure at the FRA 13 node to less than the performance criteria of 60 psi, this option does not meet the hydraulic criteria. **Table 20** shows the water supply available at the nodes with a 60 psi residual.

Table 19 Residual Pressures for Option 2

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	45.1
34	No325	Vista Del Mar (west of Outer Richmond)	162.2
37	No185	Outer Richmond	171.4
38	10329	Inner Richmond	93

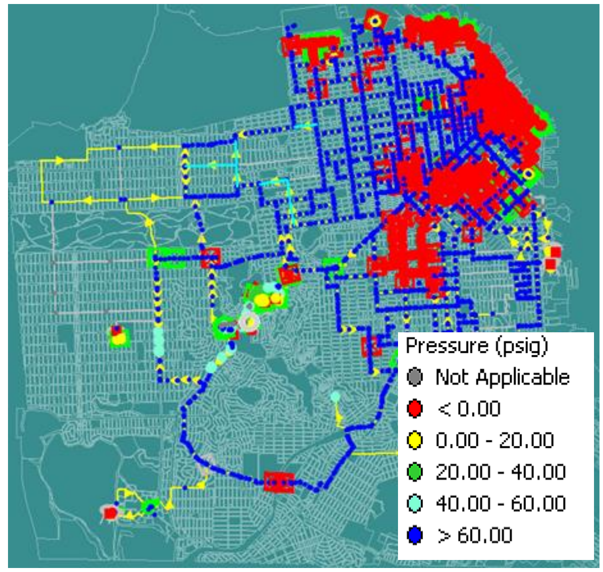


Figure 46 Residual Pressures for Option 2

The reliability scores for Option 2 (see Appendix A) show significant reduction in reliability scores of FRAs 1 and 13 to levels below the LOS objective.

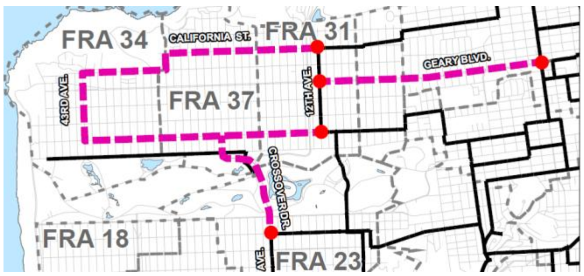
Table 20 Option 2 Pressure Driven Model Results

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	0
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	2695

D.3 Option 3 - AWSS with 5 Connections: Additional AWSS around Laurel Heights, Full Use of Geary Blvd with Crossover

Option 3 provides a similar expansion in hydraulic capacity through the Ashbury zone as Option 2, using a single connection through Geary Boulevard instead of multiple main connections. Though Geary Boulevard is a major street, the new connection improves the conveyance with a straight alignment and less new pipe length. **Figure 47** shows Option 3, each red circle indicates a connection point with the existing AWSS.

Figure 47 Option 3 - AWSS with 5 Connections



with Crossover

Figure 48 and **Table 21** summarize the residual pressures from this option. The residual pressure in FRA 13 dropped from 91 psi to 51 psi. Since Option 3 reduces the residual pressure at the FRA 13 node to less than the performance target of 60 psi, the pressure driven model was run. The pressure driven model results show that no water supply is achieved at the FRA 13 node at 60 psi, so this option does not meet the unbroken system hydraulic performance criteria.

Table 21 Residual Pressures for Option 3

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	51.4
34	325	Vista Del Mar (west of Outer Richmond)	167.9
37	185	Outer Richmond	177.9
38	10329	Inner Richmond	102

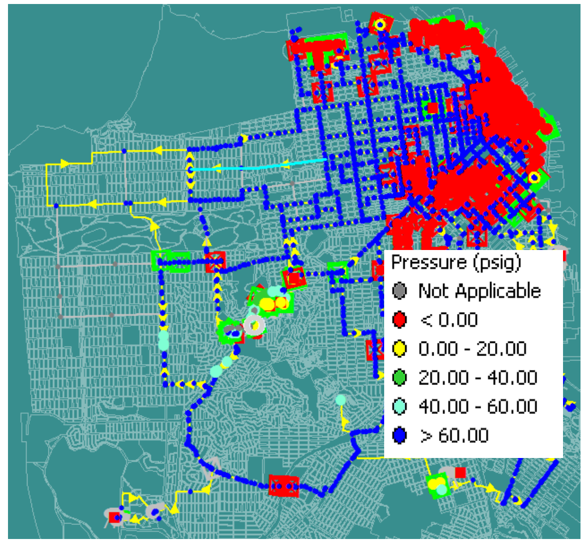


Figure 48 Residual Pressures from Option 3

The reliability scores for Option 3 (see Appendix A) show significant reduction in reliability scores of FRAs 1 and 13 to levels below the LOS objective.

Table 22 shows the water available at the nodes with a 60 psi residual.

Table 22 Option 3 Pressure Driven Model Results

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	0
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	2695

D.4 Option 4 - AWSS with 9 Connections: Additional AWSS around Laurel Heights, Limited AWSS on Geary Blvd without Crossover

Option 4 includes the same layout as Option 2 without the crossover. **Figure 49** shows the layout, each red circle indicates a connection point with the existing AWSS. **Figure 50** and **Table 23** show the hydraulic modeling results.

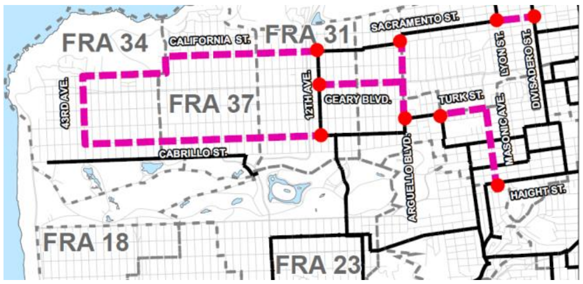


Figure 49 Option 4 AWSS with 9 Connections (Similar to Option 2 with Cross Over removed)

The residual pressure for FRA 38 drops below the 60 psi criteria, therefore this option does not meet the hydraulic performance criteria. The reliability scores for Option 4 shows slight reduction in reliability scores of FRAs 31 and 38 however they remain above levels of the LOS objective.

Table 23 Residual Pressures for Option 4 (Option 2 with no cross over)

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	1271
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	2695

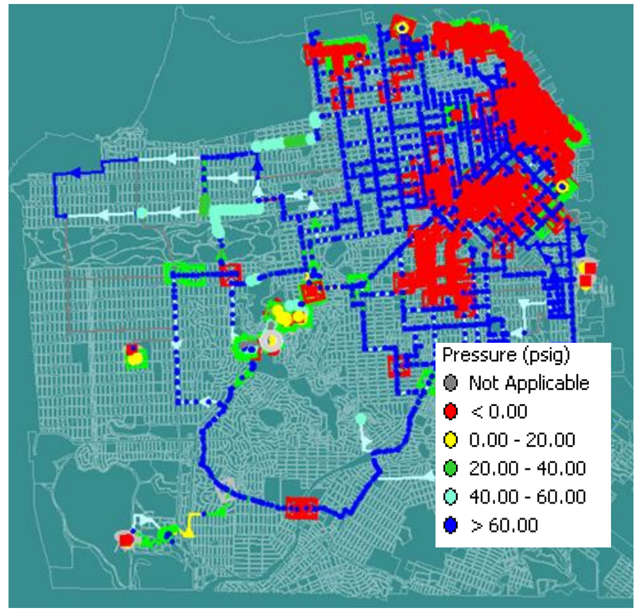


Figure 50 Residual Pressures for Option 4

Table 24 shows the water available at the nodes with a 60 psi residual.

Table 24 Option 4 Pressure Driven Model Results

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
34	392	Vista Del Mar (west of Outer Richmond)	79
37	363	Outer Richmond	70
38	10329	Inner Richmond	30

D.5 Option 5 - AWSS with 4 Connections: Additional AWSS around Laurel Heights, Full Use of Geary Blvd without Crossover

Option 5 includes all elements of Option 4 except with the crossover from the south removed. **Figure 51** shows the layout, each red circle indicates a connection point with the existing AWSS. **Figure 52** and **Table 25** show the hydraulic modeling results for Option 5.

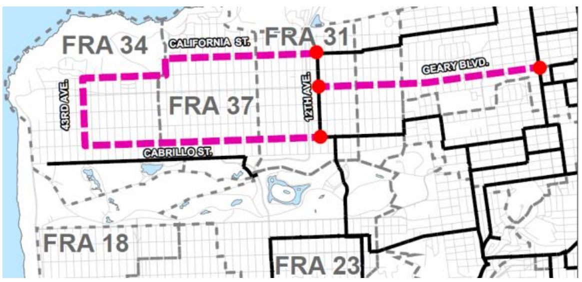


Figure 51 Option 5 AWSS with 4 Connections

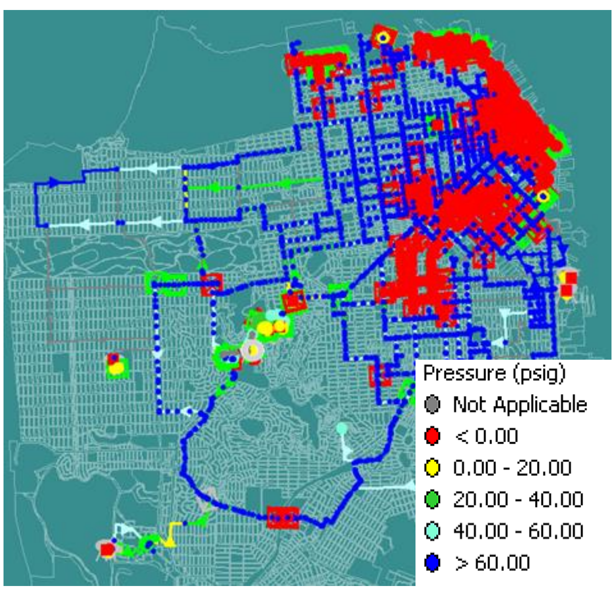


Figure 52 Residual Pressures from Option 5

Table 25 Residual Pressures for Option 5

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
34	No392	Vista Del Mar (west of Outer Richmond)	138
37	No363	Outer Richmond	129
38	10329	Inner Richmond	72

This option meets the unbroken system hydraulic criteria. The reliability scores for Option 5 (see Appendix A) show a slight reduction in reliability scores of FRA 38 however they remain above the LOS objective.

Table 26 shows the water available at the nodes with a 60 psi residual.

Table 26 Option 5 Pressure Driven Model Results

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	1271
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	2248

D.6 Option 6 - AWSS with 4 Connections and Lake Merced Pump

Option 6 uses Lake Merced as a potential water source by installing an inline booster pump at the connection point between the Ingleside Pipeline project and Park Merced AWSS network. The pump output at this location is modeled at 15,000 gpm at 250 psi. At the same time, the division gate between Ingleside Pipeline and Ocean Avenue AWSS is opened to allow this booster pump to deliver water into the Twin Peaks zone. In order to take full advantage of this additional supply from Park Merced to the Twin Peaks zone, the division gates on both sides of I-280 are closed so that water from Lake Merced does not pass beyond I-280. **Figure 53** shows Option 6.

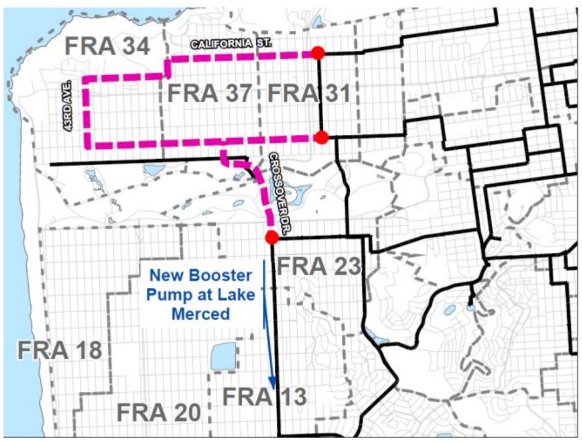


Figure 53 Option 6 – AWSS with 4 Connections and Lake Merced Pump

As shown in **Figure 54** and **Table 27**, the residual pressures in FRAs 13, 34 and 37 were all above 60 psi. Although it meets the performance criteria the residual pressure for FRA 13 was reduced from 91 psi to 67 psi. **Table 28** shows the water available at the nodes with a 60 psi residual.

However, this option requires the construction of the Ingleside Project, the Lake Merced Pump Station improvements and the Park Merced AWSS mains that are currently planned to be developer constructed and funded. The Ingleside Project is currently planned to be constructed in at least two phases, the initial phase is recommended to be included in the ESER 2014 projects.

Since construction of these projects would be dependent on the developer and potential future funding the timing is unknown. If a method can be found to accelerate the construction, the schedule uncertainty could be reduced.

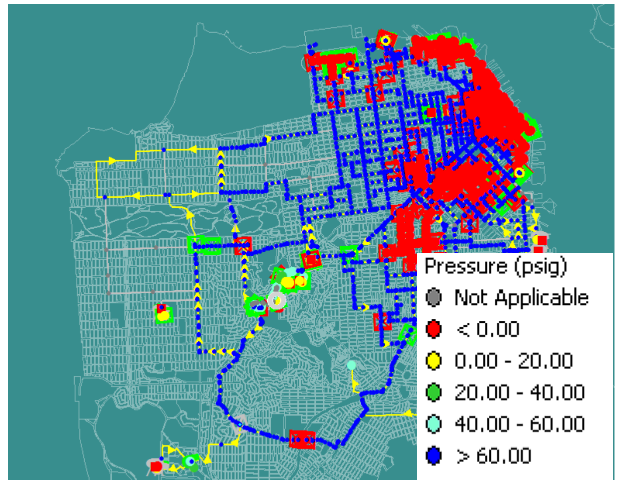


Figure 54 Residual Pressures from Option 6

The reliability scores for option 6 (see Appendix A) show that performance of FRAs 13 and 38 were kept at post ESER 2014 level (above the LOS objective).

Table 27 Residual Pressures for Option 6

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	67
34	325	Vista Del Mar (west of Outer Richmond)	174
37	185	Outer Richmond	160
38	10329	Presidio Heights	105

Table 28 Option 6 Pressure Driven Model Results

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	2839
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	2695

D.7 Option 7 - AWSS with 4 Connections and Sunset Pump

Sunset Reservoir provides another potential supply opportunity for future EFWS in the western part of San Francisco. Option 7 assessed the hydraulic performance of connecting Sunset Reservoir to the non-potable AWSS (assuming an air gap for cross connection control) with an inline booster pump. **Figure 55** shows Option 7, each red circle indicates a connection point with the existing AWSS.

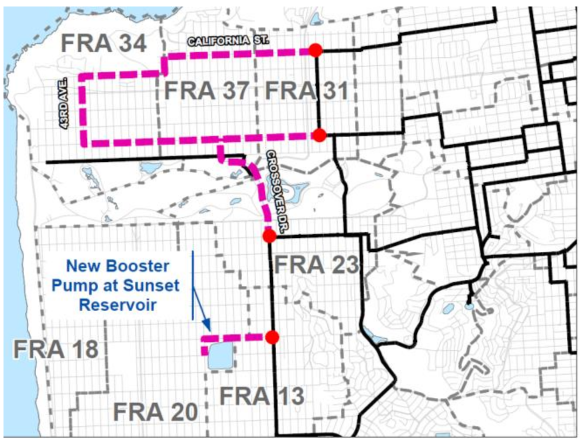


Figure 55 Option 7 - AWSS with 4 Connections and Sunset Pump

Figure 56 and **Table 29** indicate that the Sunset Reservoir supply can increase the residual pressure at FRA 13 to above 90 psi with a booster pump discharge of 7,500 gpm at 150 psi. This water supply reduces the impact of additional demands from FRAs 34 and 37 on the Twin Peaks zone. The demands in FRAs 34 and 37 are met without compromising the residual pressure in FRA 13. **Table 30** shows the water available at the nodes with a 60 psi residual.

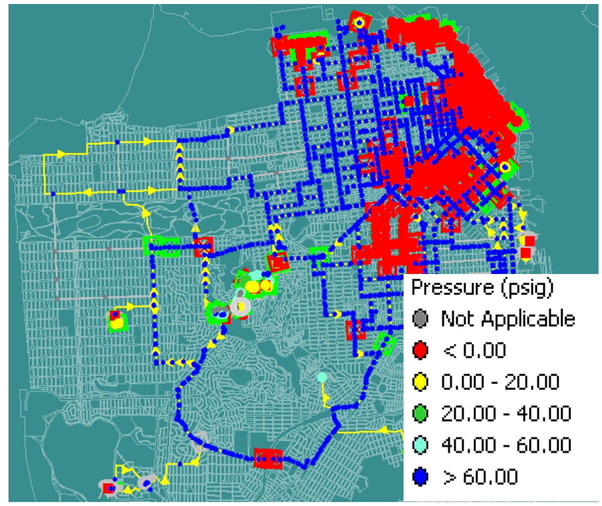


Figure 56 Residual Pressures from Option 7

Table 29 Residual Pressures for Option 7

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	94
34	325	Vista Del Mar (west of Outer Richmond)	191
37	185	Outer Richmond	176
38	10329	Presidio Heights	116

The reliability scores for option 7 (see Appendix A) show that FRAs 13 and 38 were kept at post ESER 2014 levels (meeting the LOS objectives).

Table 30 Option 7 Pressure Driven Model Results

FRA ID	Node ID	Location	Water Supplied at 60 psi (gpm)
13	1870	Inner Parkside	3551
34	325	Vista Del Mar (west of Outer Richmond)	2271
37	185	Outer Richmond	2944
38	10329	Presidio Heights	2695

Options 8 through 12 utilize the other approach to supply water to the Richmond District to eliminate the impact of the Richmond AWSS Extension on the existing AWSS. The Potable AWSS approach utilizes a dual purpose pipeline that is independent from the existing AWSS network, which would be used as a potable water transmission line in normal daily operations and provide fire water supply under emergency conditions. Providing water to FRAs 34 and 37 with a Potable AWSS line does not rely on water supply from existing AWSS water sources so it does not impact the residual pressures in the AWSS.

D.8 Option 8 – Potable AWSS (22,200 LF Pipe)

Option 8 is shown in **Figure 57.**

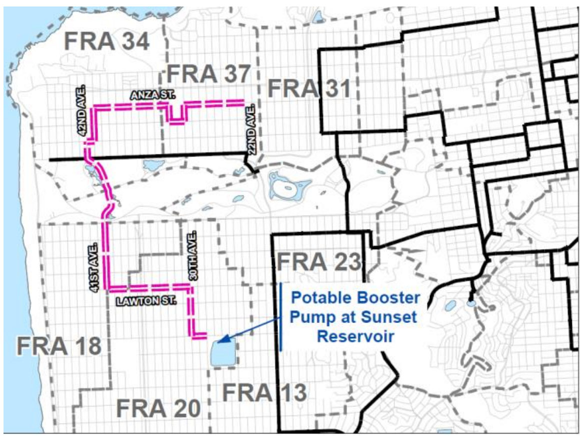


Figure 57 Option 8 – Potable AWSS (22,200 LF Pipe)

Figure 58 and **Table 31** summarize the hydraulic results from the Sunset Pipeline that includes 22,200 LF of pipeline that serves both the Sunset and Richmond areas. The project includes an inline booster pump station set at 150 psi while the total flow is determined by the FRA demands from the four FRAs inside the Sunset and Richmond Districts. The total FRA demands of Sunset and Richmond Area FRAs that are not served by existing AWSS are 7,935 gpm and 5,215 gpm respectively. Therefore, the minimum flow capacity of the new booster pump is 13,150 gpm. The demands of FRAs 34 and 37 are met without compromising the residual pressures in the AWSS. This option also meets the demands in FRAs 18 and 20 in the Sunset District that are also currently unserved by the AWSS high pressure system.

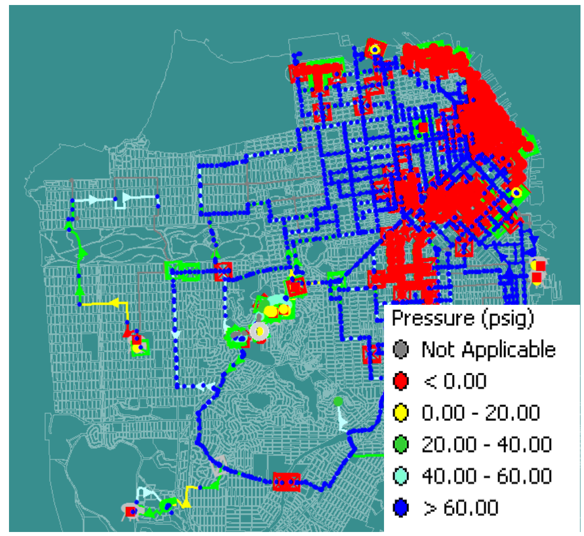


Figure 58 Residual Pressures from Option 8

Table 31 Residual Pressures for Option 8

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
18	327	Outer Sunset	195
20	389	Outer Sunset	180
34	325	Vista Del Mar (west of Outer Richmond)	137
37	185	Outer Richmond	159
38	10329	Presidio Heights	79

Options 8 through 12 meet the demands of FRAs 34 and 37 without compromising the AWSS. These options also meet the demands in FRAs 18 and 20 in the Sunset District that are also currently unserved by the AWSS high pressure system.

There was no methodology identified during CS-199 to assess the reliability scores for Potable AWSS. The pipeline reliability is assumed to be very high since it will be constructed to AWSS standards. Other reliability factors could be applied to the other key system features such as the pumps and motorized valves. For this reason this report assumes 90% reliability for the water supply provided by Potable AWSS. Other water sources (cisterns etc.) are also available in certain FRAs and these are added to the Potable AWSS supply for calculation of the reliability score. Further analysis and refinements may be made to the reliability scoring.

This report also assumes equal reliability for each of the Potable AWSS options even though the options provide different area coverages. The reliability scores for the areas of the City served by AWSS for Options 8 through 12 are identical and are shown in **Figure 59**. Options 8 through 12 meet the LOS objectives.

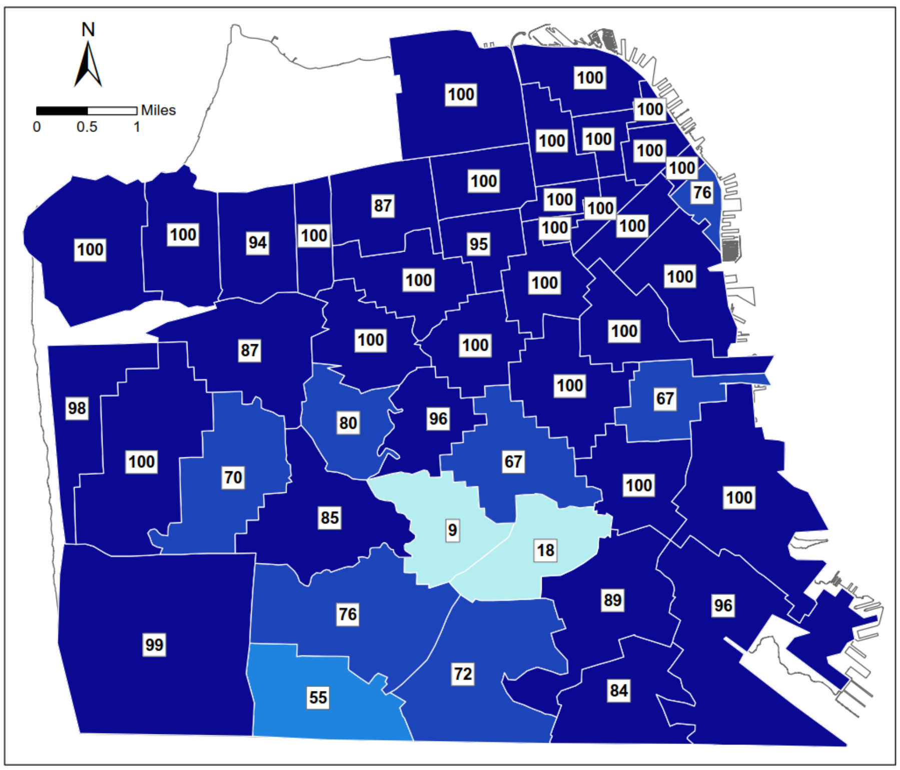


Figure 59 Reliability Scores for Options 8 through 12

D.9 Option 9 - Potable AWSS (37,500 LF Pipe)

Similar to Option 8, Option 9 connects a dual use potable pipeline to the Sunset Reservoir in the western portion of San Francisco. Instead of building a single pipeline connecting in the Richmond District, this option includes a potable water system loop following an alignment similar to the Richmond AWSS Extension. **Figure 60** shows Option 9.

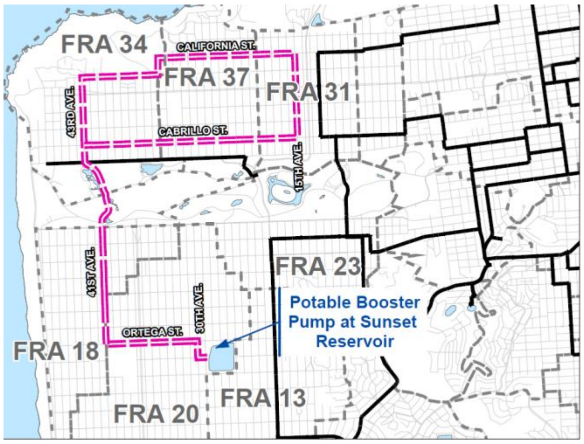


Figure 60 Option 9 - Potable AWSS (37,500 LF Pipe)

Figure 61 and **Table 32** summarize the hydraulic results from this variant of the Sunset Pipeline project. With the same pump used in Option 8, the additional loop provides larger conveyance capacity in the Richmond area, resulting in slightly higher pressures in the Richmond area. The demands of FRAs 34 and 37 are met without compromising the residual pressures in the AWSS. This option also meets the demands in FRAs 18 and 20 in the Sunset District that are also currently unserved by the AWSS high pressure system. The extended pipeline provides additional benefits to the Richmond District than Option 8 by providing better area coverage to the FRAs.

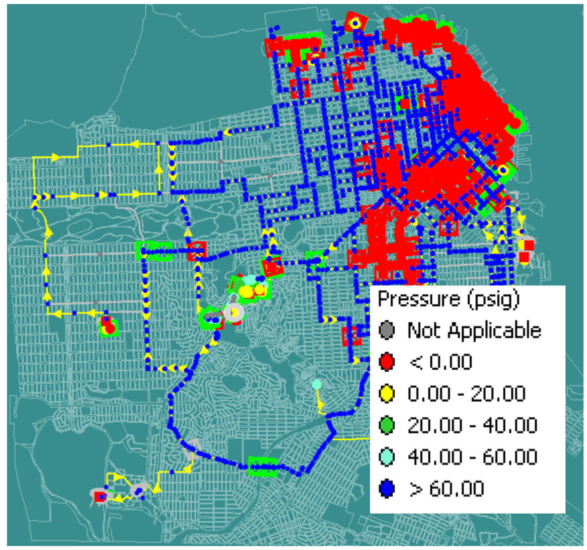


Figure 61 Residual Pressures from Option 9

Table 32 Residual Pressures for Option 9

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
18	327	Outer Sunset	195
20	389	Outer Sunset	180
34	325	Vista Del Mar (west of Outer Richmond)	175
37	185	Outer Richmond	164
38	10329	Presidio Heights	79

D.10 Option 10 – Potable AWSS (23,600 LF Pipe)

Option 10 includes a similar route as Option 8 but is extended further east and includes a branch extended north towards the VA Hospital. The total length of Potable AWSS pipe is 23,600 LF and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi. **Figure 62** shows Option 10.

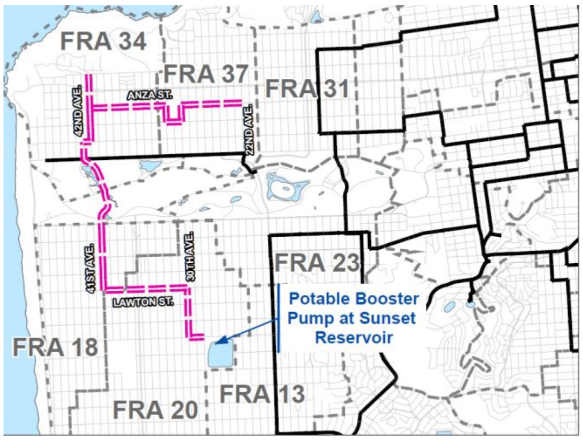


Figure 62 Option 10 – Potable AWSS Branching (23,600 LF Pipe)

Figure 63 and **Table 33** summarize the hydraulic results from this variant of the Sunset Pipeline project. With the same pump used in Options 8 and 9, the additional pipeline provides additional coverage into areas in the Richmond District. The demands of FRAs 34 and 37 are met without compromising the residual pressures in the AWSS. This option also meets the demands in FRAs 18 and 20 in the Sunset District that are also currently unserved by the AWSS high pressure system. The extended pipeline provides additional benefits to the Richmond District, but less than Option 9, by providing better area coverage to the FRAs.

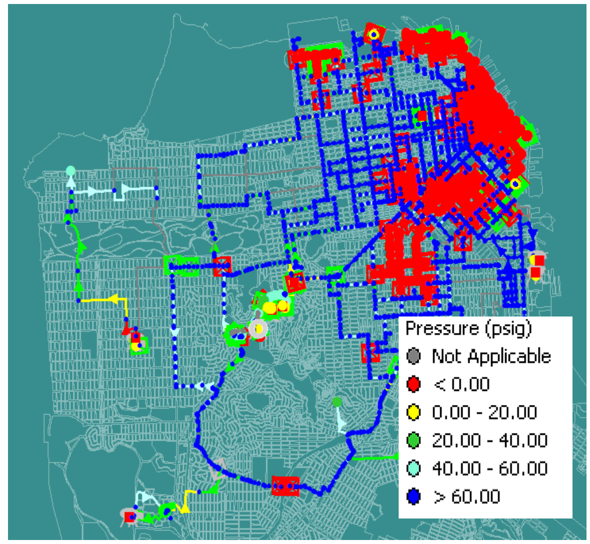


Figure 63 Residual Pressures from Option 10

Table 33 Residual Pressures for Option 10

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
18	332	Outer Sunset	200
20	394	Outer Sunset	146
34	392	Vista Del Mar (west of Outer Richmond)	85
37	363	Outer Richmond	159
38	10329	Presidio Heights	79

D.11 Option 11 – Potable AWSS Loop (37,900 LF Pipe)

Option 11 includes a route similar to Options 8 and 10 but includes a complete loop back to the supply point. The total length of Potable AWSS pipe is 37,900 LF and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi. **Figure 64** shows Option 11.

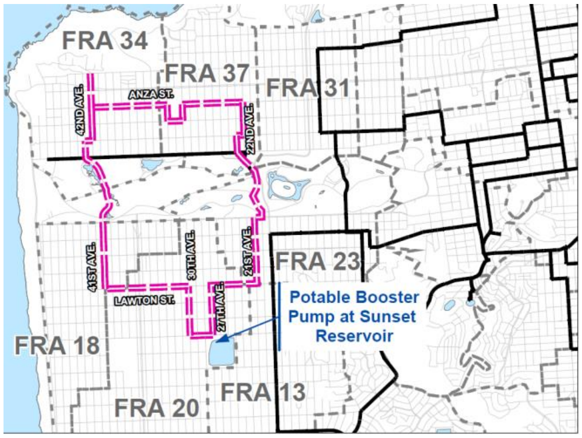


Figure 64 Option 11 – Potable AWSS Loop (37,900 LF Pipe)

Figure 65 and **Table 34** summarize the hydraulic results from this variant to the Sunset Pipeline project. With the same pump used in Options 8 through 10, the additional pipeline provides additional coverage into areas of the Richmond and Sunset Districts. The demands of FRAs 34 and 37 are met without compromising the residual pressures in the AWSS. This option also meets the demands in FRAs 18 and 20 in the Sunset District that are also currently unserved by the AWSS high pressure system. The looped system pipeline provides additional benefits to the Richmond District by providing better area coverage and resilience to the FRAs.

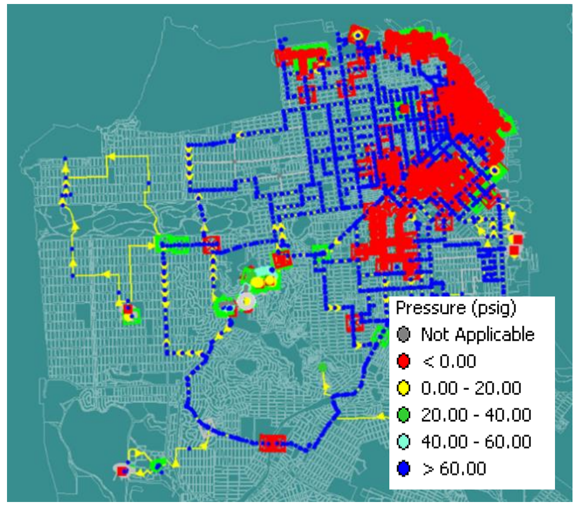


Figure 65 Residual Pressures for Option 11

Table 34 Residual Pressures for Option 11

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
18	332	Outer Sunset	222
20	394	Outer Sunset	155
34	392	Vista Del Mar (west of Outer Richmond)	123
37	363	Outer Richmond	204
38	10329	Presidio Heights	77

D.12 Option 12 – Potable AWSS with Two Loops

Option 12 includes a route similar to Option 11 but includes a second loop back to the supply point. The total length of Potable AWSS pipe is 51,500 LF and the option includes a booster pump station at the Sunset Reservoir. The booster pump capacity is 13,500 gpm at 150 psi. **Figure 66** shows Option 12.

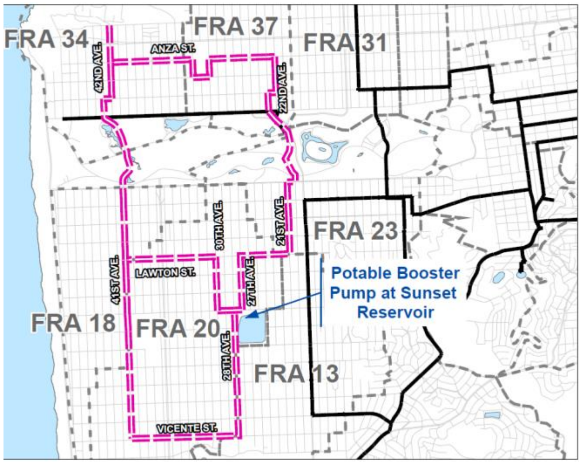


Figure 66 Option 12 – Potable AWSS Two Loop (51,500 LF Pipe)

Figure 67 and **Table 35** summarize the hydraulic results from this variant to the Sunset Pipeline project. With the same pump used in Options 8 through 11, the additional pipeline provides additional coverage into areas of the Richmond and Sunset Districts. The demands of FRAs 34 and 37 are met without compromising the residual pressures in the AWSS. This option also meets the demands in FRAs 18 and 20 in the Sunset District that are also currently unserved by the AWSS high pressure system. The looped system pipeline provides additional benefits to the Richmond District by providing better area coverage and resilience to the FRAs.

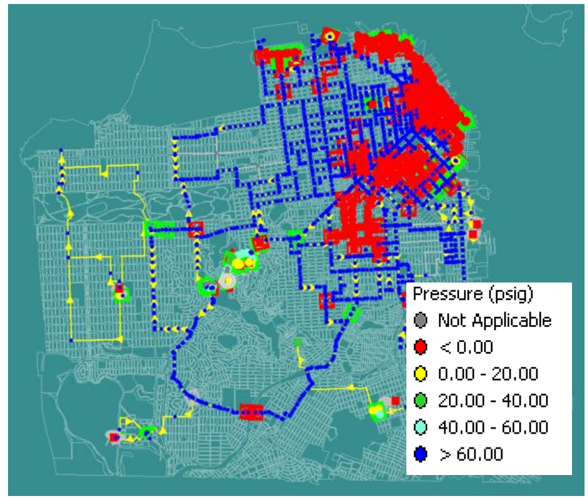


Figure 67 Residual Pressures for Option 12

Table 35 Residual Pressures for Option 12 Modeled at original demand locations

FRA ID	Node ID	Location	Residual Pressure (psi)
13	1870	Inner Parkside	91
18	332	Outer Sunset	238
20	394	Outer Sunset	165
34	392	Vista Del Mar (west of Outer Richmond)	137
37	363	Outer Richmond	217
38	10329	Presidio Heights	77

Appendix E – Sensitivity Analysis Detailed Results

Sensitivity Analysis Results in Reliability Scores																			
Option ID		Post ESER 2010	Post ESER 2014	Base	1	2	3	3a[1]	4	5	5a[2]	6	7	8	9	10	11	12
FRA ID	Location	Reliability Score %																	
13	Inner Parkside	27	70	70	18	25	19	18	70	70	72	76	77	70	70	70	70	70
18	Sunset	8	8	8	8	8	8	8	8	8	8	8	8	98	98	98	98	98
20		10	10	10	10	10	10	10	10	10	10	10	10	100	100	100	100	100
31	Inner Richmond	82	94	42	94	94	94	94	85	92	91	94	94	94	94	94	94	94
34	Outer Richmond	46	46	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
37		39	39	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
38	Presidio Heights	78	87	52	100	100	100	100	84	68	64	100	100	87	87	87	87	87

Blue highlight indicates a drop in reliability score from previous options but still above the FRA target of 50%
Pink highlight indicates a LOS score less than the FRA target of 50%
1. Sensitivity performed in Option 3a by utilizing 24-inch diameter Ductile Iron Pipe instead of the 20-inch diameter pipe used in the same layout for Option 3. No significant differences were noted in the reliability scores.
2. Sensitivity analysis performed in Option 5a by utilizing a Hazen-Williams C factor of 100 in Option 5a versus the factor of 130 used in Option 5. C=130 is typically used for new ductile iron pipe and C=100 would reflect aged ductile iron pipe. No significant differences were noted in the reliability scores.

Pressure Driven Unbroken Model Results for 60 PSI Residual (capped at FRA demand)

Option ID		FRA Demand gpm	Post ESER 2010	Post ESER 2014	Base	1	2	3	3a	4	5	5a	6	7	8	9	10	11	12
FRA ID	Location		Water Supplied (gpm) at 60 psi Pressure (Capped at FRA demand)																
13	Inner Parkside	3745	0	1271	1271	0	0	0	0	1271	1271	1271	2839	3551	1271	1271	1271	1271	1271
18	Sunset	3124	-	-	-	-	-	-		-	-		-	-	3124	3124	3124	3124	3124
20		4720	-	-	-	-	-	-		-	-		-	-	4720	4720	4720	4720	4720
34	Richmond	2271	-	-	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271	2271
37		2944	-	-	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944	2944
38	Presidio Heights	2695	2401	2614	1568	2695	2695	2695	2695	2695	2248	2049	2695	2695	2614	2614	2614	2614	2614

Pressure Driven Unbroken Model Results for 0 PSI Residual (not capped at FRA demand)

Option ID		FRA Demand gpm	Post ESER 2010	Post ESER 2014	Base	1	2	3	3a	4	5	5a	6	7	8	9	10	11	12
FRA ID	Location		Water Supplied (gpm) at 60 psi Pressure																
13	Inner Parkside	3745	0	1705	1706	0	0	0	0	1705	1706	1706	1136	4798	1706	1706	1706	1706	1706
18	Sunset	3124	-	-	-	-	-	-	0	-	-	0	-	-	7653	7563	7653	7724	9243
20		4720	-	-	-	-	-	-	0	-	-	0	-	-	7547	7549	7547	8469	7923
34	Richmond	2271	-	-	3034	8472	4513	5095	5428	3681	8472	3797	1345	1345	4199	4202	4199	7193	7650
37		2944	-	-	2400	4700	0	4653	5022	3187	3997	3344	1817	1817	4641	4635	4641	7670	8081
38	Presidio Heights	2695	0	1026	0	772	1866	973	1300	0	0	0	873	1011	1026	1026	1026	1026	1026

Demand Driven Unbroken Model Results (Residual Pressure)

Option ID		FRA Demand	Post ESER 2010	Post ESER 2014	Base	1	2	3	3a	4	5	5a	6	7	8	9	10	11	12
FRA ID	Location	Residual Pressure (psi)																	
13	Inner Parkside	3745	-	91	91	24	45	51	52	91	91	91	67	94	91	91	91	91	91
18	Sunset	3124	-	-	-	-	-	-		-	-		-	-	195	195	200	222	238
20		4720	-	-	-	-	-	-		-	-		-	-	180	180	146	155	165
34	Richmond	2271	-	-	-44	128	162	168	183	79	138	129	174	191	137	175	85	123	137
37		2944	-	-	-34	141	171	178	174	70	129	120	160	176	159	164	159	204	217
38	Presidio Heights	2695	>60	>60	>60	72	93	102	105	30	72	65	105	116	79	79	79	79	77

Appendix F - Cost Estimating Detail

	LF of Pipe	No. of Hydrants	No. of Connections	No. of Seismic Connections	Booster Pump Station	Other Costs	Cost
Richmond Base Option	22800	46	2				$ 24,940,000
Richmond Option 1	28,000	56	3				$ 30,900,000
Richmond Option 2	43,500	87	10				$ 50,675,000
Richmond Option 3	37,100	74	5				$ 41,450,000
Richmond Option 4	38,400	77	10				$ 45,320,000
Richmond Option 5	32,000	64	5				$ 36,100,000
Richmond Option 6	28,000	56	3		a	$ 8,800,000	$ 52,700,000
Richmond Option 7	31,500	63	3		b		$ 40,575,000
Richmond Option 8	22,200	44		5	c		$ 35,310,000
Richmond Option 9	37,500	75		5	c		$ 51,375,000
Richmond Option 10	23,600	47		5	c		$ 36,780,000
Richmond Option 11	37,900	76		5	c		$ 51,795,000
Richmond Option 12	51,500	103		5	c		$ 66,075,000
Sunset Gravity Tee	13,000	26	0	1			$ 14,150,000

Booster PS	Booster PS Cost	Notes	Ingleside Project Cost
a	$ 13,000,000	15,000 gpm 250 psi	
b	$ 6,000,000	7,500 gpm 150 psi	
c	$ 9,500,000	13,500 gpm 150 psi	

Project Name	Capital Cost	Soft (25%)	Design contingency (10% of Capital Cost)	Contingency (30%)	Rounded Total
Richmond Base Option	$ 24,940,000	$ 6,235,000	$ 2,494,000	$ 7,482,000	$ 41,150,000
Richmond Option 1	$ 30,900,000	$ 7,725,000	$ 3,090,000	$ 9,270,000	$ 50,990,000
Richmond Option 2	$ 50,675,000	$ 12,668,750	$ 5,067,500	$ 15,202,500	$ 83,610,000
Richmond Option 3	$ 41,450,000	$ 10,362,500	$ 4,145,000	$ 12,435,000	$ 68,390,000
Richmond Option 4	$ 45,320,000	$ 11,330,000	$ 4,532,000	$ 13,596,000	$ 74,780,000
Richmond Option 5	$ 36,100,000	$ 9,025,000	$ 3,610,000	$ 10,830,000	$ 59,570,000
Richmond Option 6	$ 52,700,000	$ 13,175,000	$ 5,270,000	$ 15,810,000	$ 86,960,000
Richmond Option 7	$ 40,575,000	$ 10,143,750	$ 4,057,500	$ 12,172,500	$ 66,950,000
Richmond Option 8	$ 35,310,000	$ 8,827,500	$ 3,531,000	$ 10,593,000	$ 58,260,000
Richmond Option 9	$ 51,375,000	$ 12,843,750	$ 5,137,500	$ 15,412,500	$ 84,770,000
Richmond Option 10	$ 36,780,000	$ 9,195,000	$ 3,678,000	$ 11,034,000	$ 60,690,000
Richmond Option 11	$ 51,795,000	$ 12,948,750	$ 5,179,500	$ 15,538,500	$ 85,460,000
Richmond Option 12	$ 66,075,000	$ 16,518,750	$ 6,607,500	$ 19,822,500	$ 109,020,000
Sunset Gravity Tee	$ 14,150,000	$ 3,537,500	$ 1,415,000	$ 4,245,000	$ 23,350,000

American Association of Cost Engineering (AACE) Cost Estimate Classifications:

	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Notes:
[a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.
[b] If the range index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools.

Appendix G – Analytical Hierarchy Process

Analytic Hierarchy Process

The Analytical Hierarchy Process (AHP) is used for the evaluation of alternatives and the selection of a Preferred Program Alternative. AHP is a structured technique for organizing and analyzing complex decisions. Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goals and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem. AHP allows decision makers to represent and quantify its elements, relate those elements to overall goals, and evaluate alternatives.

The decision is broken into evaluation criteria, each of which can be analyzed independently. The decision makers systematically evaluate the various elements by comparing them to one another two at a time, with respect to their impact on the criteria. In making the comparisons, the decision makers use the available data and quantitative analysis but also their judgments about the elements' relative meaning and importance. AHP allows human judgments, not just data, to be critical in performing the evaluations.

The evaluation criteria are a reflection of organizational policy governing the selection of the proposed solution from a number of alternatives that satisfy or address the same problem. Ideally, evaluation criteria should:

- Differentiate meaningfully between solutions without bias;
- Apply to all organizational operations;
- Relate to the organizational goals;
- Reflect qualities that are important to the success of the projects;
- Reflect characteristics that can be measured or assessed;
- Be independent; and
- Be understood.

The AHP converts these comparisons to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is assigned to each criterion, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes AHP from other techniques (Saaty, 2008). AHP has been utilized in numerous public works projects including facility siting, evaluating municipal water main performance (Al-Barqawi and Zayed, 2008), bridge design, watershed analysis, traffic planning, and risk assessment. It has also been utilized in other SFPUC projects such as the selection of a Preferred Alternative for the Bay Division Pipelines and the Irvington Tunnel.

AHP was used for the alternative analysis performed in CS-199. AHP could be applied to the Richmond EFWS as a decision support tool to help decision makers assess the weight or importance of the criteria, and the performance of each option for in comparison to the others for each criteria. Other pairwise comparison methods are also useful for multi criteria decision making.

An example of the AHP process based on the CS-199 analysis (CS-199 Task 9 TM) is shown below:

The evaluation process performed under CS-199 Task 3 to develop LOS Criteria and Performance Objectives also identified considerations for project alternatives analysis, as follows:

1. Water Supply Delivery Reliability
2. Fire Fighting (Resources and Deployment Time)
3. Cost (Capital, Annual Operations and Maintenance, and Life Cycle)
4. Schedule
5. Operations and Maintenance
6. Insurance Premiums Benefits
7. Environmental/Community Impacts

These considerations were quantified and compared for each Program Alternative. The project information was aggregated to evaluate and compare the Program Alternatives, and used in the AHP to select a Preferred Program Alternative.

The Program Alternatives were compared using a pair-wise comparison method on seven different criteria. These evaluation criteria can be weighted. For the CS-199 alternatives analysis, each criterion was weighted equally.

Evaluation Criteria Weighting

Evaluation Criteria	Criterion Weight
Delivery Reliability	1.00
Firefighting Capability	1.00
Cost	1.00
Schedule	1.00
Operations and Maintenance	1.00
Insurance Premiums	1.00
Environmental / Community Impacts	1.00

The following is an example of one of the pairwise comparisons, that of cost. Each Alternative is ranked versus the others, based in this case on the quantitative data prepared for the study. Each of the above criteria is scored similarly.

Cost Criteria Scoring

Auxiliary Water Supply System Capital Improvement Program
Alternatives Analysis Pairwise Comparisons

Evaluation Criteria: Capital & Life Cycle Cost

Pairwise Comparisons:
Alternative A is worse than Alternative B
Alternative A is significantly better than Alternative C
Alternative B is significantly better than Alternative C

How to Score:

Comparing Alternative 1 (Row) to Alternative 2 (Column)	SCORE
1 is significantly better than 2	10
1 is better than 2	5
1 is about the same as 2	1
1 is worse than 2	1/5
1 is significantly worse than 2	1/10

Scoring Matrix:

	A	B	C	TOTAL	% OF TOTAL
A		0.20	10.00	10.20	40.16%
B	5.00		10.00	15.00	59.06%
C	0.10	0.10		0.20	0.79%
			Total	25.40	100.00%

The following tables summarize the results of the evaluations and the reasoning behind their ranking. The first table shows the Program Alternatives score by each evaluation criteria using the pair-wise scoring system. The second table shows the ranking of the three Program Alternatives.

Alternative Scoring

	Alternative	A	B	C
Evaluation Criteria	Delivery Reliability	40.2%	59.1%	0.8%
	Firefighting Capability	49.5%	49.5%	0.9%
	Cost	40.2%	59.1%	0.8%
	Schedule	48.4%	48.4%	3.2%
	Operations and Maintenance	25.4%	73.2%	1.5%
	Insurance Premiums	33.3%	33.3%	33.3%
	Environmental / Community Impacts	40.2%	59.1%	0.8%
Cumulative Score		40%	55%	6%

Evaluation Ranking of Alternatives

	Alternative	Ranking		
		1	**2**	**3**
Evaluation Criteria	Delivery Reliability	B	A	C
	Firefighting Capability	A/B tie		C
	Cost	B	A	C
	Schedule	A/B tie		C
	Operations and Maintenance	B	A	C
	Insurance Premiums	A/B/C tie		
	Environmental / Community Impacts	B	A	C
	Final Ranking	**B**	**A**	**C**

Based on the rankings above, Alternative B was the Preferred Program Alternative.

References:

Al-Barqawi, H. and Zayed, T. (2008). ”Infrastructure Management: Integrated AHP/ANN Model to Evaluate Municipal Water Mains’ Performance.” J. Infrastruct. Syst., 14(4), 305–318.

Saaty, T.L. (2008). "Relative Measurement and its Generalization in Decision Making: Why Pairwise Comparisons are Central in Mathematics for the Measurement of Intangible Factors - The Analytic Hierarchy/Network Process". RACSAM (Review of the Royal Spanish Academy of Sciences, Series A, Mathematics.

Appendix H - Pressure and Flow Results without FRA Demand Capped

FRA	Demand	Post ESER 2010		Post ESER 2014		Base Option		Option 1		Option 2		Option 3		Option 3a		Option 4		Option 5		Option 5a		Option 6		Option 7		Options 8-10		Options 11		Options 12		FRA
		Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	Flow	Pressure	
	(gpm)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	
1	3,122	622	1	1,897	8	1,897	8	452	0	542	1	632	1	321	0	1,901	8	1,897	8	1,897	8	5,117	58	2,846	18	1,897	8	1,897	8	1,897	8	1
2	2,230	5,350	64	5,350	64	5,350	64	5,375	64	5,350	64	5,350	64	5,350	64	5,350	64	5,350	64	5,350	64	5,350	64	5,350	64	5,350	64	5,350	64	5,350	64	2
3	3,498	2,080	10	2,135	10	2,133	10	2,136	10	0	0	12,067	28	2,139	10	2,145	10	0	0	0	0	2,137	10	13,568	30	2,135	10	2,135	10	2,135	10	3
4	1,681	8,472	160	8,472	160	8,472	160	8,472	160	8,472	160	8,472	160	8,472	160	8,472	160	8,472	160	8,472	160	9,038	182	8,472	160	8,472	160	8,472	160	8,472	160	4
5	4,994	4,248	40	4,592	47	4,592	47	4,228	40	4,238	40	4,250	40	4,216	40	4,590	47	4,592	47	4,592	47	6,153	84	5,031	56	4,592	47	4,592	47	4,592	47	5
6	1,018	4,789	51	4,789	51	4,789	51	4,784	51	4,789	51	4,789	51	4,789	51	4,789	51	4,789	51	4,789	51	4,789	51	4,789	51	4,789	51	4,789	51	4,789	51	6
7	1,907	6,663	99	6,663	99	6,663	99	6,661	99	6,663	99	6,663	99	6,663	99	6,663	99	6,663	99	6,663	99	6,663	99	6,663	99	6,663	99	6,663	99	6,663	99	7
8	1,999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
9	2,675	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
10	4,397	3,415	26	4,252	40	4,252	40	3,341	25	3,379	25	3,420	26	3,291	24	4,250	40	4,252	40	4,252	40	5,335	63	5,097	58	4,252	40	4,252	40	4,252	40	10
11	645	3,027	20	3,027	20	3,027	20	3,024	20	3,027	20	3,027	20	3,027	20	3,027	20	3,027	20	3,027	20	3,027	20	3,027	20	3,027	20	3,027	20	3,027	20	11
12	449	3,300	24	3,300	24	3,300	24	3,297	24	3,300	24	3,300	24	3,300	24	3,300	24	3,300	24	3,300	24	3,300	24	3,300	24	3,300	24	3,300	24	3,300	24	12
13	3,745	0	0	1,706	6	1,706	6	0	0	0	0	0	0	0	0	1,705	6	1,706	6	1,706	6	1,136	3	4,798	51	1,706	6	1,706	6	1,706	6	13
14	3,562	1,931	8	1,984	9	1,980	9	1,984	9	1,983	9	1,983	9	1,983	9	1,930	8	1,982	9	1,982	9	1,980	9	1,984	9	1,984	9	1,984	9	1,984	9	14
15	1,974	2,066	9	2,411	13	2,395	13	2,415	13	2,217	10	2,975	18	2,394	13	2,273	11	0	0	1,805	1	2,419	13	3,615	16	2,411	13	2,411	13	2,411	13	15
16	1,107	0	0	4,007	36	4,007	36	3,540	28	3,561	28	3,584	29	3,511	27	4,007	36	4,007	36	4,007	36	3,952	35	4,115	38	4,007	36	4,007	36	4,007	36	16
17	859	1,007	2	1,068	3	1,064	3	1,068	3	1,068	3	1,067	3	1,067	3	1,009	2	1,067	3	1,067	3	1,064	3	1,068	3	1,068	3	1,068	3	1,068	3	17
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7,548	127	8,469	159	9,243	190	18
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7,653	130	7,724	133	7,923	139	20
21	2,274	3,144	22	3,172	22	3,170	22	3,172	22	3,172	22	3,172	22	3,172	22	3,143	22	3,171	22	3,171	22	3,170	22	3,172	22	3,172	22	3,172	22	3,172	22	21
23	2,736	4,854	52	6,368	90	6,368	90	4,480	45	4,591	47	4,704	49	4,323	42	6,367	90	6,368	90	6,368	90	5,080	57	5,730	73	6,368	90	6,368	90	6,368	90	23
24	2,772	6,214	86	6,471	93	6,458	93	6,474	93	6,372	90	6,536	95	6,459	93	6,373	90	8,341	155	6,242	86	6,477	93	6,488	93	6,471	93	6,471	93	6,471	93	24
25	1,854	3,507	27	4,156	38	4,118	38	4,166	39	3,693	30	4,112	38	4,096	37	3,593	29	4,529	45	3,972	35	4,175	39	4,180	39	4,156	38	4,156	38	4,156	38	25
26	521	2,757	17	2,803	17	2,799	17	2,803	17	2,802	17	2,802	17	2,802	17	2,756	17	2,801	17	2,801	17	2,800	17	2,803	17	2,803	17	2,803	17	2,803	17	26
27	2,348	3,832	33	4,011	36	3,914	34	4,038	36	4,909	54	3,917	34	3,917	34	4,739	50	3,870	33	3,736	31	4,059	37	4,085	37	4,011	36	4,011	36	4,011	36	27
28	889	5,622	70	5,695	72	5,678	72	5,698	72	5,574	69	5,545	68	5,540	68	5,504	67	5,500	67	5,472	67	5,701	72	5,706	72	5,695	72	5,695	72	5,695	72	28
29	924	5,797	75	5,878	77	5,859	76	5,881	77	5,746	73	5,686	72	5,680	72	5,661	71	5,621	70	5,596	70	5,885	77	5,890	77	5,878	77	5,878	77	5,878	77	29
30	495	5,875	77	5,961	79	5,956	79	5,961	79	5,960	79	5,960	79	5,960	79	5,875	77	5,959	79	5,959	79	5,956	79	5,961	79	5,961	79	5,961	79	5,961	79	30
31	3,186	2,333	12	2,422	13	0	0	2,377	13	3,090	21	3,480	27	3,638	29	0	0	1,643	6	1,462	5	2,658	16	2,980	20	2,422	13	2,422	13	2,422	13	31
32	1,240	3,500	27	3,594	29	3,588	29	3,594	29	3,593	29	3,592	29	3,592	29	3,499	27	3,592	29	3,592	29	3,588	29	3,595	29	3,594	29	3,594	29	3,594	29	32
33	195	4,256	40	4,335	42	4,329	42	4,335	42	4,334	42	4,333	42	4,333	42	4,255	40	4,332	42	4,332	42	4,329	42	4,335	42	4,335	42	4,335	42	4,335	42	33
34	2,271	0	0	0	0	3,034	20	4,700	49	4,946	54	5,099	58	5,428	65	3,664	30	4,030	36	3,797	32	4,894	53	5,134	59	4,199	39	7,193	115	7,650	130	34
36	830	4,960	55	5,047	57	5,041	56	5,047	57	5,046	57	5,045	57	5,045	57	4,960	55	5,045	57	5,045	57	5,042	56	5,047	57	5,047	57	5,047	57	5,047	57	36
37	2,944	0	0	0	0	2,401	13	4,144	38	4,491	45	4,657	48	5,022	56	3,167	22	3,595	29	3,344	25	4,321	41	4,535	46	4,641	48	7,670	131	8,081	145	37
38	2,695	0	0	1,026	2	0	0	772	1	1,866	8	973	2	1,300	4	0	0	0	0	0	0	873	2	1,011	2	1,026	2	1,026	2	1,026	2	38
41	2,354	3,927	34	4,033	36	4,001	36	4,032	36	3,871	33	3,738	31	3,734	31	3,722	31	3,615	29	3,602	29	4,037	36	4,046	36	4,033	36	4,033	36	4,033	36	41
42	1,010	0	0	3,182	22	3,710	21	3,182	23	3,178	22	3,176	22	3,175	22	0	0	3,174	22	3,173	22	3,719	21	3,182	23	3,182	22	3,182	22	3,182	22	42
43	1,971	4,185	39	4,227	40	4,219	40	4,228	40	4,179	39	4,150	38	4,148	38	4,389	38	4,124	38	4,118	38	4,228	40	4,231	40	4,227	40	4,227	40	4,227	40	43
44	491	6,175	85	6,370	90	6,356	90	6,370	90	6,368	90	6,367	90	6,367	90	6,173	84	6,366	90	6,366	90	6,356	90	6,370	90	6,370	90	6,370	90	6,370	90	44
45	3,937	4,382	42	4,596	47	4,581	47	4,596	47	4,595	47	4,594	47	4,594	47	4,382	42	4,594	47	4,594	47	4,581	47	4,596	47	4,596	47	4,596	47	4,596	47	45
46	1,553	5,763	74	5,969	79	5,955	79	5,969	79	5,967	79	5,966	79	5,966	79	5,760	74	5,966	79	5,965	79	5,955	79	5,969	79	5,969	79	5,969	79	5,969	79	46
47	1,469	2,793	17	2,917	19	1,465	5	3,225	23	3,064	21	3,521	28	3,593	29	1,460	5	2,351	12	2,231	11	3,424	26	3,662	30	2,917	19	2,917	19	2,917	19	47

Resulting flow is greater than FRA demand
Resulting flow is 0 gpm
Resulting pressure is less than 20 psi

To: D. Myerson, S. Huang 5 January 2018

Fr: Charles Scawthorn, S.E.

Re: Review of "Westside Emergency Firefighting Water System Options Analysis"

Summary: Assuring emergency firefighting water for the western portion of San Francisco is a serious issue for the City. This memo reviews the 5 January 2018 report "Westside Emergency Firefighting Water System Options Analysis". The Outer Richmond and Sunset Districts are currently not served by the city's Auxiliary Water Supply System (AWSS) and the report shows that if the AWSS is extended to these districts, a shortfall of capacity emerges. The report assesses thirteen options for eliminating this shortfall by improving firewater supply to the Richmond District, with some options also serving the Sunset. A Base Case and five options consist solely of a Richmond loop connected directly to the existing AWSS. These options tend to strain the existing AWSS to its limits, although by judicious choice of piping two of these options (options 4 and 5) can be made to provide adequate supply in the Richmond District. Option 6 is sourced from Lake Merced rather than the existing AWSS and meets hydraulic criteria. Option 7 connects the existing AWSS to Sunset Reservoir via an "air gap" (so as to avoid cross-contamination) and also meets hydraulic criteria.

However, for about the same cost as these options, both the Richmond and Sunset districts can be served using a "Potable AWSS" network fed from Sunset Reservoir that has the added benefit of enhancing day-to-day potable supply to the Richmond District. The Potable AWSS concept is examined in Options 8 to 12. Although the Potable AWSS supply draws on the Sunset Reservoir, a precious asset in time of emergency, the size of the reservoir may be adequate for EFWS needs. The Potable AWSS concept is new and will require careful design, and continued O&M procedures, to attain the required reliability.

Two of the Potable AWSS options (11 and 12) are preferred due to being looped pipe networks which are inherently more reliability. A phased implementation program is suggested for option 12 whereby the Potable AWSS can be integrated with other projects being implemented by the City so as to ultimately result in an integrated multi-sourced redundant highly reliable AWSS that provides EFWS for the Richmond and Sunset Districts commensurate with other parts of the City.

Overall, the report and underlying analyses are reasonable and a valuable source of information by which to select one or a few options for detailed investigation using more rigorous reliability analyses, which should be conducted in close cooperation with the Fire Department.

Introduction

This memo reviews the report entitled "Westside Emergency Firefighting Water System Options Analysis" prepared for the San Francisco Public Utilities Commission and dated 5 January 2018 (AECOM, 2018, the "report").

It is important to understand the context of the report, particularly four aspects:

i. The report addresses a portion of San Francisco's Emergency Firefighting Water System (EFWS). In 1903 in recognition of San Francisco's potential for a catastrophic earthquake and fire, an Auxiliary Water Supply System (AWSS, also termed High Pressure System, HPS) was proposed by Chief of Department Dennis T. Sullivan (Postel, 1992), but was rejected as "too costly". In 1905 the National Board of Fire Underwriters in their Report on San Francisco in 1905 found "*…In fact, San Francisco has violated all underwriting traditions and precedent by not burning up. That it has not done so is largely due to the vigilance of the fire department, which cannot be relied upon indefinitely to stave off the inevitable*" (NBFU, 1905). Subsequent events are well-known – in 1906 the City was destroyed in the largest peace-time conflagration in history. Following the fire, the City built the AWSS funded by a $5.2 million bond issue, and the City was largely rebuilt of the same flammable wood construction as before (outside the Central Business District, which had also burned, even though of non-wood construction).

ii. The design of the AWSS is rather unique (see Figure 1) – it seeks high post-earthquake reliability via multiple sources of supply (Twin Peaks, two salt-water pump stations and fireboat manifolds), a gridded network and other features. The high pressure supply reduces the need for fire engines and permits a continuous water curtain to be sprayed from a line of high pressure hydrants along a defensive line, without fire engines. The AWSS buried piping network was designed from the beginning to be highly earthquake resistant with extra heavy walled pipe and restrained joints at numerous points. Because San Francisco has areas of highly liquefiable soils, the system is designed to quickly isolate these "infirm zones" so that the rest of the system isn't drained. In the 1980s gate valves isolating the infirm zones were motorized so as to be seismically actuated and also remotely controllable via radio. Further backing up the AWSS are 182 cisterns, each typically providing a one hour supply for a fire engine. Designed over a century ago with great foresight and skill, the AWSS is a seismically reliable water supply system for catastrophic fire protection. In summary, the AWSS achieves high reliability by having multiple sources, a highly redundant network and special piping and valves. Additions and expansion of the EFWS should seek to provide comparable reliability, using today's best available technology.

iii. The report focuses on the Richmond District, but should be understood as part of a broader picture – it addresses only one of many projects being undertaken by SFPUC under Earthquake Safety and Emergency Response (ESER) Bond funding, as part of an eventual City-wide full build-out of EFWS, as outlined in AECOM/AGS JV (2014).

iv. The report is a planning level <u>comparison</u> of a number of alternatives, not a design of a Richmond extension in detail. Thus, it makes assumptions (all pipe is 20" diameter, booster pumps shall be 150 psi etc) with the understanding that these parameters are likely to change when an alternative (or a few) are selected for more detailed examination. Its results should be understood as being relative results between alternatives, not final results – that is, pipe and pump sizes and routes should be understood to be approximate and only indicative, not final.

Review

The AWSS as originally built covered virtually all of then-built San Francisco. Since then, the city's outlying neighborhoods, such as the Richmond and Sunset Districts, have been almost entirely built out, still largely of flammable wood frame construction. In recognition of this situation a set of future projects were identified in the CS-199 report (AECOM/AGS JV, 2014), Figure 2, of which the current report addresses one:

> "[The report} addresses the Richmond District portion" of a "set of future projects that enhance and expand the city-wide fire protection water supply reliability."

That is, this report and its analysis of options for the Richmond District is only one of dozens of projects being implemented, within the context shown in Figure 2. The Richmond District is addressed because "The Richmond District EFWS … supplies do not meet the Level of Service (LOS) goals", which are that the AWSS shall:

> "reliably provide water to supply the "probable fire demands" after a magnitude 7.8 San Andreas earthquake. Each FRA [Fire Response Area] will have a minimum of 50% reliable water supply to meet probable fire demands. The Citywide average will be a minimum of 90% reliable water supply to meet probable fire demands."

The Options

In order to increase the EFWS supply to the Richmond, the report compares thirteen options which may be grouped in four sets of alternatives:

(1) **Extensions of the existing AWSS** further into the Richmond District are considered in a "Base Case" and five options, all of which consist of a new pipe loop from the existing AWSS westward to cover the entire Richmond (see Figure 3), with some options also connecting across Golden Gate Park to the existing AWSS loop there. Of these six cases, only Option 4 and 5 meet LOS goals. Simply put, the existing AWSS is strained to supply water from its sources all the way to the Outer Richmond – judicious piping arrangements in options 4 and 5 manage to achieve this but the existing system is reaching its limits. These options add no new sources, but are supplied from the multi-sourced redundant existing AWSS, and the new Richmond extension is a looped network.

(2) Option 6 is also a Richmond loop similar to option 2, but with an additional pipe connecting to a **booster pump station at Lake Merced.** While similar to option 2, this adds a new source (Lake Merced) which is of significant value to the entire AWSS. This alternative depends on funding from a planned development at Park Merced however, and is uncertain as to schedule. Thus, while likely and beneficial in the long run, its short term feasibility is unclear.

(3) Option 7 is similar to options 2 and 6 but differs from Option 6 in **connecting to the existing AWSS via an "air gap" at Sunset Reservoir** rather than Lake Merced. To avoid

cross-contamination from the non-potable AWSS to the potable Sunset Reservoir, an "air gap" in the pipe network is required, which can have one of several designs: (a) a pipe from Sunset Reservoir can dump from above with an air gap into an intermediate relatively small tank or reservoir, from which pumps then inject water into the AWSS. This design assures no cross-contamination but has control issues; (b) pipe from Sunset Reservoir can be connected directly to the pump station with however one short piece of pipe (a "spool section") omitted from the line. This design also removes the possibility of cross-contamination (except when the spool section is actually connected) but is unfavorable due to the time required for installing the spool section, as well as the potential for this not occurring in the confusion following an earthquake.

(4) **Options 8-12 are that of a "Potable AWSS"** pipe network supplied from the Sunset Reservoir (a potable supply) to the western part of the Richmond District. In concept, the Potable AWSS would serve on a day-to-day basis as a potable distribution main (increasing potable water supply and quality to the Richmond) and in the event of an earthquake would automatically be isolated from the remainder of the potable distribution system by seismically actuated valves and further pressurized by a booster pump station at Sunset Reservoir so as to be a dedicated high pressure EFWS, similar in many ways to the AWSS (but not connected to the AWSS). The Potable AWSS would be built to meet or exceed the current AWSS standards as well as meet applicable potable water quality standards, would use Sunset Reservoir as its source and would provide EFWS to part of the Sunset as well as the Richmond District. Options 8-12 are all variations on this basic Alternative, and all these options satisfy the LOS goals.

Options 8-10 however have a significant vulnerability in that they are supplied by only one pipe, from the pump station at Sunset Reservoir. These options differ from the general AWSS approach in that their pipe networks lack redundancy – a failure at any one of many points in the pipe network would result in loss of service downstream, in general to the entire Richmond District. Such "single point of failure" designs should be avoided.

Options 11-12 overcome this lack of redundancy by a looped pipe network from the Sunset Reservoir booster pump station, with Option 12 actually having two loops – one extending north from Sunset Reservoir into the Richmond District, and the other loop extending south to serve a larger portion of the Sunset District.

All Potable AWSS options improve potable water supply and quality to the Richmond District, using potable water drawn from Sunset Reservoir, as distinct from the AWSS which is supplied from Twin Peaks Reservoir and/or San Francisco Bay and is not a potable supply. The Potable AWSS would have design features that would seek to assure post-earthquake reliability comparable to the existing AWSS's reliability, although actually achieving this would be difficult due to the Potable AWSS options having only one source, with options 8-10 lacking redundancy in their pipe networks.

However, if the longer view is taken, then option 12 can be regarded as the first phase of a longer term buildout of the AWSS in the western portion of San Francisco. Figure 4 shows how this might be accomplished – option 12 as a Potable AWSS is built first, and provides EFWS to the Richmond and Sunset Districts, as well as improved potable water supply and quality to the Richmond. Later, Lake Merced is connected to the southern loop of option 12 (shown as a dashed green line), and a link (dashed orange line) is built in the Richmond connecting the northern option 12 loop to the existing AWSS. The solid magenta portion of option 12 is then disconnected from Sunset Reservoir (or the air gap feature is maintained) and becomes part of the AWSS, which now has Lake Merced (and possibly Sunset Reservoir) as sources to a redundant looped network. A portion of option 12 (shown as solid blue) maintains the potable supply from Sunset Reservoir to the Richmond District, but this portion of Option 12 is not connected to the AWSS (the link shown in black would be severed).

Discussion

Level of Service goals: The measure of LOS is to "reliably provide water to supply the "probable fire demands" after a magnitude 7.8 San Andreas earthquake" and the goals are 50% for each FRA and 90% for the citywide average. "Reliably" is a key word, which is discussed in the next paragraph. "provide water" is also a key term which has two measures: flow (the amount delivered, in gallons per minute, gpm) and pressure (in pounds per square inch, psi).

The report's flow demands are shown in Figure 5 and are based on results of a fire demand analysis performed for CS-199 – the results were 1,000 simulations of minute-by-minute estimates of fire flow demands required at each block in the city, which are summarized in Figure 6. The median flow required at the end of 60 minutes was 113,589 gpm with a standard deviation of 58,597 gpm. Because these were based on no Fire Department intervention, the CS-199 in consultation with the Fire Department reduced the flow requirements to account for some fires be quickly suppressed, resulting in median estimates shown in Figure 5, which sum to 89,526[1] gpm. These required fire flow values were used in CS-199 and the current report. In summary, there is considerable variation in fire size and water demands, but the report is based solely on median estimates.

The report's initial pressure criteria is 60 psi[2] – the intent is not that final design hydrant pressures will be 60 psi, but rather that any option which could not furnish at least 60 psi in all FRAs was a criteria for rejecting that option from further consideration. Actual pressures that would be delivered by an unbroken system for each of the options are shown in Appendix C Table 10 (p. 66 of the report pdf), and are satisfactory for the Richmond and Sunset Districts although Inner Parkside and Presidio Heights FRAs are drawn down to less satisfactory pressures.

Reliability analysis: Similar to CS-199 the report is based on median conditions (ground motions, ignitions and other parameters) so that "therefore worse conditions and greater water demands, would be expected half of the time". That is, the only degree of conservatism in the analysis is the choice of the scenario event magnitude (Mw 7.8 on the San Andreas fault, intended to represent an event

[1] For reference, one Class A fire engine (such as used by San Francisco Fire Department) pumping capacity varies from about 1,500 to 2,000 gpm.

[2] Effectively, 60 psi is the minimum pressure sufficient for a good hose stream for a 1 inch nozzle on a hand line such as might be used directly off of an AWSS hydrant via a Gleeson (pressure reducing) valve (in all cases of taking a hose line directly off of a high pressure hydrant, a Gleeson valve is to be employed). A pressure at the hydrant of 150 psi is preferable since pressure losses in several hundred feet of hose might occur before reaching the nozzle, and is what the AWSS is designed to provide: "T*he pressure head above city base is: Twin Peaks Reservoir, 328 pounds; Ashbury Tank, 214 pounds; Jones Street Tank, 100 pounds. In the lower zone, which includes the area below the 150~foot contour, the average pressure maintained at hydrants is 130 pounds and in the upper zone, 143 pounds."* (Murray, 1939). See also SFFD (2008).

similar to the 1906 earthquake) in that the scenario is, sort of, the "worst case" magnitude for San Francisco[3]. However, for a given magnitude event it is widely understood that ground motions have significant uncertainty and in some cases may be significantly above (or below) the median estimates. This uncertainty, together with other uncertainties such as in pipe failure or fire demands, is not considered in the analysis. Moreover, as was pointed out during the CS-199 project, the "reliability score" methodology does not actually represent an estimate of reliability but rather is a ratio of the EFWS capacity and demand. A problem thus arises when for options 8-12 the report "assumes 90% reliability for the water supply provided by Potable AWSS" since this assumed reliability is inconsistent with a "reliability score". In essence, the methodology result is that if an option achieves 100% LOS goals for an FRA (or the entire City), it means that there is some unknown likelihood, perhaps "half of the time", that the water demands will not be met. This approach is not a state-of-the-practice reliability analysis. Given the importance of the issue, more rigorous reliability analyses should be performed, as noted in the report.

Potable AWSS Concept: The overall concept of a Potable AWSS, which would require isolation from the remainder of the potable system so as to serve as a high pressure EFWS, deserves discussion. This concept depends on several factors:

- The pipe network will be required to be built to equal or exceed current AWSS standards, in terms of pressure rating and bell and spigot joint capacity[4]. Bell and spigot pipe is typically lengths of pipe with one end enlarged, so that pipelines are assembled by inserting one end (the spigot) into the enlarged end (the bell). This type of assemblage has proven vulnerable to pull-out when subjected to ground movement. To prevent pull-out, the AWSS originally and still today ties these joints together with steel rods, to develop 'restrained joints'. Recently, Earthquake Resistant Ductile Iron Pipe (ERDIP) has emerged which is considered perhaps more reliable than even the restrained joints currently used for the AWSS. Initially developed in Japan in the 1980s by the Kubota Company, there are now several thousand miles of ERDIP pipe in service in Japan which have been subjected to strong ground shaking and ground failure in the 1995 Kobe, 2004 and 2007 Niigata, 2011 Tohoku and 2014 Kumamoto earthquakes, without an observed failure. This substantial empirical record, reinforced by recent testing at Cornell University and pilot programs by San Francisco and Los Angeles, indicates that this product would enhance AWSS reliability. Several US pipe manufacturers are bringing comparable products to market, which have also been tested at Cornell University. ERDIP sections cost significantly more than ordinary bell and spigot pipe (perhaps 50% more, just for material) but may offer cost savings over restrained joints (which however are not used everywhere in the AWSS) – in any event, the pipe material cost is but a modest fraction of the overall construction cost. The report assumes all new pipelines will be ERDIP, which would enhance reliability.
- The report assumes the Potable AWSS pipe network will have a limited (perhaps four) connections to the potable network, via seismically actuated valves which would close when

[3] There is uncertainty as to the magnitude of the 1906 event, and also to what a future large San Andreas event magnitude would be, but Mw 7.8 is probably a "close enough" magnitude.

[4] All thinking to date has been to use segmented ("bell and spigot") pipe, which is commonly used for water systems and was used in the AWSS original construction (because that was the only technology at the time). However, welded steel pipe would be an alternative that has not been considered – both segmented and continuous pipe have their pro's and con's. The emergence of ERDIP enhances the viability of segmented pipe.

strong ground motions are detected. As the report discusses, such valves were installed in the AWSS in the 1980s and this technology, so long as regularly maintained, should meet reliability needs for Potable AWSS concept. However, it must be emphasized that this requires regular maintenance, which should be assured by SFPUC Operation and Maintenance (O&M) rules (that cannot later be relaxed). Additionally, the temptation will always exist as years go by for additional potable system connections to be made to the Potable AWSS, and this temptation will have to be removed by clear SFPUC Operation and Maintenance (O&M) rules. Similarly, due to higher flow in the Potable AWSS, accumulation of silt in hydrant laterals may be higher, so that O&M procedures should require more frequent hydrant flushing than for other sections of the potable system. Thus, the Potable AWSS system is subject to certain operational vulnerabilities that will require active, not passive, defenses.

- For Options 8 to 12, the booster pump station at Sunset Reservoir would be a potential single point of failure, and would require reliability engineering to assure its performance when needed. The existing AWSS Pump Stations 1 and 2 also of course are required to function but, being redundant sources, inherently afford greater reliability. Utilization of parallel pump lines and prime movers at the booster pump station would be required to meet reliability needs. On a preliminary basis the report sizes the booster pumps at typically 150 psi, but the pumps in final design may need to be larger in order to achieve pressure and flow requirements.

Use of Sunset Reservoir: Another key aspect deserving discussion is the whole concept of using Sunset Reservoir as an EFWS source. For emergency firefighting, western San Francisco has four possible sources of EFWS water supply:

- The Pacific Ocean: it was ironic that San Francisco burnt for three days due to lack of firefighting water, when it is surrounded on three sides by the largest body of water on earth. Construction of a West Side Salt Water Pump Station (WSSWPS) would be very beneficial and eliminate the need for using the potable water in Sunset Reservoir, a precious resource particularly following a major earthquake. While the scope of the report did not include consideration of a WSSWPS, this concept is being considered as part of the larger set of projects.
- Lake Merced: this is a very large body of water, sufficient for EFWS needs. As discussed above, it is considered in option 6 as well as being among the larger set of projects identified in CS-199.
- Groundwater: there is substantial amounts of ground water under the Richmond and Sunset Districts. However, this resource is currently being used for other purposes and is not available for EFWS purposes.
- Sunset Reservoir: Sunset Reservoir is the source of potable supply for the Sunset and Richmond Districts and, if not replenished following a major earthquake, would only provide several days potable supply. While the major source of potable supply to western San Francisco, the size of this facility may allow for both potable and EFWS needs. The Potable AWSS will connect to only one of the two 90 million gallon bays, emptying of which would require all of the fire department’s engines pumping at maximum capacity for 24 hours. Even so, the Reservoir is constantly being replenished by the seismically strengthened Hetch Hetchy system. Thus, due to its location, size and recent seismic reinforcement, Sunset Reservoir may not be an unreasonable source for EFWS.

Costs: Buried in the report and not emphasized in the Executive Summary or tables presenting cost data is that "These estimates are based on costs from the CS-199 study and have not been updated to 2017 costs." – in other words, the costs are in 2014 (or, at the time the work was done, perhaps 2012) dollars. Given the level of uncertainty associated with the estimates ("potential accuracy range of -20% to -50% and +30% to +100%.") the difference between 2012 and 2017 estimates (about 7%, using Bur. Labor Statistics CPI Inflation Calculator, https://www.bls.gov/data/inflation_calculator.htm), may not be a major issue, although 7% may still be about $5 million.

Option selection: Another aspect deserving discussion is how to select one or a few options for more detailed examination? The report suggests further analyses which will be justified when the choice is narrowed to one or a few options, and justly identifies that non-technical considerations such as citywide LOS goals, Fire Department operations, project phasing, financing and future urban development are factors not within the scope of the report that call for some guidance from decision-makers. The report suggests a multi-criteria decision-making technique known as Analytical Hierarchy Process (AHP) which is widely utilized and could be useful for this situation. One criteria however cannot be over-emphasized – while sections 5, 6 and 7 of the report discusses a number of aspects of the options, including reliability scoring, cost and potable benefits for the Richmond, the fundamental criterion is as stated in the LOS goals: reliability. Given the risk that exists in San Francisco, if a less than reliable system is built, cost, potable benefits and other factors will be irrelevant. It should be noted that the differential in cost between the least and most costly of the options ($42 million) is far less than the property value of one city block in the Richmond or Sunset Districts, not to mention the risk to people.

Other aspects of the report deserving comment include:

- Pipe diameters were all assumed to be 20" initially. A limited sensitivity analysis of this assumption showed that, at this planning level of examination, the assumption was reasonable.
- Hydraulic and other calculations were spot checked by this Reviewer and found to be correct.

Conclusions

The need for EFWS for the western portion of San Francisco is a serious issue for the City. The experience of 1906 led prudent and skilled engineers of that day to build a separate and redundant AWSS – while fire resistive-ness most buildings has since improved, much is not dissimilar and the post-earthquake fire risk of San Francisco is the most extreme of any US city.

The report shows that a fundamental shortfall of capacity exists in the current AWSS's capacity to serve the Richmond and Sunset districts. By judicious piping (options 4 and 5) the Richmond can be served, but for about the same cost both the Richmond and Sunset districts can be served using a Potable AWSS network that has the added benefit of enhancing day-to-day potable supply to the Richmond District. Although the Potable AWSS supply draws on the Sunset Reservoir, a precious asset in time of emergency, this supply may be adequate for EFWS needs. Two of the Potable AWSS options (11 and 12) are preferred due to their inherently greater reliability due to being looped pipe networks. A phased implementation program is suggested whereby the Potable AWSS can be integrated with other projects being implemented by the City so as to ultimately result in an integrated multi-sourced redundant highly reliable AWSS that provides EFWS for the Richmond and Sunset Districts commensurate with other parts of the City.

While there are areas for improvement, such as use of more rigorous hydraulic and reliability methods and use of current costs, overall the report and underlying analyses are reasonable and a valuable source of information by which to select one or a few options for more detailed investigation, which should be conducted in close cooperation with the fire department.

References

AECOM (2018) "Westside Emergency Firefighting Water System Options Analysis", Report prepared for the San Francisco Public Utilities Commission, 5 January 2018, 94 pgs.

AECOM/AGS JV (2014). "Planning Support Services for Auxiliary Water Supply System (AWSS), Final Report." Pp. 288. San Francisco: CS-199 Project Report Prepared for San Francisco Public Utilities Commission by AECOM/AGS JV.

NBFU (1905) "Report of National Board of Fire Underwriters by Its Committee of Twenty on the City of San Francisco", Cal., Henry Evans, Chmn." Pp. 64pp.

Postel, F.F. (1992) "The Early Years of the Fire Department", address delivered at the Palace Hotel during 1992 Ceremonies Marking the 125th Anniversary of the San Francisco Fire Department, By Frederick F. Postel, Chief of Department (available online at http://www.sfmuseum.net/hist1/hist2.html)

Marsden Manson, H. D. H. Connick, T. W. Ransom, and W. C. Robinson. 1908. Reports on an Auxilary Water Supply System for Fire Protection for San Francisco, California. San Francisco Board of Public Works., San Francisco, Calif.,: Britton & Rey. Pp. 205.

Murray, G.H. , and C.J. Brennan. 1939. Fireman's Handbook, 3rd Edition Revised. San Francisco: David Scannell Club, Inc.

SFFD. 2008. "Hose and Hose Appliances." Pp. 200. San Francisco: San Francisco Fire Department.

Figures

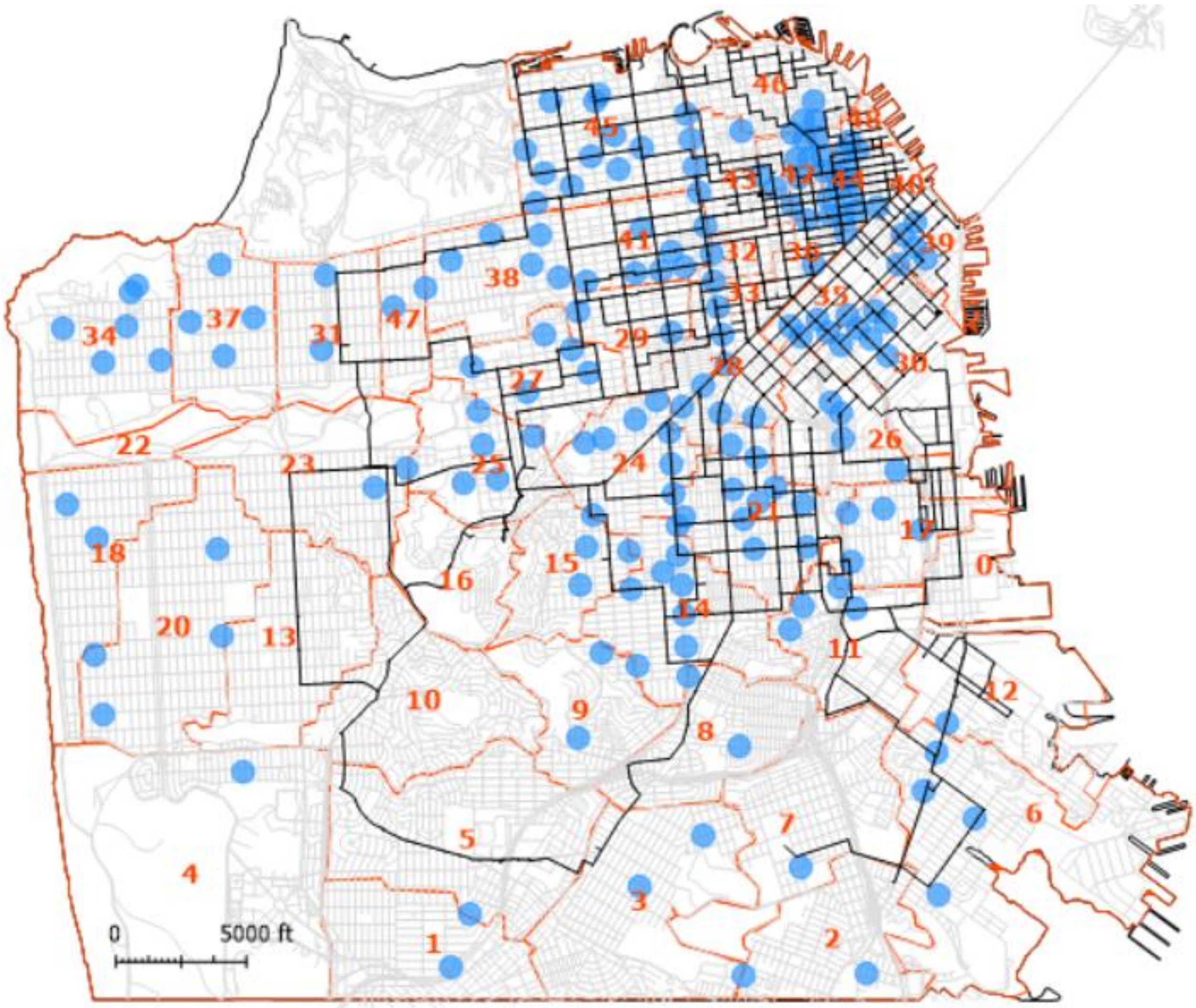


Figure 1 Existing AWSS (ESER 2010 AND 2014 improvement omitted), FRAs (red numbers and boundaries) and cisterns (blue circles)

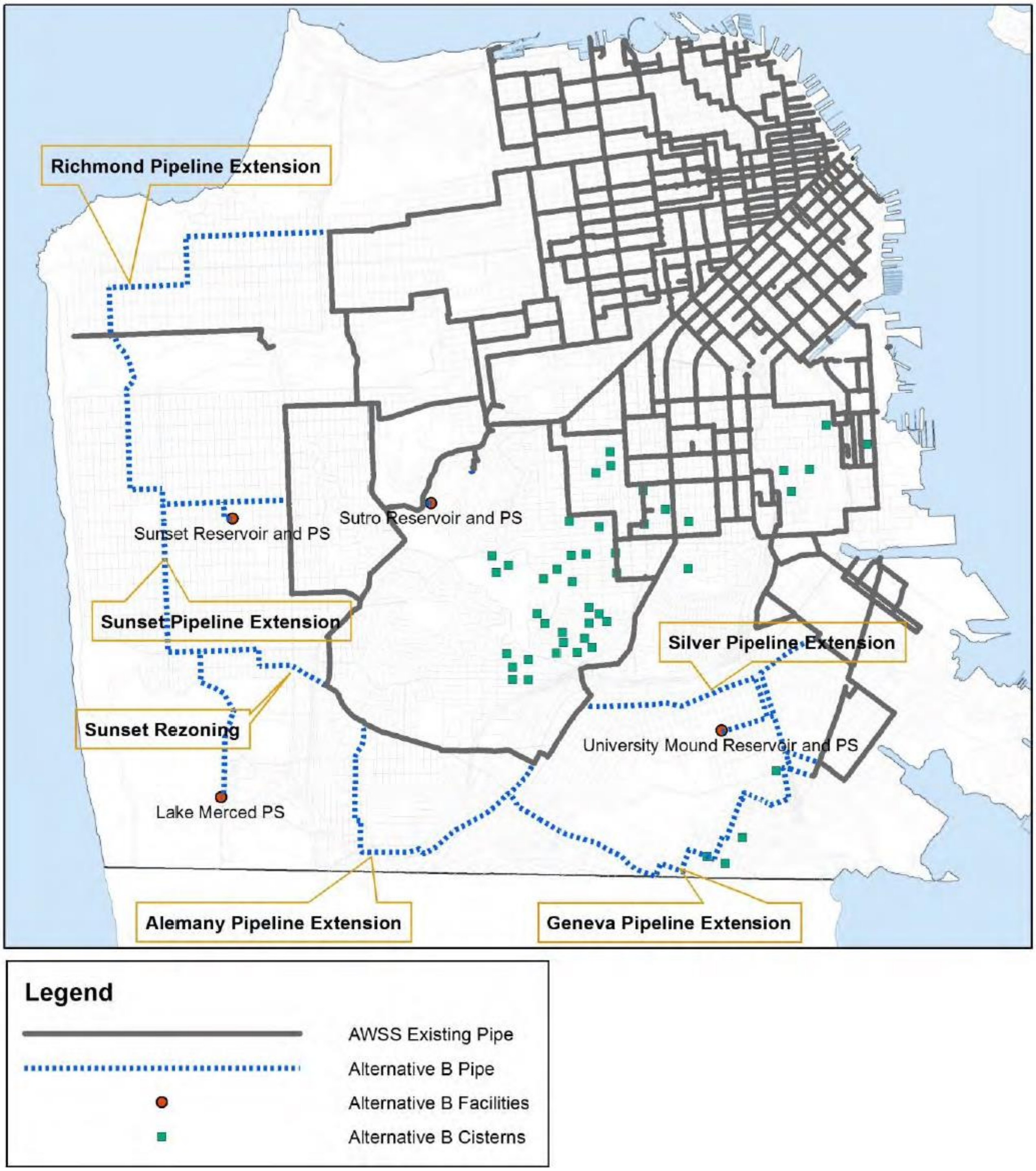
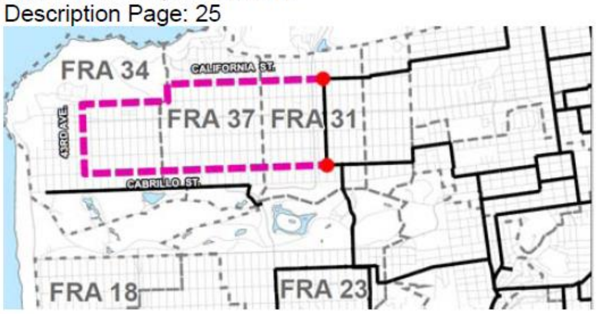
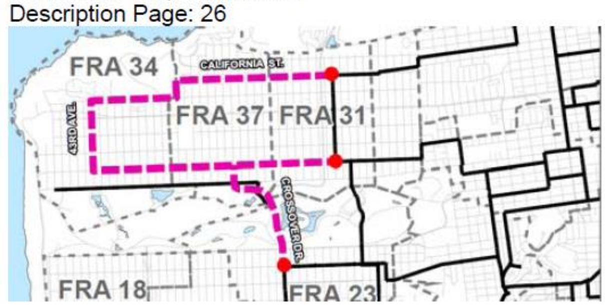


Figure 2 AWSS Program Alternative B as presented in CS-199 (AECOM/AGS JV, 2014)

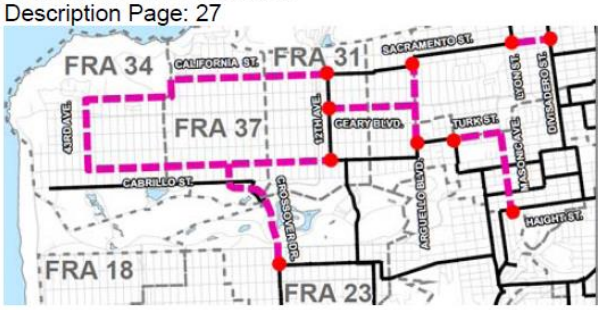
Base Option. AWSS Extension
AWSS connections: 2
Pipe Length: 22,900 LF
Additional Pump Station: No
Description Page: 25



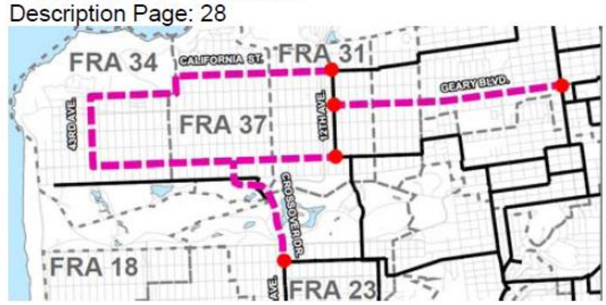
Option 1. AWSS Extension
AWSS connections: 3
Pipe Length: 28,000 LF
Additional Pump Station: No
Description Page: 26



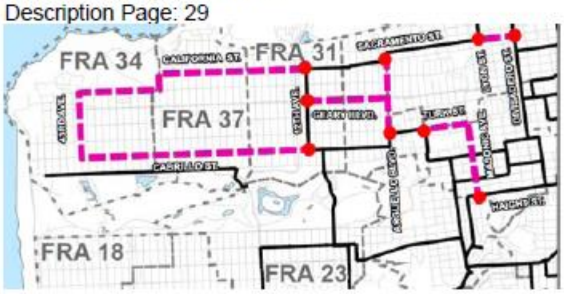
Option 2. AWSS with crossover
AWSS connections: 10
Pipe Length: 43,500 LF
Additional Pump Station: No
Description Page: 27



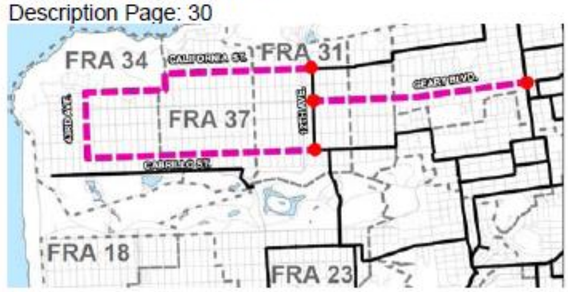
Option 3. AWSS with crossover
AWSS connections: 5
Pipe Length: 37,100 LF
Additional Pump Station: No
Description Page: 28



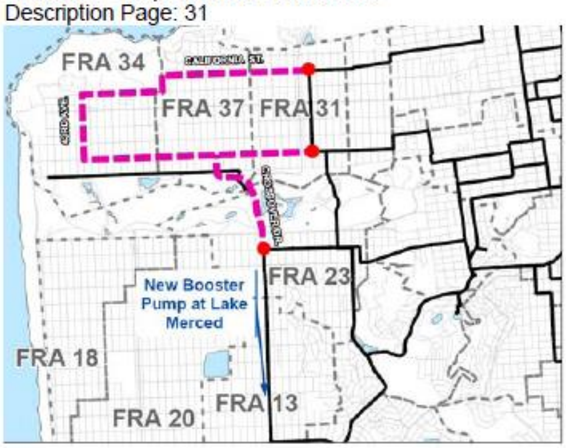
Option 4. AWSS without crossover
AWSS connections: 9
Pipe Length: 38,400 LF
Additional Pump Station: No
Description Page: 29



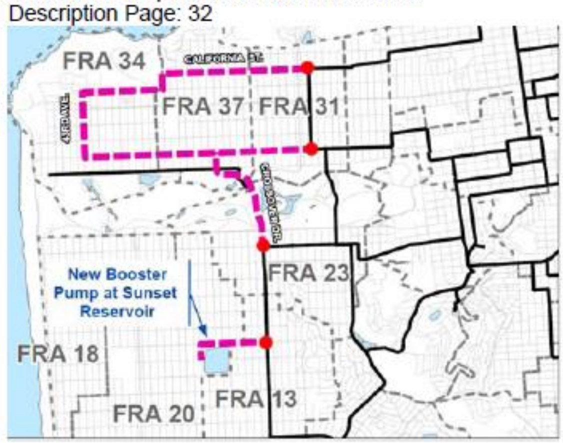
Option 5. AWSS without crossover
AWSS connections: 4
Pipe Length: 32,000 LF
Additional Pump Station: No
Description Page: 30



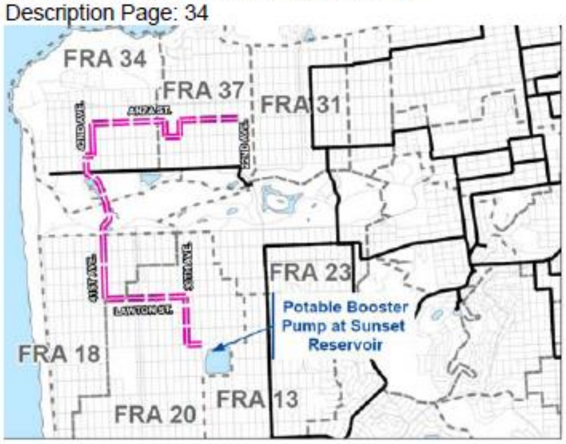
Option 6. AWSS with Additional Pump Station
AWSS connections: 4 (1 on Ocean Ave. not shown)
Pipe Length: 28,000 LF
Additional Pump Station: Lake Merced
Description Page: 31



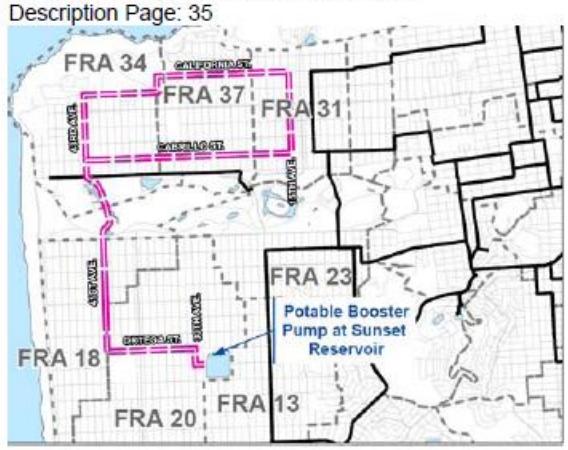
Option 7. AWSS with Additional Pump Station
AWSS connections: 4
Pipe Length: 31,500 LF
Additional Pump Station: Sunset Reservoir
Description Page: 32



Option 8. Potable AWSS with Pump Station
Pipe Length: 22,200 LF
Additional Pump Station: Sunset Reservoir
Description Page: 34



Option 9. Potable AWSS with Pump Station
Pipe Length: 37,500 LF
Additional Pump Station: Sunset Reservoir
Description Page: 35



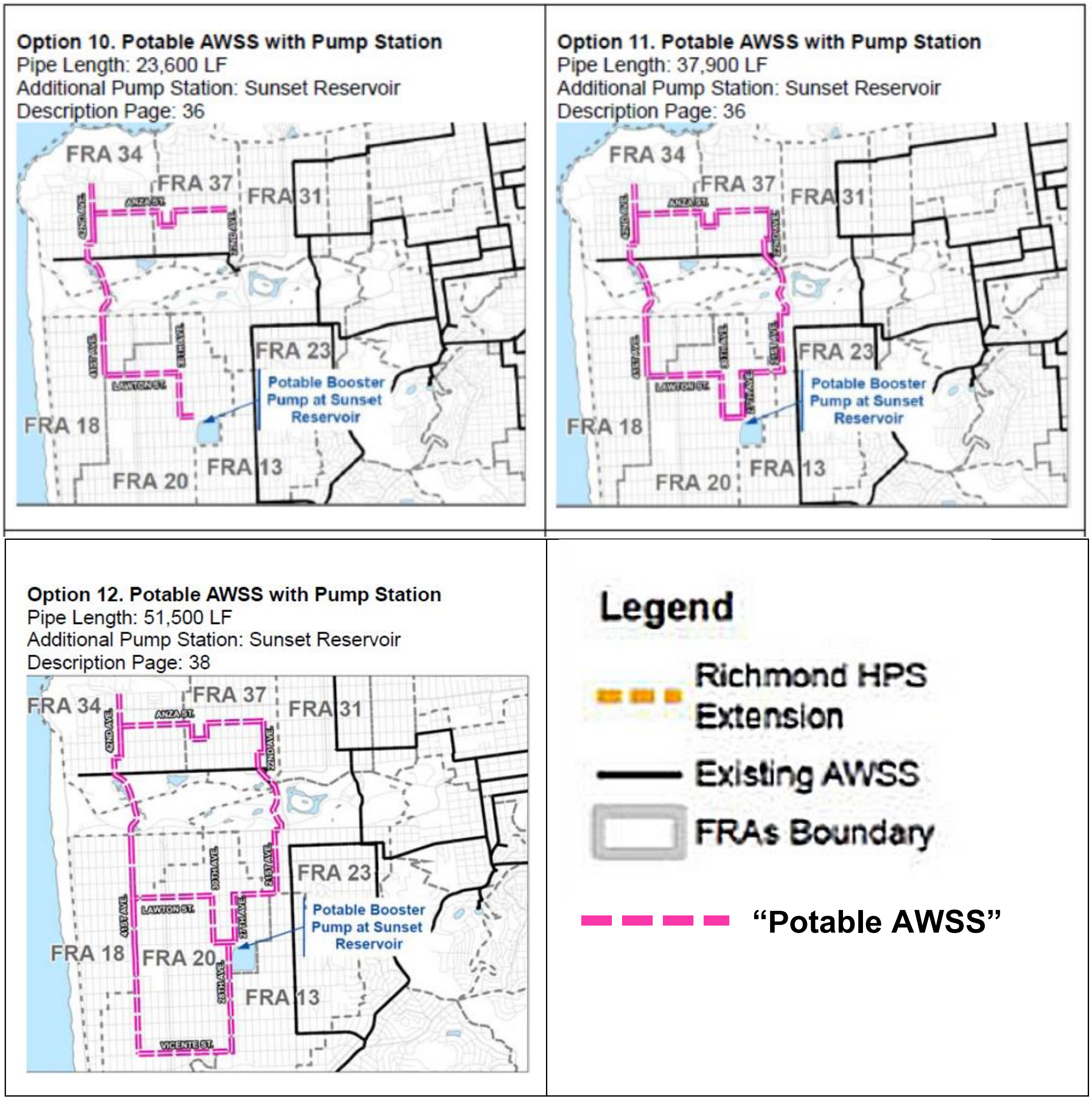


Figure 3 Options considered in the report (after AECOM, 2018)

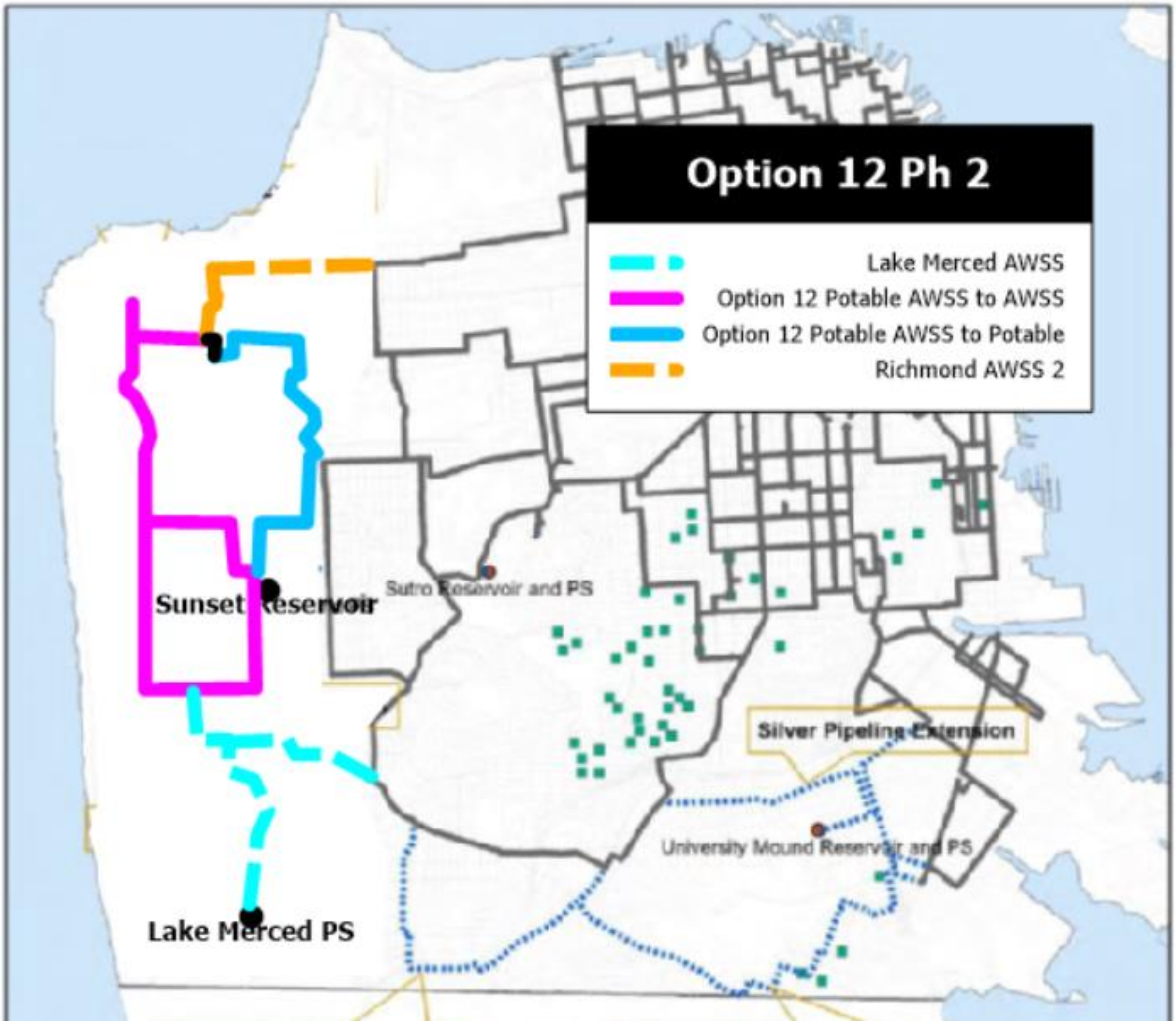


Figure 4 Phased implementation program (conceptual): current Option 12 (solid lines) with future projects dashed. Lake Merced (dashed green) and Richmond AWSS 2 (dashed orange) connect to portion of Option12 (solid magenta). Third pump station (at Lake Merced) serves entire AWSS with looped service to Richmond and Sunset Districts. Portion of Option 12 (solid blue) remains potable supply to Richmond District but link (solid black) to AWSS is severed.

Table 2 CS-199 FRA Demands (Averaged 60 Minute Aggregated Demands)

FRA ID	FRA Demand (gpm)	FRA ID	FRA Demand (gpm)
1	3122	25	1854
2	2230	26	521
3	3498	27	2348
4	1681	28	889
5	4994	29	924
6	1018	30	495
7	1907	31	3186
8	1999	32	1240
9	2675	33	195
10	4397	34	2271
11	645	35	463
12	449	36	830
13	3745	37	2944
14	3562	38	2695
15	1974	39	162
16	1107	40	144
17	859	41	2354
18	3125	42	1010
19	NA	43	1971
20	4720	44	491
21	2274	45	3937
22	NA	46	1553
23	2736	47	1469
24	2772	48	91

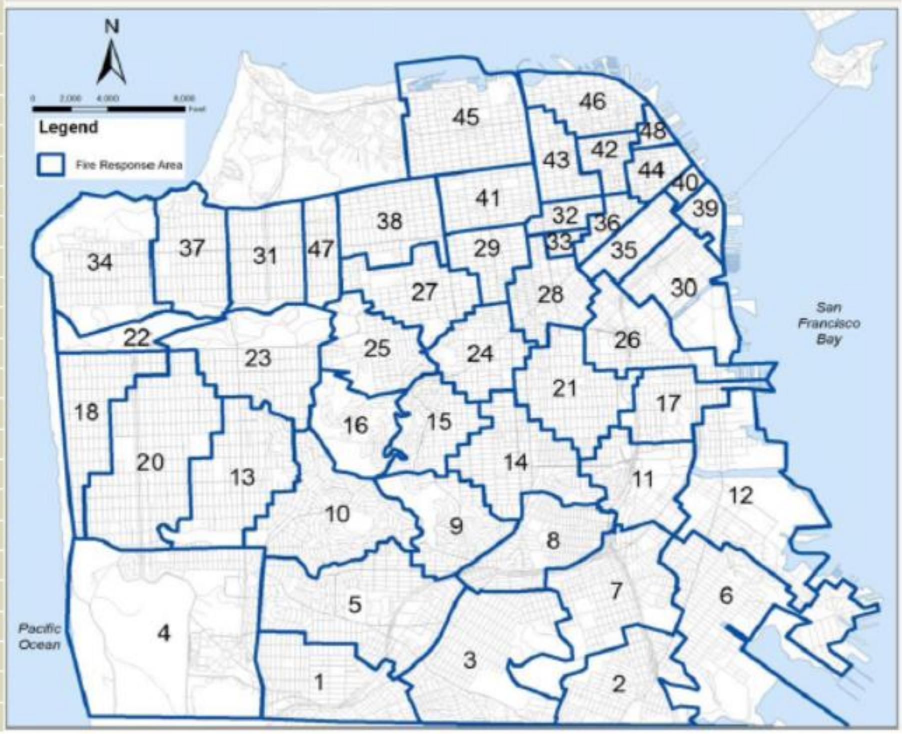


Figure 5 Fire flow demands used in the report (identical to Figure 2 of AECOM, 2018). The demands are median values and sum to 89,529 gpm.

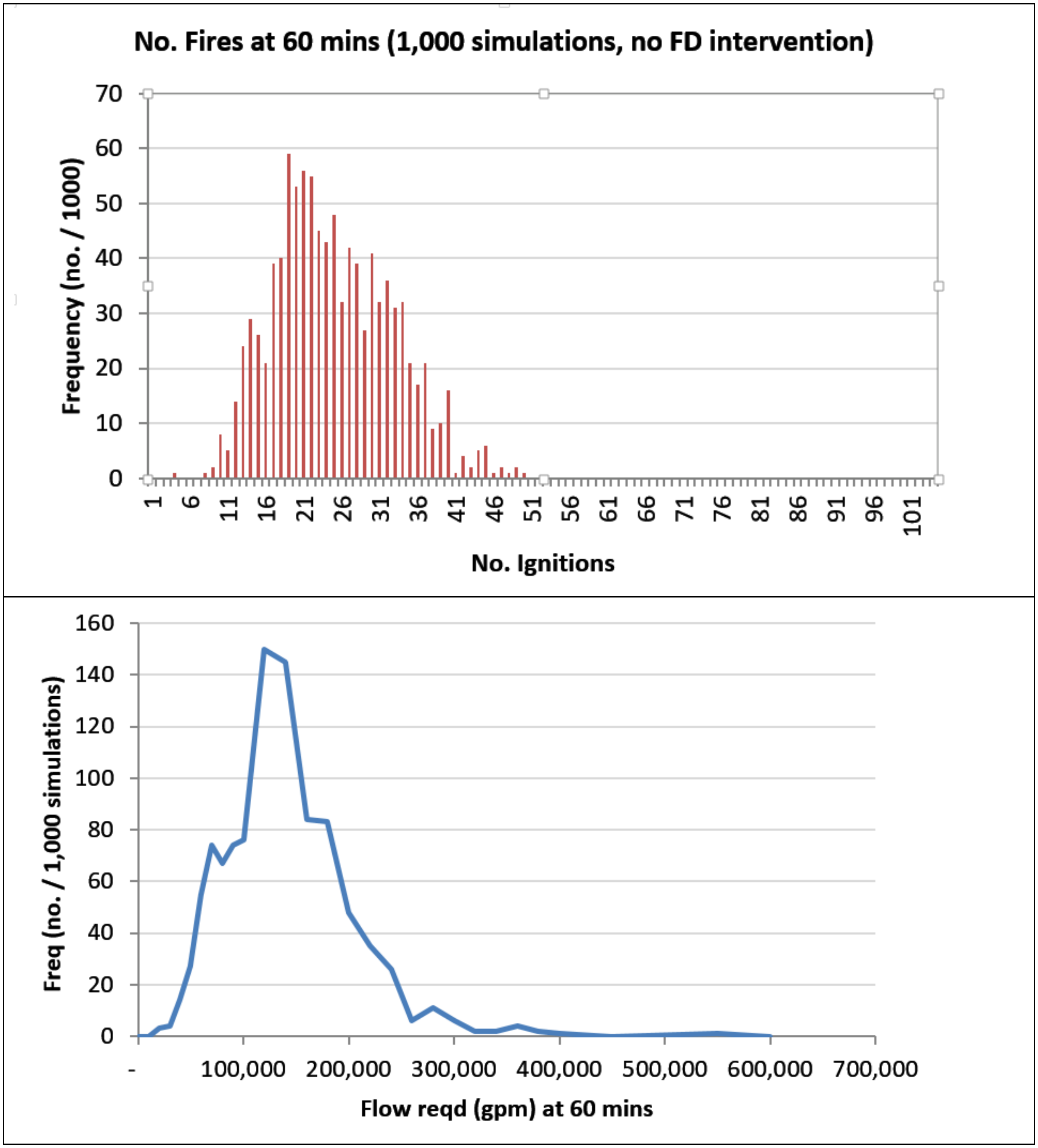


Figure 6 Fire demand analysis total demand results at 60 minutes, provided to CS-199: (top) number of fires assuming no FD intervention, and (b) total flow required.

End of Figures