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San Francisco Public Utilities Commission

Emergency Firefighting Water System 2050 Planning Study

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ACRONYMS

AWSS	Auxiliary Water Supply System
CDD	City Distribution Division
City	City and County of San Francisco
CS-199 Study	CS-199 Planning Support Services for AWSS
Spending Plan	CS-229 EFWS Spending Plan
CSPL	Crystal Springs Pipeline
EFWS	Emergency Firefighting Water System
ERDIP	Earthquake-resistant ductile iron pipe
ESER	Earthquake Safety and Emergency Response
FFEWR Study	Fire Following Earthquake Water Requirements Study
FRA	Fire Response Area
gpm	gallons per minute
MG	million gallons
PCCP	prestressed concrete cylinder pipe
PEFWS	Potable Emergency Firefighting Water System
PWSS	Portable Water Supply System
Richmond EFWS Analysis	Richmond District EFWS Options Analysis
SAPL	San Andreas Pipeline
SCADA	Supervisory Control and Data Acquisition
Seawater Pre-Feasibility Study	EFWS Seawater Supply Pre-Feasibility Study
SFFD	San Francisco Fire Department
SFPUC	San Francisco Public Utilities Commission
SSPL	Sunset Supply Pipeline
US 101	U.S. Highway 101
WSP	welded steel pipe

Executive Summary

The Emergency Firefighting Water System (EFWS) is a high-pressure fire protection water supply and distribution system that was constructed following the 1906 earthquake. The EFWS provides water for firefighting to protect people and property from risk of fire following a major earthquake, but the existing system does not serve all of San Francisco. This study identifies approximately 78 miles of pipeline improvements and eight additional water supply sources to provide coverage throughout San Francisco, and meet firefighting water demands projected for the city's growth through the year 2050. The cost of these improvements is estimated to be approximately $1.9 billion (2021$).

In October 2019, the San Francisco Board of Supervisors issued Resolution 422-19, responding to recommendations in the 2018-2019 City and County of San Francisco Civil Grand Jury Report, "Act Now Before it Is Too Late: Aggressively Expand and Enhance Our High-Pressure Emergency Firefighting Water System" to address needed improvements to the EFWS. Those recommendations form the objectives of this planning study:

1. Develop a plan to provide pipelines and water supply sources for emergency firefighting water supply to all parts of San Francisco.
2. Use results from the EFWS Seawater Supply Pre-Feasibility Study (AECOM 2021) in the evaluation of firefighting water supplies.
3. Use results from the Fire Following Earthquake Water Requirements Study (Scawthorn 2021) in developing the EFWS infrastructure layout, including addressing demands that are higher than median-level, and performing analysis at finer geographical resolution than by Fire Response Area.

The fundamental starting point for evaluating and improving San Francisco's EFWS is to assess how much water is needed. The Fire Following Earthquake Water Requirements Study (Scawthorn 2021) provides these critical data—not just for current conditions, but also through the year 2050 so that plans can be developed to protect San Francisco well into the future. Given the uncertainty associated with post-earthquake fire and the seismic response of water systems, it is prudent to consider conservative water demand targets that are higher than median level. In that regard, the 255,000-gallon-per-minute water demand target established for this study reflects the 75th percentile level. In addition, the study used input parameters to the selected target that contribute to more conservative citywide demand values, such as selection of maximum demand levels anticipated through the 25th hour after an earthquake.

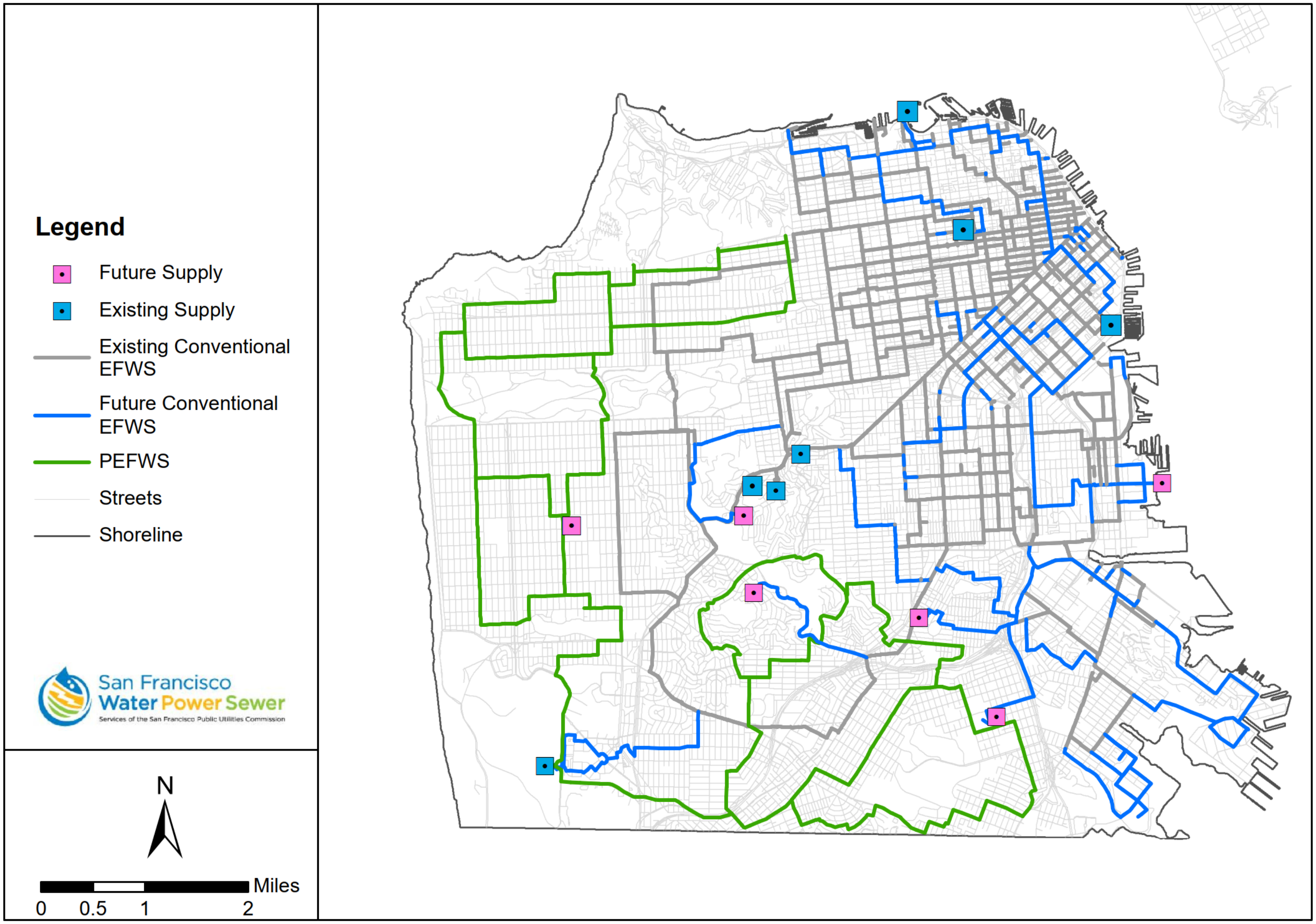
Improvements to the EFWS, shown on Figure ES-1, the Recommended Alternative, were identified to expand system coverage to all parts of San Francisco and to meet the established demand targets. Approximately 78 miles of pipeline improvements were identified. These new pipelines provide the following benefits:

- They extend coverage to areas of San Francisco that currently do not have water supply from the EFWS pipe network.
- They improve conveyance capacity and reduce the hydraulic constraints of the existing system.
- They improve water supply reliability to areas subject to liquefaction.
- They connect new water supply sources to the EFWS.

Two EFWS approaches were used to achieve the study objectives: expansion and enhancement of the existing conventional EFWS; and implementation of the Potable EFWS (PEFWS). The PEFWS is a high-pressure firefighting water supply network similar to the conventional EFWS. It can also function as part of the municipal water supply system during non-earthquake conditions and as an emergency water supply backbone under earthquake conditions when fire suppression is no longer needed.

The estimated firefighting water needs exceed the existing EFWS water supply. Additional water sources that were considered include freshwater storage, City potable water storage, and seawater. A combination of all three categories of supplies was used to meet the water supply deficit. The type of supply to use, and whether to implement conventional EFWS or PEFWS, was determined based on analysis of where the water is needed, where the supply is located, proximity to existing EFWS infrastructure, and pipe network hydraulics.

Figure ES-1: Proposed EFWS Improvements – Recommended Alternative



The performance assessment approach for the proposed EFWS captures the ability of the system to deliver water to meet demand targets geographically across San Francisco. The performance metric used in this study, the delivery capability, is defined as the percentage of the water demand met by the EFWS pipeline network. The delivery capability is calculated by dividing the flow delivered by the demand, reflecting the flow provided by the pipeline network.

The delivery capability of the improved system is shown on Figure ES-2. The improvements to the EFWS resulted in a high delivery capability across the majority of the areas in San Francisco. In 91 percent of the grids (excluding those without demands), a delivery capability of 90 percent or greater was achieved. In 7 percent of the grids, a delivery capability of 80 to 90 percent was achieved; the remaining 2 percent of the grids had a delivery capability of 70 to 80 percent. It should be noted that the delivery capability does not take into account the supply from other components of the EFWS, such cisterns, suction manifolds, and fireboats. These other sources of supply provide an additional layer of reliability and redundancy to the EFWS supply.

The costs for the proposed EFWS improvements are shown in Table ES-1. In 2021 dollars, the total cost is estimated to be approximately $1.9 billion. With a 6-year or 14-year construction period, improvements would be completed in the years 2034 and 2046, respectively. Escalated costs for the 6- and 14-year construction period scenarios are estimated to be approximately $2.9 billion and $4.1 billion, respectively.

Table ES-1: EFWS Improvement Costs

Improvements	Costs ($M)		
	Unescalated (2021$)	Escalated Completion in 2034	Escalated Completion in 2046
Pipelines	$1,133	$1,714	$2,369
Pump Stations	$609	$922	$1,274
Other Facility Improvements	$205	$310	$429
Total	**$1,947**	**$2,945**	**$4,072**

This study assumes that San Francisco Fire Department (SFFD) resources increase commensurately with the growth in San Francisco's population. The pipelines and water supply sources provide water to the hydrants, but sufficient SFFD resources are needed to fully use the water provided by the improved EFWS.

Supplying seawater on the west side of San Francisco to the PEFWS is not recommended at this time, but, as requested by Supervisor Mar in November 2021, an option to provide this supply was assessed. The option consists of construction of an array of well stations along Ocean Beach and connecting pipelines to the PEFWS, as shown on Figure ES-3. The cost of providing seawater supply on the west side is approximately $800 million more costly than this report's Recommended Alternative, but is not needed to meet any supply deficit of the proposed supply approach. Additionally, supplying seawater to the PEFWS would likely cause the system to lose its emergency water supply backbone function immediately after an earthquake.

Figure ES-2: Delivery Capability of the Proposed System

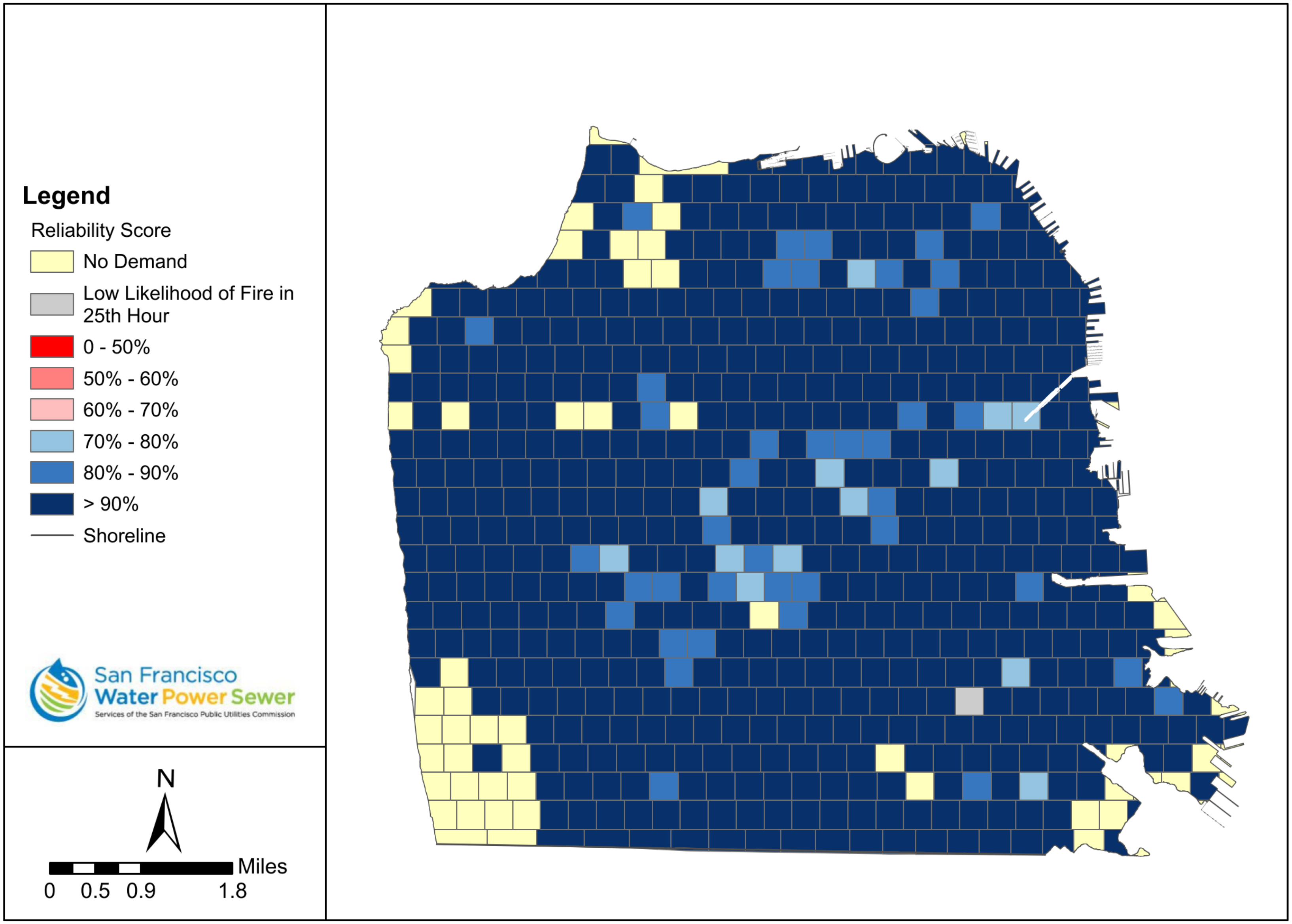
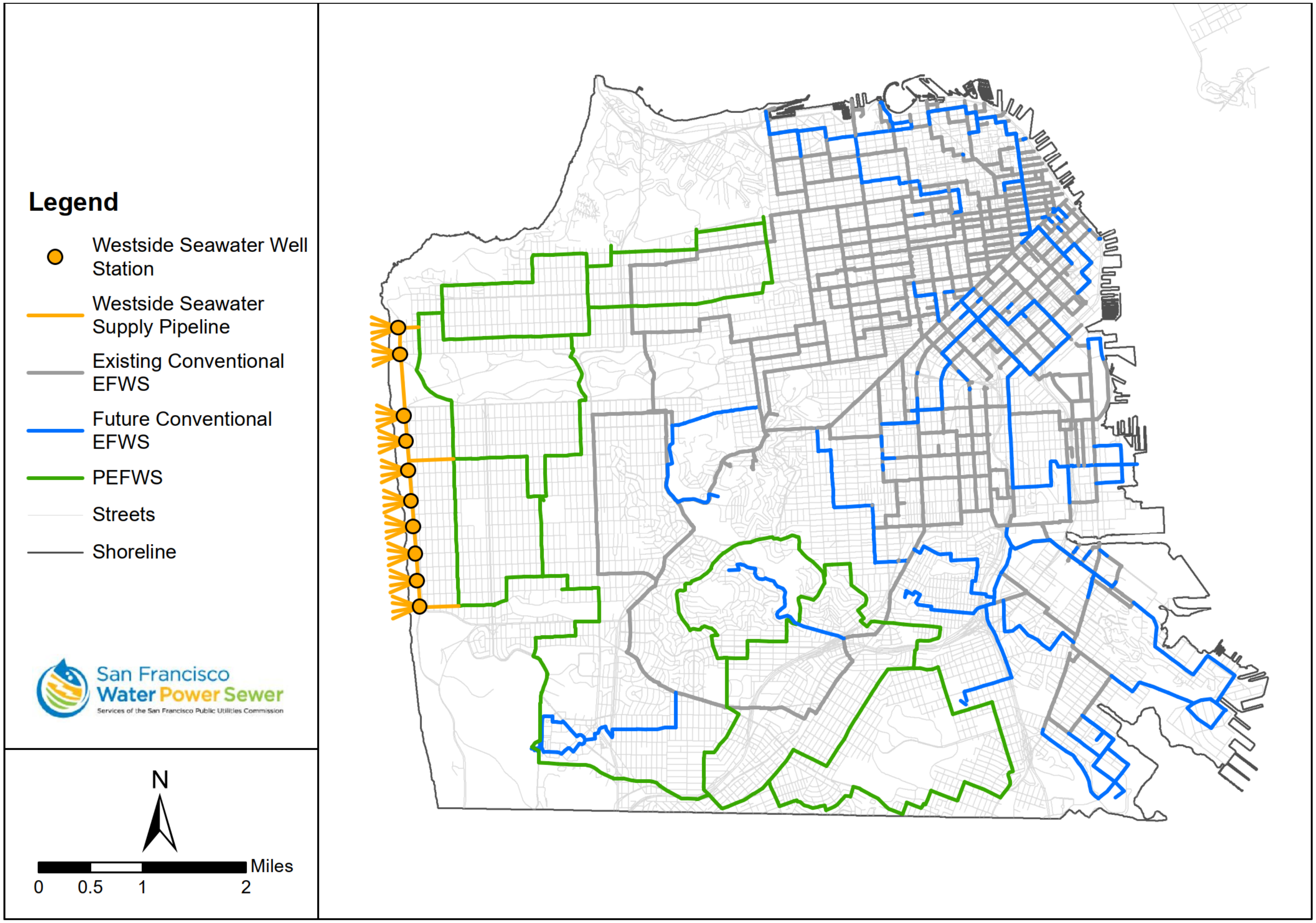


Figure ES-3: Westside Seawater Supply Option



1. Introduction

1.1 Background

The Emergency Firefighting Water System (EFWS) is a high-pressure fire protection water supply and distribution system that was constructed following the 1906 earthquake. Construction of the original system, called the Auxiliary Water Supply System (AWSS) at the time, was completed in 1913. The system consists of pipelines, one storage reservoir, two tanks, cisterns, suction and fireboat manifolds, and two seawater pump stations. The EFWS provides high-pressure water supply for firefighting to protect people and property from risk of fire following a major earthquake.

The EFWS provides emergency firefighting supply to a significant portion of San Francisco, but the existing system does not serve the entire city. Pipelines currently do not extend west of 19th Avenue in the Sunset District or west of 12th Avenue in the Richmond. There are also no EFWS pipelines in the southern and central areas of San Francisco, south of Ocean Avenue, in the area surrounding McLaren Park, or in the area surrounding Mount Davidson and Glen Canyon Park. Although these areas do have EFWS cisterns, the cisterns alone are not able to meet the anticipated firefighting water demand in those areas.

The San Francisco Public Utilities Commission (SFPUC) is responsible for the operation and maintenance of the EFWS. SFPUC, in partnership with the San Francisco Fire Department and San Francisco Public Works, is actively improving and expanding the existing infrastructure for the EFWS (Figure 1-1). The Earthquake Safety and Emergency Response (ESER) Bonds approved by the voters in 2010, 2014, and 2020 provided San Francisco with funds to plan, design, and construct projects to enhance the reliability of the EFWS.

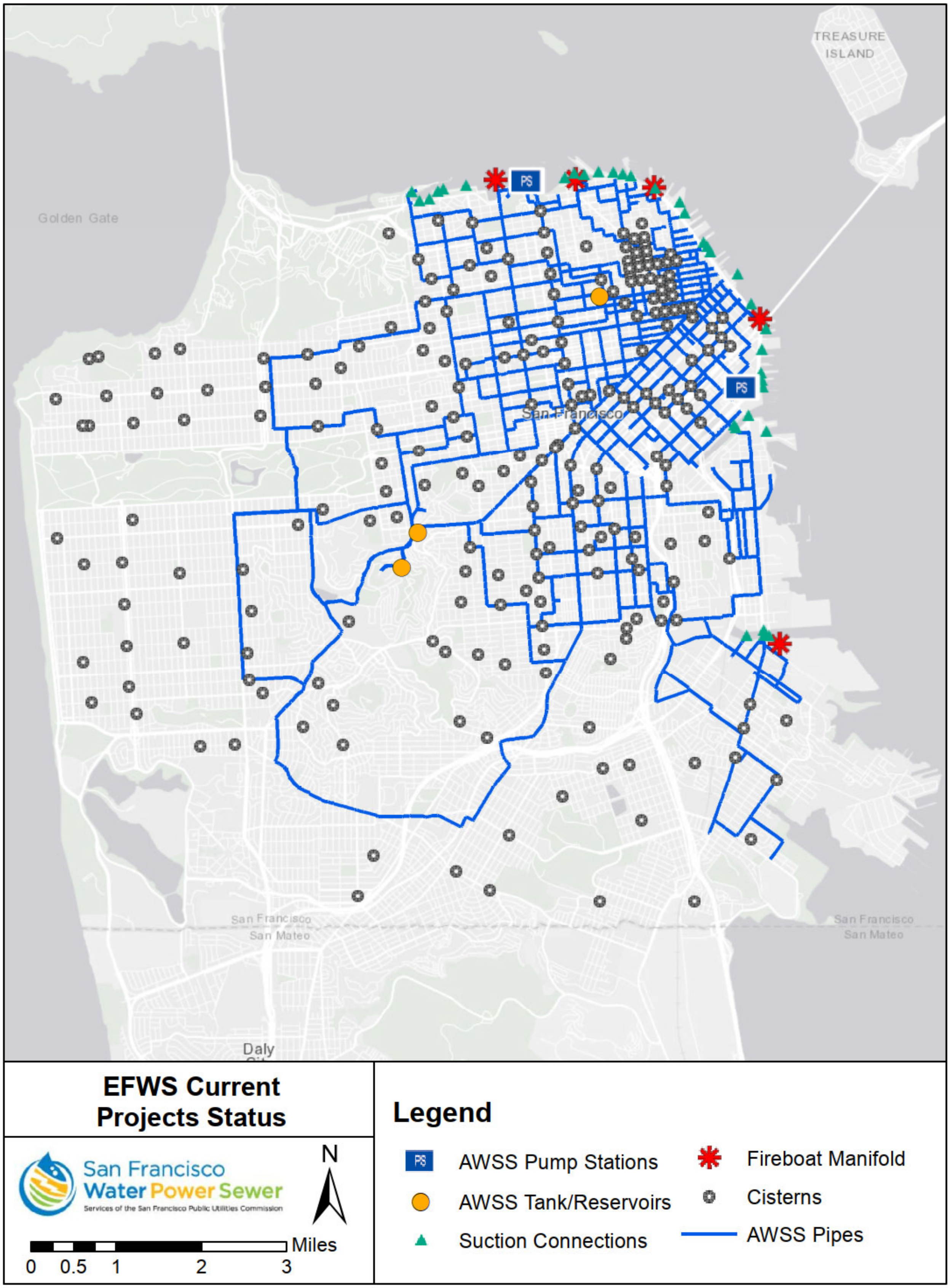
The 2010 and 2014 ESER Bonds included funds for EFWS projects, including improvements to core facilities, cisterns, and pipelines and tunnels. Funding in the 2020 ESER Bond focuses on improving EFWS capabilities in San Francisco's western neighborhoods. Planning studies—including the CS-199 Planning Support Services for AWSS (CS-199 Study) (AECOM 2014), CS-229 EFWS Spending Plan (Spending Plan) (AECOM 2015), and the Richmond District EFWS Options Analysis (Richmond EFWS Analysis) (AECOM 2018)—evaluated the performance of the EFWS and identified projects that improve and expand the citywide fire protection water supply and enhance its reliability. The CS-199 Study developed an evaluation strategy and long-term capital improvement recommendations for retrofit, improvement, and expansion of the EFWS. 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. Subsequent studies evaluated alternatives and selected pipeline alignments and water supply options to provide EFWS pipeline supply to the Sunset and Richmond Districts. These facilities are currently in various stages of planning, design, and construction, funded by the ESER 2020 Bond.

In October 2019, the San Francisco Board of Supervisors issued Resolution 422-19, responding to recommendations in the 2018-2019 City and County of San Francisco Civil Grand Jury Report "Act Now Before it Is Too Late: Aggressively Expand and Enhance Our High-Pressure Emergency Firefighting Water System" (City 2019) to address needed improvements to the EFWS. The primary planning efforts pertaining to the EFWS pipeline and water supply infrastructure include:

1. Study adding salt-water pump stations to improve the redundancy of water sources, especially on the west side.
2. Complete a more detailed analysis of emergency firefighting water needs (including above-the-median needs) by neighborhood, and not just by Fire Response Area (FRA).
3. Develop a plan to ensure that San Francisco is well prepared to fight fires in all areas within its boundaries in the event of a 1906-magnitude (7.8) earthquake. The plan should include a high-pressure, multi-sourced, seismically safe emergency water system for those parts of San Francisco that do not currently have one.

This study, the EFWS 2050 Planning Study, addresses item 3 in the list above. It builds on prior EFWS studies and incorporates the results from prior reports completed in response to items 1 and 2.

Figure 1-1: Existing EFWS Infrastructure



1.2 Study Objectives

The objectives of this study are to:

1. Develop a plan to provide pipelines and water supply sources for emergency firefighting water supply to all parts of San Francisco.

2. Use results from the EFWS Seawater Supply Pre-Feasibility Study (Seawater Pre-Feasibility Study) (AECOM 2021) in the evaluation of citywide firefighting water demands and supply needs.

3. Use results from the Fire Following Earthquake Water Requirements Study (FFEWR Study) (Scawthorn 2021) in developing the EFWS infrastructure layout, including addressing demands that are higher than median-level, and performing analysis at finer geographical resolution than by FRA.

2. EFWS Components

2.1 Conventional EFWS

The conventional EFWS was originally built between 1908 and 1913. It consists of primary water supplies, consisting of one water storage reservoir (Twin Peaks) and two water storage tanks (Ashbury Heights and Jones Street). Additionally, the conventional EFWS has secondary water sources consisting of two seawater pump stations (Pumping Stations 1 and 2). Other system components include approximately 135 miles of piping, 3,800 valves, 1,600 hydrants, and 177 underground storage cisterns. The Clarendon EFWS Upgrade Project is in progress to provide supply from Summit Reservoir, protected by an air gap, to the EFWS. There are also 52 suction connections along the northeastern waterfront that allow fire engines to pump water from San Francisco Bay, and five manifolds that can be connected to fire boats to pump water from the San Francisco Bay. In the Richmond District, a pipeline connected to Stow Lake in Golden Gate Park supplies firefighting water by gravity to hydrants along Fulton Street. The Portable Water Supply System (PWSS) is an above-ground, large-diameter hose system that the SFFD can use to extend the reach of the EFWS pipelines. The conventional EFWS delivers water under high pressure solely for firefighting and is designed to withstand a large seismic event. The San Francisco Fire Department (SFFD) uses the conventional EFWS, and the SFPUC City Distribution Division (CDD) is responsible for its operations and maintenance. Recent improvements to the conventional EFWS have been performed to extend the pipelines and construct underground storage cisterns in areas of San Francisco that do not currently have service.

The conventional EFWS is divided into three pressure zones: the lower zone (blue-top hydrants), the upper zone (red-top hydrants), and the Twin Peaks zone (black-top hydrants). The lower zone consists of all hydrants on the eastern side of San Francisco at an elevation of 150 feet and below. The lower zone is normally served by the Jones Street tank (water elevation 369 feet). Both the pressure and the supply can be increased to the lower zone with the use of the Ashbury Heights Tank (water elevation 494 feet) and the Twin Peaks Reservoir (water elevation 758 feet). The upper zone consists primarily of hydrants on the eastern side of San Francisco that are between 150 feet and 494 feet in elevation. The upper zone is normally served by the Ashbury Heights tank. Pressure and supply to the upper zone can also be increased by the Twin Peaks Reservoir. The Twin Peaks zone consists of hydrants west of Twin Peaks above 494 feet and is supplied by Twin Peaks Reservoir. In general, depending on the operational scenario, the high pressure in the system provides high flow at a greater reach without using a pumper engine. If the system pressure is too high, a pressure-reducing valve may be secured to the hydrants before connecting the hose.

2.2 Potable EFWS

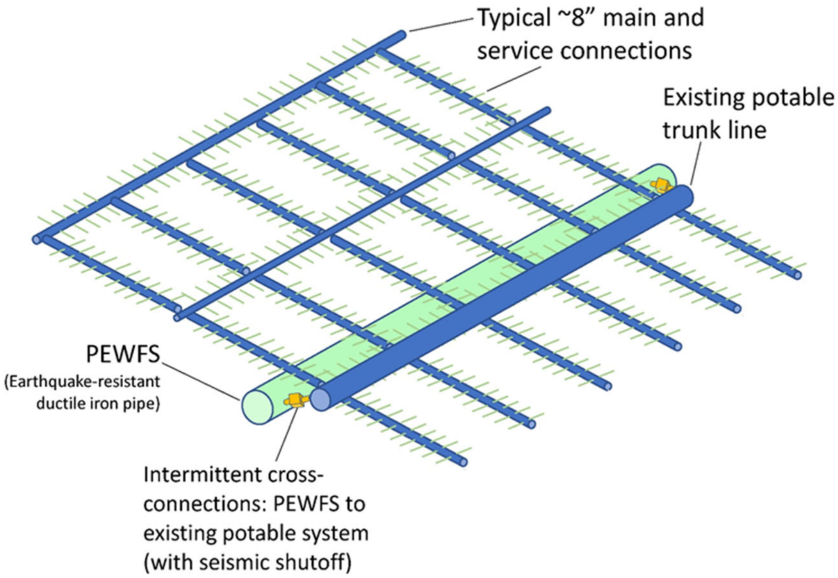
The potable EFWS (PEFWS) approach uses a dual-purpose pipeline that is independent from the existing conventional EFWS network. Under normal conditions, PEFWS pipelines would be used as potable water transmission mains. The PEFWS will use NSF61 certified pipeline, hydrant, and other appurtenance materials. NSF61 is a standard for products that come into contact with drinking water.

The system would also supply water to fight fires following an earthquake, and to fight greater alarm fires under non-seismic conditions. The PEFWS would be built to modern earthquake-resistant standards, including use of earthquake-resistant ductile iron pipe (ERDIP) or welded steel pipe (WSP). A critical benefit provided by the PEFWS pipeline network is its function as a seismically reliable emergency supply backbone system. When the system is no longer needed for fire suppression purposes, and while repairs are being made to the municipal water system, the PEFWS can be used to convey emergency water supply throughout its service area. The PEFWS will provide the same high-pressure fire suppression supply as the existing conventional EFWS.

The connections to the potable system would be limited in number (see schematic on Figure 2-1) to allow easier isolation from the potable system distribution pipe grid following an earthquake, thus precluding pressure loss due to breaks and leaks. The system will use seismically actuated control valves (in accordance with EFWS standards) on the limited connections to the potable system, allowing it to be automatically isolated following an earthquake. Once the PEFWS network is isolated from the municipal water system, the pipelines would be pressurized to a pressure similar to the conventional EFWS.

To ensure that sufficient water turnover occurs, the connections to the potable system will be located in coordination with the SFPUC Divisions that provide potable water supply. Isolation of the PEFWS does not cut off supply to any municipal water system service areas, because all areas of the municipal system are also fed by other transmission mains.

Figure 2-1: Potable EFWS Schematic (Illustration by Charles Scawthorn) (Not To Scale)



Following the firefighting, the PEFWS pipeline would become a water supply backbone for post-earthquake emergency water supply. The PEFWS provides daily reliability for the potable water system, reliable water supply for post-earthquake fire protection, and emergency water supply. The PEFWS is currently being designed and constructed to serve the areas on the west side of San Francisco that do not have an emergency firefighting water supply.

3. Planning Methodology

3.1 System Demands

3.1.1 Demand Development

The foundations for the present study are the flow and distribution of water required for firefighting following an earthquake. These factors define the water demands, and the objectives of the EFWS are to supply the water required to meet these demands. A separate study performed for this project, the FFEWR Study (Scawthorn 2021), estimated these quantities using modeling based on decades of research and development that has been employed for fire departments, insurance companies, and other entities (Scawthorn et al. 2005). Central to the FFEWR Study is the recognition that the water and fire services are co-equal members of the fire suppression team, and that understanding this partnership is crucial to the estimation of water requirements for fire suppression; one service complements the other in fire suppression. This co-dependence greatly affects the total demand on the water system. If a rapid and adequate fire department response is met with adequate readily available water at the fireground, the fire is relatively small and the total water demand modest. If the fire department response is delayed or water is a long time coming to the fireground, the fire rapidly grows to multi-alarm (or even multi-block) proportions, and the amount of required water is orders of magnitude greater. For these reasons, the FFEWR Study necessarily modeled the performance of both the fire and water services.

The FFEWR Study began by defining two earthquake scenarios for analysis: (1) a Mw 7.9 event on the San Andreas fault like the 1906 event, and (2) a Mw 7 event on the Hayward fault in the East Bay, either of which would cause very strong ground motions in San Francisco. The Mw 7.9 San Andreas event is similar to the 1906 event and is generally the more damaging event—especially in the western portions of San Francisco, which are only a few miles from the fault. The Hayward event is considered more likely to occur in the near future. Ground motions and permanent ground deformations for these two events were defined probabilistically, taking into account local soil conditions and spatial correlation. These two events were then applied to San Francisco's built environment, considering both the current population of about 880,000 and projected growth to 2050, to estimate the number and pattern of ignitions.

The FFEWR Study then modeled the response by the SFFD, which will be very challenged by these events—SFFD's 44 on-duty engine companies will be confronted in the Mw 7.9 San Andreas event by an average of about 130 fires in the first 24 hours under (current conditions increasing to perhaps 160 fires by 2050 with growth of San Francisco), with mutual aid probably taking many hours to arrive. The FFEWR Study then modeled the availability of firefighting water at each fireground, considering all possible sources, including the potable water supply system; the existing high-pressure EFWS; SFFD's fireboats and Portable Water Supply System; the numerous special-purpose cisterns throughout San Francisco; and the bay, ocean, lakes, swimming pools, and other bodies of water. This availability of water was modeled considering the effects of earthquakes, under current and future conditions, for 21 different scenarios or cases of EFWS and SFFD improvements. This modeling considered weather, time of day, season, and many other variables in a probabilistic format, resulting in a time-varying probabilistic distribution of required firefighting water over the first 25 hours following the earthquake.

Results of the analysis of the 21 cases for current and future variations in EFWS and SFFD improvements showed that effective firefighting under current conditions is estimated to require flows of about 140,000 gallons per minute (gpm) (median; 75th percentile is 200,000+ gpm) after the first few hours, equivalent to a total volume of about 200+ million gallons (MG) in the first 24 hours after an earthquake. Results also showed that future water requirements can remain about the same, or be much larger, depending on the improvements made to the EFWS and SFFD.

As noted above, the FFEWR Study is the basis for this EFWS 2050 Planning Study report. As discussed below, Case D was selected from the 21 cases in the FFEWR Study, and its water requirements for the year 2050 are employed in much of the remainder of this report. Case D's results are in the form of a probability distribution of the required water at any moment following the earthquake. Prudence dictates that the EFWS design be based on some upper fractile of the probability distribution of required water. That is, if the median value were to be employed, then by definition the water required for firefighting would exceed the EFWS design basis 50 percent of the time, which is clearly not satisfactory. On the other hand, if for example the 99th percentile were used as the design basis, the EFWS design basis would be relatively "safe" (adequate firefighting water 99 percent of the time) but the cost of the system would be prohibitive. Based on a review of the probability distribution and experience in the performance of water and fire systems in previous earthquakes, the 75th percentile was employed as an initial design objective for EFWS planning, to be examined further and refined as discussed below.

3.1.2 Selection of Demand Target

The FFEWR Study provided 21 demand cases, representing a range of system conditions and resource scenarios. The demand cases and their respective input parameters were reviewed and narrowed down to the four cases shown in Table 3-1, which capture the applicable conditions for this study. Of the four cases, the input parameters for Case D are the most appropriate to the project objectives. The conservative parameters included in Case D were selected to provide a more robust demand set, which results in a water system that is less likely to be impacted by variations in future conditions. The input parameters are described as follows:

- Development Decade This parameter denotes the year of projected City Growth reflected in the demand case. Case D assumes City Growth conditions for 2050, consistent with the planning horizon of this study.
- System Damage: This parameter indicates whether earthquake damage to EFWS pipelines is considered. Given that this study is intended to evaluate post-earthquake fire conditions, all cases in Table 3-1 take into account damage to the EFWS pipelines.
- System Operational Efficiency: This parameter reflects system response capability and response time to assess damage and implement mitigation measures. A high efficiency results in more water getting to the fireground, and therefore generally results in higher water demands on the system.
- System Improvements: This parameter denotes whether EFWS improvements are considered. Cases with “No” use the existing (2020) pipe network and water sources; cases that use “Yes,” including Case D, consider the proposed improvements identified in this study.
- SFFD Resources: This parameter reflects whether or not SFFD resources, specifically fire engines and hose tenders, increase in proportion to population growth. Case D assumes that SFFD fire engines will be added as the population of San Francisco grows. This assumption is conservative; it results in water system planning that is consistent with growth in SFFD resources, but is not impacted if resources do not increase as anticipated. The supply capacity will be in place regardless of the rate of growth in resources.
- City Growth: “Current” indicates that population and building inventory growth are not considered in the demand case, while “Future” indicates that growth corresponding to the development decade is included in the analysis. Case D includes “Future” conditions to plan the EFWS for the 2050 planning horizon.

Table 3-1: Firefighting Water Demand Cases

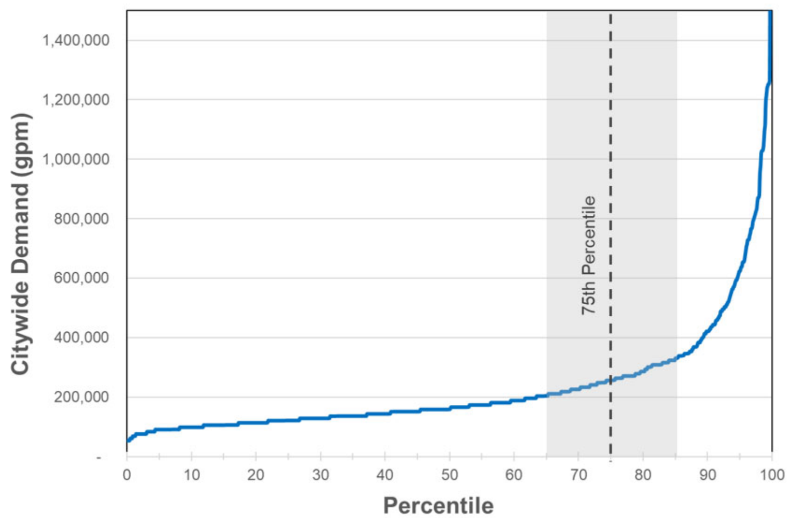
Case	Development Decade	System Damage	System Operational Efficiency	System Improvements	SFFD Resources	City Growth	75th Percentile Demand (gpm)
A	2020	Damage	Low	No	Current	Current	240,000
B	2050	Damage	Low	No	Current	Future	241,000
C	2050	Damage	Low	Yes	Current	Future	240,000
D	2050	Damage	High	Yes	Additional	Future	255,000

Notes:

gpm = gallons per minute
SFFD = San Francisco Fire Department

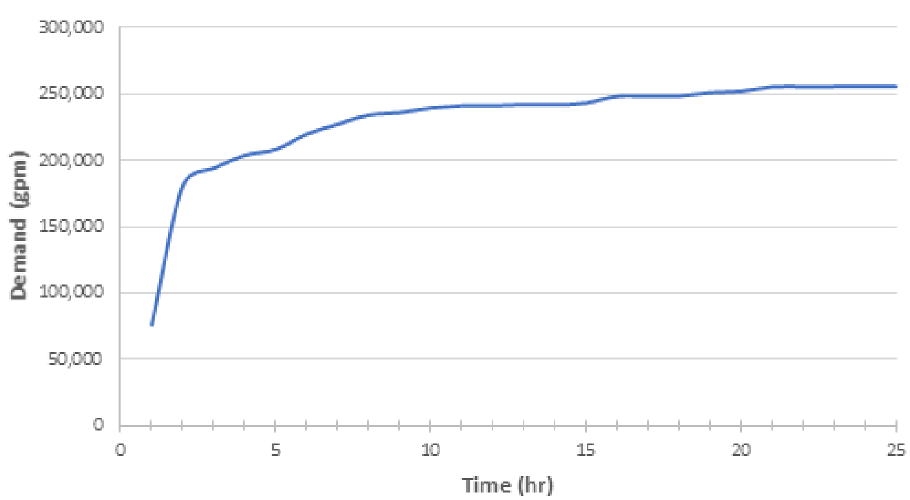
Figure 3-1 shows the distribution of demand values for demand Case D. As a matter of prudent planning for critical infrastructure, a percentile range above the median (50th percentile), from 65th to 85th percentile, was evaluated for this study. Demand values below this range do not provide the level of assurance that the system can deliver the water required to fight fires. Above this range, in excess of the 85th percentile, the graph shows that demands increase exponentially; improvement costs would be expected to follow accordingly, with diminishing returns as the percentile increases. For this study, the midpoint of the range, at the 75th percentile, was selected as the demand target. As shown in Table 3-1, this equates to 255,000 gpm.

Figure 3-1: 75th Percentile for Demand Case D



The FFEWR Study post-earthquake firefighting demand modeling was based on a number of seismic, fire response, and water system simulation parameters over time. Figure 3-2 shows the 75th percentile water demand for Demand Case D over the initial 25 hours after an earthquake occurs. The graph shows that firefighting water requirements follow an increasing trend after the earthquake occurs, reaches a maximum after several hours, and remain at that level through at least the 25th hour. For this study, the maximum level, at the 25th hour, has been used for design of the EFWS. It is believed to be a reasonable estimate of citywide demands to identify water supply sources and pipelines to convey the water.

Figure 3-2: 75th Percentile Water Demand Following Earthquake Occurrence



3.2 Hydraulic Analysis

This study uses EPANET as the hydraulic modeling engine to design and evaluate the performance of the EFWS pipe network. EPANET is a water system hydraulic modeling software application developed by the U.S. Environmental Protection Agency. It is an open source application that is widely used throughout the water industry to analyze pipe networks similar to the EFWS.

The EPANET application was implemented on this project using QuakeNet, a software developed by San Francisco Public Works to analyze the seismic performance of the EFWS. QuakeNet uses pipeline earthquake damage modeling methodologies developed by T. O'Rourke and colleagues at Cornell University to simulate hydraulic networks under damaged states. The methodologies, from the Graphical Iterative Response Analysis of Flow Following Earthquakes (GIRAFFE) tool, estimate pipe damage based on ground motion data and pipe fragility equations. The estimated pipe leaks and breaks are then modeled using EPANET to simulate water loss from the system due to the damaged pipes. For this study, the damage estimation methodology was updated based on recent information in the paper "Influence of Diameter on Seismic Response of Buried Segmented Pipelines" (O'Rourke and Vargas-Londono 2018). The updated approach improves pipe leak and break estimation by considering the pipe diameter.

To capture the uncertainty associated with the seismic performance of the EFWS pipe network, a Monte Carlo analysis was used to model system damage during an earthquake. Input data to each Monte Carlo simulation, including demand, pipe network, pipe fragility, and ground motions, were used to develop the EFWS system damage states modeled by the hydraulic model; 1,000 simulations were run to capture the range of potential outcomes resulting from the variability.

The results from the hydraulic modeling were used to evaluate the reliability of the EFWS after a major earthquake, using a probabilistic approach. The results from the 1,000 Monte Carlo simulations provide the system performance data set analyzed and presented in Section 5.

3.3 Improvements Development Approach

Development of the proposed system configuration involved the following primary steps:

1. Develop the pipeline alignments to provide coverage to areas not served by the EFWS.
2. Identify water supply sources to meet the required firefighting demands.
3. Analyze the ability of system hydraulics to convey water from the supply sources to demand needs throughout the system.

3.3.1 Pipeline Coverage

The map of the existing conventional EFWS pipelines shown on Figure 1-1 readily shows those areas of San Francisco that are not served by EFWS pipelines. Although there are cisterns in many of those areas, this study focuses—based on input from project stakeholders, including SFFD—on improvements to supply water via EFWS pipelines. Using the pipeline supply to meet demand ensures the ability to provide high flow rates for sustained durations. Although cisterns provide a distributed network of stored water in many locations, the typical cistern storage of 60,000 gallons would sustain pumping at a rate of 1,500 gpm for only approximately 40 minutes. Fire following a major earthquake would be expected to last multiple hours.

Extension of the EFWS into new areas has been analyzed for decades, and many prior studies and concepts have been developed over time. Some examples of prior studies include the CS-199 Study (AECOM 2014), Spending Plan (AECOM 2015), Richmond District EFWS Analysis (AECOM 2018), PEFWS Pipeline Alternatives Analysis Report (AECOM 2020a), and the PEFWS Pipeline Conceptual Engineering Report (AECOM 2020b). Concepts from these prior studies, along with ideas from project team members and technical advisors, were reviewed and consolidated.

The suite of pipeline improvements was presented and discussed with project stakeholders, including the SFFD, SFPUC Infrastructure, and CDD. Some pipeline improvements, such as the Westside PEFWS, have been vigorously reviewed and refined in prior studies and are currently in the project design and construction stages. Solutions for the remaining gaps in coverage were developed and reviewed with stakeholders during brainstorming sessions. The final design of the pipeline network seeks to extend pipeline coverage into all areas of San Francisco, using loop configurations. Loop configurations increase hydraulic performance by conveying water through dual pathways. They also increase seismic reliability by providing two ways to get water to any specific point in the system.

Once pipeline alignments were developed to provide coverage to new areas, a determination was made whether to connect to the pipes to the conventional EFWS or to the PEFWS. This was based on the following considerations:

- Proximity to conventional EFWS or currently planned PEFWS pipelines
- Capacity of connecting infrastructure
- Need and opportunities to concurrently provide an emergency water supply backbone pipeline

On the west side of San Francisco, the evaluation of alternatives and selection of PEFWS as the preferred approach has been performed in several studies, as described above. In other areas, such as the southern area of San Francisco, implementation of PEFWS with separate supply sources reduces the water demand load on the conventional EFWS. A significant portion of the existing conventional EFWS is constructed of 10- and 12-inch-diameter pipelines, which cause hydraulic constraints under high flows. Adding new service areas to the conventional EFWS would increase demands and flows through the pipelines. The additional flows would result in higher head losses in the pipes and hydraulically inefficient conveyance to the new service areas. New pipelines in areas already within the conventional EFWS service area are connected to that system for efficiency.

3.3.2 Water Sources

An analysis of the citywide demands and existing EFWS supplies was performed to determine the water supply deficit and the required additional supplies. As described later in Section 4.3, there is a significant deficit between the target demand and the existing supplies. The water supply sources available immediately after an earthquake that were considered include stored water supplies in San Francisco, including potable reservoirs and freshwater lakes, as well as seawater from San Francisco Bay and the Pacific Ocean.

The feasible new water supply sources were connected through pipelines to the conventional EFWS and PEFWS. The pipelines and their connection points to the system were determined based on the geographic distribution of the demands (i.e. where the water was needed), system hydraulics, and water source location and elevation in relation to the pressure zone boundaries.

3.3.3 System Hydraulics

The hydraulics of the system were analyzed after the coverage pipelines were configured, and the supply sources were identified. The purpose of the analysis was to identify and mitigate hydraulic constraints that limited the flow of water from the source to where it is needed to fight fires. The hydraulic model was used to determine where issues such as excessive head losses occur in the system due to inadequately sized pipes. In areas of high liquefaction susceptibility, pipeline breaks or closed isolation valves can impede flow. The model was also used to identify areas in the system where pipe loops can be incorporated to improve hydraulic efficiency and reliability.

4. System Improvements

This section describes the improvements to the EFWS needed to meet the demand targets. The improvements are grouped into the following categories:

- Conventional EFWS Pipeline Improvements
- PEFWS Pipeline Improvements
- Water Supply Sources (including required pump station facilities)
- Other EFWS Improvements

The improvements, shown on Figure 4-1, are discussed individually by category in this section.

Although pipeline improvements are discussed in this section by their primary function, such as extending water supply coverage or increasing conveyance capacity, they have multi-purpose benefits due to the systemic nature of pipeline networks. New pipelines will have hydrants along their alignment and will therefore provide coverage, and they all provide conveyance capacity. All new PEFWS pipelines will provide potable seismic backbone benefits in addition to their expansion of firefighting water supply coverage. Pipeline alignments for the proposed improvements are planning level, and are expected to be refined during subsequent phases of engineering planning and design. The diameters of new pipelines are generally 24 inches, unless larger diameters are required by hydraulics, such as pipelines that connect water sources to the system. Because construction of EFWS pipelines on every block is not feasible, the pipeline configurations work in conjunction with deployment of the PWSS to extend the reach of EFWS hydrants to defend those areas between pipelines.

4.1 Conventional EFWS Pipeline Improvements

4.1.1 Connections to Additional Water Supply Sources

Additional water supply sources will be required to meet firefighting water demands. New pipelines must be constructed to connect the water supplies to the EFWS, as shown on Figure 4-2. The pipelines would serve a dual purpose: not only would they connect the source to the system, but because they would have hydrants along their alignment, they would also expand the coverage area of the system. The supply connection pipelines are generally larger in diameter because they convey flow from the source to the network, at which point the flow will split and water will be conveyed in multiple directions.

- The pipeline connecting Sutro Reservoir to the conventional EFWS runs from the reservoir and through the Inner Sunset District. Portions of the existing system, which connect this pipeline to the upper zone, will require upsizing, as described later in Section 4.1.4.
- To connect Stanford Heights Reservoir to the Ashbury Zone, a pipeline would run through the Miraloma Area along O'Shaughnessy Boulevard and connect to the conventional EFWS just west of Interstate 280.
- The pipeline that conveys supply from College Hill Reservoir extends east through the Bernal Heights District and connects to the conventional EFWS, in the lower zone, just east of U.S. Highway 101 (US 101).
- University Mound Reservoir would supply water to both the conventional EFWS and PEFWS. Supply to the conventional EFWS would be through a pipeline running along Bacon Street and Bayshore Boulevard, connecting to the conventional EFWS near the Interstate 280/US 101 interchange.
- For the purposes of this study, the additional seawater supply to the conventional EFWS on the eastern side of San Francisco was assumed to be adjacent to San Francisco Bay near the end of 22nd Street. The supply pipeline runs along 22nd Street and connects to the conventional EFWS at 3rd Street.

Figure 4-1: Recommended EFWS Improvements

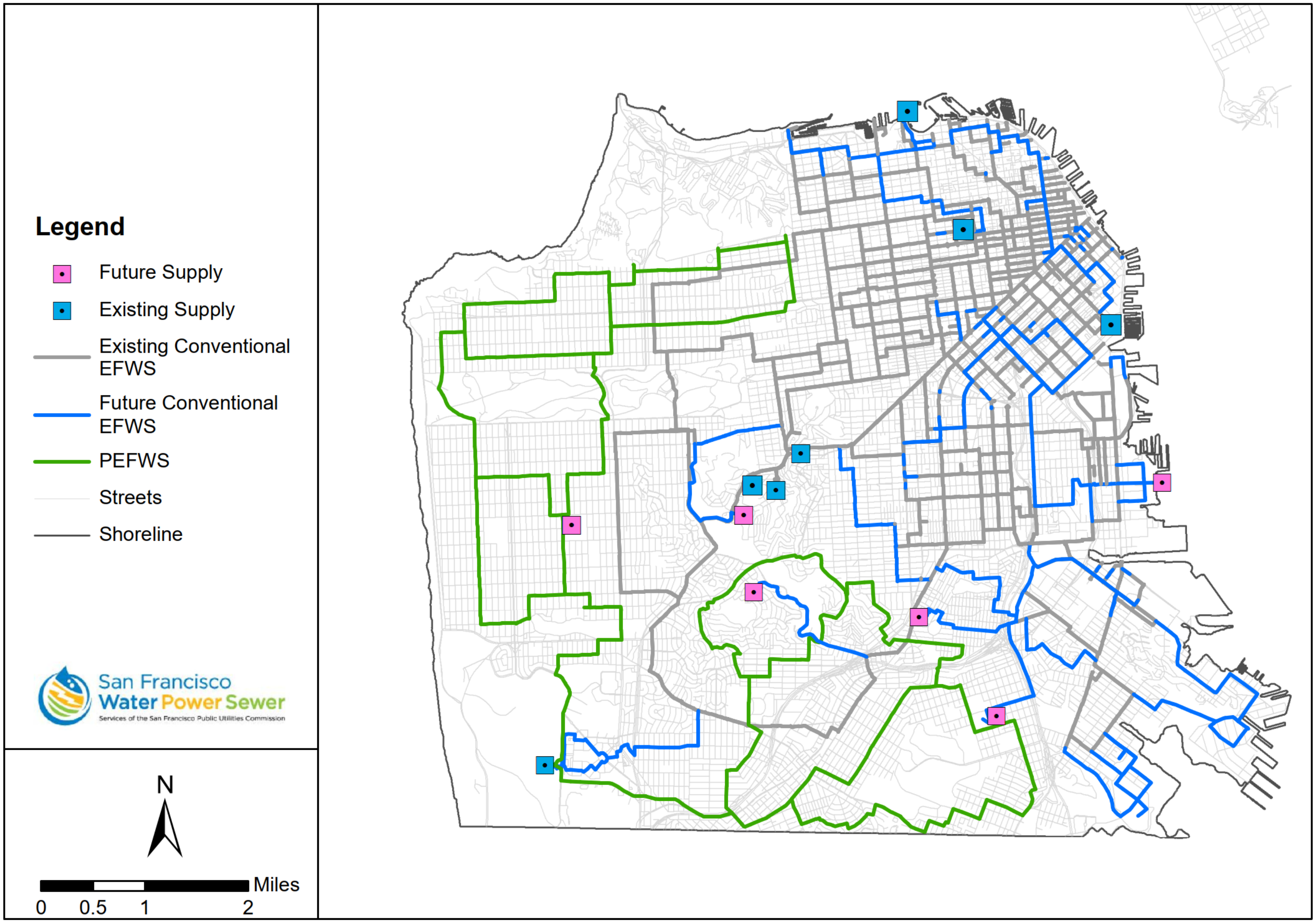
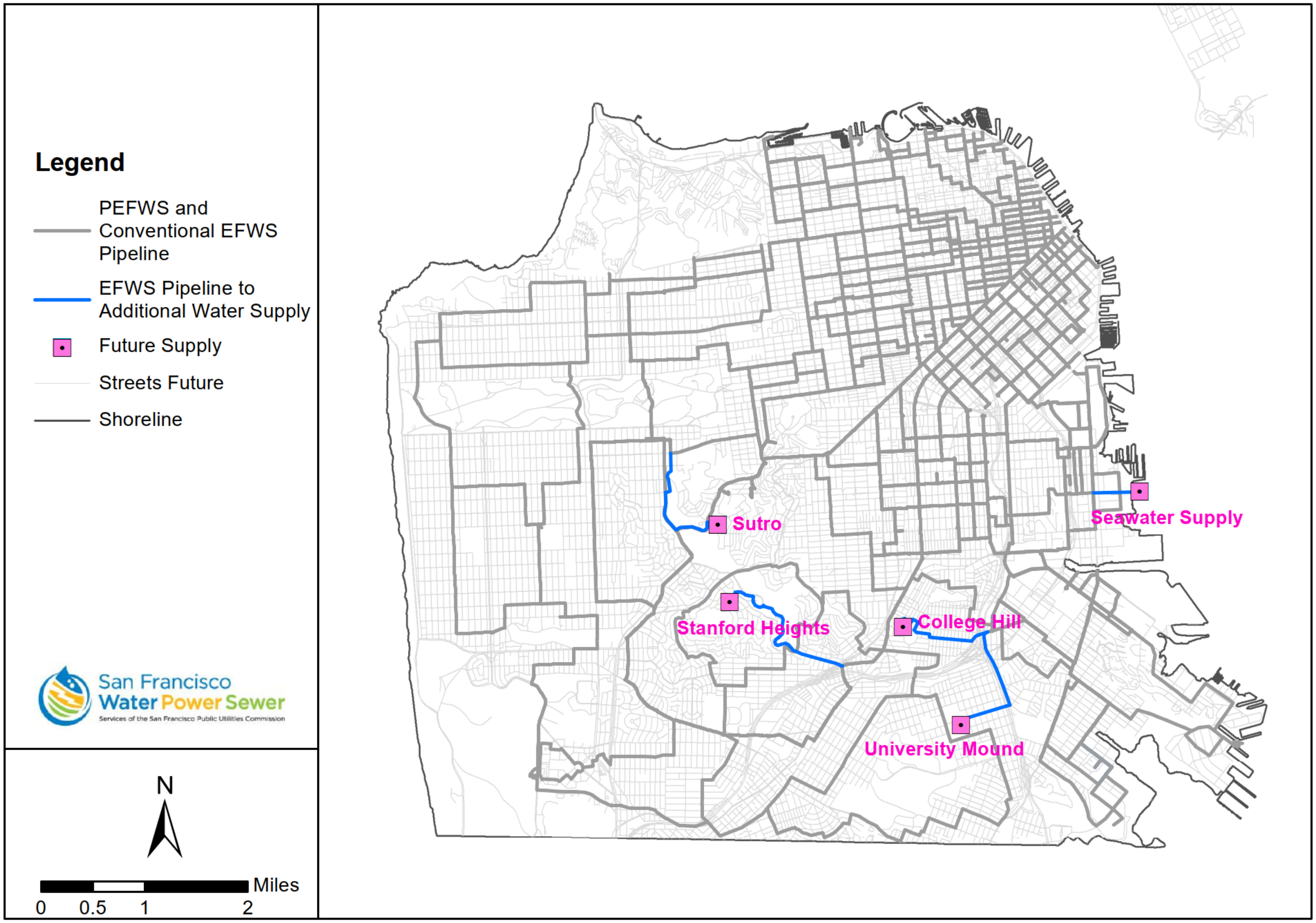


Figure 4-2: Pipeline Connections to Additional Water Supply Sources



4.1.2 Infirm Area Backbone Pipelines

Ten zones in San Francisco, shown on Figure 4-3, have been identified as infirm in previous studies. These are areas that may be subject to liquefaction and will likely cause damage to the AWSS piping during an earthquake. The current strategy, developed in the 1980s and based on experience from prior earthquakes, is to isolate the piping in the infirm areas to reduce leakage and prevent the draining of system supply storage. Isolation is achieved by keeping some valves closed and by providing seismically triggered valves that automatically isolate these areas following an earthquake.

The infirm area isolation valves would not be reopened until damaged pipes are repaired, or until it could be confirmed that pipe damage would not result in the draining of system storage. It may take a significant amount of time to reopen the valves. In the interim, those areas served by the isolated pipes would not have EFWS supply to fight fires. Therefore, five groups of infirm area backbone pipes, constructed of ERDIP, have been identified to provide supply to those areas immediately after an earthquake. Because of their proximity, some of the infirm area backbone pipes address multiple infirm areas.

The infirm area backbone pipes would connect to EFWS outside of the infirm area boundaries and therefore have a much higher likelihood of serving as a viable conduit to the infirm areas. The backbone pipe isolation valves would remain open under normal conditions and would not be seismically triggered, so that water supply would be available immediately after the earthquake. To improve system hydraulic connectivity, some additional pipe replacements at select boundaries and valving connections near the infirm areas have also been identified. To maximize the benefits of the infirm area backbones, current geotechnical information on liquefaction zones should be incorporated during the detailed design phase of the infirm backbone pipelines. Figure 4-3 shows the infirm areas, liquefaction zones, and backbone pipeline improvements.

4.1.3 Extension Into Areas Without Coverage

Park Merced/Ingleside

The Park Merced and Ingleside pipeline extensions would provide firefighting water to the Park Merced, Merced Heights, and Ingleside areas, which are not currently served by EFWS pipelines. In addition, these pipelines would connect to the conventional EFWS along Ocean Avenue and therefore convey additional supply from Lake Merced Pump Station to the conventional EFWS.

Dogpatch

Additional seawater supply to the conventional EFWS has been assumed to be located in the area adjacent to San Francisco Bay, at the foot of 22nd Street. There would be additional pipes in this area to extend water supply and to also improve conveyance of the new supply source.

Hunters Point

Currently, there are no EFWS pipelines that provide firefighting water supply to the Hunters Point area. New pipes are proposed to provide service to the area through two connections to the existing EFWS: on Evans Avenue and on Revere Avenue. The pipes would form a hydraulic loop through the area to improve conveyance capacity and reliability.

Candlestick Point

Similarly, although EFWS pipe was constructed in the vicinity of Candlestick Point, there are currently no pipelines providing firefighting service directly in the area. A multi-loop network through the area would provide service and connect to the EFWS at three locations: Carroll Avenue, Gilman Avenue, and 3rd Street.

Figure 4-3: Infirm Areas and Backbone Pipelines

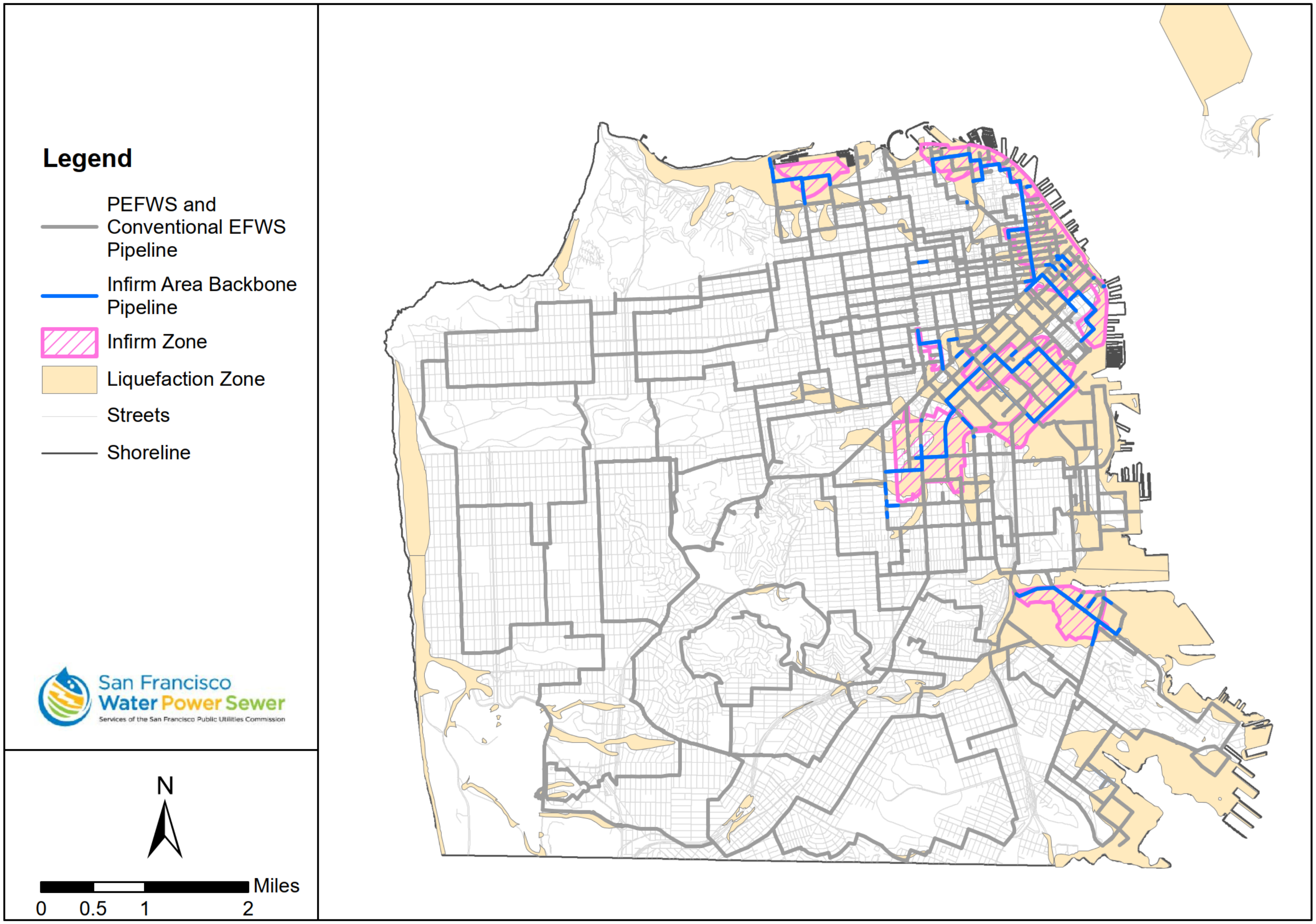
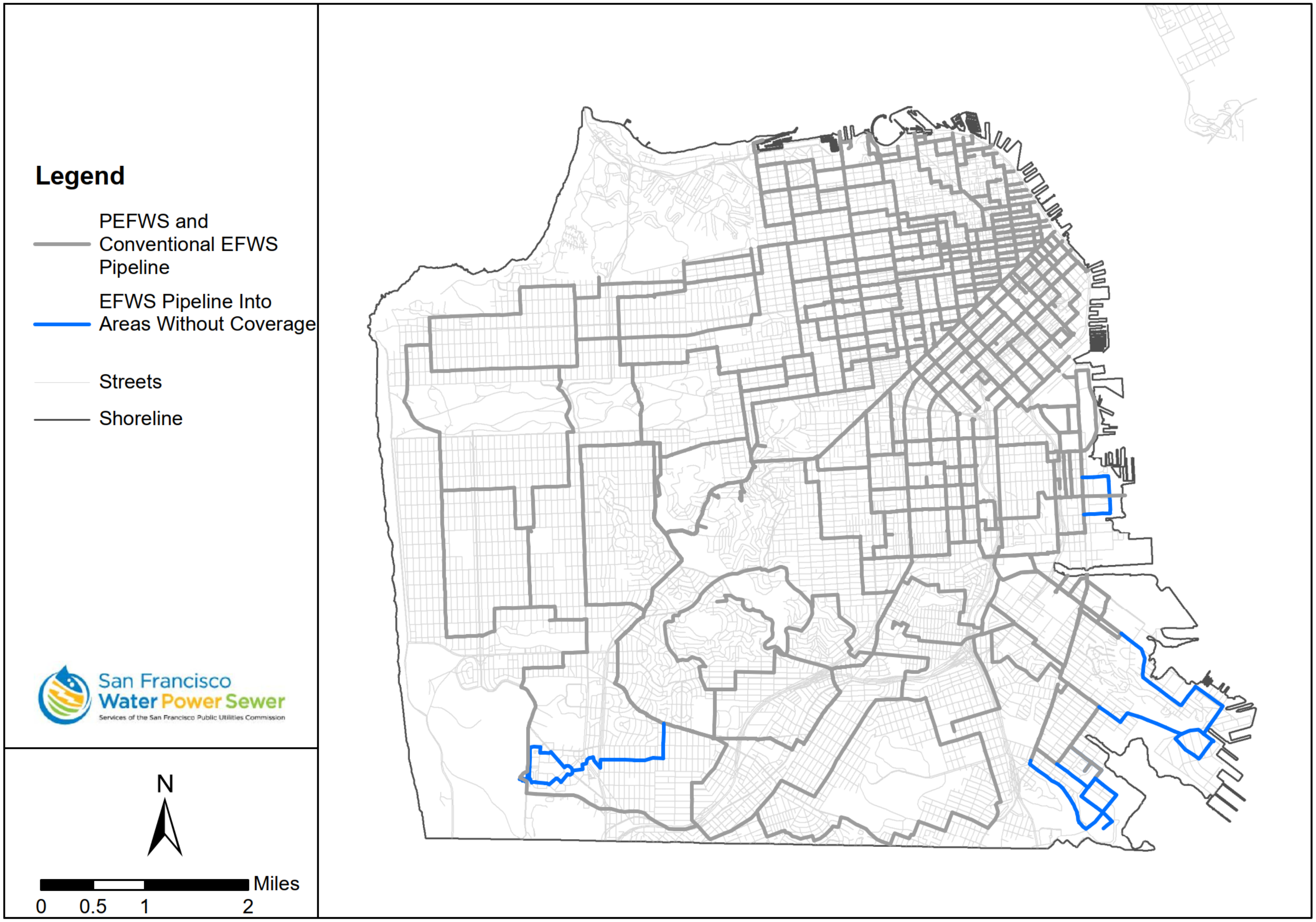


Figure 4-4: Pipelines to Extend Conventional EFWS Coverage



4.1.4 Conveyance Capacity Improvements

Earlier portions of the EFWS were constructed using pipes of a smaller diameter than would be used today, given the future estimated firefighting flow requirements. As shown on Figure 4-5, approximately 50 percent of the existing pipelines are 10 to 12 inches in diameter, 40 percent are 14 to 16 inches in diameter, and 10 percent are 18 to 20 inches in diameter. Where the smaller-diameter pipes are close together, they create a network that helps mitigate the limited capacity. However, where the small-diameter pipes are sparsely spaced, significant hydraulic restrictions can occur and the system can be challenged in delivering the required flow at the required pressure.

Where a water supply source is connected to the system, larger-diameter pipelines are generally required to accommodate the large flow entering the system; flows are high until they split and flow to the various service areas. Hydraulic restrictions in the existing system occur in the vicinity of new supply sources at several locations. Pipeline improvements are proposed to improve conveyance capacity, including construction of additional pipes or increasing the size of existing pipes. Figure 4-6 shows the pipeline improvements proposed to increase conveyance capacity of the conventional EFWS.

Marina District

In the Marina District and extending down toward Russian Hill, the conventional EFWS consists mainly of 12- and 14-inch-diameter pipes. In the vicinity of the existing Pump Station No. 2, the small pipe diameters result in high head losses. Those pipes that are nearer to the source of supply have a greater impact on system hydraulics because they convey higher flows, before the pipes branch out and distribute flow in multiple directions. Under the 2050 demand targets, these pipelines will convey even higher flows and will require upgrades to increase their size.

Sutro

Under improved system conditions, pipes that run through the Inner Sunset, Cole Valley, and Haight-Ashbury would convey water from Sutro Reservoir to the conventional EFWS. These would consist of 12-, 14-, and 18-inch-diameter pipes. Sutro reservoir would supply approximately 30,000 gpm to the conventional EFWS. The existing pipes are inadequately sized for the new flows and would result in high friction losses. Construction of larger-diameter pipe and some new pipe is needed to address the hydraulic constraints of the smaller-diameter pipes and convey flow from Sutro to the rest of the system more efficiently.

Noe Valley

The existing pipeline that traverses Noe Valley provides north-south conveyance and connection between two areas of the conventional EFWS upper zone. This pipeline consists of 12-inch and 16-inch pipe. With higher flows under 2050 target demand conditions, greater conveyance capacity is needed, particularly because flow from Stanford Heights Reservoir needs to be conveyed to other parts of the upper zone.

Potrero/SOMA

The pipelines in the Potrero/SOMA area provide service to the Potrero Hill area, as well as additional conveyance capacity from east to west through the Potrero Hill area and south to north through Potrero Hill and SOMA. Large transmission capacity is either lacking north to the SOMA area, or constrained by smaller-diameter 12-inch pipes. This group of pipes increase capacity to convey supply from the east seawater pump station to other parts of the conventional EFWS and provides additional hydrants along Kansas Street.

Bernal Heights

A new pipeline in Bernal Heights north of Bernal Heights Park is needed to complete a hydraulic loop, where the pressure zone boundary along Mission Street limits hydraulic circulation through the area. This loop would provide significant hydraulic improvement in an area of the pipe network consisting almost exclusively of smaller 12-inch-diameter pipes. In addition, two potable reservoir supplies, College Hill Reservoir and University Mound Reservoir, would connect to the conventional EFWS near the eastern end of the new pipeline in Bernal Heights. This pipeline would provide additional flow paths to convey the supply from these reservoirs to the other areas of the lower zone. The pipeline through Bernal Heights would also improve coverage in this area.

Figure 4-5: Diameters of Existing EFWS Pipes

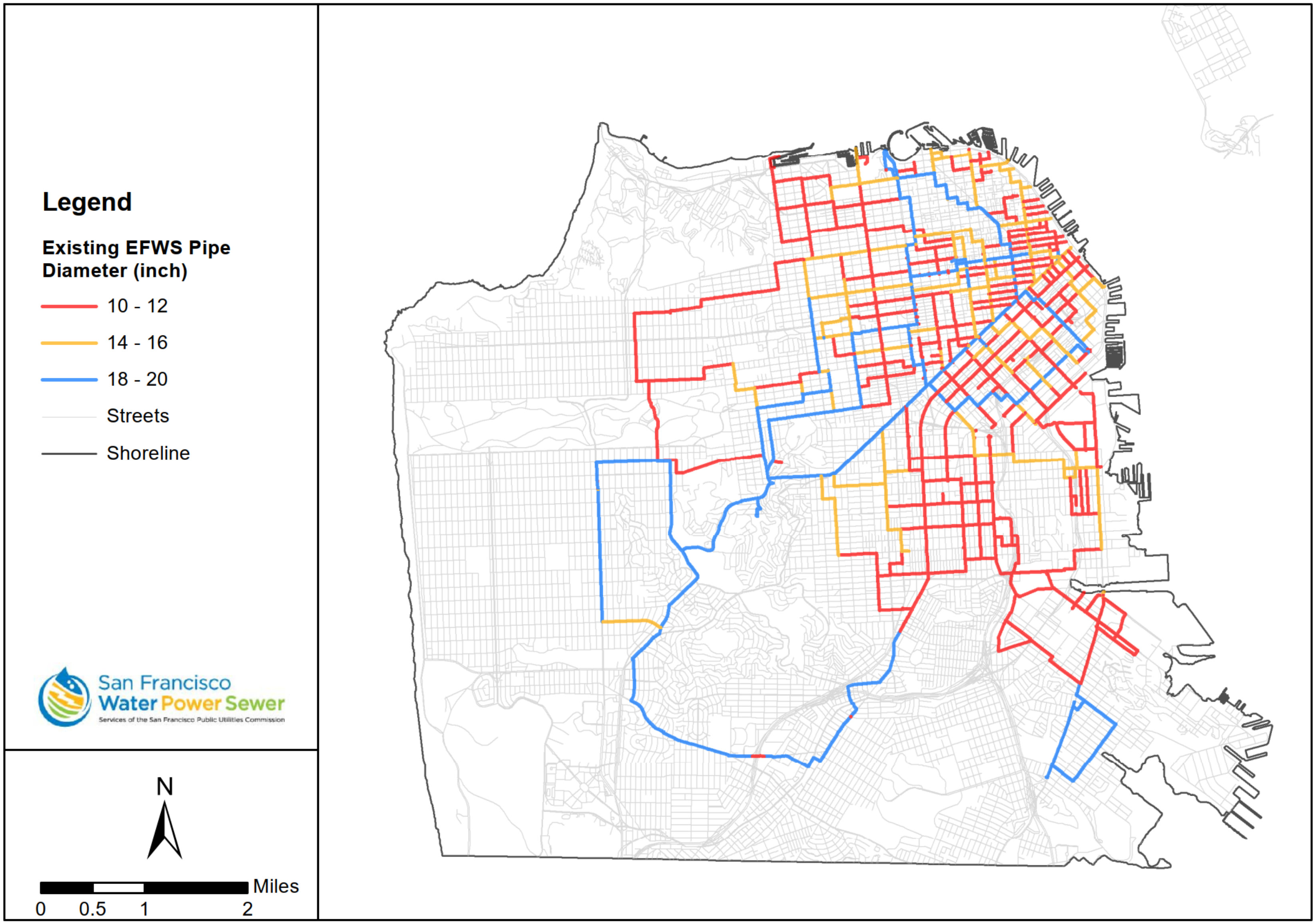
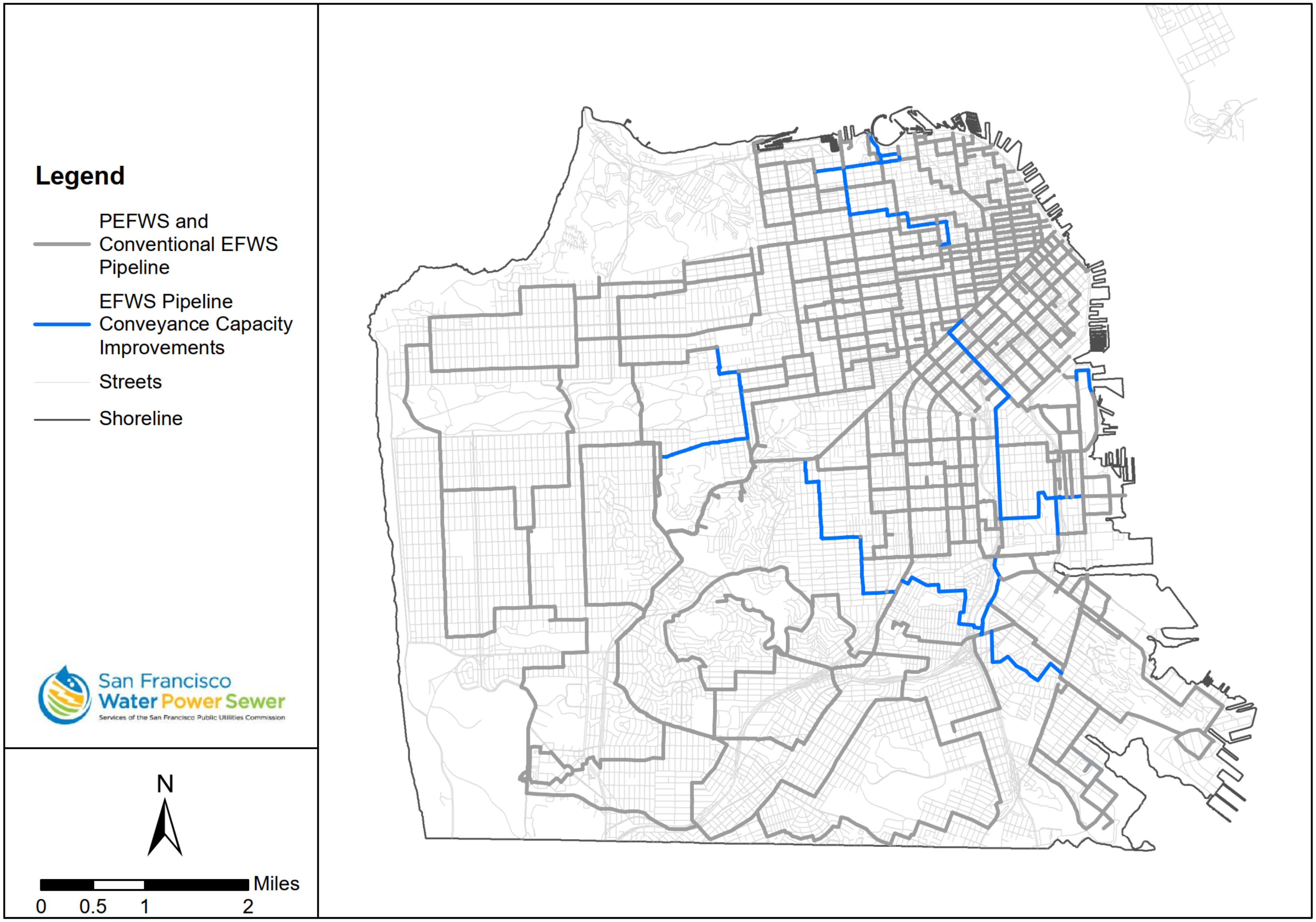


Figure 4-6: Pipeline Improvements to Increase Conveyance Capacity



An additional pipeline running north-south along Bayshore Boulevard would increase the size of the existing pipeline along this alignment and provide an additional connection to the pipes to the north.

Silver Terrace

The pipeline through the Silver Terrace area would increase conveyance capacity and also provide additional coverage in the area. The areas in the southeastern corner of San Francisco, including Bayview, Hunters Point, and Candlestick Point, are supplied by two smaller 12-inch-diameter pipelines, one of which runs through a liquefaction zone. The pipeline through the Silver Terrace area would provide an additional conduit to the areas in the southeast.

Mission Bay

A short segment of pipe in the Mission Bay area near Mission Creek would be added to the pipe network in the area to complete a hydraulic loop. This addresses a dead end created by the loss of flow continuity across Mission Creek at 4th Street.

4.2 PEFWS Pipeline Improvements

4.2.1 Westside

Although the Sunset and Outer Richmond Districts are served by cisterns, some of which were recently constructed under the 2010 ESER bond, they are not served by EFWS pipelines. The Westside component of the PEFWS, shown on Figure 4-7, provides pipeline supply to these areas. In addition, because these pipes are a part of the PEFWS network, they will also serve as a seismically reliable emergency supply backbone. Phase 1 of the Westside has been funded by the 2020 ESER Bond, and portions of the project are currently in design and construction. The Westside PEFWS consists of three pipeline loops to increase hydraulic performance and enhance the reliability of the network. The pipeline reach that connects Lake Merced to the southernmost loop on Ulloa Street provides supply, from Lake Merced or the Regional Water Pipelines, to the Westside. The southernmost loop serves the southern and central areas of the Sunset. Its western alignment is adjacent to Sunset Reservoir, where supply from that reservoir and its pump station connect to the system.

The central loop of this system provides service to the northern Sunset District and the southern portion of the Outer Richmond. This loop crosses Golden Gate Park at two locations, providing critical park crossings for both firefighting and post-earthquake emergency supply. The northern loop of the Westside PEFWS serves the majority of the Outer Richmond District.

4.2.2 Richmond Extension

Although conventional EFWS serves portions of the Inner Richmond District east of Park Presidio, the majority of the pipelines are 12 inches in diameter. The Richmond Extension of the PEFWS would provide supply to the Inner Richmond through an eastern extension of the PEFWS pipe network. As shown on Figure 4-8, the extension would overlay and provide coverage to areas between the existing conventional EFWS pipelines.

In addition, the Richmond Extension would include three turnouts along its northern alignment from which supply to the Presidio of San Francisco could be taken and distributed throughout the Presidio grounds.

4.2.3 Portola Loop

The existing pipelines that surround the central areas of San Francisco near Mount Davidson and Glen Canyon are in some cases more than a mile away. These distances, combined with the elevation and difficult street navigation, result in challenges to get firefighting water supply to these areas. The Portola Loop component of the PEFWS, shown on Figure 4-9, would help mitigate these challenges by adding a pipeline loop in this central area, providing high-pressure supply to better serve the higher elevations. The loop would be supplied through two connections to the PEFWS in the east and south.

Figure 4-7: Westside PEFWS Pipelines

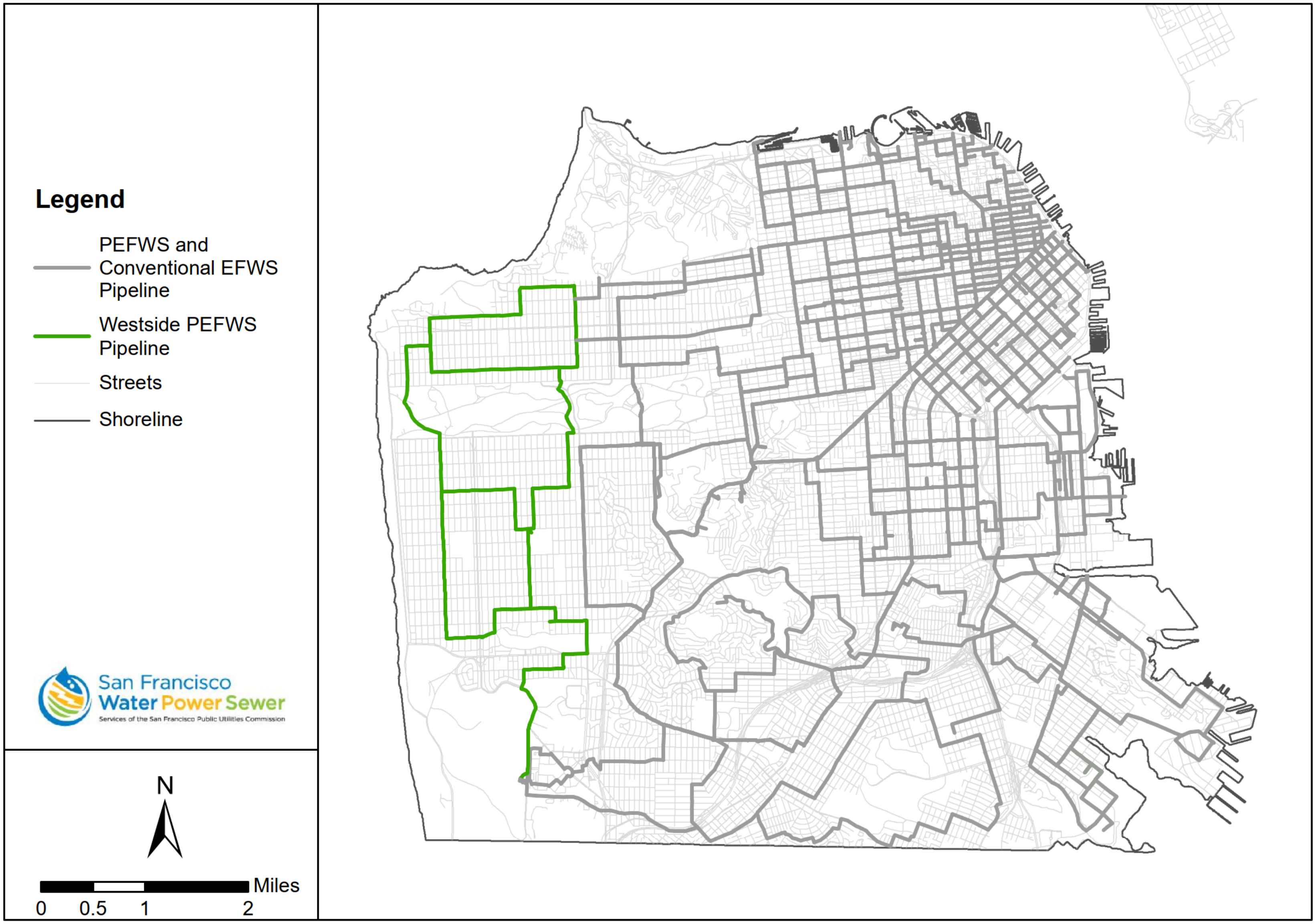


Figure 4-8: Richmond Extension Pipelines

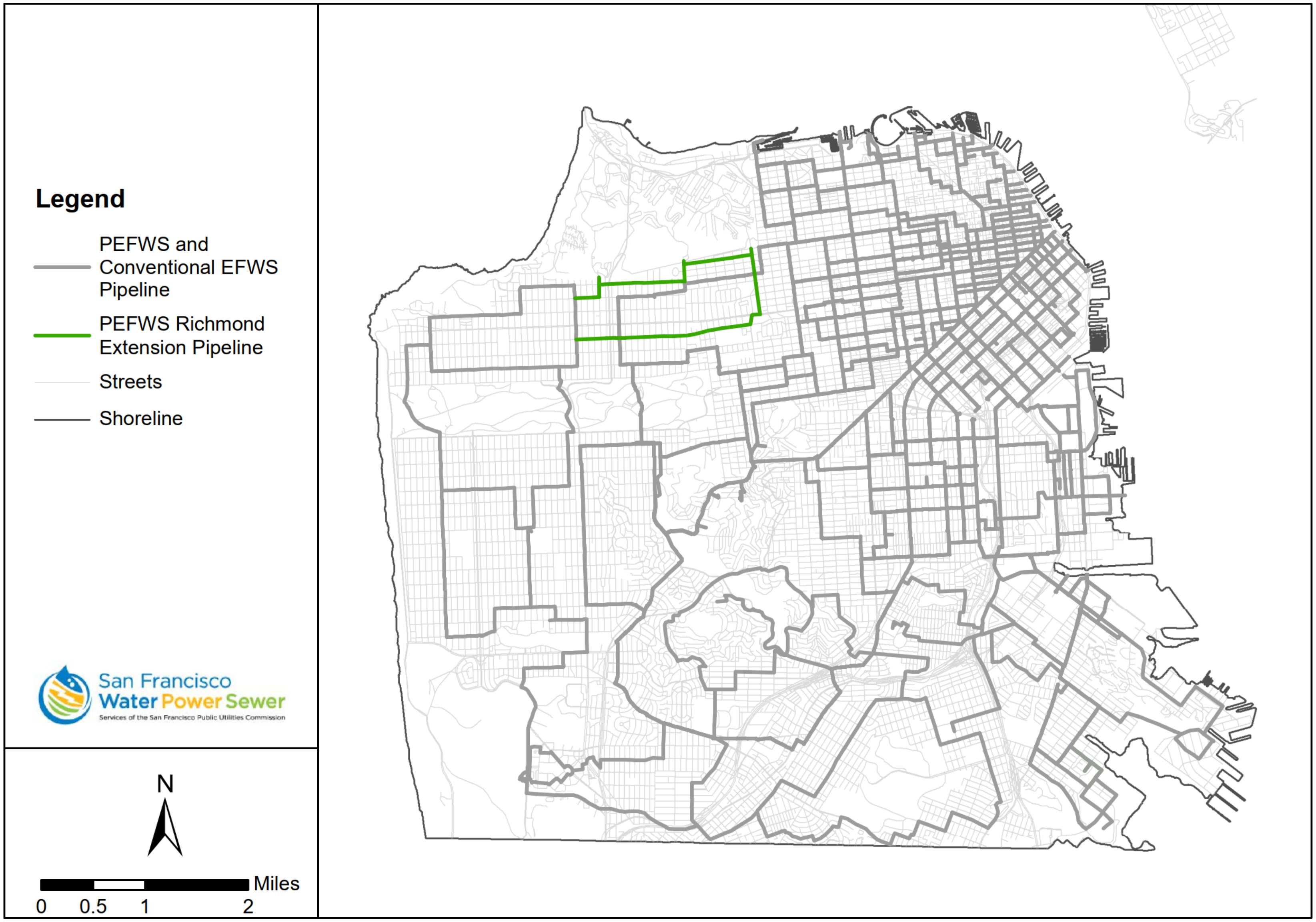
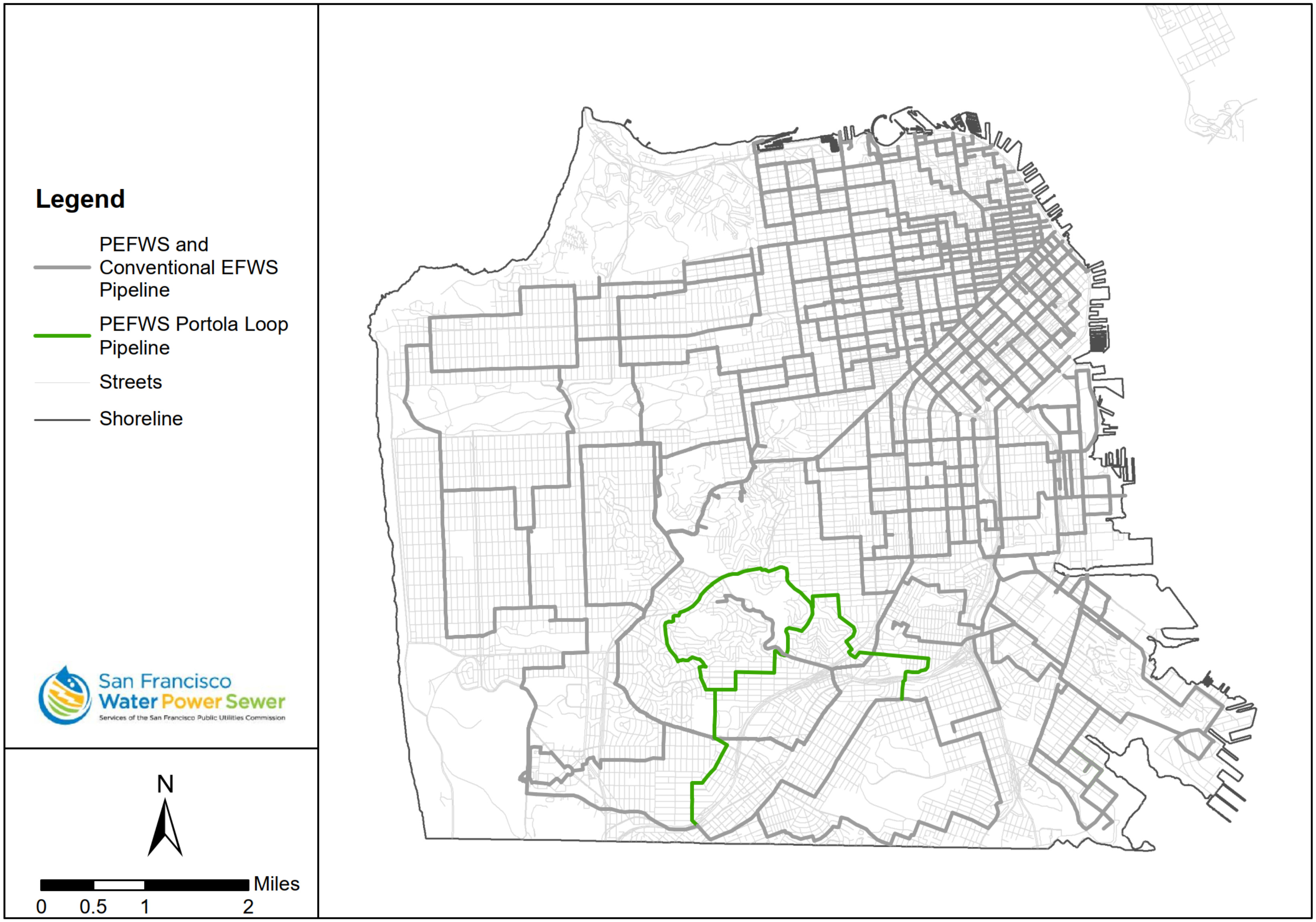


Figure 4-9: Portola Loop Pipelines



If needed, additional pressure could be provided to the areas served by the Portola Loop through booster pump stations. The loop would be isolated from rest of the system to protect it from excessive pressure, and booster pump stations on the supply pipeline on the southern and eastern sides of the loop would provide additional pressure.

4.2.4 Southern Area

Significant portions of the southern areas of San Francisco are not currently served by EFWS pipelines. Two proposed conventional EFWS pipelines address the Bernal Heights area. A network of PEFWS pipelines, referred to in this study as the PEFWS Southern Area, would provide coverage to the unaddressed areas in the south. The pipelines that comprise the Southern Area component of the PEFWS are shown on Figure 4-10.

The Southern Area network was developed to provide firefighting supply to the general areas of the Excelsior, Visitacion Valley, Sunnydale, Crocker Amazon, Outer Mission, and Ocean View. The pipeline alignments are laid out to distribute coverage in the areas between existing pipelines and the McLaren Park boundary, focusing on the developed areas in the southern part of San Francisco. Water supply to the Southern Area pipelines would be provided on the west from Lake Merced and on the east from University Mound Reservoir. The dual supply sources and loop configuration would result in increased hydraulic efficiency and delivery reliability.

The Southern Area pipelines were developed to work in conjunction with the Portola Loop to provide three interconnected hydraulic loops. The Portola Loop and Southern Area comprise the northern and southern loops, respectively. The central loop is formed by the boundaries and pipelines that connect the two loops. All three loops would share dual supplies from University Mound Reservoir on the east and Lake Merced/Regional Water supplies on the west.

4.3 Water Supply Sources

4.3.1 Water Supply Analysis

The demand target for this study, 255,000 gpm on a citywide basis, is much higher than the capacity of existing EFWS supply facilities, and significant additional water sources are needed. A water supply analysis was performed to determine where demands were located geographically, identify the new sources, and develop the connections to the pipeline network in a hydraulically efficient manner.

Based on the service areas of the PEFWS and conventional EFWS pipe networks, approximately 90,000 gpm of firefighting demand is served on the PEFWS, and the remaining 165,000 gpm is served from the conventional EFWS system. New water sources available immediately after an earthquake include stored water supplies in San Francisco, including potable reservoirs and freshwater lakes, as well as seawater from San Francisco Bay and the Pacific Ocean.

The potable reservoirs considered include Sunset, University Mound, Sutro, College Hill, and Stanford Heights. These represent the largest potable reservoirs in San Francisco and have storage volumes greater than 10 MG, sufficient to sustain at least 16 hours under a withdrawal rate of 10,000 gpm. Summit Reservoir, another large potable reservoir, is currently being connected to the conventional EFWS via pipeline and air gap, so it is considered an existing supply in this study. Because all of the above-mentioned reservoirs store potable water, an air gap would be required between the reservoir and the connection to the conventional EFWS.

As shown on Figure 4-11, Sunset Reservoir is on the west side of San Francisco, in the PEFWS service area, and is most effectively used as a water source for that system. The Sutro, Stanford Heights, and College Hill Reservoirs are more centrally located and are adjacent to both PEFWS and conventional EFWS systems. Because of the greater supply need on the eastern side of San Francisco, it was determined that these sources should be connected to the conventional EFWS. Similarly, University Mound is on the border between PEFWS and the conventional EFWS. It is proposed that this reservoir serve both the PEFWS and the conventional EFWS. By connecting to the Southern Area of PEFWS, University Mound would increase the supply reliability to the Southern Area and the Portola Loop. Those pipelines would have supply from the west via Lake Merced as well as supply from the east from University Mound.

Figure 4-10: Southern Area Pipelines

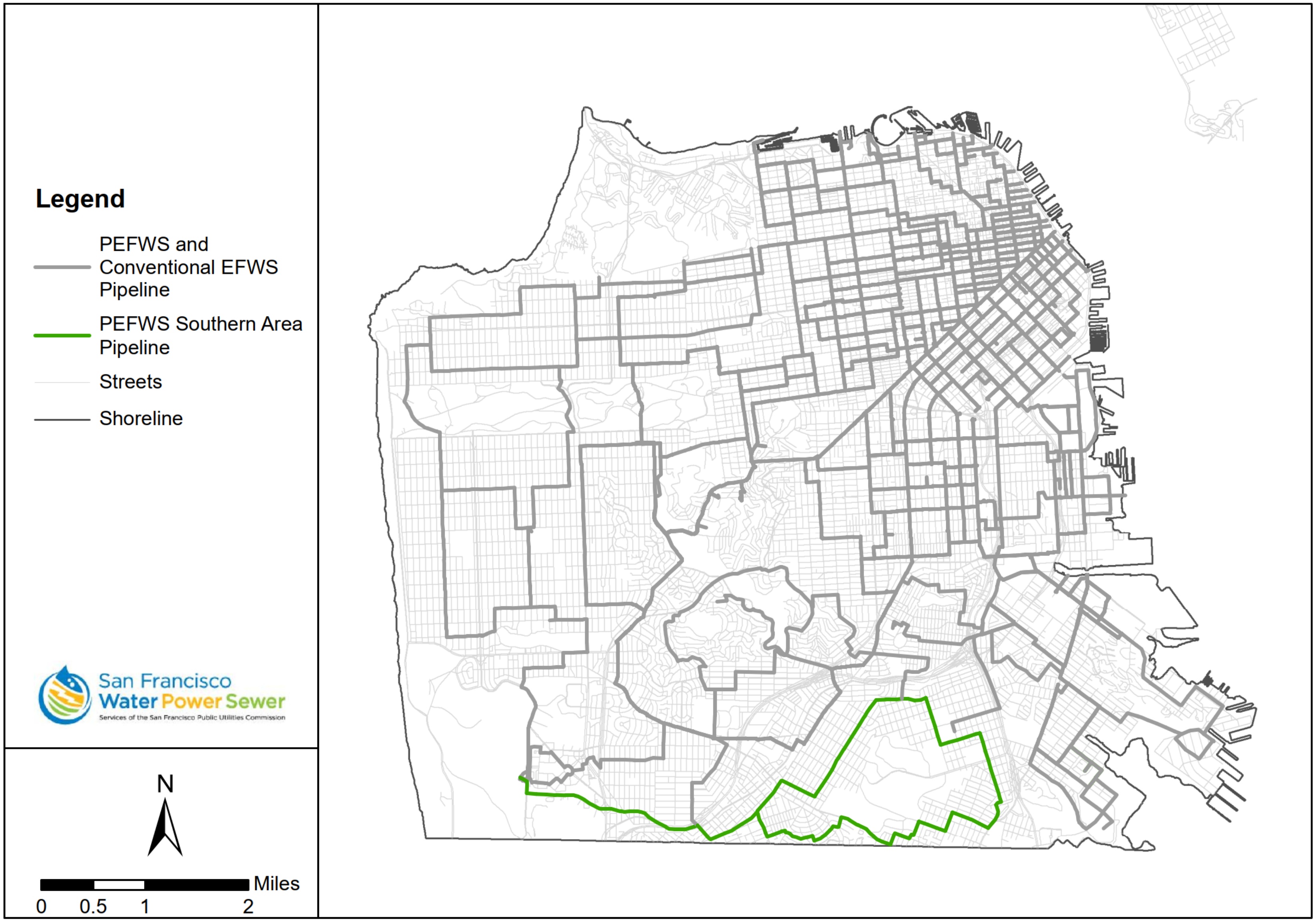
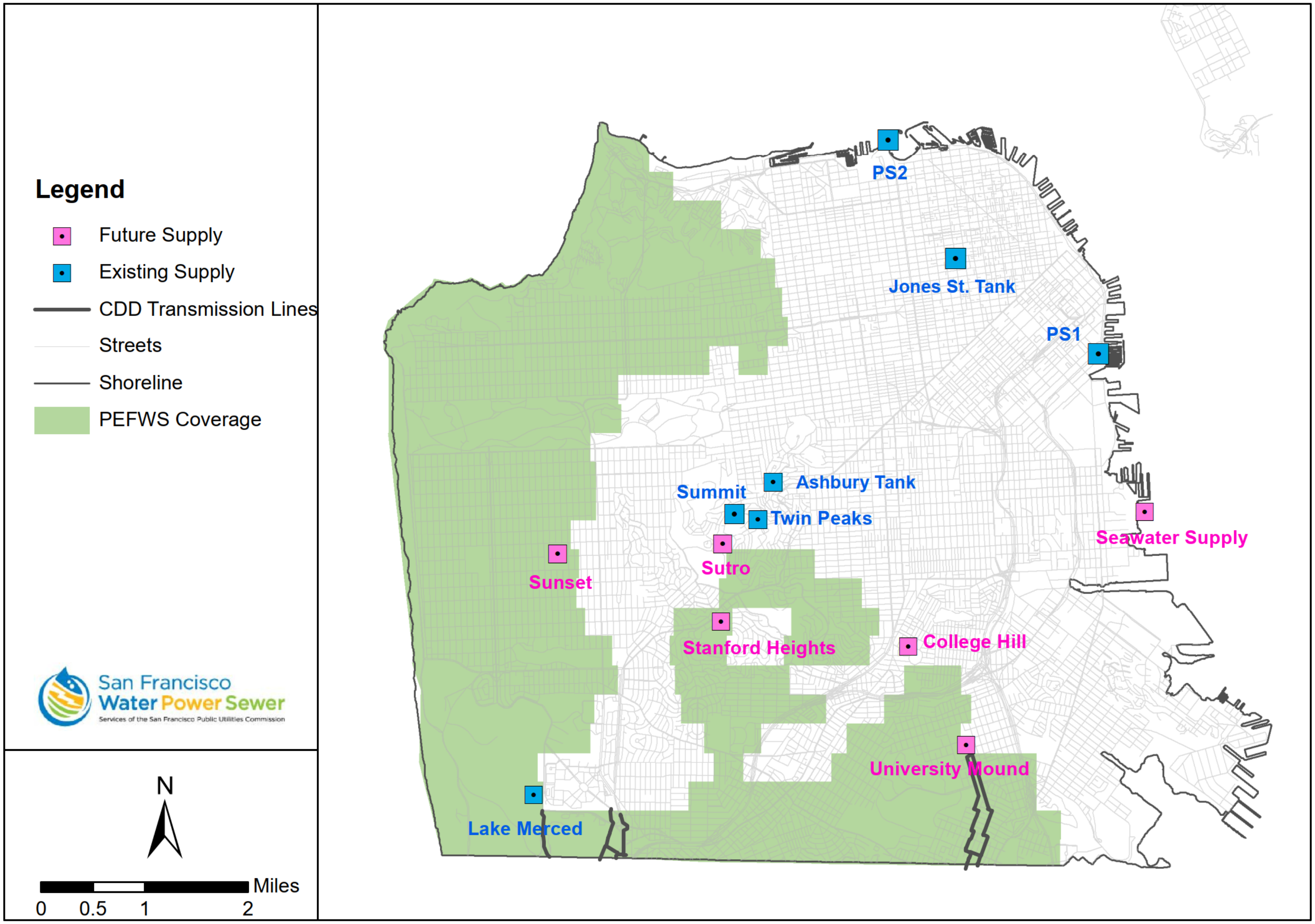


Figure 4-11: Conventional EFWS and PEFWS Water Supply Sources



The freshwater lakes considered include Lake Merced, Laguna Honda, and several lakes in Golden Gate Park and McLaren Park. As with the potable reservoirs, the larger lakes were given higher consideration because of their ability to provide high flows for longer durations. Lake Merced, Laguna Honda, and Stow Lake were considered. Lake Merced, in the southwestern corner of San Francisco, has an estimated storage of 1.7 billion gallons, providing an essentially unlimited supply for firefighting. Because it is a designated emergency water supply for San Francisco, it is also consistent with the emergency potable backbone pipeline function of the PEFWS. Lake Merced is ideally situated to supply the PEFWS, providing water to the north for the Westside and Richmond Extension and to the east to the Southern Area and Portola Loop. Laguna Honda, near the Forest Hill area, stores approximately 40 MG of freshwater. Prior initial investigations regarding the feasibility of siting an intake and pump station at the Laguna Honda site identified challenges with site access and the steep topography surrounding the lake. Stow Lake, in Golden Gate Park, is currently designated as an emergency firefighting supply. It is connected to a pipeline and hydrants along Fulton Street on the northern side of the park.

A study prepared for the SFPUC in June 2021, the Seawater Pre-Feasibility Study (AECOM 2021), evaluated seawater supply from both the Pacific Ocean and San Francisco Bay. The Seawater Pre-Feasibility Study determined that supply from either water body was feasible, with slant wells being more likely to be feasible on the Pacific Ocean and open water intakes on San Francisco Bay. This 2050 Planning Study considered both options. Based on the evaluation of demands and available supplies, it was determined that the PEFWS would have adequate supply from Lake Merced, Sunset Reservoir, and University Mound Reservoir to meet demands. However, the conventional EFWS would have a supply deficit of approximately 60,000 gpm after the existing and new water sources above were accounted for. Therefore, approximately 60,000 gpm of additional seawater supply would be needed on the conventional EFWS. Table 4-1 shows water supply sources identified for the PEFWS and conventional EFWS as a result of the water supply analysis.

Table 4-1: Water Demands and Supply Analysis

Supply Sources		Flow (gpm)	Totals (gpm)
Conventional EFWS	University Mound Reservoir	29,000	210,000
	College Hill Reservoir	13,000	
	Stanford Heights Reservoir	11,000	
	Sutro Reservoir	29,000	
	Summit Reservoir	10,000	
	Lake Merced	7,000	
	Twin Peaks	7,000	
	Pump Station 1	19,000	
	Pump Station 2*	55,000	
	East Seawater Pump Station(s)	30,000	
Potable EFWS	Lake Merced	43,000	89,000
	Sunset Reservoir	33,000	
	University Mound Reservoir	13,000	
Total			**299,000**

Notes:

* Expansion of Pump Station 2 Capacity, or additional seawater pump station

gpm = gallons per minute
EFWS = Emergency Firefighting Water System

Based on the flows shown in Table 4-1, it is estimated that approximately 190 million gallons of water from potable storage reservoirs would be used for firefighting during the first 24 hours. The total potable water storage capacity in San Francisco is approximately 400 million gallons. Therefore, over 50 percent of the potable water storage within San Francisco will remain available after the initial 24 hours of firefighting following an earthquake. This analysis of remaining storage uses the maximum demand occurring at the 25th hour as a conservative assumption for firefighting water use.

4.3.2 Lake Merced

Lake Merced is a freshwater lake in the southwestern corner of San Francisco. The SFPUC manages the lake for uses including emergency water supply, habitat for birds, and recreation. Lake Merced has a significant storage capacity, estimated at approximately 1.7 billion gallons.

Lake Merced is proposed as a water source for both the PEFWS and conventional EFWS. From the intake location at the Lake Merced Pump Station, supply would flow in three directions. Supply north to the Westside and Richmond Extension portions of the PEFWS would be conveyed through a pipeline along Lake Merced, connecting to the southern end of the Westside along Ulloa Street. Supply in the southern direction to the Southern Area and Portola Loop portions of the PEFWS would be conveyed via a pipeline along Brotherhood Way. Supply in the eastward direction would provide water to the conventional EFWS through the Park Merced and Ingleside pipelines. Intake pumping and pressure boosting would be achieved through a combination of existing and new pumps at the Lake Merced Pump Station and Merced Manor.

Lake Merced greatly enhances the water supply on the west side of San Francisco. It is a logical and prudent source of supply for the PEFWS due to its significant storage, designation as an emergency water supply, and strategic location within the PEFWS and conventional EFWS pipe network. With approximately 1.7 billion gallons of water storage, Lake Merced can sustain well over 2 weeks of supply at a continuous pumping rate of 60,000 gpm. This represents a significant duration of firefighting supply following an earthquake. It is unlikely that fires in San Francisco would continue for two weeks. Analysis of the water demands and supplies of the PEFWS and conventional EFWS systems indicate that the flow provided by Lake Merced would be adequate. Because the water in Lake Merced is managed as an emergency water supply, its use in the PEFWS would maintain the system as a seismically reliable emergency water system, subject to a boil water order.

Lake Merced and the associated existing and new infrastructure are strategically located to connect the supply for emergency firefighting use. From its location in the southwestern corner of San Francisco, it can easily be connected to supply the new PEFWS pipe networks along the western and southern areas of the city. Common pumping infrastructure can also be used to leverage Regional Water System supplies, as described later in this section. During the implementation phase for the Lake Merced supply, geotechnical investigations of embankments that surround Lake Merced and the facilities that would be used to supply the EFWS may be warranted.

4.3.3 Seawater

Based on an analysis of firefighting demands, existing supplies, and available new supplies throughout San Francisco, it is estimated that an additional 60,000 gpm of seawater supply is needed on the eastern side of San Francisco, in the area served by the conventional EFWS. This additional supply could be implemented in a number of ways, such as one or more new consolidated seawater pumping stations, new distributed pump stations, upgrades to existing seawater Pump Stations 1 and 2, or combinations of these approaches. The Seawater Pre-Feasibility Study (AECOM 2021) identified considerations and conceptual costs for implementing seawater on the bay side of San Francisco. The specific approach for meeting the additional 60,000 gpm and the locations of the associated infrastructure needed will require significant further evaluation.

For the purposes of this study, the additional seawater to the system has been analyzed as a consolidated pump station on the eastern shore of San Francisco near 22nd Street and a second seawater source on the northern shore, near the existing Pump Station 2.

4.3.4 In-City Potable Reservoirs

Sunset Reservoir

Sunset Reservoir is a 176 MG potable reservoir on the west side of San Francisco. The reservoir is composed of two connected basins, the North Basin and the South Basin, with capacities of 89 MG and 87 MG, respectively. The North Basin was constructed in 1938 and was seismically upgraded in 2010, and the South Basin was constructed in 1960. A project in the 10-year Capital Improvement Program is planned to implement seismic improvement recommendations to the South Basin identified in recent studies. Sunset Reservoir is supplied by the regional water system from two pipelines, the 54-inch San Andreas Pipeline (SAPL) No. 2 and the 60-inch Sunset Supply Pipeline (SSPL), via pumping from the Lake Merced Pump Station.

Sunset Reservoir would supply water to the PEFWS through a connection to the Westside portion. A pump station with a capacity of approximately 30,000 gpm would increase the water pressure as it is supplied to the PEFWS pipe network.

University Mound Reservoir

The University Mound Reservoir is a 140 MG potable reservoir in the southeastern area of San Francisco. The reservoir has two basins, the North Basin and the South Basin, that were constructed in 1885 and 1937, respectively. In 2011, the North Basin underwent a general upgrade that included a seismic retrofit. A project in the 10-year Capital Improvement Program is planned to implement seismic improvement recommendations to the South Basin identified in recent studies. This reservoir receives water from the Regional Water System through Crystal Springs Pipeline (CSPL) No. 1 (44-inch) and No. 2 (54 to 60-inch).

University Mound Reservoir would supply water to both the conventional EFWS and PEFWS. A pump station would be required to increase pressure. This pump station, with a total capacity of approximately 40,000 gpm, would have independent pumping capability to supply both the conventional EFWS and PEFWS. An air gap between the reservoir and the connection to the conventional EFWS would be required.

Sutro Reservoir

Sutro Reservoir is centrally located in San Francisco, near Twin Peaks. It is a potable reservoir with a storage capacity of 30 MG and receives its supply from the Regional Water System via the Lake Merced or Central Pump Station. Sutro Reservoir supplies water to the conventional EFWS through connecting pipelines in the Inner Sunset. A pump station with a capacity of approximately 30,000 gpm would increase the pressure of the supply from Sutro Reservoir. An air gap would be required between the reservoir and the connection point to the conventional EFWS.

Stanford Heights Reservoir

Stanford Heights Reservoir is a 12 MG potable reservoir near Mount Davidson. The reservoir would provide approximately 11,000 gpm of supply to the conventional EFWS and would connect to the Upper Pressure Zone in the Glen Park Area. Because its elevation of 618 feet is higher than that of the Upper Zone, Stanford Heights could supply the zone by gravity, and a pump station is not required. However, because the reservoir serves the potable distribution system under normal conditions, an air gap would be required between the reservoir and the connection to the conventional EFWS.

College Hill Reservoir

College Hill Reservoir is a 13.5 MG potable reservoir in the Bernal Heights area. The reservoir would provide approximately 7,000 gpm of supply to the conventional EFWS and would connect to the Lower Pressure Zone near the US 101 and Interstate 280 interchange. A pump station would be needed to increase pressure prior to connecting to the Lower Zone. An air gap would be required between the reservoir and the connection to the conventional EFWS.

4.3.5 Regional Water System Pipelines

Crystal Springs Pipelines

The CSPL system consists of CSPL Nos. 1, 2 and 3. These pipelines convey Regional Water System supply from Hetch Hetchy and/or the Sunol Valley Water Treatment Plant, by gravity, along the Peninsula and to the University Mound Reservoir. CSPL No. 1 is constructed of WSP, 44 inches in diameter. CSPL No. 2 ranges in diameter from 54 to 60 inches and is constructed of WSP and riveted wrought iron with a sliplined WSP. CSPL No. 3 is constructed of 60-inch-diameter prestressed concrete cylinder pipe (PCCP).

Sunset Supply Pipeline

The SSPL transports water from the Hetch Hetchy System north to San Francisco, by gravity. The pipeline is constructed of WSP, 60 inches in diameter. The SSPL delivers water to the Sunset Reservoir ("high zone") after being pumped at the Lake Merced Pump Station. Flow through the SSPL is controlled at several valves and valve lots along its alignment. The SSPL can also receive pressure-reduced high-zone flow from the 60-inch Sunset Branch Pipeline via the Capuchino Pressure-Reducing Valve.

San Andreas Pipelines

SAPLs Nos. 2 and 3 are the primary high-zone transmission lines for the Regional Water System. From Harry Tracy Water Treatment Plant, SAPLs Nos. 2 and 3 parallel each other up to the San Pedro Valve Lot, supplying water to high-zone service locations in the Peninsula and San Francisco. The terminus of SAPL No. 2 is at the Sunset Reservoir. SAPL No. 3 terminates at the Merced Manor Reservoir. The completion of the Peninsula Pipelines Seismic Upgrade addressed seismic vulnerabilities along SAPL Nos. 2 and 3 and provided an operational work-around to ensure delivery of high-zone water to terminus reservoirs after a seismic event. SAPL No. 2 is made of 54-inch steel; SAPL No. 3 is made of 66-inch PCCP, sliplined with steel, and 36-inch steel for the extension from San Pedro Valve Lot to Merced Manor Reservoir.

4.4 Other EFWS Improvements

4.4.1 Enhancements to System Response Capability

The extent and complexity of both the conventional EFWS and PEFWS will increase significantly with the proposed improvements. Enhanced monitoring and control systems will be necessary to operate the facilities and the system as a whole to quickly and effectively respond to fires after a major earthquake. As improvements are planned and designed, the operational schemes will be defined in more detail to identify specific system response improvements. However, the following improvements would enhance the data available to system operators and reduce the resources required to respond.

- **Seismic Valves.** Seismic valves are triggered by ground motions and are programmed to operate (generally to close) when an earthquake is detected. Strategically placed on the boundary of liquefaction zones, seismic valves can be used to automatically isolate portions of the EFWS so that pipe breaks do not drain the system. In addition, if placed on the connection between PEFWS and the municipal water system, valves could automatically isolate the PEFWS so that it can be pressurized for emergency firefighting.
- **Remote Operated/Motorized Valves.** If key valves, such as isolation valves and divide gates, are fitted with motorized valves that can be remotely operated, the system can be operated much more quickly and with fewer resources because staff do not need to be deployed to open or close the valves locally. System operation will also be less impacted by the transportation challenges that are likely after an earthquake.
- **Enhanced Supervisory Control and Data Acquisition (SCADA) Functionality.** Information about the status and condition of the EFWS is critical to response and operation of the system after an earthquake. For example, a remotely operated valve will not be opened if the condition of the pipes in the area is not known, due to the potential to exacerbate leakage from the system if they have been damaged. Therefore, enhanced SCADA functionality, such as a well-planned network of pressure transducers and a means of communicating status to system operators, will inform decision making and status reporting during response.

5. System Performance

5.1 Assessment of System Performance

The performance assessment approach for the proposed EFWS captures the ability of the system to deliver water to meet demand targets geographically across San Francisco. The performance metric used in this study, the delivery capability, is defined as the percentage of the water demand met by the EFWS pipeline network. This metric is similar to the reliability score used in prior EFWS studies, such as the CS-199 and Spending Plan Studies; but is modified to include only flow provided by the pipeline network, to reflect the focus of this study.

As described in Section 3, San Francisco has been divided into more than 600 50-acre grids. The firefighting water demands were calculated for each grid by aggregating demands for the city blocks in each grid. The hydraulic model simulated flow in the EFWS pipe network, accounting for post-earthquake damage to pipes, to determine how much water can be delivered to each grid. The delivery capability was calculated by dividing the flow delivered by the demand.

A Monte Carlo analysis consisting of 1,000 hydraulic modeling simulations was performed to generate a system performance data set that reflects the variability of post-seismic conditions. The system performance results presented in this study are reported for the 75th percentile of the performance data set.

5.2 Performance of Existing System

The existing EFWS will be extremely challenged to meet future firefighting demands if no improvements are made. As described in Section 3.1, demands under 2050 conditions represented by demand Case B are estimated to be 241,000 gpm. Areas in the western, southern, and central areas of San Francisco that would have been served by the PEFWS improvements would not have supply from existing EFWS pipelines. These areas would therefore have a zero delivery capability. Similarly, those areas that would have been served by extensions of the conventional EFWS—including the Park Merced/Ingleside, Hunters Point, and Candlestick areas—would also not be served by EFWS pipelines and would have a zero delivery capability.

For demand Case B, the firefighting water demand in the conventional EFWS service area is approximately 155,000 gpm. The existing supply sources—including PS1, PS2, Twin Peaks, and Summit Reservoir—can provide approximately 80,000 gpm via the existing EFWS pipe. Following an earthquake, a portion of the supply will be lost through leaks and breaks in the pipeline network. Therefore, in the conventional EFWS service area, the existing water sources would meet significantly less than 50 percent of the overall firefighting demand.

Figure 4-5 shows that 50 percent of the conventional EFWS is constructed of 10- and 12-inch-diameter pipes. The smaller-diameter pipes further lower the ability of the existing system to convey water from the limited supply sources to where the water is needed throughout the service area.

In summary, under future demand conditions, the delivery capability of the existing system will be extremely low if improvements are not made. Areas that would have been served by PEFWS and extensions of the conventional EFWS will have zero delivery capability. Delivery capability in the service area of the existing conventional EFWS will be significantly less than 50 percent on an area-wide basis, due to the limited water supply capacity and the hydraulic constraints of the existing pipelines.

5.3 Performance of Proposed System

The performance of the proposed recommended EFWS, including the system improvements described in Section 4, is shown on Figure 5-1. The legend is divided by color into two performance categories: blue gradations represent performance between 70 to 100 percent and red gradations represent performance less than 70 percent. The yellow grids represent those areas where the probability of ignition is so low that no fires occurred in the 1,000 Monte Carlo simulations for the 25th hour.

As described in Section 3.1.2, the 75th percentile of firefighting water requirements at the 25th hour following the earthquake has been used for design of the EFWS. This level is believed to be a conservative target for both citywide demands and for most of the grid cells. Figure 5-1 shows some cells as having no demand; in most cases, this is because those cells are bodies of water, open spaces (parks or golf courses), and other areas where there is very little likelihood of significant fire. In a very few cells, the “no-demand” arises because there may have been fires soon after the earthquake which were extinguished, so that by the 25th hour, those cells no longer require water. This is within the random nature of what will happen following the earthquake. By designing for the maximum level and providing good coverage in all parts of San Francisco, firefighting water will be available soon after and through at least the 25th hour following the earthquake.

The improvements to the EFWS resulted in a high delivery capability across the majority of the areas in San Francisco. In 91 percent of the grids (excluding those without demands), a delivery capability of 90 percent or greater was achieved. In 7 percent of the grids, a delivery capability of 80 to 90 percent was achieved; the remaining 2 percent of the grids had a delivery capability of 70 to 80 percent. No areas in San Francisco had a delivery capability of less than 70 percent.

As described in Section 1, the objectives of this study are to:

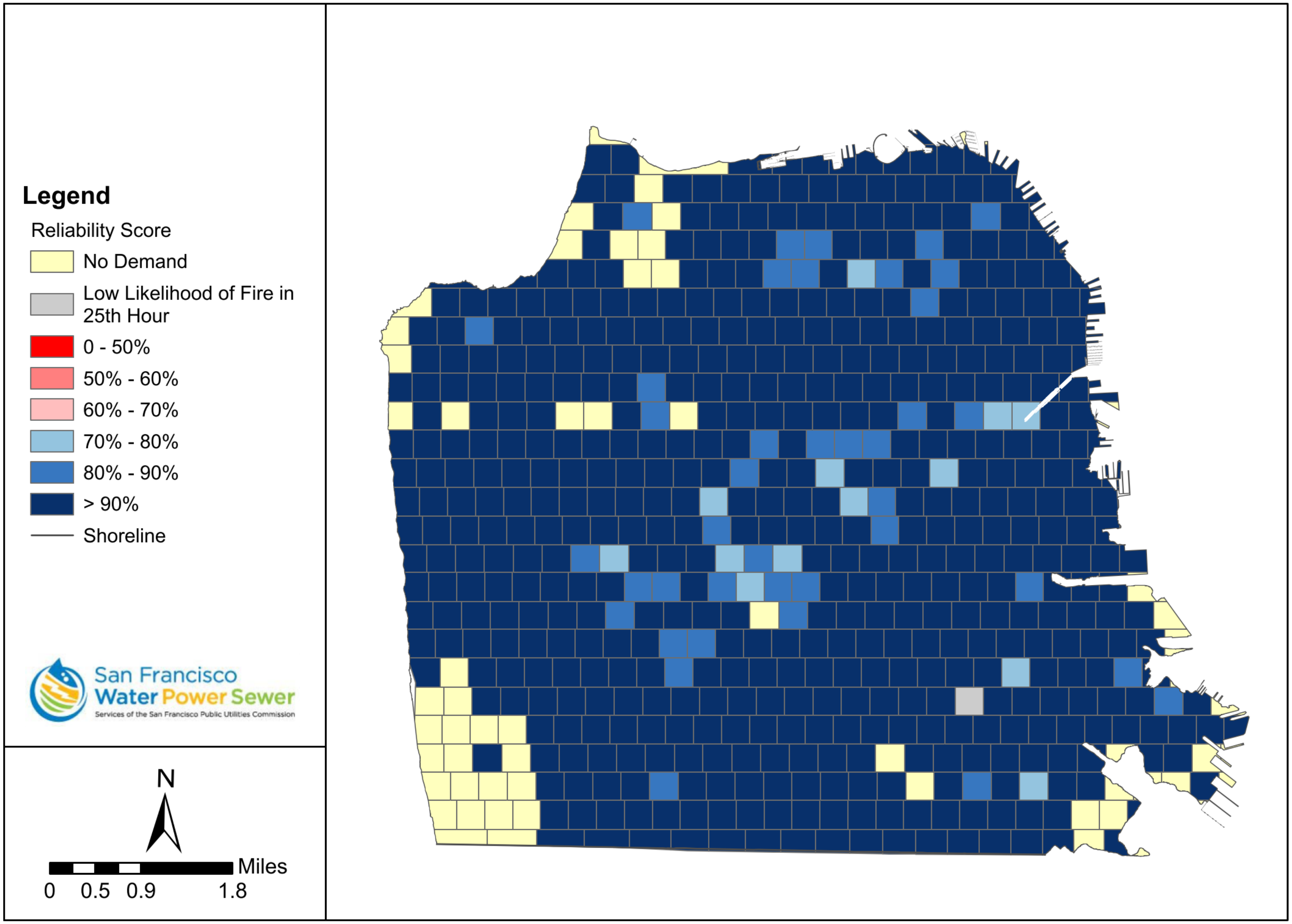
- Establish demand targets for the study that are higher than median level and perform analysis at a finer geographical resolution than by FRA
- Develop a system of pipelines and water sources to meet firefighting water demands in all parts of San Francisco

The performance results presented on Figure 5-1 demonstrate that the proposed system improvements meet the study objectives. The demand targets established for the study incorporate the most current firefighting demand data available and have been established at the 75th percentile level. This demand target represents a significant increase in performance level over the median and provides a higher level of confidence that the system can deliver the water needed to fight fires after an earthquake.

Use of a gridded system consisting of 50-acre grids provides improved resolution over larger FRA study areas. The smaller study areas allow more precise determination of areas of insufficient delivery capability and identification of appropriate improvements to address them.

The results on Figure 5-1 show that all parts of San Francisco are able to receive water for emergency firefighting from the EFWS pipe network. Most of San Francisco achieves a delivery capability of at least 90 percent, and a minimum of 70 percent is achieved throughout San Francisco. It should be noted that the delivery capability does not take into account the supply from other components of the EFWS, such cisterns, suction manifolds, and fireboats. These other sources of supply provide an additional layer of reliability and redundancy to the EFWS supply.

Figure 5-1: Delivery Capability of the Proposed System



6. Improvement Costs

Planning-level cost estimates, shown in Table 6-1, were prepared for the proposed improvements to the EFWS. Costs include pipeline improvements to the conventional EFWS and PEFWS; pump stations required for new water supply; and other improvements, including an air gap required for the new connection to Stanford Heights Reservoir and improvements to existing EFWS infrastructure. The estimated cost is approximately $1.9 billion in 2021 dollars. Because Phase 1 of the Westside PEFWS has been funded by the 2020 ESER bond, the associated approximately $170 million funding has been excluded from the PEFWS pipeline costs.

Escalated costs were also prepared, based on two construction period scenarios:

- 6-year construction period, corresponding to a completion year of 2034
- 14-year construction period, corresponding to a completion year of 2046

Table 6-1: Estimated Cost of Proposed System Improvements (2021$)

Improvements		Unit Cost ($M)	Total ($M)
Pipelines			$1,133
	Conventional Pipelines (39 miles)	$16.7	$651
	PEFWS Pipelines (39 miles)	$16.7	$481
Pump Stations			$609
	University Mound	$102	$102
	College Hill	$51	$51
	Sutro	$51	$51
	Lake Merced	$102	$102
	PS2/North Seawater Pump Station	$76	$76
	East Seawater Pump Station	$76	$76
	Sunset	$51	$51
	Central Pump Station	$51	$51
	Portola Pump Stations	$51	$51
Other Facility Improvements			$205
	Stanford Heights		$5
	Improvements to Existing Facilities		$200
Total			**$1,947**

Notes:

1) Pipeline unit cost from AECOM 2020b.
2) PEFWS Pipelines excludes previously funded Phase 1 of Westside PEFWS.
3) Pump Station costs from AECOM 2019.
4) Stanford Heights cost from AECOM 2017..
5) Pipeline costs do not include onsite distribution pipes on future development sites.
6) Improvements to existing facilities estimated based on preliminary facility assessments.

EFWS = Emergency Firefighting Water System
PEFWS = Potable Emergency Firefighting Water System

Table 6-2 shows the costs assuming completion by 2034, including a 6-year construction period. The total escalated cost is approximately $2.9 billion. This scenario assumes that notice to proceed from the Board of Supervisors is received in the second quarter of 2022 and that there is a 1-year start (including funding) and an accelerated 5-year planning, design, and permitting period. The year 2034 completion scenario represents an extremely compressed program schedule. Table 6-2 also shows the costs assuming completion by 2046, including a 14-year construction period. The total escalated cost is approximately $4.1 billion. This scenario assumes that notice to proceed from the Board of Supervisors is received in 2023 and that there is a 2-year start (including funding) and a 7-year planning, design, and permitting period. Completion by year 2046 represents a more feasible program schedule. Both scenarios assume 4 percent annual escalation.

Table 6-2: Escalated Costs, Completion by 2034 and 2046

	Costs ($M) Escalated	
	Completion by 2034	Completion by 2046
Pipelines	$1,714	$2,369
Pump Stations	$922	$1,274
Other Facility Improvements	$310	$429
Total	**$2,945**	**$4,072**

Notes:

1) Completion by 2034 assumes notice to proceed in 2nd quarter 2022; 1-year start (including funding); and 5-year planning, design, and permitting (accelerated).
2) Completion by 2046 assumes notice to proceed in 2023; 2-year start (including funding); and 7-year planning, design, and permitting.
3) Assumes 4 percent annual escalation.

7. Westside Seawater Supply Feasibility

As described in Section 4.3.1, the water supply analysis determined that the PEFWS service area could be adequately served by supplies from Lake Merced, Sunset Reservoir, and University Mound Reservoir. However, the conventional EFWS service area had a water supply deficit of approximately 60,000 gpm after existing EFWS and selected potable reservoir sources were connected to the system. This deficit necessitated additional seawater pumping capacity on the conventional EFWS. A similar need for seawater supply on the PEFWS was not deemed necessary, because there is sufficient water to meet firefighting demand on the west side with the recommended citywide system. However, at the request of Supervisor Gordon Mar in November 2021, a concept to provide seawater supply on the west side of San Francisco to the PEFWS was developed. Analysis of this concept is based primarily on the prior Seawater Pre-Feasibility Study (AECOM 2021).

7.1 EFWS Seawater Supply Pre-Feasibility Study

The Seawater Pre-Feasibility Study identified the factors to be considered for development of additional seawater supply for the EFWS. The study did not develop recommendations for implementing or siting new seawater supply facilities, but documented items that would need to be considered in future evaluations. The study addressed regulatory and engineering aspects, as well as rough estimates of costs for different types of potential seawater pumping stations. The study analyzed new seawater intake supplies with flows from 3,000 gpm to 50,000 gpm.

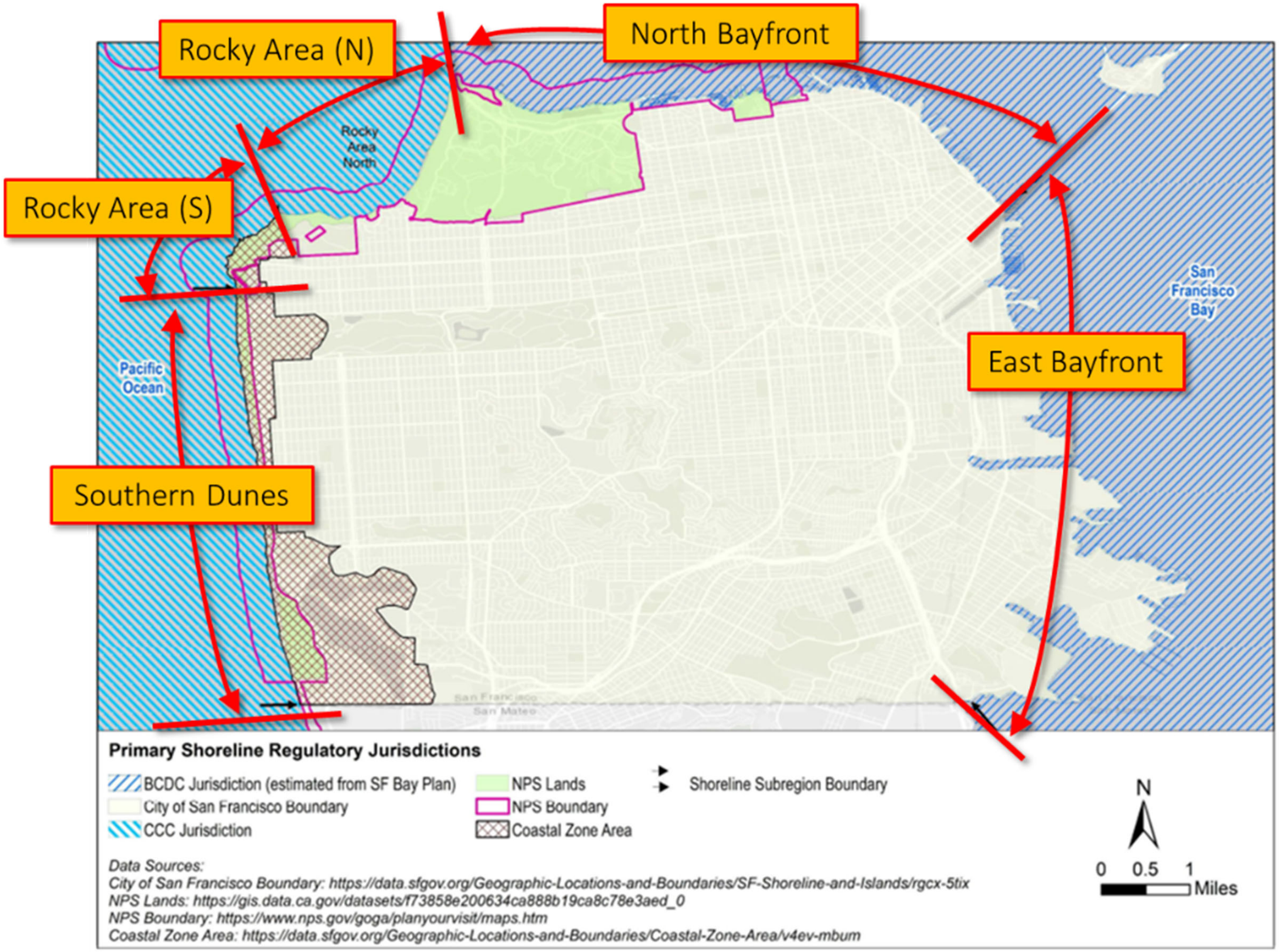
Based on the geography of San Francisco and the division of primary regulatory jurisdictions, evaluation of potential seawater intakes was considered in five subregions of San Francisco. These shoreline subregions include the Southern Dunes, Rocky Area South, Rocky Area North, North Bayfront, and East Bayfront, shown on Figure 7-1.

The potential challenge or degree of difficulty in obtaining permits from the primary shoreline regulatory agencies is considered to be moderate to high. One of the greatest permitting challenges for implementing additional seawater sources to the EFWS would be approval of a new seawater withdrawal from either the Pacific Ocean or San Francisco Bay. The California Ocean Plan, which applies to the Pacific Ocean on the west side of San Francisco, requires subsurface seawater intakes, rather than open water intakes. Subsurface intakes have not been deemed infeasible at this time for the Pacific Ocean on the west side of San Francisco. Similar (though perhaps slightly less stringent) open water intake criteria exist for waters on the bay side of San Francisco under the Bay Conservation and Development Commission’s Bay Plan. Subsurface intake systems in silty muds on the bay side are deemed infeasible. If subsurface intakes are not feasible, open water intakes must be screened to reduce entrainment of marine life. With any screening system for open water intakes, consideration must be made for screen cleaning and inhibition of growth of marine organisms.

The number of pumps required to supply seawater to the EFWS is a function of the overall flows required and the type of intake. For a flow of 20,000 gpm, three conventional pumps rated at 10,000 gpm each (two duty, one standby), fed by an open water intake would be suitable. For the same flow, eight submersible pumps mounted in slant wells rated at 3,000 gpm each (seven duty, one standby) would likely be required. For smaller or larger flows, the number and capacity of pumps changes accordingly.

Order-of-magnitude cost estimates for new intake seawater supplies for each of the five subregions were developed for pump stations with capacities ranging from 3,000 to 50,000 gpm. Initial design, permitting, and construction costs are generally lowest for pump stations fed by open water intakes on the bay side of San Francisco, and greatest for open water intakes on the ocean side of San Francisco. Initial costs for slant well intakes on the ocean side are generally in the middle range. The cost of a 10,000 gpm seawater slant well pump station on Ocean Beach is estimated to be $89 million. This cost includes environmental, permitting, land acquisition, pump station, and recirculation piping costs, as well as the cost to replace the wells and pumps at 15-year intervals (twice over a 45-year facility life span).

Figure 7-1: San Francisco Subregions Considered for Seawater Supplies to EFWS (Source: AECOM 2021)



7.2 Westside Seawater Supply Option

An option was developed to supply seawater for emergency firefighting along the west side of San Francisco. Under this option, the proposed pipeline configurations for PEFWS and the conventional EFWS do not change from those described in Section 4. Information developed in the Seawater Pre-Feasibility Study was used as the basis for development of this option. However, unlike the Seawater Pre-Feasibility Study, which assumes that seawater supply would be connected to the conventional EFWS, the Westside Seawater Option assumes that seawater would be put into the PEFWS.

The demand in the PEFWS service area is approximately 90,000 gpm, including the Westside, Richmond Extension, Southern Area, and Portola Loop. The Seawater Pre-Feasibility Study included a conceptual layout of slant well stations along Ocean Beach that could supply up to 50,000 gpm. The layout consists of series of seven stations distributed along Ocean Beach. Each station consists of three slant wells, which were deemed to be the more feasible type of intake from a permitting standpoint. The Westside Seawater Option expands this layout to provide the 90,000 gpm needed to meet the PEFWS demand. It is estimated that 10 well stations, each with a capacity of 10,000 gpm, would be required. This allows for the total supply to be met with nine well stations in service and one station as a standby. The configuration of the Westside seawater supply option is shown on Figure 7-2.

Each well station would pump into a common collector pipeline running in the north-south direction parallel to Ocean Beach, east of the Great Highway. The collector pipeline would then be connected to the PEFWS at three locations. This configuration provides operational flexibility by allowing all well stations to supply water to the PEFWS through multiple connection points along the west side.

When the Westside seawater supply is implemented following an earthquake, the PEFWS isolation valves with the City’s low-pressure system are closed, and the PEFWS pipelines are pressurized using seawater. Once the PEFWS is supplied with seawater, it can no longer function as an emergency water supply backbone until the seawater is flushed. A boil water order would not allow the seawater to be used as an emergency water supply. Further study is required to determine the approach and duration for flushing of the PEFWS pipe network.

An order-of-magnitude cost estimate was developed for the Westside Seawater Option. The costs consist of the 10 well stations estimated based on the EFWS Seawater Pre-Feasibility Study, and the pipelines required to connect the wells to the PEFWS pipe network. Table 7-1 shows the total cost of approximately $1 billion to supply the PEFWS using seawater. The costs are an initial conceptual estimate of the well station and pipelines only. Significant additional study is required to identify the many other costs associated with implementation of this option, such as modifications to the pipe network at Lake Merced, backup power to provide post-earthquake reliability, and air gaps at connection points between the well stations and PEFWS.

Table 7-2 shows the comparative costs for three supply options for PEFWS:

- Option 1: Freshwater supply to the PEFWS, using Lake Merced, Sunset, and University Mound Reservoirs, as described in Section 4
- Option 2: Seawater supply to the PEFWS using the 10 well stations, described in Section 77
- Option 3: Both freshwater and seawater supply to PEFWS, providing 100 percent supply redundancy to PEFWS

Based on the initial estimates, implementation of the freshwater supply (Option 1) is the least costly option, costing approximately $1.9 billion. Replacing the freshwater supply with seawater (Option 2) increases the total system improvement cost by approximately $800 million over the recommended citywide proposal discussed in Section 4 of this report. Implementing the seawater supply as a redundant source in addition to the freshwater supply (Option 3) increases the total cost by approximately $1 billion over Option 1.

Figure 7-2: Westside Seawater Supply Option

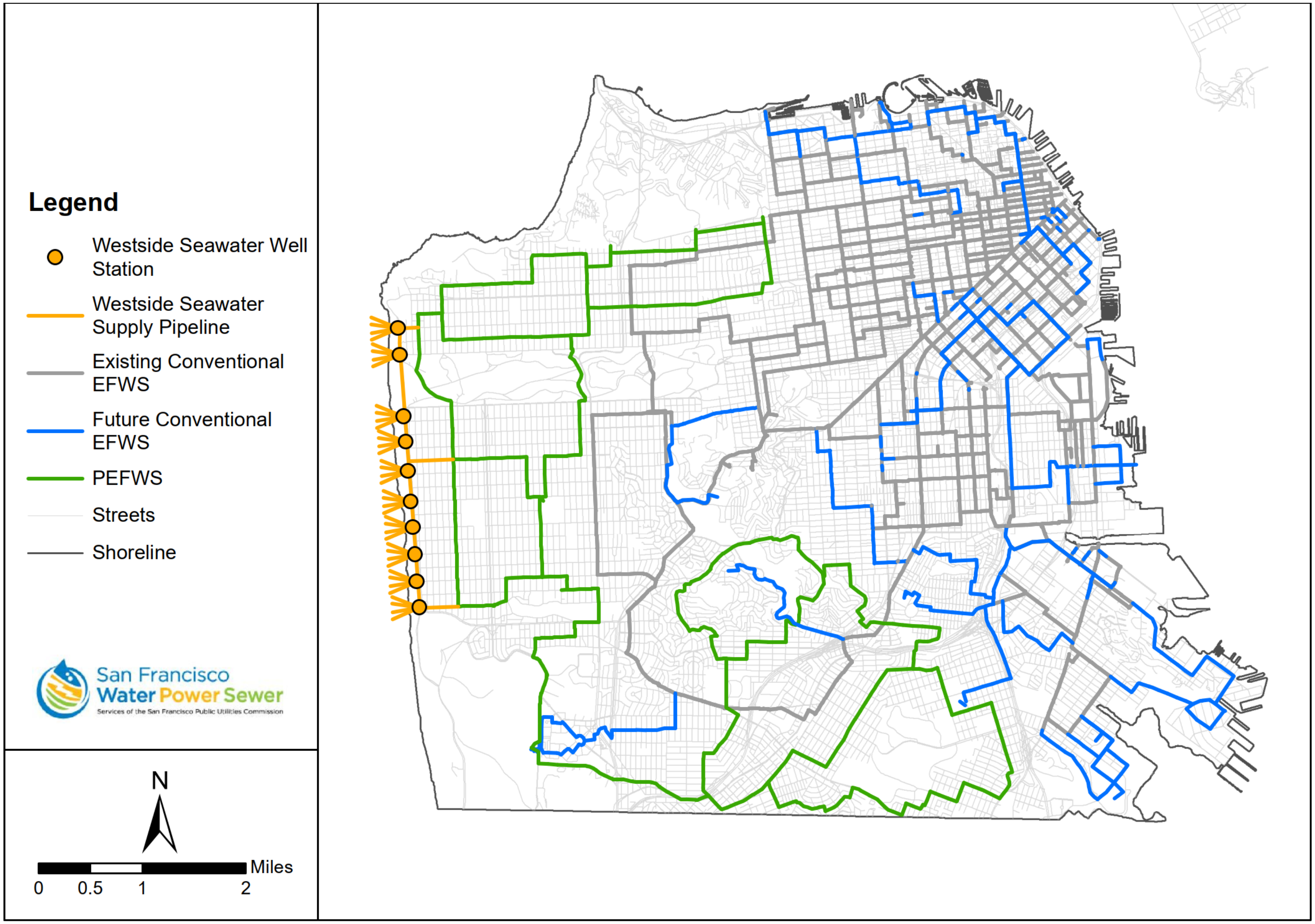


Table 7-1: Westside Seawater Supply Option Cost

Improvements		Quantity	Unit	Unit Cost ($M)	Total ($M)
Well Stations		10	station	$89	$890
Pipelines	Collector pipeline	3.0	mile	$16.7	$50
	Well station connection to collector pipe	2.5	mile	$16.7	$42
	Collector pipeline connection to PEFWS	1.0	mile	$16.7	$17
Total					**$999**

Notes:

1) Pipeline unit costs based on AECOM 2020b.
2) Well station cost based on AECOM 2021, including replacement of well and pump at 15 year intervals over 45-year life.
3) Costs in 2021$.

PEFWS = Potable Emergency Firefighting Water System

Table 7-2: Westside Freshwater and Seawater Supply Option Costs

Improvements	Option 1 ($M)	Option 2 ($M)	Option 3 ($M)
	Supply: • Lake Merced/Potable	Supply: • Seawater	Supply: • Lake Merced/Potable • Seawater(Redundant)
North, West, South Areas			
PEFWS Pipelines	$481	$481	$481
Freshwater Pump Stations	$254	$51	$254
Seawater Well Stations		$890	$890
Seawater Connecting Pipelines		$109	$109
Subtotal	$735	$1,531	$1,734
Conventional EFWS			
Pipelines	$651	$651	$651
Pump Stations	$355	$355	$355
Other Facility Improvements	$205	$205	$205
Subtotal	$1,212	$1,212	$1,212
Total	**$1,947**	**$2,742**	**$2,945**

Notes:

1) Costs in 2021$.

EFWS = Emergency Firefighting Water System
PEFWS = Potable Emergency Firefighting Water System

8. Conclusions

The fundamental starting point for evaluating and improving San Francisco's EFWS is to assess how much water is needed for firefighting after an earthquake. The FFEWR Study provides these critical data—not just for current conditions, but also through the year 2050 so that plans can be developed to protect San Francisco well into the future. Given the uncertainty associated with post-earthquake fire and the seismic response of water systems, it is prudent to consider conservative water demand targets that are higher than median level. In that regard, demand targets have been established for this study at the 75th percentile level. In addition, input parameters that contribute to more conservative targets, such as selection of maximum demand levels anticipated through the 25th hour after an earthquake, have been selected.

This plan identifies the infrastructure needs to provide firefighting water supply citywide. The improvements include additional sources of water supply to meet demands, and the pipelines to convey water from the supply sources to the fireground where the water is needed. These objectives are achieved through two components of the EFWS: the conventional EFWS and the PEFWS. The approach implemented in each area of the system is based on factors such as engineering analyses and geography to maximize the benefits of the new infrastructure.

The improved system has a high delivery capability. The performance assessment demonstrates that the majority of the City of San Francisco's system achieves a delivery capability of at least 90 percent. The concept for the future system has been developed to meet demand targets, and optimization and design details would be developed in future phases of engineering planning and design. Future design phases should also include evaluation of the seismic reliability of existing facilities and infrastructure which support the EFWS.

The estimated cost of the recommended citywide improvements is approximately $1.9 billion in 2021 dollars. If the construction is completed in a 6-year period to meet the 2034 completion date recommended to the Board of Supervisors, the escalated cost would be $2.9 billion. This represents an extremely compressed program schedule. If construction were to be completed over a 14-year period, ending in 2046, the escalated cost would be $4.1 billion. Completion by 2046 represents a much more feasible program implementation schedule.

This study assumes that SFFD resources increase commensurately with the growth in San Francisco's population. The pipelines and water supply sources provide water to the hydrants, but sufficient SFFD resources are needed to fully use the water provided by the improved EFWS. Because construction of EFWS pipelines on every block is not feasible, the pipeline configuration in the proposed improvements work in conjunction with deployment of the PWSS to extend the reach of EFWS hydrants to defend the areas between pipelines.

The water demand and supply analysis performed indicate that the potable and freshwater supplies are sufficient to meet the PEFWS demands. Supplying seawater on the west side of San Francisco to the PEFWS is not recommended at this time, but an option to provide this supply was assessed. The option consists of constructing an array of well stations along Ocean Beach and connecting pipelines to the PEFWS. The cost of providing seawater supply on the west side is approximately $1 billion. Supplying seawater to the PEFWS would likely cause the system to lose its emergency water supply backbone function immediately after an earthquake.

The basis of the system design and results of the performance assessment reflect that the proposed improvements meet the study objectives:

- Updated and conservative demand targets above the median based on the FFEWR Study have been established.
- Information from the EFWS Seawater Pre-Feasibility Study has been incorporated into the evaluation of water supply sources.
- The system evaluation demonstrates that emergency firefighting supply can be delivered to all parts of San Francisco with high delivery capability.

9. References

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