SEPTEMBER 2020

THE CITY AND COUNTY
OF SAN FRANCISCO

ONESF
Building Our Future

Building on a Legacy of Lifeline Resilience

We are pleased to release the report of the Lifelines Restoration Performance Project on behalf of the San Francisco Lifelines Council. Building on the 2014 Lifelines Interdependency Study, we worked closely with many lifeline providers serving the City and County of San Francisco to develop a more in-depth understanding of how lifelines will be impacted by a significant earthquake, how long it will take lifeline providers to restore service, and what actions we can take now to improve restoration time. We gratefully acknowledge the significant contributions of the public and private lifeline providers that contributed to this project, out of a deep understanding that collaborating and sharing information now will benefit all of us when the next earthquake strikes.

Shortly before his passing, the late Mayor Edwin M. Lee renewed his commitment to working with private and public utilities to speed the recovery of lifelines systems, protect public health and safety, and increase the level of service provided by the City and County of San Francisco following a major earthquake. Mayor Lee was a champion of the Lifelines Council from the beginning and saw the Council as a having a significant role in enhancing San Francisco's resilience. This project is an effort to fulfill those recommendations and the late Mayor Lee's vision of a more resilient San Francisco. Today Mayor London N. Breed has picked up the mantle and is continuing the work to collaboratively build our City's resilience.

For many, the Loma Prieta earthquake demonstrated the critical importance of lifelines when failure of the transportation network and other lifelines brought the region to a halt. That event spurred decades of investment to retrofit and upgrade key systems. The City and County San Francisco has spent more than $20 Billion upgrading its own facilities and infrastructure, and many lifeline providers have recently completed significant seismic retrofit programs that will improve the resilience of the City and the region.

As we now confront a different kind of disaster in the Coronavirus (COVID-19), we are reminded once again that we must keep our lifelines operating. This emergency has demonstrated that power, water, wastewater, and natural gas must be kept running to allow people to remain in their homes, communications systems are critical to allowing business and personal connections to continue even when we must remain at home, and transportation networks must continue to operate for those who must work in person.

This project highlights the significant progress we have made and identifies some key actions that remain to be done. We look forward to continuing the work in collaboration with all the members of the San Francisco Lifelines Council to improve San Francisco's earthquake resilience.

Sincerely,

Naomi Kelly
City Administrator
Co-Chair, Lifelines Council

Christopher Barkley
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Section 1 Introduction

Lifelines provide the critical services we rely on but often take for granted until they are disrupted. It doesn't take long to feel the effects of not having water for drinking and cleaning, lights to see, devices to communicate, or transportation to get around. Learning lessons from recent earthquakes, fires, and power shut-off programs, San Francisco and cities across the globe are coming to understand the importance of lifeline systems and their complex, interdependent networks.

> *The slow recovery of one or more lifeline systems will impair restoration of other systems and delay recovery of the whole community.*

San Francisco's Lifelines Restoration Performance Project (referred to as the Project) studies the impact of a large disruption to critical services and describes steps underway and needed to restore these systems as fast as possible. The Project builds on San Francisco's 2014 Lifelines Interdependency Study that highlighted the interconnected relationships between lifeline systems and aligns with resilience objectives in San Francisco's Hazards and Climate Resilience Plan, Community Safety Element, Community Action Plan for Seismic Safety (CAPSS) and ResilientSF, the City's resilience strategy.

San Francisco has already begun to prepare and mitigate the risk of future earthquakes with a variety of policies and programs. The Earthquake Safety Implementation Program's (ESIP's) soft-story retrofit ordinance, for example, has yielded seismic improvements to thousands of vulnerable households. Since the Loma Prieta earthquake, San Francisco has invested an estimated $20 billion in seismic improvements to public infrastructure and commits to further resilience investments through the 10-year Capital Plan. We will continue to advance the ESIP work plan to mitigate earthquake risk and prepare for a strong recovery.

Even with recent and planned investments to better protect our lifelines, many vulnerabilities remain, and collective action is necessary to enhance our ability to quickly recover from an earthquake. The goal of the Project is to help the City and County of San Francisco and its people recover from a major earthquake as fast as possible by assessing the current restoration performance of lifelines and establishing a framework for improvements.

It is important to recognize that an equitable recovery for San Francisco will not be possible if people cannot remain in their homes or businesses cannot get back up and running. As seen in New Orleans, Puerto Rico, and more, prolonged lifeline disruptions disproportionately impact vulnerable populations. San Francisco felt the disruptions from damaged regional freeways, bridges, and utilities after the Loma Prieta earthquake (see **Table 1** for a fuller description of lifelines impacts). We know that the restoration of normalcy after a major event must proceed as quickly as possible while attending to those most vulnerable to lifelines disruptions.

The complexity of lifeline systems – their differing purposes, physical structures, ownerships, and regulations – pose a challenge for local leaders setting expectations for restoration plans and timeframes. This report creates a basis for informed planning and decision-making going forward.

For the first time, we have a common understanding of what restoration will look like across all lifeline systems in San Francisco.

The Restoration Performance Project provides a common metric to compare currently expected post-earthquake restoration times with future timelines or targets across lifeline systems. It also describes how lifeline systems rely on one another. In doing so, the Project identifies key actions needed to reach target restoration times and improve our ability to plan for communitywide recovery.

TABLE 1: DAMAGE TO LIFELINES IN THE LOMA PRIETA EARTHQUAKE

Lifeline System	Description of Damage
Electric Power	Damage to two power plants (Hunters Point and Moss Landing) and five substations. PG&E restored 90% of service within 32 hours.
Natural Gas	Liquefaction damage to low pressure mains in the Marina District required replacement of over 42,000 feet of pipe. Over 15,000 customers reported to be without gas service, approximately 90 percent of shut-offs were customer initiated.
Water	Approximately 1,200 breaks in water mains and connections in the Bay Area. Damage to the Municipal Water Supply System in the Marina District resulted in total loss of flow to customers and fire hydrants, and required replacement of over 36,000 feet of pipe.
Wastewater	Damage to collection sewers in the Marina District required replacement of nearly 7,000 feet of pipe.
Regional and Local Roads	Liquefaction caused buckling of sidewalks and cracking of asphalt pavement in the Marina District. 80 bridges closed with $2 billion in damage to bridges and roads regionally. Collapse of upper deck section on eastern span of the Bay Bridge. Collapse of Cypress Street Viaduct (1-880) in Oakland with 42 deaths. Damage and eventual removal of Embarcadero and Central Freeways in San Francisco.
Fuel	The Kinder Morgan fuel pipeline system that terminates at SFO airport and nearby storage facilities in Brisbane were not damaged.
Transit	Disruption to BART and MUNI service due to power outages. BART reopened within 12 hours.
Airport	SFO closed for 12 hours to repair damage to control tower. 3,000 feet of runway damaged at Oakland International Airport
Port	Piers 45, 80, 94/96 experienced damage from liquefaction; Piers 27/29 and Ferry Plaza experienced pile damage. The Embarcadero Freeway was damaged, closed and subsequently replaced by the Embarcadero Roadway.
Firefighting Water	Liquefaction damage to Earthquake Firefighting Water System (EFWS) system reduced water supply available for firefighting in the Marina District.

Sources: SPUR 2009, SF LHMP 2014, ABAG 2014

Scope and Approach

Lifelines systems are those essential utility and transportation systems that serve communities.[1] The lifeline systems evaluated for this project include electric power, natural gas, fuel, communications, water and wastewater systems, solid waste and transportation (transit, highways and roads, airport and port). The operators of these lifeline systems also make up the San Francisco Lifelines Council.

"...lifelines sustain modern communities and are vital for the economic well-being, security, and social fabric of the people they serve."[2]

They are generally geographically distributed systems, rather than isolated facilities and provide products and services through a networked system. Some of the lifelines systems studied here serve only San Francisco, while others serve the entire Bay Area region or state. The focus of this Project is on service delivery to the City and County of San Francisco.

The lifeline systems and the organizations that own and operate them are shown in **Table 2**.

About the San Francisco Lifelines Council

In 2007, former Mayor Edwin Lee toured the devastation that Hurricane Katrina caused in New Orleans. Upon his return, he partnered with the Harvard Kennedy School of Government's "Acting in Time Initiative" to identify what investments the City & County of San Francisco should make to ensure a rapid recovery from a major disaster. A key recommendation was to create a Lifelines Council that would bring together lifeline providers to develop a unified set of post-event performance standards, both individually and collectively, for public and private utility providers. In addition, in 2009, SPUR published the "The Resilient City", which addressed the vulnerability of San Francisco's lifelines and recommended establishing a Lifelines Council to support comprehensive planning. As a result of these efforts, San Francisco officially formed its Lifelines Council in 2009.

The Lifelines' Council's objectives are to:

- Develop and improve collaboration in the City and across the region
- Understand inter-system dependencies to enhance planning, restoration and reconstruction
- Share information about recovery plans, projects and priorities
- Establish coordination processes for lifeline restoration and recovery following a major disaster event.

[1] American Lifelines Alliance (ALA). 2005. *Protecting Our Critical Infrastructure:* Findings and Recommendations from the American Lifelines Alliance Roundtable.
[2] National Institute of Standards and Technology (NIST). 2014. *Earthquake-Resilient Lifelines: NEHRP Research, Development and Implementation Roadmap*, NIST GCR 14-917-33 Report, prepared by the NEHRP Consultants Joint Venture

TABLE 2: LIFELINE OPERATOR AND SYSTEM DESCRIPTIONS

Lifeline System	Operator and System Description
Electric Power	Pacific Gas and Electric Company (PG&E): Distribution to residential and commercial customers. San Francisco Public Utilities Commission (SFPUC): Uses the Hetch Hetchy system to generate hydropower to provide municipal power, including power for transit, streetlights, traffic lights, airports, municipal buildings, and Treasure Island.
Fuel	Kinder Morgan: Refineries process crude oil to make petroleum products. The Kinder Morgan fuel pipeline system delivers finished petroleum products (gasoline, diesel and aviation fuel) from refineries to fuel terminals where the product is picked up by fuel trucks for delivery to end users.
Communications	AT&T, Verizon and Comcast were included in this Project. Systems include telephone, wireless, data, fiber and cable networks. City and County of San Francisco: The Department of Technology provides technology services to City departments and agencies throughout San Francisco, including radio, video, internet access, business systems, public warning sirens, emergency call boxes, traffic signals, and the Mayor's Emergency Telephone Systems (METS).
Highways and Local Roads	California Department of Transportation (Caltrans): Interstate and state highways and the San Francisco-Oakland Bay Bridge. Golden Gate Bridge, Highway, and Transportation District: Golden Gate Bridge City and County of San Francisco: The Department of Parking and Traffic is responsible for traffic engineering; the Department of Public Works is responsible for street repair.
Water and Wastewater	San Francisco Public Utilities Commission (SFPUC): Systems include the Hetch Hetchy system, which serves not only San Francisco, but nearly 2 million Bay Area customers outside the City; potable water treatment and distribution and wastewater collection and treatment systems within the City.
Transit	San Francisco Municipal Transportation Agency (MUNI): Owns and operates bus, metro, and streetcar lines. Bay Area Rapid Transit (BART): Heavy rail system connecting San Francisco and Oakland with urban and suburban areas in Alameda, Contra Costa and San Mateo Counties.
Natural Gas	PG&E: Operates the distribution system within the City, including regulation, high- and low-pressure distribution lines, and service lines
Solid Waste	Recology: Collects, processes, and hauls waste, recycling and organics and operates recycling plants and San Francisco's Household Hazardous Waste Facility.
Port	Port of San Francisco: Manages 7.5 miles of waterfront infrastructure, including the Embarcadero roadway, open-space and parks, mooring and berthing facilities, a number of finger piers, and the Seawall. The Port property also supports lifeline infrastructure including critical utilities, transportation corridors, and emergency response areas. The Water Emergency Transportation Authority (WETA) and Golden Gate Ferry (GGF) administer all ferry service on the San Francisco Bay, serving San Francisco, Alameda, Oakland, South San Francisco, Vallejo and Marin County. WETA and GGF were not included in this project.
Airport	San Francisco International Airport (SFO): The airport is owned and operated by the City and County of San Francisco and served 57.8 million passengers in 2018.
Firefighting Water	SFPUC: High-pressure water supply network for post-earthquake firefighting. System includes 5" hose tenders, AWSS salt-water inlet manifolds, water reservoirs, pump stations, cisterns, suction connections and fireboats.

Adapted from: 'Lifelines: Upgrading Infrastructure to Enhance San Francisco's Earthquake Resilience" (SPUR, 2009)

To assess the current restoration performance of these lifelines and establish a consistent framework for charting improvements, the Project addresses three main questions:

- If a large earthquake occurred today, how would our lifelines perform?
- How do we want lifelines to perform in a large earthquake?
- What strategies are needed to close the gap between where we are today and where we want to be?

The answers to these questions were developed through a structured interview process with lifeline providers (see **Appendix A**). The answer to the final question should guide future infrastructure resilience planning for members of the San Francisco Lifelines Council.

Scenarios

The Project used two realistic but extreme earthquake scenarios: a magnitude 7.9 earthquake on the San Andreas Fault and a magnitude 7.0 earthquake on the Hayward Fault. These two scenarios provide the opportunity to examine the different effects of very near and more distant major earthquakes, as well as the variations in impact to regional lifeline systems that also serve San Francisco. Details about the selection of these scenarios is provided in **Appendix B**. A significant focus of this project was on the potential impact liquefaction may have on lifeline damage. **Figure 1** shows liquefaction susceptibility in the Bay Area.

The Lifelines Restoration Performance Project adapted the methodology developed by Chang et al.[3] to characterize lifeline system vulnerability and resilience in earthquakes. The approach utilized a structured interview process to elicit expert judgement from key members of each lifeline organization. The interviewees were asked to consider the physical performance, restoration goals and assumptions of lifeline systems in the two earthquake scenarios. Interviewees were asked to inform their responses with as much data collection, modelling, experience in previous disasters, studies and information as the organization has developed to date.

Following the interviews, a cross sector workshops was organized to bring all the lifeline providers together to validate and revise the key findings, restoration goals and

[3] S.E. Chang, T. McDaniels, J. Fox, R. Dhariwal, H. Longstaff. 2014. Toward disaster-resilient cities: Characterizing resilience of infrastructure systems with expert judgments. Risk Analysis, 34 (3) (2014), pp. 416-434, 10.1111/risa.12133

assumptions, and to identify key actions to speed restoration. A summary of the workshop is included in **Appendix E**.

The key product of this study is a set of restoration curves or timelines for each lifeline system that depicts an averaged citywide level of service disruption based on extent and impact at key time intervals following an earthquake.

Limitations

The Project was not designed to model damage on specific system components, but rather to identify broad patterns of resilience across the whole city, key interdependencies, and what actions would be required to restore function of the system.

We recognize that the broad categories of service disruption do not provide details of the impacts, they are rather intended for overall comparisons in broad classifications, across many kinds of systems. This method also recognizes the tradeoffs between insight, precision, and effort given the information at hand. The results represent general conclusions across the city, not neighborhood or location specific impacts.

Lifeline providers were asked to define their own restoration targets. In some cases, these have been adopted through public process, but in other cases, they have not been publicly vetted. This project did not address whether those goals were adequate.

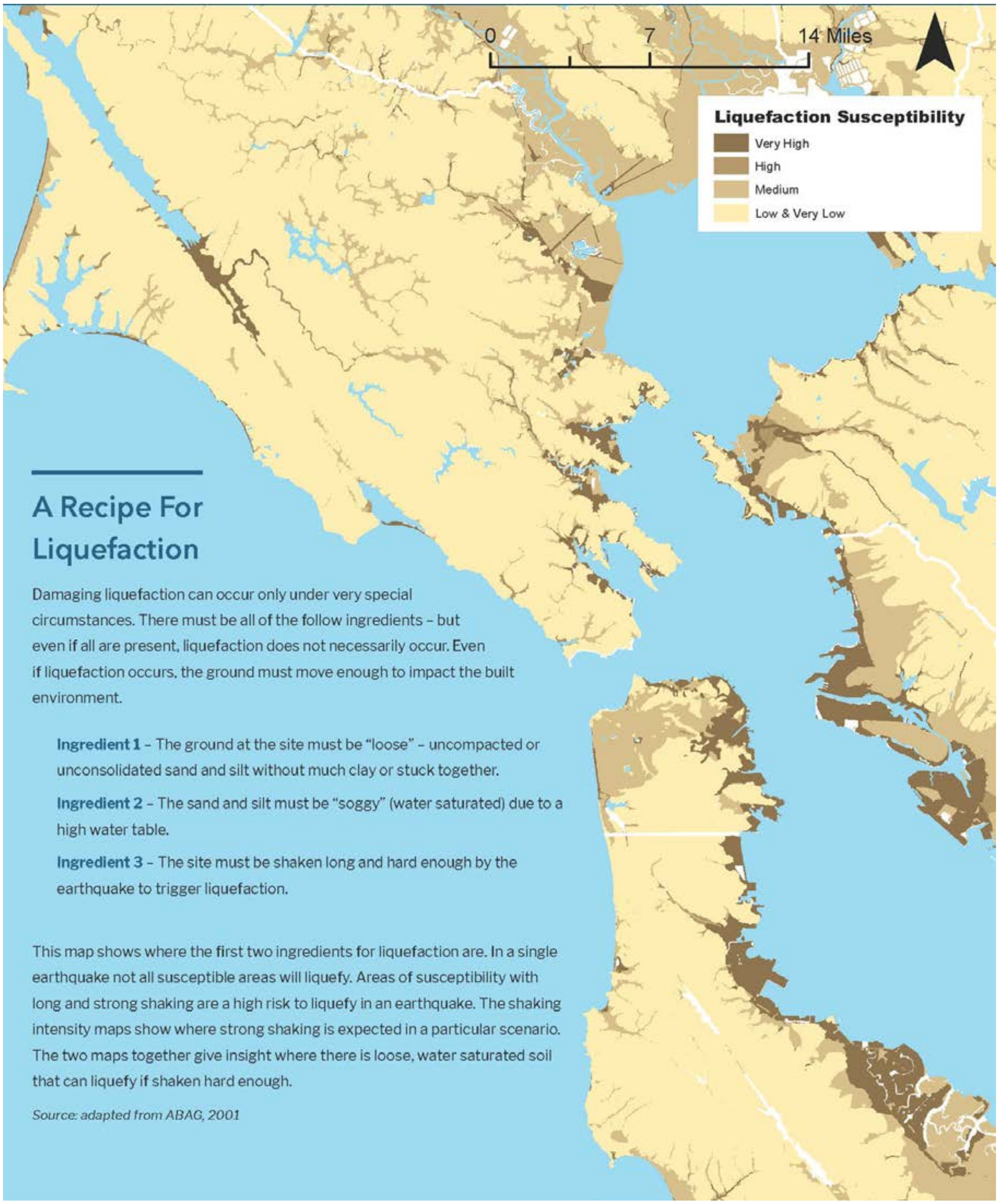
The results of the project rely primarily on information provided by infrastructure operators, and are limited to their knowledge of the system, their inherent biases and the level of detail of their own internal studies. We tried to capture a measure of the level of rigor underlying the interview responses by quantifying the confidence level. We did not perform any independent analysis or verification of the information provided.

Finally, a single scenario is not representative of what could really happen in an earthquake. An actual event could have a smaller or larger magnitude, with a wide range of actual ground motions and impacts. The scenarios are intended to elicit the general types of impacts, restoration issues and restoration time that could be expected from an event of this magnitude.

This Project does not address those systems that are sometimes considered lifelines but are primarily based on buildings, such as schools, hospitals, and grocery stores. The focus is on the systems that allow those buildings to perform their function.

The Project also did not consider those systems that are not organized around fixed, physical assets; for example, it does not consider buses and ferries. These systems are critical to supporting emergency response and recovery of the community, but they primarily depend on the functioning lifeline systems of roads and ports to operate.

FIGURE 1: LIQUEFACTION SUSCEPTIBILITY IN THE BAY AREA



Section 2 System Wide Findings

Restoration Performance

These findings relate to the overall process and timing of lifeline restoration. The issues presented in this section are common across many lifeline sectors.

For the first time, we have a common understanding of what restoration time across all lifeline systems in San Francisco.

Figure 2 summarizes the restoration timeline for each lifeline system. Some of the key takeaways from these restoration timelines include:

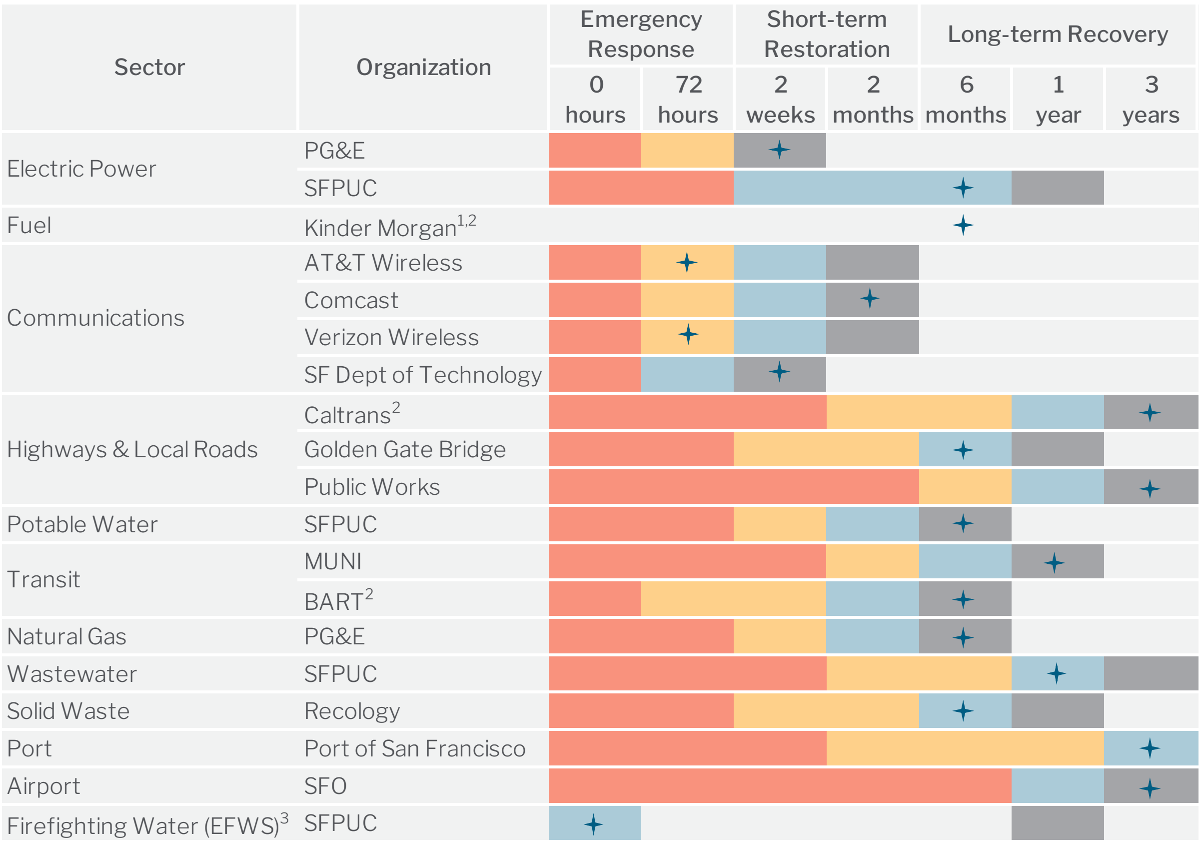
- **Power and telecommunication** are the fastest to recover because of flexibility of those systems.
- **Water, wastewater, roads, natural gas, port and airport** take longest to recover because of complex reconstruction needs.
- **The Golden Gate and Bay Bridges** are designed to be immediately open for emergency vehicles, and potentially repair crews.
- **Different systems will experience varying levels of impact, depending on the scenario**. While the San Andreas scenario is the worst case for most sectors in San Francisco, the Hayward fault scenario is the worst case for Kinder Morgan, Caltrans and BART due to impacts outside San Francisco.

We have developed **49** recommendations on how to improve restoration of each individual system, which are summarized at the end of this chapter and detailed in each sector summary.

Because these restoration timelines are based on information provided to us by the lifeline provider, the confidence we have in each timeline varies significantly depending on whether a detailed and comprehensive evaluation has been performed, the organization's experience restoring its system in recent disasters, and the extent of response planning it has undertaken.

As we build on this effort over time, it will be important to continue to refine our understanding of the restoration performance and issues for each sector. That continued development requires that each lifeline operator adopt restoration performance goals, refine its own understanding of how its system will perform, and collaborate for integrated restoration planning.

FIGURE 2: SUMMARY RESTORATION TIMELINES



[1] Kinder Morgan has not provided expcted restoration performance. Kinder Morgan has many unknown and externalities that make estimating restoration of fuel delivery challenging.

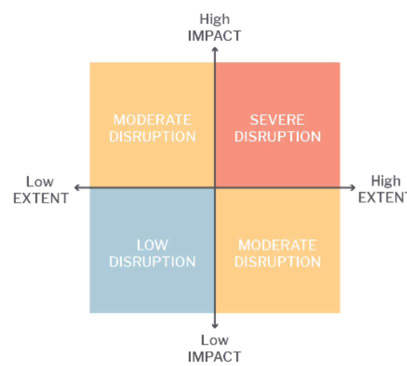
[2] Wost case scenario is Hayward Fault

[3] Goal of EFWS is low disruption immediately after an earthquake. After post-earthquake fire fighting needs are met, SFPUC will focus efforts on restoring potable water first and then return to complete needed repairs to AWSS system.

The service disruption levels are defined as:

- Severe = disruptions with high spatial extent & high impact disruptions.
- Moderate = disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Low = disruptions with low spatial extent and low impact;
- No disruption

SERVICE DISRUPTION LEVELS



Where,

- Extent = spatial reach of the disruption and proportion of people within the area that are affected.
- Impact = severity of consequences and the duration of the disruption. For example, complete loss of water supply is high impact (independent of how many people are affected), whereas a boil water advisory is low impact.

Decades of investment in infrastructure improvements will improve post-earthquake restoration performance

It has now been more than 30 years since San Francisco experienced a significant earthquake, and more than 110 since the last earthquake of the scale contemplated in this Project. Despite this length of time between large earthquakes, lifeline operators are making significant investments to retrofit and upgrade their infrastructure systems.

Building on decades of previous investment, several major retrofit programs have been completed in recent years, and others are now underway, further reducing expected levels of system damage in a future earthquake. Detailed system wide risk analyses and engineering studies are important components of these programs. The organizations listed below have made significant progress toward improving their own systems and as a result, the resilience of the entire city and region. Additional details can be found in the Sector Summaries.

- **Completed programs:** Caltrans retrofits of elevated freeways and bridges crossing the Bay, BART Earthquake Safety Program, SFPUC Water System Improvement Program, Golden Gate Bridge retrofit, PG&E power and natural gas system upgrades.
- **Programs underway:** SFPUC Sewer System Improvement Program, SFPUC Auxiliary Water Supply System, SF Port Seawall Resilience Program.

These analyses have enabled the organizations making large capital investments to have a greater understanding of their systems and how they will

LIFELINE RESTORATION PROCESS

The lifeline restoration process includes three phases.

Emergency Response: Most operators will immediately shut down the system as a precaution to ensure safety and will perform an initial damage assessment. This initial screening allows operators the opportunity to identify priorities, organize response activities, as well as determine needs for additional resources and logistics. This phase generally lasts about 24-72 hours.

Short term restoration: During the short-term restoration or stabilization phase, key repairs or temporary measures and workarounds are performed in order to return the system to some state of function. Those systems for which significant retrofit programs have been performed or those (such as communications and electric power) that have operational flexibility, are likely to be restored quickly, perhaps within 24-72 hours. For other systems, short term restoration may take weeks or months.

Long term recovery: The long-term recovery phase may last for months or years as permanent repairs are made and heavily damaged components are rebuilt. The extent of damage and the restoration approach taken by the organization, as well as extent of dependence on the restoration of other systems, largely dictates how long a system will take to recover. Those sectors that have undertaken comprehensive infrastructure improvement programs will largely experience less damage and disruption and faster restoration times.

perform. Continuing this work collaboratively will make San Francisco and the greater Bay Area more prepared to minimize and address disruptions quickly in the wake of a major earthquake.

Recommendation:

- Continue to invest in seismic improvements that speed system restoration

While some organizations have adopted restoration performance goals, more are needed.

Four lifeline organizations have adopted restoration performance goals (seismic performance objectives or level of service goals): SFPUC Water and Wastewater treatment, Caltrans, Golden Gate Bridge Highway and Transportation District and BART. The Port of San Francisco is in the process of developing performance goals for individual facilities in the Seawall Program which may inform development of a system wide performance goal. These performance goals have guided investments for their earthquake retrofit programs. Other organizations have developed informal restoration goals. Every organization strives to restore service as quickly as possible.

Adopting official restoration performance goals helps the public have a clear understanding of what to expect from the system in an earthquake and helps agencies track progress towards improved restoration performance.

Recommendation:

- Lifeline operators that have not yet done so should adopt restoration performance targets and measure progress towards their goals

Many organizations have undertaken robust emergency response planning that will speed their system restoration.

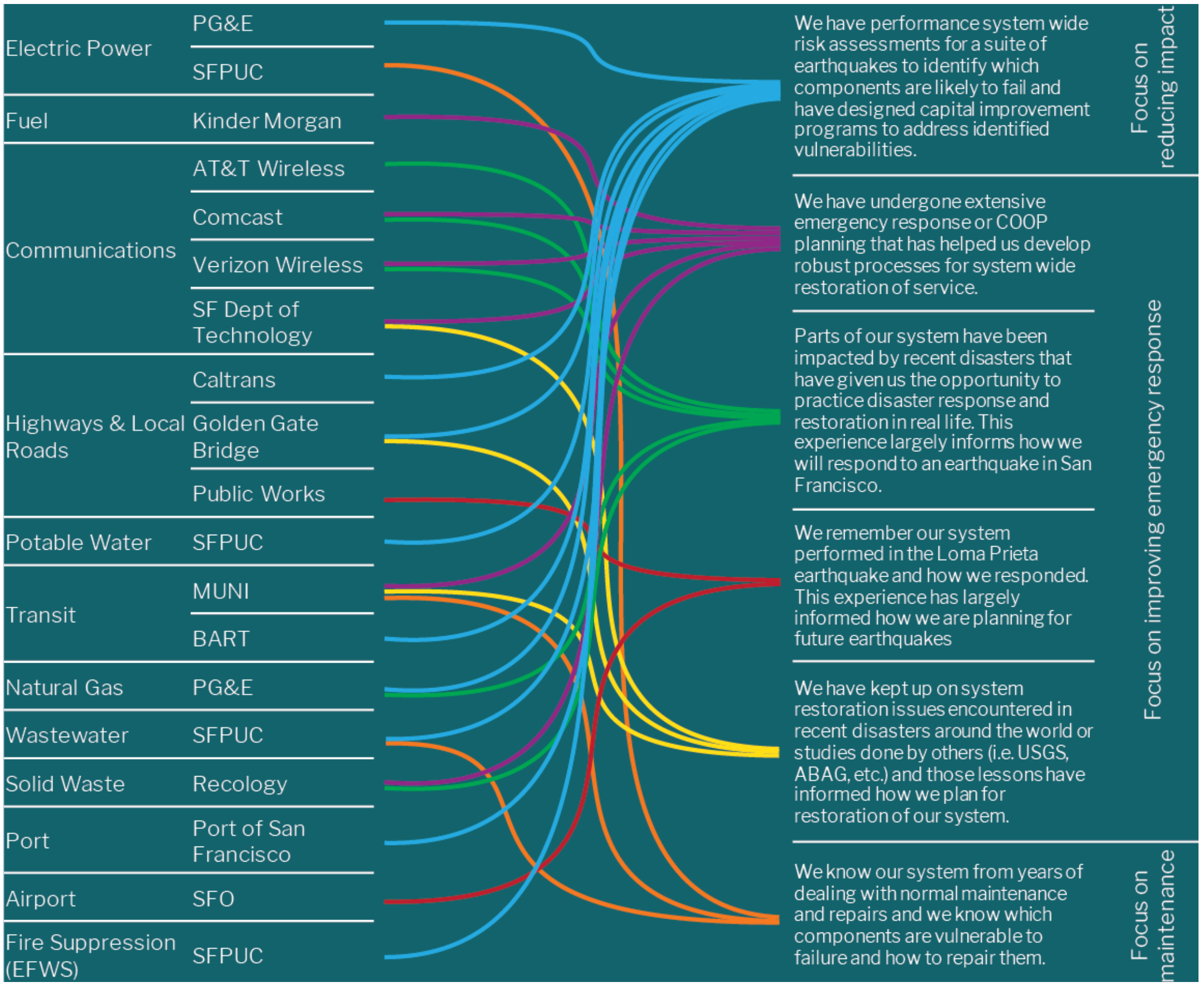
Recent local disasters and other emergencies are a reminder of the impacts an earthquake can have on our city and region. The 2004 Napa earthquake, significant wildfires across northern and southern California, and several Public Safety Power Shut-off events in 2019 are providing new lessons and lots of practice for disaster recovery and utility restoration for those sectors that have service areas beyond City boundaries. Many local lifeline utilities agencies have supported the responses to those incidents with mutual aid and have been carefully following these and other events around the world to identify lessons learned to support their own restoration efforts.

Some organizations have undertaken a significant effort to improve their emergency response plans either in response to recent events or because of what they learned in the Loma Prieta earthquake, from other disasters, or from published studies such as the USGS Haywired scenario. **Figure 3** below demonstrates the primary approach that each lifeline organization has taken in its approach to planning for earthquakes. While every organization has made system improvements in recent years and has emergency response plans in place, some organizations have approached their capital improvements in a more systematic risk-based way, and some have focused heavily on emergency response planning or have recent real-world experience responding to disasters.

Recommendation:

- Lifeline operators that have not yet done so should perform a systematic risk analysis to assess needed retrofits and capital improvements to speed post-earthquake restoration

FIGURE 3: HOW LIFELINES ORGANIZATIONS APPROACH PRE-EVENT PLANNING FOR RESTORATION



The type and extent of restoration each system may require varies significantly across systems.

Restoration may look very different for different lifeline systems. The restoration approach used for a given system will depend on many factors, including the actual damage, the needs of the system's customers, and the priorities of the community at the time of the event. As the impacts of climate change on San Francisco become clearer, we may recognize the need to change the way our infrastructure systems operate and the services they provide. Understanding future needs may also drive the nature of a systems restoration.

Four basic restoration approaches are likely to be undertaken by lifeline systems: maintenance, adaption, renewal, and transformation. The actual approach that a given system takes will depend on many factors, including the actual damage and the priorities of the community at the time of the event.

Maintenance: For those systems that have undergone significant retrofit programs or that are unlikely to want to change form significantly, the restoration process may look like a massive maintenance program, largely replacing the components that are broken to restore what existed before the earthquake. Temporary workarounds would be challenging or impossible for these systems and they will likely be shut down during restoration. While the restoration effort will not be trivial, there are likely to be fewer big questions to address about whether the system will look different than it was before and restoration should happen relatively quickly.

Systems likely to take a “maintenance” restoration approach include: EFWS, BART, SFPUC Water and Wastewater, Golden Gate Bridge and Kinder Morgan.

Adaptation: Some systems may experience significant and/or widespread damage. While it is not likely that major changes will be made to the form of the system, temporary networks or workarounds are possible or desired for these systems, and will help restore the function of the system more quickly while permanent repairs are made. In some cases, these temporary networks or workarounds will be short lived, such as generators, while others may be in place for months or years.

Systems likely to take an “adaptation” restoration approach include: PG&E Power, SFMTA Muni, Caltrans and Communications.

Renewal: When this approach is used, components of lifeline systems have really outlived their useful life and would be unlikely to be rebuilt in the same form again. Damage may be extensive and changing priority may provide an opportunity for renewal of the system. These kinds of decisions may require public input and broad planning efforts, beyond replacing what was there previously.

Examples of the “renewal” approach include: rebuilding the Port’s wharves and piers, adding more fiber to the communication network and replacing legacy copper systems, and replacing portions of the SFPUC power system such as the aging system on Treasure Island.

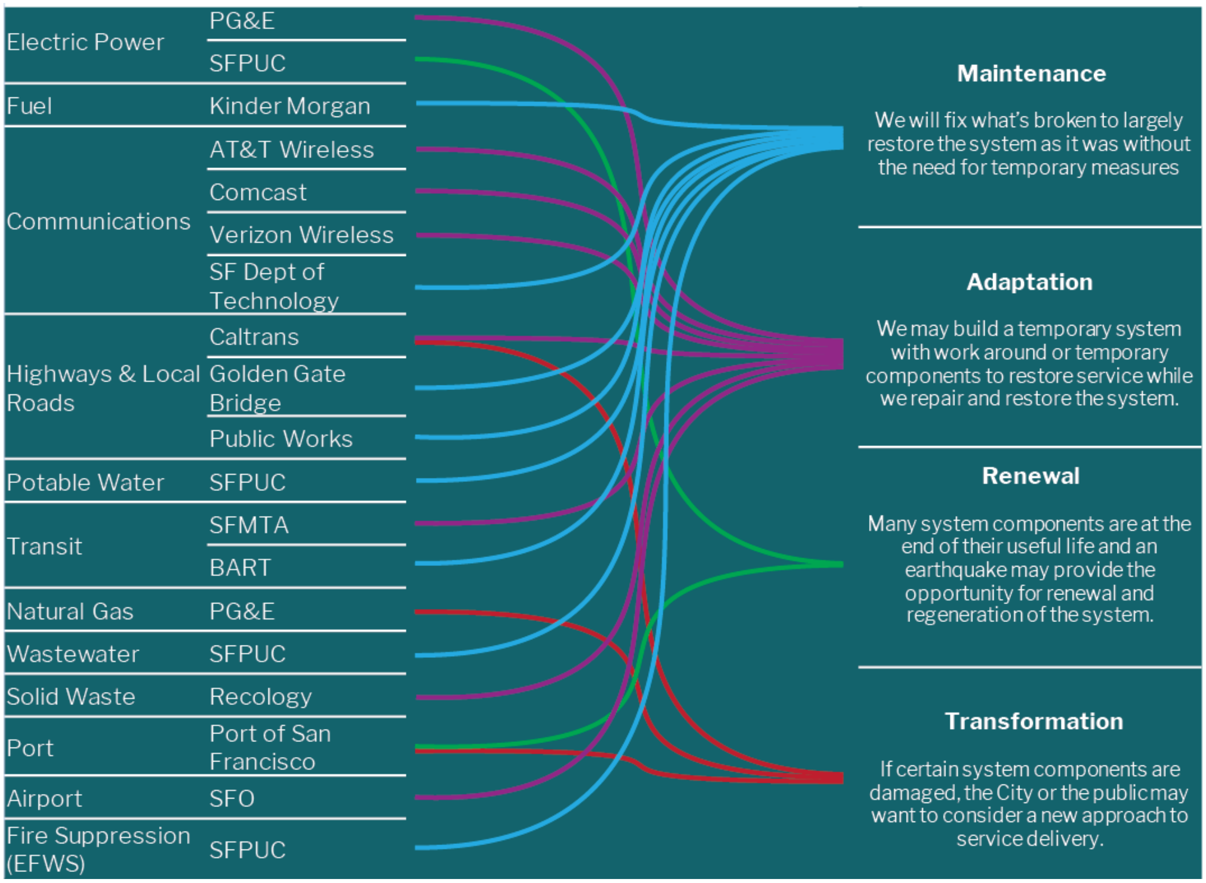
Transformation: Finally, we might expect there to be public pressure to rethink how some services are delivered or whether the system itself should be transformed. For example, if large portions of the natural gas network were damaged in liquefaction areas, there might be public pressure not to rebuild those portions of the system considering the City’s efforts to achieve net zero energy buildings by 2050 to meet greenhouse gas reduction targets. Similarly, if an earthquake were to occur before the Embarcadero Seawall is strengthened, a conversation about the future form and shape of the city's waterfront would be necessary. The Loma Prieta earthquake has already revealed that the public would be eager to discuss whether rebuilding certain freeways that cut through neighborhoods is desirable. These discussions would take significant time and resources and involve questions about the future form of the city in the face of a changing climate and changing priorities of the public.

Figure 4 summarizes the four types of restoration approaches that a system may undertake. Which approach they ultimately utilize will depend on the extent of damage, the priorities of the organization and input from system users and the public. Some systems may need to be rebuilt almost completely and some will require relatively minor repairs.

Recommendation:

- Lifeline providers should anticipate the likely restoration approach needed for their system following an earthquake to guide pre-earthquake planning decisions.

FIGURE 4: HOW LIFELINES ORGANIZATIONS WILL LIKELY APPROACH RESTORATION AFTER AN EARTHQUAKE



Interdependencies

These findings relate to how lifeline restoration will be impacted by the way lifelines rely on one another. The issues presented in this section are common across many lifeline sectors.

Disruption to some lifeline systems will significantly impact the long-term recovery of neighborhoods.

The form and pace of recovery of neighborhoods, homes and businesses will depend both on the extent of damage to buildings and the function of utilities to serve them. While power and communication systems will likely be restored quickly and will not have a significant impact on long term recovery, the time to restore other systems can have a significant, detrimental impact. Delays in repairs to city streets, months-long efforts to repair damage to the natural gas system restore service to households and businesses, and time required to repair damage to the potable water distribution and wastewater collection systems will significantly hamper recovery of neighborhoods and may lead to displacement of residents and businesses.

Recommendation:

- Evaluate and upgrade lifeline distribution systems with long restoration timelines that are especially important to neighborhoods to help prevent the displacement of vulnerable residents, including natural gas, water, sewer and local roads.

Disruption to fuel lifeline systems and key physical assets will have significant impact on business and commerce.

Some lifeline systems may not have a direct impact on the functioning of neighborhoods, but they will have significant impact on the city's economy, with potentially global reverberations. Prolonged fuel system disruption will significantly impede the ability of other systems and the economy to recover. Failure of the seawall will cause significant disruption to the Financial District. Prolonged closure of SFO airport will hamper tourism and business travel. Other regional airports may also be impacted as well, making commercial travel in and out of the region challenging.

Recommendation:

- Advance efforts to strengthen the seawall
- Develop plans to reduce disruption and speed restoration of the airport and regional fuel system.

Even lifeline systems that are not damaged may not be functional because they depend on other systems to operate.

Lifeline systems rely on one another to operate. Nearly every system studied has a significant reliance on power, fuel, roads and/or communications for operations. Following a major earthquake, these interdependencies may delay restoration of systems. While interdependencies were considered by lifeline operators when developing their restoration timelines, most operators have a somewhat limited knowledge of what the restoration process and timeline will be for other systems. However, recent PSPS power outages have crystalized the nature of the dependency on electric power for many system owners.

Figure 5 shows the extent to which each system relies on another system. Key interdependencies include:

- All systems rely on fuel either for equipment and vehicles or for backup generators when power is out. Most systems have some fuel reserves, but will require refueling within a few days of an event. If fuel cannot be delivered either because the refineries in the region are shut down or the road and pipeline networks are not operating, many systems will experience additional outages.
- Every sector has a large reliance on power to operate equipment, and backup energy sources such as generators are not always feasible.
- Every sector relies on communications for systems control and monitoring (SCADA), dispatch and communication between workers. Communication systems can be restored very quickly, depending on available power or backup power. Communications providers also rely on infrastructure owned by other communications providers, particularly for the fiber network.
- Every sector relies on highways and local roads to transport workers, materials and equipment. BART and ferries are also considered key resources for transporting workers across the Bay.
- Multiple sectors rely on the Port for water delivery of materials and equipment.
- EFWS has few significant dependencies because the system must be operational immediately after an earthquake with little repair.

Though the risks of these interdependencies can never be completely mitigated, understanding them is an important step towards planning for the fastest possible restoration. Likewise, planning collaboratively is essential.

Recommendation:

- The Lifelines Council should continue to advance and facilitate interagency efforts to understand and mitigate lifeline system interdependencies.

FIGURE 5: SUMMARY INTERDEPENDENCIES TABLE

A. Lifeline Sectors

B. Lifelines given in A are dependent on these lifelines

Sector	Electric Power	Natural Gas	Water	Wastewater	Communic-ations	Highways and Local Roads	Fuel	Transit	Solid Waste	Airport	Port	Firefighting Water (EFWS)
Electric Power	Significant	Significant	None	None	Moderate	Significant	Significant	None	None	None	Low	None
Natural Gas	Significant	None	Moderate	Moderate	Moderate	Significant	Significant	None	None	None	Low	None
Water	Significant	Moderate	Significant	Significant	Significant	Significant	Significant	Significant	Moderate	None	Moderate	Significant
Wastewater	Significant	Moderate	Significant	None	Significant	Significant	Significant	Moderate	Moderate	None	Moderate	Low
Communications	Significant	Moderate	Moderate	None	Significant	Significant	Significant	None	None	None	Moderate	Low
Highways and Local Roads	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Low	Moderate	Moderate	Moderate
Fuel	Significant	None	Significant	None	Significant	Significant	Significant	None	None	None	Moderate	None
Transit	Significant	None	Significant	None	Significant	Significant	Significant	Significant	None	Low	Significant	Low
Solid Waste	Significant	Significant	Low	Low	None	Significant	Significant	None	None	None	Significant	None
Airport	Significant	Moderate	Significant	Significant	Significant	Significant	Significant	Moderate	Moderate	Low	None	None
Port	Significant	Moderate	Significant	Significant	Moderate	Moderate	Significant	Moderate	None	None	None	Moderate
Firefighting Water (EFWS)	Moderate	Moderate	Moderate	None	Moderate	Significant	Moderate	None	None	None	Significant	None

None	No reliance on sector
Low	Minimal reliance on sector
Moderate	Large reliance on sector with significant backup available, or moderate reliance on sector with no back up available
Significant	Large reliance on sector with limited backup available

Reading the matrix across each row shows which sectors a particular sector relies on. For example, electric power has a significant reliance on natural gas, but a low reliance on the Port.

Reading the matrix down each column shows which sectors rely on the designated sector. For example, all systems, except for EFWS have a significant dependence on electric power.

Maintenance and repair workers needed for response and restoration in every sector increasingly live outside of San Francisco.

Many people who service lifeline systems within San Francisco need to cross a bridge to get to work. These workers increasingly live in the far East Bay or Central Valley, as housing prices in the inner Bay Area become increasingly out of reach for them. Depending on the time of day of the event, rapid damage assessment and immediate repairs could be constrained by staffing resources, delaying restoration of the whole city. These workers need functioning transportation networks to get to San Francisco. In the short term, this problem can be ameliorated by coordinating access across the Bay Bridge and on BART, which will reopen quickly.

Recommendation:

- San Francisco should preserve and expand affordable and workforce housing options within the City to ensure that critical responders live in San Francisco and are available to respond to emergencies.

Many lifeline operators will need to bring additional crews, materials and equipment from outside the region to support system restoration.

To respond to the demands of a major earthquake, every lifeline operator will deploy additional crews, materials and equipment to San Francisco. In a dense, geographically isolated environment such as San Francisco, it will be a major challenge to get these resources into and around San Francisco. Significant staging areas will be required to support these logistics operations. The Golden Gate and Bay Bridges are designed to be open for emergency vehicles, and potentially repair crews, nearly immediately after an event. However, CHP and Caltrans will have a major challenge of understanding which vehicles should be allowed to pass through, especially if workers are not traveling in marked company vehicles or are third party contractors.

Many of the vehicles that need access to San Francisco are heavy equipment and large trucks carrying equipment and materials. Identifying space for staging this influx of equipment and material and housing additional workers will also be a major challenge within the space constraints of San Francisco.

Recommendations:

- Develop a common and flexible identifier to help facilitate access on Bay crossings for those personnel who are not emergency responders but have critical immediate post-disaster roles in performing damage assessment, inspections, and immediate repairs of critical assets within San Francisco.
- Public Works and SFMTA should designate freight traffic routes as disaster recovery critical supply routes before an earthquake and develop mitigation plans to ensure they will be accessible immediately after an event.

Ensuring crews can access assets for damage assessment and repairs is critical to restoration of every system.

Immediately after an event, every lifeline operator will need to evaluate the extent of damage to their system and respond to leaks and breaks, and first responders such as fire fighters, police, and emergency medical personnel will be engaged in saving lives and protecting property and safety. These activities require accessible city streets. Immediately after an event, Public Works will perform windshield surveys to assess damage and identify priority streets for debris removal and reopening.

Some roads will need to be closed because of damaged buildings or utilities, however many lifeline operators and their contractors will still need to access these cordoned or closed areas to inspect and repair their facilities.

Recommendations:

- Public Works should develop risk models that predict likely road closures before an earthquake and use shaking intensity-based triggers to initiate and prioritize inspections based on likely damage to utilities and buildings, as well as for roads that provide access to critical facilities like hospitals, police and fire, and PG&E and SFPUC assets.
- As with accessing the bridges, identifying flexible, consistent ways for lifeline operators to identify their crews and contractors to CHP or San Francisco Police will facilitate their access to cordoned areas.

Loss of power will significantly impact every single lifeline system, as well as all buildings.

Every sector relies on electric power to operate. Power is expected to be available relatively quickly, but many buildings and systems will rely on generators for temporary restoration. Obtaining enough fuel for generators will be a significant challenge. Restoration of many systems could be further improved with more generators (or solar power) in places that can be easily accessed post-earthquake. However, generators are not feasible in all locations, like near building ventilation intakes and in public places where they could be tampered with or stolen. Furthermore, generators are polluting and contribute to greenhouse gas (GHG) emissions and refueling them in a disaster will be difficult.

Recommendation:

- To the extent possible and feasible, recovery critical buildings and lifeline systems should utilize solar with battery storage to provide some level of continuous power. This strategy has the added benefit of reducing system disruption in future power shut-off events.

Reducing reliance on petroleum fuel will improve restoration of all systems.

Every sector has a high reliance on fuel for generators, equipment, and vehicles. San Francisco does not have enough fuel storage capacity within city limits, and damage to the Kinder Morgan fuel pipelines and/or Bay Area refineries may cut off the regional fuel supply in the short term. Emergency delivery of fuel to the Port of San Francisco will be extremely challenging due to potential damage to Port facilities and lack of infrastructure to distribute fuel across the city.

Recommendations:

- Municipal and private lifeline owners with critical fuel needs should develop policies to maintain adequate supply of fuel within vehicles and equipment, and store fuel locally in tanks that can be pumped without electricity.
- Vehicle fleets should be electrified and powered with solar power to reduce reliance on fuel because the electric system will likely restore faster than the fuel system.
- To the extent possible and feasible, solar with battery storage should be the primary power backup source rather than generators, because of fuel supply issues.

Section 3 Sector Based Restoration

This chapter presents a summary of the Actions to Speed Restoration identified in each Sector Summary. Each of the twelve Sector Summaries are also included in this chapter.

Actions to Speed Restoration by Sector

The recommended actions to speed restoration of each lifeline sector are listed here. Details about each recommendation are included in each sector summary.

Electric Power

- Building and lifelines owners with critical electricity needs should install a grid-independent solar battery storage system.
- The Lifelines Council and PG&E should evaluate the earthquake vulnerability of power generation sources in the Bay Area.
- PG&E should share its plans for establishing an above ground temporary electrical network with San Francisco.
- PG&E should develop a clear understanding of the reliance of other lifeline systems on power supply and the implications if these partners lose power.
- SFPUC should continue to assess the vulnerability of substations at SFO to damage in an earthquake and develop a plan to address deficiencies.
- SFPUC should understand the earthquake vulnerability of critical PG&E owned power components and develop a plan to address deficiencies.
- SFPUC should develop mutual aid agreements with individual utilities in another region and improve emergency purchasing processes.

Fuel

- Kinder Morgan should strive to better understand the vulnerability of its system components to damage due to earthquake.
- San Francisco should collaborate with industry stakeholders to accelerate deployment of electric and alternative fuel for light, medium and heavy-duty vehicles.
- Municipal and private owners with critical electricity needs should develop policies to ensure adequate supply of fuel within vehicles and equipment as a first priority and then store fuel locally in tanks that can be pumped without electricity.
- The Lifelines Council should work with key fuel users, regulators and fuel providers to evaluate the impact of an earthquake on Bay Area refineries and encourage them to upgrade vulnerable components as necessary.
- The Lifelines Council should request public reports focusing on post-earthquake operational issues of marine oil terminals to assist in better understanding moderate and long-term fuel supply impacts.
- The City of San Francisco Fire Department, SFPUC, and City of Brisbane should work with Kinder Morgan to determine the vulnerability of the Brisbane water main.

Communications

- San Francisco should prioritize fuel distribution to generators at City radio communication sites and data centers to maintain City vital information systems and communications.
- Communication providers should identify locations to add permanent generators at more cell sites and nodes and co-locate cell sites with building solar and battery systems.
- Communication providers should develop agreements to provide emergency mobile wireless to priority locations in the City within a specified time.
- Identify communications providers as disaster service workers to ensure access to cordoned areas when safe for service restoration activities.
- Identify staging locations for personnel supporting communications restoration.
- Identify ways to ensure communications providers and other lifeline operators coordinate restoration activities.

Highways and Local Roads

- San Francisco should work with Caltrans and GGBHTD to identify protocols for granting access to bridges for repair crews.
- SFMTA and SF Public Works should designate freight traffic routes as disaster recovery critical supply routes and protect them from damage in an earthquake.
- Caltrans should delegate responsibility for clearing local priority state routes to local jurisdictions in an emergency.

Potable Water

- SFPUC should analyze the seismic reliability and expected restoration time of the in-city water distribution system and develop an upgrade strategy.
- SFPUC should identify key facilities that should be prioritized by PG&E for power restoration.
- SFPUC should stockpile critical spare parts needed for emergencies.
- SFPUC should work with lifeline sectors co-located in city streets to coordinate post-earthquake emergency response and restoration work.

Transit

- BART and SFMTA should work with PG&E to better understand when power will be restored to components of the transit system.
- BART should work with SFPUC and EBMUD to better understand when water will be restored to the BART system.
- SFMTA should assess the feasibility of providing battery backup for critical traffic signals to ensure basic level of post-earthquake traffic flow.
- SFMTA should study resilience issues related to the overhead catenary systems

Natural Gas

- San Francisco Department of Building Inspection should require all new buildings to be fully electric.
- San Francisco Department of Building Inspection should require electrification of existing buildings with gas shut-off valves as an interim measure.

Wastewater

- SFPUC should develop service level agreements and MOUs to ensure adequate staffing for post-disaster evaluations and emergency repairs.
- SFPUC should communicate power restoration needs of treatment plants and pumps to PG&E.
- SFPUC should characterize its needs and impact to the pumps and treatment plants of lengthy power outages, and work with PG&E to prioritize restoration of power accordingly.
- SFPUC should adopt and implement measures to achieve performance goals pertaining to restoration of the wastewater collection system.
- SFPUC should develop a coordinated plan and public messaging for handling biological waste when toilets won't flush.

Solid Waste

- Recology should increase its understanding of post-disaster fuel availability and the regional prioritization process to enable better planning for post-disaster fuel needs.
- Port of San Francisco should complete a vulnerability study to determine the likelihood that Pier 96 will be operational after the scenario earthquake and determine alternate recycling collection and debris processing locations.
- Recology should explore alternative methods for waste transfer, such as activation of the existing rail spur and connection to the rail line would reduce likelihood of surpassing Recology's waste storage capacity.
- Large building owners should consider redundant power source for trash compactors for commercial buildings.

Port

- The Port should evaluate potential seismic upgrades to Pier 1 and a plan to upgrade Pier 50 or relocate these operations to support the Port's role in waterfront restoration.
- The Port, the Department of Emergency Management and the ferry operators should evaluate the impact of a major earthquake on ferry operations and the expected timeline for restoration of service.
- The Port should identify additional resources, partnerships, projects, policies and actions necessary to continue to reduce the risk of seawall failure.

- The Port should perform a seismic vulnerability assessment of southern waterfront with a particular focus on piers that are important to the City's post-disaster response.
- The Port should develop Memoranda of Understanding (MOUs) with Resource agencies responsible for permitting along the shoreline to expedite post-disaster construction.

Airport

- SFO should identify ways to improve the reliability of fuel delivery in the event of an emergency.
- SFO should improve the reliability of priority utility systems in an earthquake.

Firefighting Water

- SFPUC should complete studies and analysis, and implement capital projects to improve and expand the Earthquake Firefighting Water System (EFWS), emphasizing capital investments in areas of the City with limited access to the EFWS.

How to Read the Sector Summaries

Each Sector Summary describes the systems and issues in detail. Each sector summary is organized into the following sections with a brief description of what that section includes.

Key Findings provides a quick summary of the key findings which will be described in more detail throughout the Summary. Findings include brief description of restoration timeline and issues, key dependencies, and other important issues.

Actions to Speed Restoration provides a quick summary of the recommended actions which are provided at the end of the Summary.

Restoration Performance Goals provides the goal for system restoration provided by the operator and describes whether this goal has been officially adopted.

System Restoration Timeline provides a graphical overview of the extent of service disruption at specific time points after a San Andreas scenario earthquake.

Sector Overview provides a description of the system function, its major components, and the organization(s) that operate it; includes a map of the system components.

System Upgrade and Disaster Planning Efforts includes a description of investments to improve the seismic performance of the system and planning efforts undertaken to improve post-disaster restoration.

Expected Impacts of an Earthquake provides a description of how each earthquake scenario will impact the sector.

System Restoration Timelines and Considerations provides a detailed description of the existing level of anticipated service disruption and restoration actions that will be undertaken by the operator at each recovery time period.

Level of Confidence provides a description of the sources of information the operators drew on to inform their responses to the interview questions.

System Interdependencies describes the extent of this sector's dependence on other sectors.

Actions to Speed Restoration provides key actions that should be taken to improve the post-earthquake restoration of the system and meet the system's restoration goals.

Electric Power

Photo: Unsplash/Flickr

Most electricity in northern California is provided by PG&E, an investor owned utility headquartered in San Francisco serving approximately 16 million people. The City of San Francisco also operates its own public utility system, the San Francisco Public Utilities Commission (SFPUC), which provides power to municipal customers, as well as a growing number of residential and commercial customers, providing nearly 20% of the City's electricity needs.

Electric Power

Operators: PG&E, SFPUC

At A Glance

Key Findings

- Moderate restoration of PG&E power within 72 hours and fully restored with long-term temporary measures within two weeks. SFPUC power may take up to two weeks for moderate restoration and up to a year for no disruption, largely due to the likely need to replace major electrical equipment.
- Restoring PG&E power system will require mobilization of significant resources and the movement of large equipment through San Francisco.
- SFPUC municipal customers are highly dependent on restoration of the PG&E system and will likely be without power until PG&E power is restored.
- Electric power has significant dependencies on power generators and transmission lines, natural gas for generation, highways and roads for transporting crews and equipment, and fuel for generators and maintenance crews. Communication systems are also important for power operation, but backups are available. SFPUC power is highly reliant on PG&E.

Actions to Speed Restoration

- Building and lifelines owners with critical electricity needs should install a grid-independent solar battery storage system.
- The Lifelines Council and PG&E should evaluate the earthquake vulnerability of power generation sources in the Bay Area.
- PG&E should share its plans for establishing an above ground temporary electrical network with San Francisco.
- PG&E should develop a clear understanding of the reliance of other lifeline systems on power supply and the implications if these partners lose power.
- SFPUC should continue to assess the vulnerability of substations at SFO to damage in an earthquake and develop a plan to address deficiencies.
- SFPUC should understand the earthquake vulnerability of critical PG&E owned power components and develop a plan to address deficiencies.
- SFPUC should develop mutual aid agreements with individual utilities in another region and improve emergency purchasing processes.

Restoration Performance Goals

PG&E and SFPUC have not adopted performance targets for system restoration or level of redundancy needed in the system.

System Restoration Timeline

The service restoration timelines shown in **Figure 6** represent the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after a San Andreas earthquake scenario. In setting the service disruption level for each time period, each operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact disruptions.

SERVICE DISRUPTION LEVELS

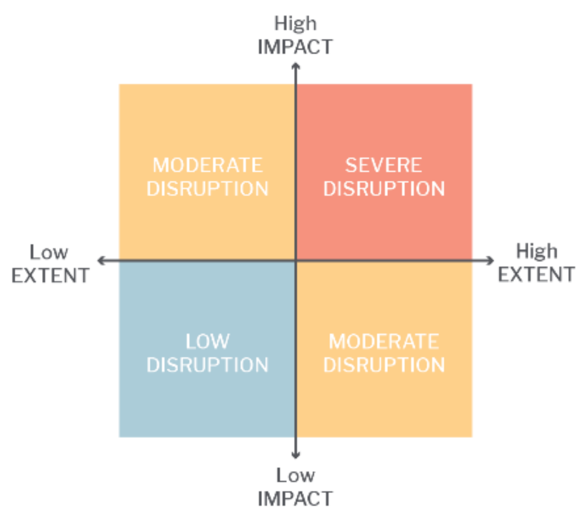
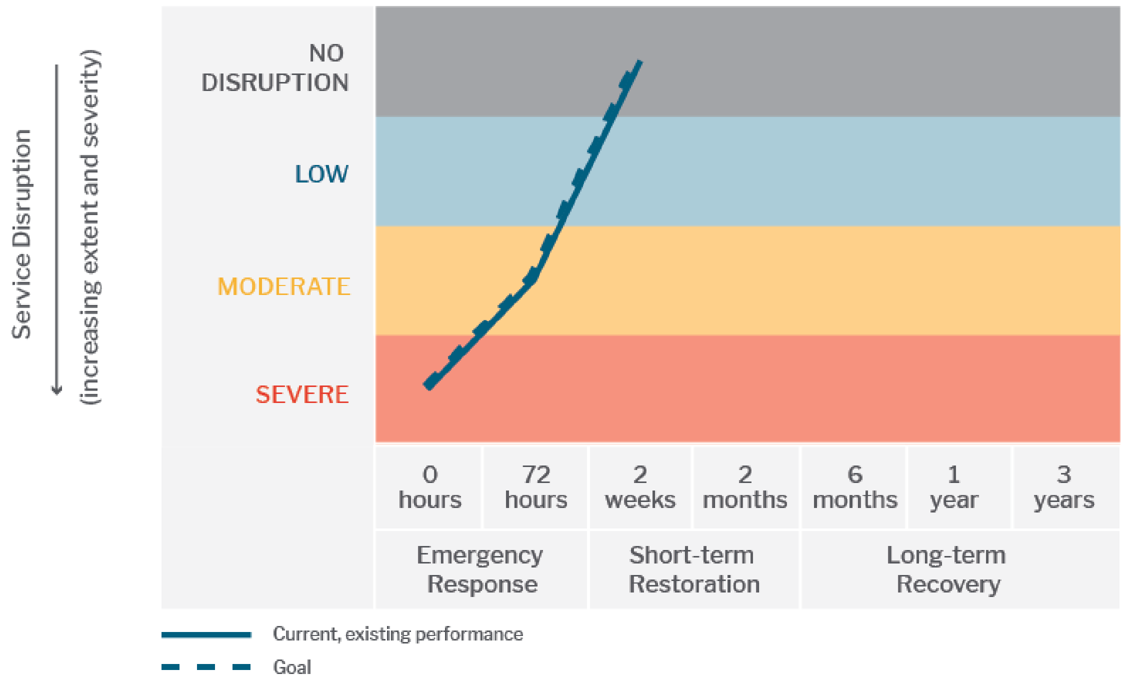


FIGURE 6: ELECTRIC SYSTEM RESTORATION TIMELINES

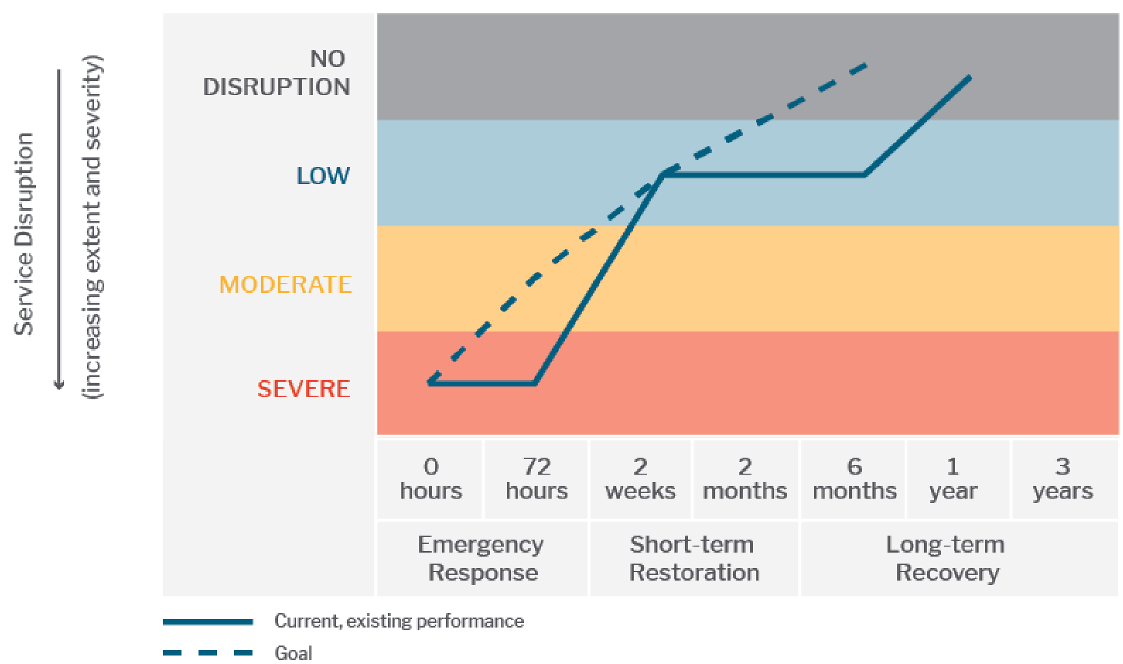
PG&E

San Andreas Fault Scenario



SFPUC

San Andreas Fault Scenario



Sector Overview

The electric system consists shown in **Figure 7** of four major components: generation, transmission, substation transformation from high voltage to lower voltage, and distribution to customers. Substations contain expensive and highly sensitive equipment such as large power transformers, which change the voltage of electrical current; capacitors, which store energy in an electric field; voltage regulators, which maintain a constant voltage; and switchgears, which control, protect and isolate electrical equipment.

PG&E

PG&E electricity comes from a variety of generation sources. In 2018, PG&E's power mix was comprised of 39% renewable sources (including solar, wind, geothermal, biomass and small hydro), 34% nuclear, 13% large hydropower, and 15% natural gas and other fuels.[4] Since the closure of the Potrero Generating Station in 2006, there are no power generating plants in San Francisco, except for solar. San Francisco's power primarily comes from geothermal plants in the North Bay, and natural gas plants along the Carquinez Strait and South Bay.

PG&E owns generation sources and purchases power from independently owned plants elsewhere in the state, the Pacific Northwest, and Southwest. CAISO, a nonprofit public benefit corporation, is responsible for managing electric flow on the transmission grid. PG&E owned generation sources include hydroelectric, nuclear, natural gas, solar and fuel cell generation with 7,686 MW of generating capacity.[5] In addition, PG&E has connected more than 400,000 customers with private rooftop solar to the grid.[6] In 2018, 55% of the Bay Area's electricity demand was generated within the nine county region.[7] Ninety two percent of the regionally produced power is generated at 39 large

[4] Pacific Gas and Electric. "Exploring Clean Energy Solutions: Delivering Low Emission Energy". https://www.pge.com/en_US/about-pge/environment/what-we-are-doing/clean-energy-solutions/clean-energy-solutions.page?WT.mc_id=Vanity_cleanenergy. Accessed February 18, 2020.
[5] Pacific Gas and Electric. 2019. "Corporate Responsibility and Sustainability Report 2019: PG&E Overview". Retrieved from http://www.pgecorp.com/corp_responsibility/reports/2019/bu01_pge_overview.html.
[6] Pacific Gas and Electric. 2019. "Corporate Responsibility and Sustainability Report 2019: Renewable Energy". Retrieved from http://www.pgecorp.com/corp_responsibility/reports/2019/bu01_pge_overview.html..
[7] California Energy Commission. "Electric Consumption by County" (San Francisco, Total Consumption, 2018) http://www.ecdms.energy.ca.gov/elecbycounty.aspx and "California Power Plants". https://cecgis-caenergy.opendata.arcgis.com/datasets/california-power-plants?geometry=-125.202%2C37.627%2C-119.972%2C38.385. Accessed February 24, 2020.

facilities with the remaining 8% generated at 143 small facilities with less than 50 MW capacity.[8] Of the regionally-generated power, two-thirds is produced by natural gas facilities, which are mostly located along the Carquinez Strait and in the South Bay. Damage to these facilities in an earthquake would impact a large portion of local electrical generation.

High voltage transmission lines delivering power from generation sources to the east cross the Bay from Fremont via submarine cables or up the Peninsula from San Jose via overhead and underground lines, terminating at substations in San Francisco.[9] Another 53-mile submarine transmission line, owned by Trans Bay Cable, delivers power between two PG&E substations in Pittsburg and San Francisco. The Trans Bay Cable transmission line delivers approximately 40% of the electric power used daily in San Francisco and the surrounding area. Most transmission lines within San Francisco are below ground. The few overhead lines are in the Hunters Point neighborhood.

Downtown San Francisco is served by a secondary power network designed to be highly reliable. This system delivers electricity through an integrated system of transformers and underground cables that operate in parallel. Power can flow in either direction on lower voltage service delivery lines, called secondary distribution lines. The loss of a single transformer in a secondary network does not cause an interruption of power. Areas outside of downtown San Francisco are served by a radial network, which has only one path for power to flow. If a radial line experiences an outage, service is interrupted until repairs are made.

SFPUC

SFPUC owns and operates the municipal Hetch Hetchy power system which is composed of three hydroelectric powerhouses located in the Sierra Nevada: Moccasin Powerhouse, Kirkwood Powerhouse and Holm Powerhouse. The combined total hydroelectric generating capacity for these facilities is approximately 385 megawatts.

Combined, the Hetch Hetchy power system delivers power to all municipal facilities, streetlights, customers in Hunters Point and Treasure Island, redevelopment areas and critical facilities, such as the airport, San Francisco General Hospital, SFMTA, and the Police and Fire Departments.

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[8] California Energy Commission. "California Power Plants". https://cecgis-caenergy.opendata.arcgis.com/datasets/california-power-plants. Accessed February 24, 2020.
[9] Trans Bay Cable. http://www.transbaycable.com/home.html. Accessed May 7, 2020.

160 miles of high voltage transmission lines owned by SFPUC deliver power from Hetch Hetchy to a PG&E substation in Newark. Power to the City is transmitted through a network of PG&E transmission lines before it is distributed via PG&E's distribution grid to San Francisco customers. SFPUC does not own the distribution system in San Francisco. SFPUC owns only the intervening facilities that picks up load from the PG&E grid at multiple service points within the City to provide power to municipal customers.

Two substations at SFO provide redundant power to the airport, SFPUC's largest retail customer. Power to Treasure Island and Yerba Buena Island (TI/YBI) is provided via a 12kV submarine cable from the Port of Oakland (not mapped). This submarine cable is owned by the Treasure Island Development Authority (TIDA) and maintained by SFPUC. Backup generators located on Treasure Island have enough capacity to meet the needs of both islands. SFPUC has a contract with a supplier to provide fuel in case of a prolonged outage. SFO also has backup generators to provide enough power to operate the airport.

SFPUC also owns about 50% of the street lights in the city and PG&E owns the remainder, but all the streetlights are powered through PG&E's distribution system with Hetch Hetchy Power.

Hetch Hetchy Power also includes 8.6 MW of distributed renewable generation capacity in solar and biogas facilities, predominantly located within San Francisco.[10] In 2018, San Francisco used 5,640 GWh of electricity, however the only utility-scale generation source located within San Francisco is a 5 MW solar array at Sunset Reservoir.[11] As of 2019, another 38.77 MW of interconnected photovoltaic (PV) generation capacity is distributed across 8,710 private sites in San Francisco.[12]

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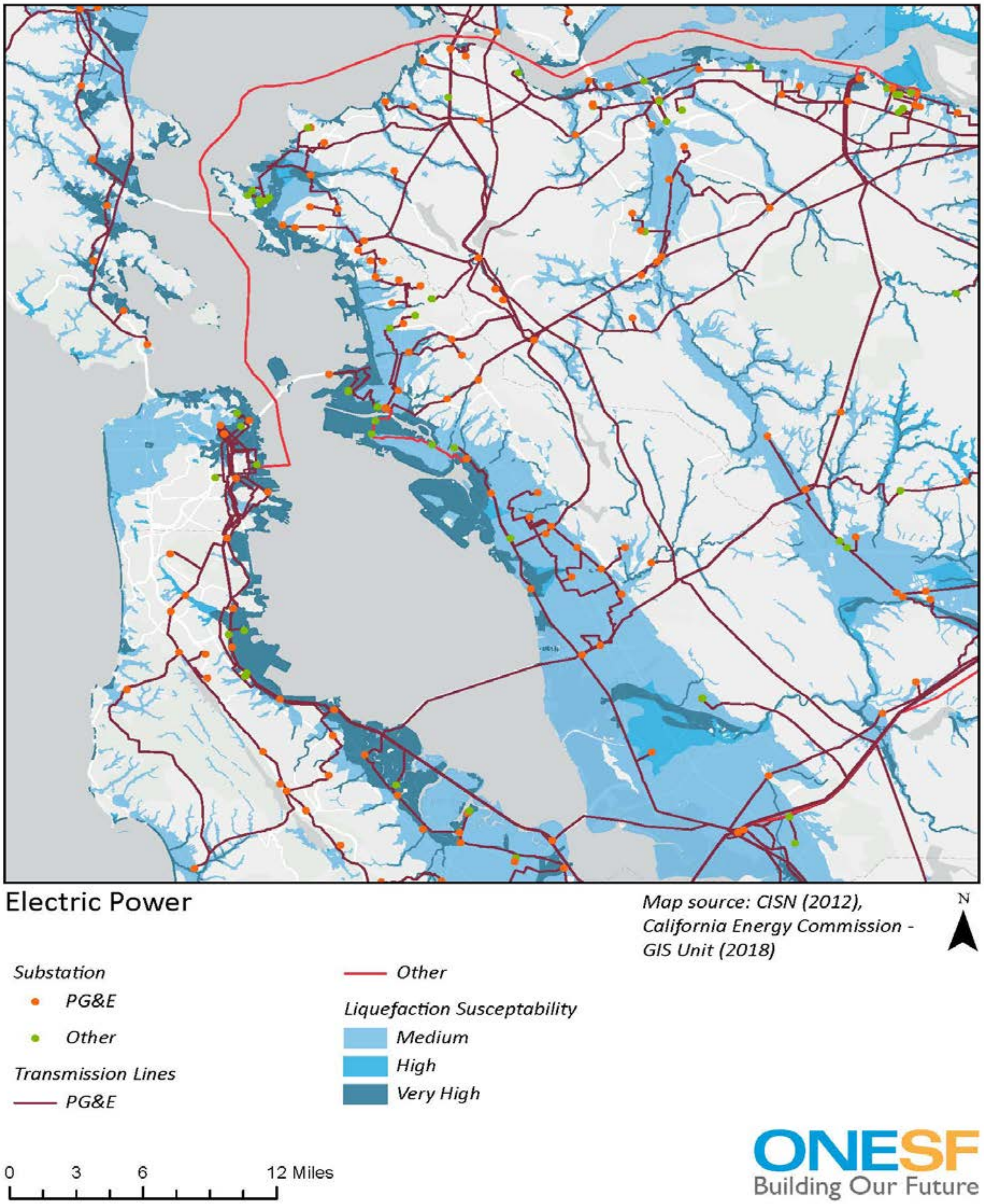
[10] SFPUC. "Solar Installations". https://www.sfwater.org/index.aspx?page=403. Accessed March 4, 2020.
[11] California Energy Commission. "Electricity Consumption by County" (San Francisco, Total Consumption, 2018). http://www.ecdms.energy.ca.gov/elecbycounty.aspx. Accessed March 4, 2019.
[12] California Distributed Generation Statistics. "Statistics and Charts: NEM Solar PV" (San Francisco County, All Years, Projects and Capacity). https://www.californiadgstats.ca.gov/charts/. Accessed May 8, 2019.

FIGURE 7: ELECTRIC POWER SYSTEM MAP



System Upgrade and Disaster Planning Efforts

PG&E

PG&E has approached system upgrades in three ways: upgrading older equipment that is vulnerable to damage to higher standards, adding redundancy to the system and improving restoration capability.

Upgrading older equipment

Between 2005 and 2025, PG&E will invest $2.5B in transmission cable upgrades in San Francisco to protect San Francisco's transmission lines in future earthquakes, which are primarily underground in high liquefaction zones. Newer transmission lines are built with slack in them to allow for ground movement in earthquakes. Underground cables are installed in conduits to protect them from earthquake damage. Transmission lines are challenging to replace and repair after an earthquake, so upgrading them before a disaster is critical. PG&E is also investing in distribution system upgrades, consisting of line work, equipment upgrades and replacement. The distribution system is much easier and faster to restore after a disaster.

Over 20 years, PG&E has also upgraded 80% of its large power transformers to meet higher seismic performance standards, based on IEEE 693. PG&E continues to upgrade all its vulnerable equipment to meet these standards.

Adding redundancy

There are five major substations that service most of San Francisco. Each substation has at least three transmission lines serving them and each line can serve the base load of the station. PG&E has installed a submarine transmission cable between the Embarcadero and Potrero substations as a third path and performed upgrades at both stations to provide internal redundancy within the stations. PG&E has also completed upgrades to its Mission, Larkin and Martin substations within San Francisco

Improving restoration capability

The Greater Bay Restoration Project includes developing contingency plans in case of underground damage, stockpiling spare parts and securing basecamp locations. If the underground transmission cables break in an earthquake, PG&E is planning for temporary construction of above ground transmission lines (putting up poles in the sidewalk). Potholing and utility surveys have already been completed to predetermine specific locations for driving poles that go 20 feet below ground and 60 feet above ground and is building a warehouse to stockpile these materials in Brisbane. PG&E is prepared bring significant assets to clear debris from any streets needed to restore the network. PG&E has secured the Cow Palace parking lot as a basecamp post-disaster and also has other laydown yards along US-101. A Bay Area restoration warehouse is being built for indoor equipment. The majority of PG&E's stockpiled equipment is east of San Francisco in Fremont, Fresno, and Marysville.

SFPUC

The SFPUC Power Enterprise is expanding and constructing its own distribution substructure. The first project is the Bay Corridor Transmission and Distribution Project (BCTD). It is currently in progress and slated to be in service in 2021. The BCTD will deliver power from Hetch Hetchy and other renewable resources to municipal loads such as the Southeast Plant and Pier 70 development project. The BCTD project is designed to the latest seismic requirements for a critical facility.

TIDA and SFPUC are coordinating to purchase a new generator for Treasure Island to improve the reliability of backup power for TI/YBI.

The SFPUC Utility Yard is located at 5th and Bryant Street in a seismically safe structure, however it is being relocated to a new facility at Pier 23 by summer of 2020.

SFPUC is making improvements to the two substations that serve SFO to improve reliability. Upgrades to the substations to increase the power capacity are in planning stages. The upgrades will improve the resiliency of the substations and reliability of service to the SFO.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

PG&E

PG&E's generation sources are all located outside of the City of San Francisco, however those sources located within the San Francisco Bay Area could experience shaking or liquefaction damage in this scenario, particularly the geothermal plants in the North Bay, and natural gas plants along the Carquinez Strait and in the South Bay. However, because of PG&E's diverse mixture of generation sources, enough power could most likely be purchased from other sources to compensate for any local damages. Delivery of power will be dependent on the availability of transmission resources.

Within San Francisco, significant damage is expected to underground transmission and distribution cables, and equipment needed to provide power, as well as telecom equipment needed to talk to the devices and equipment in the system. Above ground power lines may be damaged by falling debris.

Substations have all recently been upgraded to minimize likelihood that they will experience significant damage in the scenario earthquake. Each substation has three transmission lines serving it capable of providing the base load of the station, reducing the likelihood that damage to any particular transmission line will result in loss of power to customers, including SFPUC municipal customers.

SFPUC

SFPUC's three hydropower plants are all located far from San Francisco in the Sierra Nevada and will not experience damage in this scenario earthquake. SFPUC's distributed power generation sources within the City of San Francisco will all be exposed to very strong shaking and may experience damage.

The vulnerability to shaking and liquefaction damage of key SFPUC substations and key facilities has not yet been assessed. However, nearly all these facilities will be exposed to strong shaking and liquefaction in this scenario with strong likelihood for damage, including the PG&E substation in Newark which receives power from the Hetch Hetchy system, portions of the transmission line serving the Newark substation, SFPUC substations at SFO which supplies power to the airport, the Port of Oakland substation which supplies power to TI/YBI, the distribution network on TI/YBI, and the intervening facilities that SFPUC has responsibility for. It is likely TI/YBI will lose power due to damage to substation and the distribution network on TI/YBI. TI/YBI have enough backup generator capacity to continue to provide power for some time. SFO has two substations at different locations. If both substations are damaged, SFO will rely on the backup generators to continue its operations. Other municipal customers, even those for which on-site power connections are SFPUC's responsibility, are highly dependent on restoration of the PG&E system and will likely be without power until PG&E power is restored.

Hayward Fault

PG&E

PG&E's generation sources located within the Bay Area are more likely to experience damage in this scenario event, particularly natural gas power plants along the Carquinez Strait and in the South Bay.

PG&E transmission system serving San Francisco comes from the East and South Bay. Transmission lines in the East Bay are primarily overhead while the transmission lines from the South Bay are overhead and underground. Extensive damage is not expected on the overhead transmission lines because the wires can sway several feet and not break, however underground transmission lines are susceptible to liquefaction damage and fault rupture. Electric transmission lines cross the Hayward Fault in five locations in the East Bay with significant displacement, including one underwater line in San Pablo Bay.[13] However, the intricate transmission system is redundant, with the ability to reroute power should any one transmission line experiences damage. There will also be some damage to older equipment and cables in very high liquefaction zones in San Francisco. Substations are expected to perform well in this scenario.

SFPUC

SFPUC's three hydropower plants are all located far from the Hayward Fault in the Sierra Nevada and will not experience damage in this scenario earthquake. SFPUC distributed power generation sources within the City of San Francisco are also less likely to be damaged in this scenario.

The vulnerability to shaking and liquefaction damage of key SFPUC substations and key facilities has not yet been assessed. Because of the location of SFPUC's key facilities, many will be exposed to high shaking and liquefaction in the Hayward fault scenario as well, including its substation in Newark, portions of the transmission line serving the Newark, its substation in Oakland, and the distribution network on TI/YBI. Intervening facilities and substations at SFO are less likely to be damaged in this scenario.

Expected damage to the Hetch Hetchy system in the Hayward Fault scenario earthquake is not yet well understood by SFPUC. Key system components that will be exposed to strong shaking in this scenario are the substations in Oakland and Newark and the electric network at TI/YBI, however the vulnerability of these components is not yet known. Damage to the Oakland substation would cut off power supply to Treasure Island.

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[13] Jones, J.L., Wein, A.M., Schweikert, A.E., and Ballanti, L.R. 2019. "Lifeline infrastructure and collocation exposure to the HayWired earthquake scenario—A summary of hazards and potential service disruptions", chap. T of Detweiler, S.T., and Wein, A.M., eds., The HayWired Earthquake Scenario—Societal Consequences: U.S. Geological Survey Scientific Investigations Report 2017–5013–R–W, 104 p., https://doi.org/10.3133/sir20175013V3.

System Restoration Timeline

San Andreas Fault Scenario

> **Loma Prieta earthquake**
>
> In the Loma Prieta earthquake, PG&E restored 90% of service within 32 hours. There was still extensive damage at this time, but PG&E was able to reroute power and bypass damage.

Table 3 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. The table reflects the current, existing performance in the Restoration Tables in **Figure 6** above and each box is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 3: ELECTRIC POWER SYSTEM RESTORATION TIMELINE

	Electric Power - PG&E	Electric Power - SFPUC
0 Hours	When an earthquake occurs, sensors will automatically trip and turn off power. Then the system will try to bring equipment back on automatically via the SCADA system. If the equipment turns on and starts operating, it will stay on. If it turns on and trips back off, it will stay off and inspection will be prioritized at these locations. Within 8 hours, all alarms should be resolved and undamaged equipment back online. *When the seismic retrofit program is completed, damage to equipment and cables will be reduced. This program is adding redundancy to the system and equipment that will improve restoration in the first 24 hours.*	SFPUC will immediately initiate damage assessment of critical components throughout the system.
72 Hours	Most quick repairs will be resolved within 3 days. More than 50% of the system will be restored. Only pockets of severe damage will remain; likely including the financial district.	*Goal is for damage assessment to be completed within 72 hours.* Damage assessment will continue and some immediate critical repairs may be made. Mutual aid resources will begin to arrive. SFO and TI/YBI will continue to be without grid power. Depending on fuel availability, they may continue to have power from backup generators, provided there is enough fuel. Municipal clients reliant on PG&E distribution may begin to have power restored.
2 Weeks	90% of service is expected to be restored within 5 days by bypassing damaged components and putting up temporary measures. By two weeks full power will be restored. The system will be running in a non-normal state at this time.	Damage assessments completed. Mutual aid and employee access to the City, SFO and TI/YBI will be a significant factor in the timely completion of damage assessments and initiation of repairs. SFPUC Power only employs five linemen and most live outside of San Francisco. Power restored to most municipal customers as PG&E power is restored.

	Electric Power - PG&E	Electric Power - SFPUC
2 Months	All customers will have power restored but the system will still be operating in a non-normal state (rerouting power to bypass damage) and with temporary measures (like above ground transmission lines). PG&E is normally required to have redundancy in the system, but to get the system back up, it may be running without redundancy.	SFO will continue to experience loss of grid power because of damage to the transmission line and substations serving the airport. If major equipment such as transformers, need to be replaced, SFPUC will initiate Mutual Aid assistance to request equipment from other utilities located in other regions not affected by the earthquake. Although PG&E owns spare transformers, it will prioritize its own facilities. Power to Treasure Island will be restored with temporary repairs. SFPUC will assess needs for permanent repairs to infrastructure.
6 Months	The system will be restored to a normal state with the required redundancy, but some component damage may still exist.	*Goal is for power to be fully restored with permanent repairs completed.* SFPUC Power will continue to provide power with temporary repairs, while permanent repairs are made.
1 Year		SFPUC Power system will be fully restored within a year, unless there are contracting issues which preclude their ability to obtain mutual aid and/or emergency contracts to make necessary repairs.
3 Years	The system will be restored to pre-event conditions with all components repaired or rebuilt.	

Hayward Fault Scenario

PG&E

In the Hayward Fault scenario, sensors will automatically trip and turn off power, as in the San Andreas scenario. However, with less intense shaking and less liquefaction there will be less damage in the system that needs to be repaired. The USGS Haywired study estimates that San Francisco power will be 90% restored in about a week, not accounting for post-earthquake fires.[14]

SFPUC

The restoration time for TI/YBI will likely be the same in the Hayward fault scenario due to similar levels of shaking and liquefaction exposure for the distribution network and Oakland substation. The Newark substation is more likely to experience damage due to

[14] Jones, J.L., et al., 2019.

closer proximity to the Hayward fault and restoration for SFPUC's municipal customers will be largely dependent on PG&E's decisions to reroute power around the substation if it is damaged. The intervening facilities in San Francisco are less likely to experience damage in this scenario, as well as SFO. Most SFPUC facilities will likely be repaired within two weeks in this scenario, with complete restoration expected within 2 months.

Level of Confidence

PG&E

PG&E has a high level of confidence in its restoration assumptions based on recent system upgrades, emergency and contingency plans it has developed, significant system modeling and recent disaster service restoration experience. PG&E combines a suite of USGS ShakeMaps scenarios with its System Earthquake Risk Assessment (SERA) vulnerability model to establish likely damage of components in the system. This model is used to design its system upgrade plan and as post-disaster decision support tool to determine where damage likely occurred. PG&E also has significant experience in disaster response and service restoration within its service area and through mutual aid to disasters outside its service area.

SFPUC

SFPUC is confident in the performance of its system in an earthquake, but has not specifically analyzed the performance. Its restoration assumptions are primarily driven by experience with routine maintenance of the system and experience in the Loma Prieta earthquake.

System Interdependencies

Electric power has significant dependencies on power generators and transmission lines, natural gas for generation, highways and roads for transporting crews and equipment, and fuel for generators and maintenance crews. Communication systems are also important for power operation, but backups are available. SFPUC power is highly reliant on PG&E.

Table 4 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;

- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 4: ELECTRIC POWER SYSTEM DEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – Both SFPUC and PG&E are heavily reliant on other parts of the electric network for the overall system to function. SFPUC is heavily reliant on PG&E's transmission and distribution systems, but owns its own generation sources. PG&E is heavily reliant on independently owned power generator sources and on the Trans Bay Cable transmission line which provides power to San Francisco.
Natural Gas	Significant – PG&E relies on natural gas plants for 15% of its power generation, with most of the plants located in the East and South Bay. SFPUC Power has no reliance on natural gas for electricity.
Water	None
Wastewater	None
Communications	Moderate – PG&E has its own fiber and microwave communication system and has a share of the fiber cable located on the Bay Bridge, however PG&E also uses AT&T and Verizon for day to day communication. SFPUC is reliant on cell service, but also have portable and base radios at the Bryant St Utility Yard.
Highways and Local Roads	Significant – Repair crews and mutual aid support rely on local and regional roads to access facilities in San Francisco, SFO and TI/YBI. PG&E's office workers may be able to work from alternate headquarters in Bishop Ranch or work from home.
Fuel	Significant – SFPUC maintenance vehicles and backup generators on TI/YBI rely on fuel. PG&E has its own fuel supply and does not rely on third party fuel suppliers.
Transit	None
Solid Waste	None
Airport	None
Port	Low – PG&E may use some barges for moving equipment.
Firefighting Water (EFWS)	None

Actions to Speed Restoration

Building and lifelines owners with critical electricity needs should install a grid-independent solar battery storage system.

The electric system may experience outages of several days or several weeks, depending on the severity of the event. Recovery critical facilities and systems that have critical and immediate power needs after an earthquake should assess the feasibility of solar battery storage systems to supply temporary power after an earthquake.

In line with the City's clean energy goals, these facilities and systems should also evaluate the benefits of independent solar energy to provide continuous clean, resilient power and cost savings in normal operations.[15] In addition to reducing monthly electricity bills during normal operations from excess power generation, a recent study showed that for every $1 invested in the installation of solar PV and energy storage systems on San Francisco shelters, more than $1.6 are generated in benefits.[16] Furthermore, in recent years, inverters which connect solar panels combined with battery storage are now able to provide a basic level of power directly to the load independent of the electrical grid during blackouts.

San Francisco should provide incentives for recovery critical facilities, such as medical buildings, schools, grocery stores and gas stations to have solar PV and battery storage systems for backup electricity supply. As inverters need to be replaced on existing solar systems, they should be replaced with newer inverters that allow grid-independent operation. Additionally, San Francisco should also invest in solar PV and storage as requirements for new public and critical facilities. Installing solar and storage has the lowest added cost and disruption when buildings are initially constructed or undergoing renovation through a capital planning process.

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[15] Arup. 2017. "Solar Market Pathways: San Francisco Solar and Storage for Resilience Project Financial Feasibility Analysis". City and County of San Francisco, Department of the Environment. Retrieved from https://sfenvironment.org/sites/default/files/fliers/files/sfe_ee_financial_analysis_summary_dec2017.pdf.

[16] Arup. 2018. "Solar and Energy Storage for Resiliency". City and County of San Francisco, Department of the Environment. Retrieved from https://sfenvironment.org/sites/default/files/fliers/files/sfe_en_solar_resilient_cost_benefit_analysis.pdf.

The Lifelines Council and PG&E should evaluate the earthquake vulnerability of power generation sources in the Bay Area.

San Francisco's electric power provided by PG&E primarily comes from the geothermal plants in the North Bay and natural gas plants located along the Carquinez Strait and in the South Bay. These facilities are likely to be impacted by both the San Andreas and Hayward Fault scenarios; however, PG&E does not understand their vulnerabilities. Through CAISO, PG&E can purchase power from farther away, but the supply will likely be reduced. A study would be needed to determine if the load in San Francisco would be curtailed due to damage of Bay Area generation plants. The likelihood of damage to these facilities in the scenario earthquakes also needs to be better understood.

The San Francisco Lifelines Council and PG&E should work with large electricity generators in the Bay Area to understand the earthquake vulnerability of power generation sources and its implications for power in San Francisco. The generation companies should be encouraged to address any deficiencies to improve San Francisco's electric system resilience.

PG&E should share its plans for establishing an above ground temporary electrical network with San Francisco.

Restoring the PG&E power system in San Francisco quickly will require mobilization of significant resources and the movement of large equipment through San Francisco. PG&E expects to deploy significant resources, including heavy machinery, into San Francisco to clear debris, inspect facilities and power lines, repair damage, and establish a temporary power network, if needed. Some repair trucks and debris removal equipment may be challenged to travel on roads with MUNI's overhead catenary system.

PG&E should share its power restoration plans with San Francisco and coordinate with the development of Disaster Recovery Critical Supply Routes (see **Highways and Local Roads** summary) to ensure that these routes don't conflict with the establishment of any temporary power network. In an emergency, this coordination can also be done through San Francisco representation in the PG&E Emergency Operations Center.

PG&E should develop a clear understanding of the reliance of other lifeline systems on power supply and the implications if these partners lose power.

PG&E prioritizes restoration of power to critical facilities; however, it does not understand what components of other lifeline systems have critical reliance on power and what the implications would be if they lost power. PG&E should coordinate with key lifeline system operators to answer the following questions:

- What components of the municipal water or AWSS system require significant power and what are the implications if they lose power?
- Will fire departments lose their ability to pump water for firefighting if there is no power?
- What are the critical pumps in the wastewater system that are dependent on power and what are the implications if they lose power?
- What is BART's critical reliance on power for stations, tracks and communications and what are the implications if they lose power?

SFPUC should continue to assess the vulnerability of substations at SFO to damage in an earthquake and develop a plan to address deficiencies.

Substations serve as key nodes in a power system by reducing high voltage power from transmission lines to medium voltage power for distribution to residences and businesses. Two key SFPUC substations at SFO provide power to the airport. The vulnerability of SFPUC substations at SFO have not yet been assessed. This assessment should include backup generator capacity and prioritization of power needs for runway lights, terminals, and air traffic control.

If one of these substations are damaged in an earthquake, SFPUC does not have major electric equipment such as transformers and circuit breakers in inventory and will rely on mutual aid agreement to request equipment with the same rating as those in the substations to expedite repairs. Purchasing high voltage equipment for substations have long lead times, which could take up to 12 months.

SFPUC should understand the earthquake vulnerability of critical PG&E owned power components and develop a plan to address deficiencies.

SFPUC has not assessed the vulnerability of critical system components owned by PG&E. The vulnerability of SFPUC critical components, including the Oakland and Newark substations, transmission system, some intervening facilities and the distribution system are owned by PG&E, but are critical to delivering power to the City of San Francisco. SFPUC owned intervening facilities are 100% reliant on PG&E's delivery system. Their vulnerability to damage in an earthquake is not well understood by SFPUC.

Substations serve as key nodes in a power system by reducing high voltage power from transmission lines to medium voltage power for distribution to residences and businesses. PG&E needs to communicate to SFPUC the vulnerability of these substations to earthquake events.

It is not known whether PG&E and SFPUC are responsible for the intervening facilities at San Francisco General Hospital, the Moscone Center, the wastewater treatment plants, and the MUNI system or what their seismic vulnerability is.

SFPUC should develop mutual aid agreements with individual utilities in another region and improve emergency purchasing processes.

SFPUC participates in statewide mutual aid agreements through the California Utilities Emergency Association (CUEA) and national mutual aid agreements through the American Public Power Association (APPA). *SFPUC will reach out to other utilities through these mutual aid agreements to request needed equipment to expedite repairs. In addition,* SFPUC should identify utilities with a similar rated system in Southern California and develop an individual mutual aid agreement. This would allow SFPUC to work out any contracting issues ahead of an emergency and expedite activation of mutual aid, as well as payment processing. If SFPUC needs to purchase equipment rather than rely on mutual aid, it should develop emergency purchasing and contracting procedures so that any equipment purchasing can be expedited in an emergency and certain San Francisco contracting requirements may be waived.

Fuel

Photo: Flickred!/Flickr

Refineries process crude oil to make petroleum products. The Kinder Morgan fuel pipeline system delivers finished petroleum products (gasoline, diesel and aviation fuel) from refineries to fuel terminals where the product is picked up by fuel trucks for delivery to end users. Kinder Morgan does not own the fuel it transports.

Fuel

Operator: Kinder Morgan

At A Glance...

Key Findings

- Regardless of damage, the fuel delivery system will be shut down for a minimum 24-48 hours for inspections. Minor repairs to critical fuel system components could take days to weeks and major repairs could take months.
- Power, communications, water, highways and local roads, and fuel are the primary interdependencies for operating the fuel system. Emergency delivery of fuel if the pipeline is not operating depends on the Port of San Francisco.
- The performance of the Kinder Morgan pipelines and above ground facilities in earthquakes is not well understood
- The performance of Bay Area refineries in earthquakes is not well understood.
- The performance of marine oil terminals in earthquakes is not well understood.
- Fuel loading racks at the Brisbane Terminal cannot operate without fire water provided by the City of Brisbane.
- San Francisco can significantly improve its resilience to earthquakes while meeting greenhouse gas reduction targets by reducing reliance on petroleum fuels.
- 100% of the fuel needed immediately after and event is stored in vehicles or local storage tanks. Ensuring adequate local supply will reduce the impacts of a fuel system disruption.

Actions to Speed Restoration

- Kinder Morgan should strive to better understand the vulnerability of its system components to damage due to earthquake.
- The Lifelines Council should work with key fuel users, regulators and fuel providers to evaluate the impact of an earthquake on Bay Area refineries and upgrade vulnerable components as necessary.
- The Lifelines Council should request public reports focusing on post-earthquake operational issues of marine oil terminals to assist in better understanding moderate and long-term fuel supply impacts.

Actions to Speed Restoration (cont.)

- The City of San Francisco Fire Department, SFPUC, and City of Brisbane should work with Kinder Morgan to determine the vulnerability of the Brisbane water main
- San Francisco should collaborate with industry stakeholders to accelerate deployment of electric and alternative fuel for light, medium and heavy-duty vehicles.
- Municipal and private owners with critical electricity needs should develop policies to ensure adequate supply of fuel within vehicles and equipment as a first priority and then store fuel locally in tanks that can be pumped without electricity.

Restoration Performance Goals

Kinder Morgan has not yet developed formal performance goals for the fuel delivery system.

System Restoration Timeline

Kinder Morgan determined that it is not possible to develop restoration curves for the fuel system because the fragility of the pipelines and system components is not well known, the pipeline cannot function without the marine oil terminals and refineries, which are wholly outside of Kinder Morgan's influence, and it has dependencies on many other lifelines systems that are difficult to quantify.

Sector Overview

The fuel system consists of refineries, pipelines, pumping stations and terminals. While the entire Bay Area fuel system is described in this report, as seen in **Figure 8**, only Kinder Morgan was interviewed and the findings are primarily related to Kinder Morgan's transmission pipeline, pumping stations and fuel terminals.

Marine Oil Terminals: Primarily used to unload crude oil from ships for delivery to refineries using pipes, pumps, electrical utilities, and other mechanical equipment.[17] All

[17] Adapting to Rising Tides. 2017. "Adapting to Rising Tides: Contra Costa County Assessment and Adaptation Project" (pg. 5). Retrieved from http://www.adaptingtorisingtides.org/wp-content/uploads/2017/03/Contra-Costa-ART-Project-Report_Final.pdf.

Bay Area refineries have access to waterborne deliveries and most also receive crude oil by pipeline. In 2017, Bay Area refineries received about two-thirds of their crude oil imports by marine vessel, and the remaining third through one of three pipelines from Southern California.[18] Except for the Richmond Products Terminal where BP delivers gasoline to Richmond, these marine facilities cannot be used for delivery of refined fuel products.

Refineries: The primary purpose of an oil refinery is to process crude oil to make petroleum products and other chemicals, including motor fuel and lubricants.[19] Refineries consist of thousands of miles of pipelines, hundreds of large tanks, and specialized equipment for various stages of the refining process. Five Bay Area oil refineries located along the Carquinez Strait in the North Bay provide fuel products to all of Northern California and Nevada and account for one-third of the gasoline used west of the Rocky Mountains.[20] These refineries are:

- Valero Energy Benicia Refinery
- Marathon Petroleum Corp, Golden Eagle Martinez Refinery (also known as Avon Refinery).
    - As of August 2020, Marathon Petroleum plans to indefinitely idle this facility with no plans to restart normal operations due to decreased demand during COVID-19.[21] The facility will be converted to a terminal fuel storage facility and may be repositioned as a renewable diesel facility.
- PBF Energy Martinez Refinery
- Phillips 66 Rodeo San Francisco Refinery
- Chevron Richmond Refinery

Most finished petroleum fuel products are delivered to end users via pipeline, some is shipped out via marine vessel for movement around the Bay Area, and exported to Southern California and foreign destinations, and truck racks at the refineries also provide some fuel directly to fuel trucks.

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[18] KQED. 2019. "Safety, Competition Concerns Raised Over Proposed Sale of Major California Oil Pipeline" https://www.kqed.org/news/11752024/industry-safety-advocates-raise-concerns-over-sale-of-large-california-oil-pipeline
[19] KQED. 2019.
[20] Detweiler, S.T., and Wein, A.M., eds. 2018.
[21] San Francisco Chronicle. 2020. "Marathon Petroleum will 'indefinitely idle' Martinez refinery" https://www.sfchronicle.com/business/article/Marathon-Petroleum-will-indefinitely-idle-15451841.php?t=f438ab62a0

Transmission pipelines and pumping stations: Kinder Morgan is the sole common carrier of petroleum product pipelines in California.[22] Refined hydrocarbons are transported from refineries to distributors and consumers through Kinder Morgan's fuel pipelines. The system also includes pumping stations and terminals. Refineries pump fuel to Richmond or Concord Stations. Most fuel passes through Concord Station on its way to terminals in Fresno, Stockton, Sacramento, Roseville, Chico, Reno and San Jose; the Concord station does not impact San Francisco fuel delivery.

The remainder of the fuel travel south from Richmond through twin multiproduct and jet fuel pipelines that generally follow the Union Pacific Railroad right of way along the I-80/800 corridor to the Oakland Airport. The pipelines then continue below the Bay to the Brisbane Fuel Terminal where the fuel is picked up by trucks for delivery to end users. The Brisbane Terminal provides all the fuel needs on the Peninsula. The multi-product pipeline, which alternatively pumps diesel, gasoline and sometimes jet fuel, terminates at the Brisbane Terminal and does not supply fuel to SFO. The dedicated jet fuel pipeline continues from Brisbane following the Caltrain right of way and breaking off at Grand Avenue to the San Francisco Airport where it terminates at SFO's North Field Fuel Farm (See SFO chapter for further discussion of SFO's Fuel Farm) and a Shell storage facility located three quarters of a mile west of the Fuel Farm.

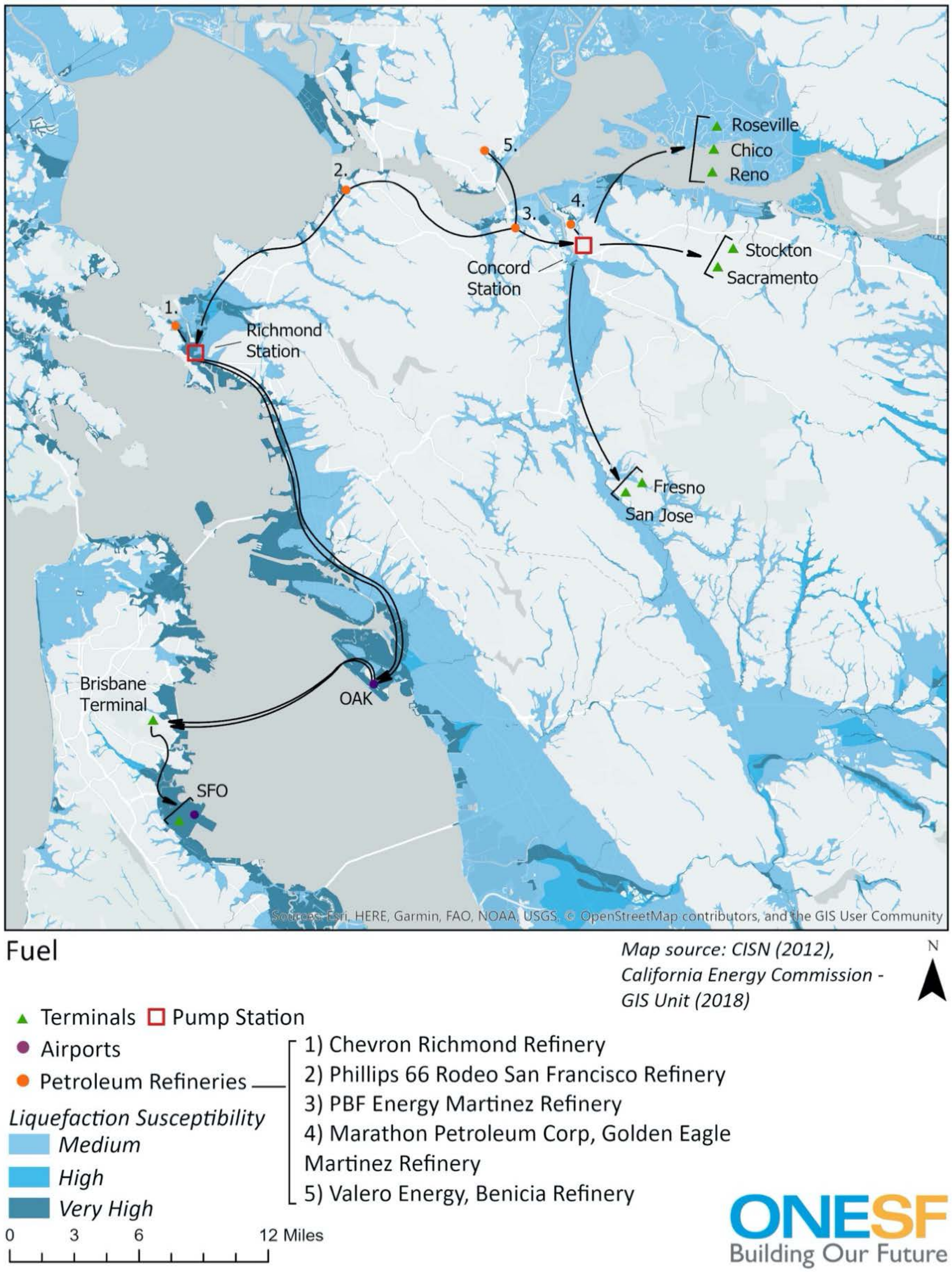
Kinder Morgan owns the transmission pipelines and pumping stations, but it does not own the product that passes through them. The product is owned by the refinery or shipper until it is picked up by a purchaser with a fuel allocation.

Terminals: Fuel trucks with allocations from the refineries can pick up fuel at the Kinder Morgan Brisbane or San Jose Terminals in the Bay Area to deliver to gas stations and other end users. Fuel terminals consist of storage tanks and fueling racks.

The Northern California fuel system is isolated from the rest of the country and products cannot be delivered from other fuel refineries into the Bay Area. The Northern California fuel system is not directly connected to Southern California. Refined fuel can be delivered in bulk to marine facilities at the Richmond Products Terminal and Port of San Francisco Pier 96.

[22] Detweiler, et al., 2018.

FIGURE 8. FUE L SYSTEM MAP



ONESF
Building Our Future

System Upgrade and Disaster Planning Efforts

As fuel tanks are coming due for inspections (15 to 20-year cycle), Kinder Morgan is making necessary upgrades, including seismic upgrades as required by regulation. Kinder Morgan is not performing other seismic assessments of its pipelines or facilities, or planning for other specific seismic upgrades.

Kinder Morgan focuses its efforts on planning to respond to disasters when they occur. When Kinder Morgan personnel at the Brisbane or Richmond facilities feel an earthquake or receive a USGS alert at the Houston Control Center, Kinder Morgan will shut down the pipeline, drain the products into tanks and inspect the facilities. Depending on findings from the facility inspection and/or evidence of pipe rupture, Kinder Morgan will also walk portions of the pipeline right of way looking for pooling, sinkholes, or other evidence of possible product in the ground. A sheen on the Bay would indicate a broken submarine pipeline, which Kinder Morgan would respond to according to procedures in its Integrated Contingency Plan. Regardless of damage to the system, many critical system components will be shut down for a minimum of 24 to 48 hours for inspection and restoration.

California Energy Commission Fuels Set Aside Program

The California Energy Commission has the authority to redirect refined product supplies from refineries to ensure first responders and essential community functions have adequate gasoline and diesel fuel to protect lives and property during a declared energy emergency.[23] The Petroleum Fuels Set-Aside Program is a formal allocation program used to ensure fuel supplies are available to emergency responders during a widespread or prolonged shortage.[24] First responders and emergency service personnel operating in direct support of emergency response activities that require emergency fuel will request assistance through emergency operating center (EOC) and the Standardized Emergency Management System (SEMS). The Energy Commission will coordinate with CalOES and the EOCs as necessary for these requests. Other critical agencies engaged in supporting emergency services will coordinate with CalOES for any requests for fuel support. Emergency requests for fuel resources will be managed through the State's Fuels Taskforce based on priorities determined by the Unified Coordinating Group and

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[23] Gordon, Schremp. 2018. "Oil, Refining & Transportation Market Trends". Presentation at Ad Hoc Refinery Oversight Committee Meeting, (pg. 13, 15, 37), Retrieved from http://www.baaqmd.gov/~/media/files/board-of-directors/2018/ahro_presentations_072518-pdf.pdf?la=en.

[24] California Energy Commission. 2019. "Emergency Petroleum Fuel Requests." https://www.energy.ca.gov/emergencies/setaside.html. Accessed May 20, 2019.

resource availability. The Energy Commission does not own fuel supplies/resources nor does the program provide means or methods of fuel delivery.

Local Fuel Emergency Plans

Many private and municipal organizations, including the City and County of San Francisco have emergency fuel plans. San Francisco is in the process of updating its plan. These plans generally rely on emergency purchasing agreements with fuel suppliers. But if the regional fuel network is disrupted, the only available fuel resources will have to be delivered by truck or marine vessel. The City and County of San Francisco has plans to use Pier 96 in conjunction with military/FEMA equipment for emergency fuel delivery for its municipal needs. However, these fuel sites will likely not be operations for at least seven days, depending availability of assets and federal and state tasking will determine who gets fuel and how. The earthquake vulnerability of Pier 96 should be assessed as part of these fuel plans (see Port Chapter).

Expected Impacts of an Earthquake

San Andreas Fault Scenario

Refineries: The five Bay Area refineries will experience moderate to very strong shaking in a San Andreas scenario earthquake. When strongly shaken, oil refineries and tank farms have typically had large fires, which have burned for days.[25, 26] In past earthquakes in Japan (2003), Turkey (1999) and Chile (2010), refineries in the shaking region were completely shut down for up to three months, with limited capacity for over a year.[27] In 2012, a fire resulting from a single pipe failure at the Chevron Richmond refinery led to a much more damaging fire. The damage from the fire required eight months to repair.[28] The degree of earthquake preparedness of Bay Area oil refineries is generally unclear and may need to be reviewed.[29]

Fuel delivery system: The Kinder Morgan Richmond Station, Brisbane Terminal and SFO will all experience Very Strong to Violent shaking and may experience liquefaction in this earthquake scenario. Pumping stations and fuel terminals have many seismically

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[25] Detweiler, S.T., and Wein, A.M., eds. 2018.
[26] California Energy Commission. 2019. "Emergency Petroleum Fuel Requests." https://www.energy.ca.gov/emergencies/setaside.html. Accessed May 20, 2019.
[27] Association of Bay Area Governments (ABAG), Dec. 2014, "Cascading Failures: Earthquake Threats to Transportation and Utilities." http://resilience.abag.ca.gov/wp-content/documents/Cascading_Failures/InfrastructureReport_2014.pdf.
[28] U.S. Chemical Safety and Hazard Investigation Board. 2015. "Final Investigation Report: Chevron Richmond Refinery Pipe Rupture and Fire". https://www.csb.gov/chevron-refinery-fire/..
[29] Detweiler, S.T., and Wein, A.M., eds. 2018.

vulnerable components that will likely be damaged in an earthquake. The Brisbane Terminal is particularly susceptible in this scenario due to its proximity to strong shaking. The seismic vulnerability of Kinder Morgan's pump stations and terminals has not yet been evaluated.

The pump stations and terminals need power and communication connections to operate. The facilities have backup power, but it is limited and not enough to run pumps at either facility. The facilities might be able to operate loading racks if needed, but will need to perform inspections and variance would be required to load fuel without vapor recovery burners.

The pipelines are constructed of high strength steel that is less likely to break in an earthquake, however the seismic vulnerability of the pipeline has not yet been evaluated. If the jet fuel line to SFO breaks, jet fuel can still be delivered via the multiproducts line. However, multiproducts cannot be delivered via the jet fuel line. Fuel pipeline rupture could result in significant fires.[30]

Product can only move through the pipeline and facilities if the refineries are producing it. If the refineries shut down, the only product available for the region will be the product already stored at Brisbane Terminal. Refined fuel delivered to the Richmond Products Terminal could possibly move through the Richmond Station to flow through the pipeline, but it would not be a significant volume. The other Kinder Morgan Richmond Terminal is solely a bulk terminal and products delivered there cannot be fed into the pipeline.

Water main: The Brisbane Terminal requires water from the City of Brisbane to run its fire suppression system. If the 14-inch water main is damaged, the Brisbane facility will not have enough water to run the fire suppression system and the loading racks can't operate without fire suppression. Kinder Morgan expects that this pipeline will rupture in a large earthquake.

Service stations: Commercial service stations will likely have disruptions as well. Fuel pumps cannot operate without electricity and electronic transactions also require communications.[31]

[30] Detweiler, S.T., and Wein, A.M., eds. 2018.
[31] Gordon, Schremp. 2018. "California Fuel Overview & Emergency Fuels Set-Aside Program". Presentation to the San Francisco Lifelines Council.

Hayward Fault

The consequences of a Hayward Fault earthquake are more severe for Kinder Morgan. The Kinder Morgan pipeline crosses the Hayward fault in several locations and could rupture with major fault offset. If the pipeline ruptures, Kinder Morgan would perform static pressure and integrity tests to determine extent of damage. Above ground components of the Richmond Station, Concord Station and Oakland facility are also likely to be damaged in this scenario. However, the fragility of the pipeline and components at these facilities is not known. Even once repairs are completed, the system cannot operate until communications and power is restored.

In this scenario the five major Bay Area refineries will also experience strong to very strong shaking such that at least one (and possibly several) refineries will have major fires that may burn for several days.[32] One of the refineries is in a high potential liquefaction area.[33]

System Restoration Timeline

San Andreas Fault Scenario

Table 5 describes the existing level of service disruption and the restoration actions that the operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 5** reflects the current, existing performance in the Restoration Timeline in **Figure 8** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

[32] Detweiler, S.T., and Wein, A.M., eds. 2018.
[33] Jones, J.L., et al. 2019.

TABLE 5. FUEL SYSTEM RESTORATION TIMELINE

	Fuel - Kinder Morgan*
0 Hours	Most earthquake damage is expected at the pump stations and terminals, with the possibility of some pipeline rupture. Tanks, manifolds and loading racks at the Brisbane Terminal are especially likely to be damaged in this scenario. However, the fragility of these components at these facilities is not known. Pipe rupture is not expected because the pipeline does not cross the San Andreas fault. The Kinder Morgan system will be shut down for a minimum of 24 - 48 hours for inspection and restoration. The duration of the inspection period will depend on the amount of damage observed and availability of roads for inspectors to get to critical locations. If repairs are needed to pipelines or facilities, Kinder Morgan has spare pipe available, but additional crews will be needed to move it and conduct repairs. Oil spill response contractors are ready to assist with releases and spills. If there is no damage to facilities or pipelines, Kinder Morgan operations could potentially be running again in 4-6 hours. If the refineries are damaged, there may be enough supply in the system to cover a short-term shutdown but there could be a shortage of certain fuel products.[34] Operators are limited to working 18 hours in a row. If the road network is down, replacement crews can't come to work. This is a particular concern at Brisbane Terminal where 5 of 6 operators live in East Bay. Six additional operators work at the Richmond Station. Each facility also has one technician and a manager.
72 Hours	
2 Weeks	Minor repairs to the fuel delivery system could be completed.
2 Months	
6 Months	Major repairs to the fuel delivery system could be completed.
1 Year	
3 Years	

*Beyond downtime for initial inspections, Kinder Morgan was not able to make estimates about potential damage to its system or restoration of its fuel delivery system or extent of disruption to the fuel refining systems.

Hayward Fault Scenario

Kinder Morgan will follow the same response and restoration procedures in the Hayward Fault earthquake, with inspections expected to take longer due to the greater extent of

[34] Association of Bay Area Governments. 2014.

damage. Damage to the fuel pipeline could halt transmission of fuel to SFO and Brisbane Terminal for a month or up to a year.[35]

The USGS Haywired study estimates that all Bay Area refineries could lose power for three days and be shut down for 14 days in this scenario (the worst case for refineries).

Level of Confidence

Kinder Morgan is confident in the performance of its system in an earthquake, but has not specifically analyzed the performance if it’s major components. Its restoration assumptions are primarily driven by experience with past disasters and in the Loma Prieta earthquake.

System Interdependencies

Power, communications, water, highways and local roads, and fuel are the primary interdependencies for operating the fuel system. Emergency delivery of bulk fuel for City and County of San Francisco if the pipeline is not operating depends on the Port of San Francisco.

Table 6 describes the extent of this sector’s dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

[35] Jones, J.L., et al. 2019

TABLE 6. FUEL SYSTEM DEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – Kinder Morgan pump stations and loading racks cannot operate without power. Commercial service stations cannot operate fuel pumps without power and the refueling of vehicles will stop. Refineries also depend on power for operation.
Natural Gas	None
Water	Significant – The Brisbane Terminal cannot operate without fire water provided by the City of Brisbane. This pipeline is expected to rupture in an earthquake.
Wastewater	None
Communications	Significant – The fuel pipeline cannot operate without communications for its SCADA system to monitor flow in the pipeline. Other communications can use satellite radios. Refineries also rely on SCADA systems for operation.
Highways and Local Roads	Significant – Roads are critical to performing inspections of the pipeline and to moving critical personnel and equipment. Some air inspections are possible.
Fuel	Significant – Kinder Morgan can only transport fuel that is produced by the five Bay Area refineries. If these refineries are not operational, the pipeline cannot deliver fuel.
Transit	None
Solid Waste	None
Airport	None
Port	Moderate – San Francisco's Fuel Plan relies on Port of San Francisco's Pier 96 and other waterfront facilities for emergency bulk fuel delivery if the fuel system is not operational. The seismic vulnerability of Pier 96 has not yet been evaluated by the Port.
Firefighting Water (EFWS)	None

Actions to Speed Restoration

Kinder Morgan should strive to better understand the vulnerability of its system components to damage due to earthquake.

The performance of the Kinder Morgan pipeline and above ground facilities in earthquakes is not well understood. The primary components of the Kinder Morgan fuel system for San Francisco include the transmission pipeline, the Richmond Station, Oakland Facility and Brisbane Terminal. Many of these assets will experience strong shaking and/or liquefaction in a San Andreas or Hayward Fault earthquake. In addition, the pipelines cross the Hayward fault in several locations and could rupture with major fault offset. Kinder Morgan has not assessed the likelihood that its pipeline or above ground facilities would be damaged in these scenario earthquakes and the extent of the damage is not known.

San Francisco should collaborate with industry stakeholders to accelerate deployment of electric and alternative fuel for light, medium and heavy-duty vehicles.

San Francisco can significantly improve its resilience to earthquakes while meeting greenhouse gas reduction targets by reducing reliance on petroleum fuels and redirecting response and recovery fuel needs to energy sources that have rapid post-event restoration, such as electricity. In the event of a disaster, the functionality of the City of San Francisco will rely in large part on the availability of fuel for first responder vehicles, heavy equipment, and backup generators for critical facilities. In the first days that follow an event there will likely be reservoirs of fuel to draw on, however, there is strong potential for prolonged disruption to the fuel system due to damage of the marine oil terminals, refineries, Kinder Morgan pipeline, pumping stations and/or terminals. While the California Energy Commission, City and County of San Francisco and other lifelines organizations have developed detailed emergency fuel plans to provide minimum fuel requirements for government emergency operations, these plans do not include private operators and the isolated and interconnected nature of the northern California fuel systems means that importing fuel without a pipeline or refineries will be a significant challenge. At the same time, the electric grid has undergone significant investments and is generally expected to be back online within a few days to a few weeks (See Electric Power Chapter).

The City and County of San Francisco has an overarching climate action goal which pledges to reduce greenhouse gas emissions 80 percent below 1990 levels by 2050 in alignment with California's climate action targets.[36] A significant part of meeting this goal is reducing the emissions from the transportation sector by diversifying the fuel needs for the transportation sector, including significantly transitioning to electric vehicles and increasing the use of renewable diesel for general transport. Cleaner vehicles and fuels are available in greater variety and lower cost now than ever before, and higher-performance alternative fuel products are being introduced on a continuous basis. To date, alternative fuel options for light, medium and heavy-duty trucks and equipment is limited. Backup generators that don't rely on fuel will also be more reliable after the immediate event. Electric powered generators and vehicles can further improve their resilience and climate impact by connecting to grid-independent solar PV and battery storage systems (see **Electric Power** summary).

Municipal and private owners with critical fuel needs should develop policies to ensure adequate supply of fuel within vehicles and equipment as a first priority and then store fuel locally in tanks that can be pumped without electricity.

100% of the fuel needed immediately after an event is stored in vehicles or local storage tanks. Ensuring adequate local supply will reduce the impacts of a fuel system disruption. For vehicles, equipment and backup generators that rely on liquid fuel, the most readily available fuel after an emergency will be those that are already in the vehicle or equipment or in storage tanks. Storage tanks, however, normally require electricity to pump the fuel out of the tanks. Best practices for ensuring adequate fuel supply include:

- Never let vehicle tanks go 25% full
- Never let electric vehicle go below 50% charge
- More frequent fuel deliveries to keep fuel storage tanks at least 50% full.

[36] City and County of San Francisco. 2008. "Ordinance 81-08: Climate Change Goals and Action Plan." https://www.sfbos.org/ftp/uploadedfiles/bdsupvrs/ordinances08/o0081-08.pdf. Accessed May 21, 2019.

The Lifelines Council should work with key fuel users, regulators and fuel providers to evaluate the impact of an earthquake on Bay Area refineries and encourage them to upgrade vulnerable components as necessary.

The performance of Bay Area refineries in earthquakes is not well understood. Refineries consist of thousands of miles of pipelines, hundreds of large tanks, and specialized equipment for various stages of the refining process. The five major refineries that produce all the petroleum fuels for Northern California and Nevada are located along the Carquinez Strait in areas that will experience strong shaking and liquefaction in a San Andreas or Hayward fault earthquake, as well as earthquakes on several other Bay Area faults. Oil refineries and tank farms have typically had large fires when shaken strongly. Damage at one or more of these refineries will severely limit fuel availability across the region. Alternative fuel delivery methods to the Bay Area are limited.

The Lifelines Council should request public reports focusing on post-earthquake operational issues of marine oil terminals to assist in better understanding moderate and long-term fuel supply impacts.

The performance of marine oil terminals in earthquakes is not well understood. Most marine oil terminals (MOTs) that deliver crude oil to refineries were built in the early 1900s, when oil was carried by smaller ships and before seismic safety standards and environmental review requirements were established. The Marine Oil Terminal Engineering and Maintenance Standards, known as MOTEMS, are guiding the upgrade of aging terminals to ensure better resistance to earthquakes, protect public health and the environment, and reduce the potential of an oil spill. MOTEMS, which is codified in the California Building Code, establishes minimum engineering, inspection, and maintenance criteria for all MOTs in California. California Building Code Section 3102F.4 addresses post-event inspection, notification, and follow-up action for Marine Oil Terminals. While these requirements are primarily directed toward establishing standards to prevent oil spills and to protect public health, safety and the environment, the specific requirements of this section address general operational elements following any significant event. Reports under this section are required to be submitted to the Marine Facilities Division of the California State Lands Commission.

The City of San Francisco Fire Department, SFPUC, and City of Brisbane should work with Kinder Morgan to determine the vulnerability of the Brisbane water main

Following assessment, the feasibility of delivering alternative fire water supply from San Francisco's fire boats should be determined. Fuel loading racks at the Brisbane Terminal cannot operate without fire water provided by the City of Brisbane. The City of Brisbane provides fire water through a 14-inch water main to the Brisbane Terminal. The seismic vulnerability of this pipeline has not been assessed, but it is very old and located in a liquefaction area. If the pipeline is damaged, there is no alternate fire water supply for Brisbane Terminal.

San Francisco's Portable Water Supply System includes fire boats and above ground hoses designed to provide unlimited supply of fire water from the Bay. Once fires are extinguished in San Francisco and the PWSS system is no longer in use, it could be utilized to provide alternative fire water delivery to Brisbane Terminal, if that is determined to be a key need. Because the fuel delivery system will be shut down for a minimum of 48 hours and fuel supply is in vehicles and local storage tanks, this water supply will likely not be needed until any post-earthquake fires are extinguished. Of course, if the fuel system is damaged, no fuel loading will be available at Brisbane Terminal.

Communications

Photo: Ian Kennedy/Flickr

The communications system is comprised of a diverse set of networks that transmit voice, video and data communications by fiber, wireless communications or radio. These networks consist of radio antennas, cell sites, data centers, fiber optic networks, and hubs for television, radio, internet, cell phone and voice communications.

Communications

Operators: Department of Technology, AT&T, Verizon, Comcast

At A Glance...

Key Findings

- Restoration times vary by operator, but initial disruption may be severe, especially after battery backup in certain locations runs out within four to 12 hours; DTIS expects all critical City IT to be restored within 10 hours.
- Communications restoration is coupled with power; significant dependencies on other communication providers, highways and roads, and fuel.
- Demand surge immediately following an earthquake could result in a lack of service even when system components are undamaged.
- Few macro cell sites in San Francisco have permanent backup generators to keep cell sites operating after battery backup runs out. Temporary generators can be brought to some sites, but it takes time. Small cell sites do not generally have either battery backup or generators.
- Many cell sites and equipment are located on private buildings. If buildings are damaged, access to the sites for restoration could be a challenge.
- Communications providers will need access to closed streets to restore service and roll out temporary cell towers and generators.

Actions to Speed Restoration

- San Francisco should prioritize fuel distribution to generators at City radio sites and data centers to maintain vital information systems.
- Communication providers should identify locations to add permanent generators at more cell sites and nodes and co-locate cell sites with building solar and battery systems.
- Communication providers should develop agreements to provide emergency mobile wireless to priority locations in the City within a specified time.
- Develop a common and flexible identifier for critical communications personnel to ensure access to cordoned areas when safe for service restoration activities.
- Identify staging locations for personnel supporting restoration.
- Identify ways to ensure communications providers and other lifeline operators coordinate restoration activities.

Restoration Performance *Goals*

Department of Technology (DTIS) has the goal of restoring all critical IT systems and assets owned by the City within 10 hours of a major incident. Restoration of other non-critical systems will take 72 hours or longer.

AT&T, Verizon and Comcast all strive to restore service to customers as quickly as possible. However, these companies have not adopted specific performance targets for system restoration due to the challenge reliably predicting service restoration given the uncertainties of a disaster.

System Restoration Timeline

The service restoration timeline shown in **Figure 9** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

SERVICE DISRUPTION LEVELS

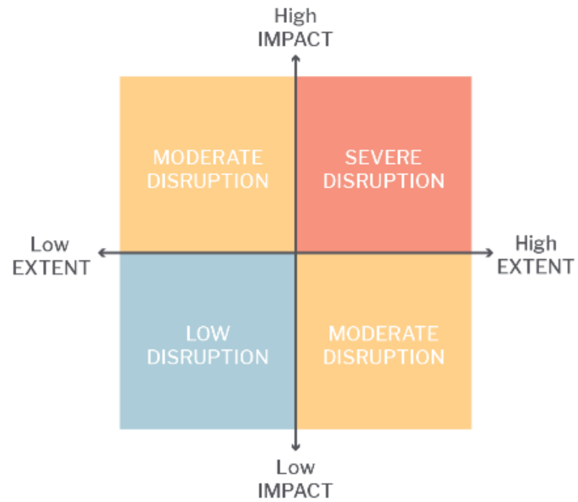
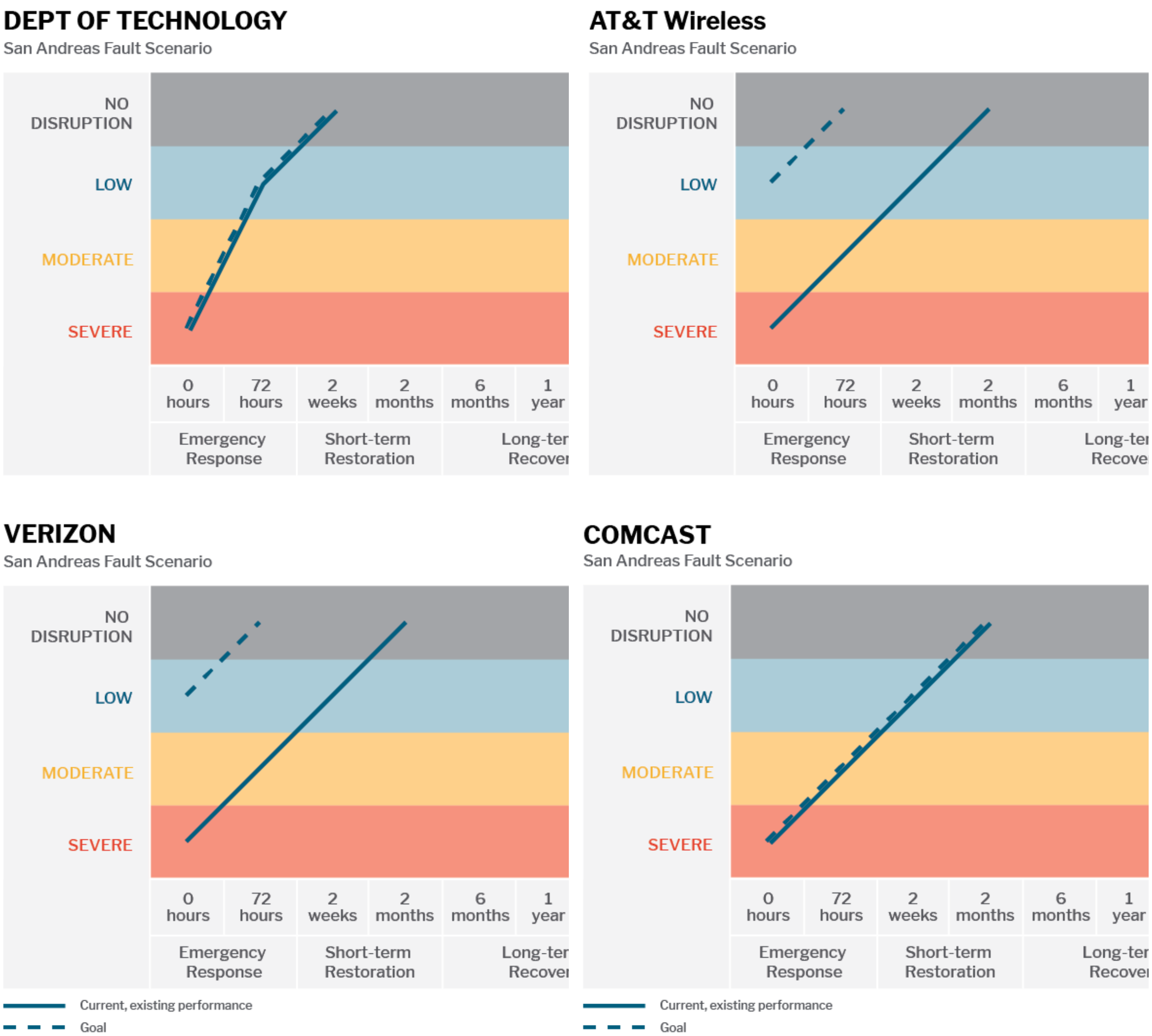


FIGURE 9: COMMUNICATION SYSTEM RESTORATION TIMELINES



Sector Overview

Department of Technology

San Francisco Department of Technology manages a wide array of communications systems including radio, video, internet access, business systems, public warning sirens, emergency call boxes, traffic signals, and the Mayor's Emergency Telephone Systems (METS).

Key City owned systems critical for city functioning, include the municipal fiber optics network, data centers, and an 800Mhz radio system. These systems are described in detail below.

Fiber optics network: Hundreds of miles of fiber optic cable owned by the City of San Francisco connect every municipal building in San Francisco. This fiber network provides internet access, email and VoIP communications for government operations.

Data centers: The primary data center located in San Francisco stores, manages, and disseminates the data for all of the City's communications systems. A back up data center has been established in Rancho Cordova, CA. Two separate cable paths to Rancho Cordova provide redundancy.

800 MHz radio: The City is transitioning to a new 800MHz radio system for emergency communications. The system relies on 11 antennas placed on shared radio tower sites on buildings or high ground throughout the city, with two antennas located outside of San Francisco in Daly City and on San Bruno Jail. The towers the antennas for located on are not owned by the City of San Francisco. The towers are built to the highest seismic standards, but the performance of the buildings on which they are placed is generally not known. Loss of one or more antennas in the network will degrade communications, but the system is designed so it can remain operational despite the loss of several antennas. The antennas are connected to each other by fiber cables and microwave paths. The radio towers have backup power.

Verizon, Comcast, AT&T

Private communications systems are owned by a wide range of operators, including Verizon, AT&T, T-Mobile, Sprint and Comcast, as well as private third-party operated fiber networks and data centers that these operators rely on. These communications systems include cellular networks (for mobile data and voice), fixed landlines and broadband internet.

Cellular Networks: Cellular networks are organized around cell sites, which transmit cell phone signals to and from the user to a receiver at the cell site via radio waves. The primary cellular companies in San Francisco are Verizon, AT&T, Sprint and T-Mobile. AT&T and Verizon were interviewed for this project about their cellular networks.

- <u>*Macro cell sites:*</u> Macro cell sites are located on cell towers and buildings and provide coverage over a large area. The seismic performance of buildings in which these sites are placed is generally not a consideration in site selection and building damage may damage cell sites.[37] In the event that power is lost, macro sites have battery backup power for four to 12 hours, but very few macro cell

[37] A. Wein and D. Witkowski, personal communication, December 18, 2019

sites in San Francisco have permanent backup generators. For example, according to Verizon, only 14% of their macro sites in San Francisco have permanent backup generators, one of the lowest penetration rates in the country. It is unknown how many of AT&T's macro cell sites have backup generators. Many macro cell sites are located on buildings where permanent or temporary generators are infeasible due to noise, proximity to air intakes, or structural limitations.

- *Small cell sites:* Small cell sites have a smaller range and are used to add capacity and density to the network. Small cell sites are typically located on existing SFMTA utility poles and use SFPUC provided power. Cellular providers have been focusing significant effort in recent years in adding small cell sites to meet growing capacity demands. Small cell sites do not have battery backup or permanent generators as they are not generally allowed on power poles or in the right of way.[38] Even when small cell sites lose power, coverage is not always lost due to adjacent cell sites that can fill in the gaps.[39]
- *Fiber:* Cell sites and hubs convert signals received from cell phones into light and send it through the fiber network to switching centers. The fiber network in San Francisco is primarily owned by AT&T and Comcast, Zayo and Extenet, and others. Wireless companies can create system redundancy by selecting different routes owned by different providers. If the fiber network goes down in an emergency, cell companies can deploy temporary microwaves over the air, point to point, depending on permitting and site location constraints.
- *Hubs:* Small cell sites route data to hub locations that aggregate the data and send it to switching centers via the fiber network. Verizon has four hubs in San Francisco. Hubs rely on power provided via the electrical grid and they have significant back up battery power, however only two of Verizon's four hubs in San Francisco have permanent backup generators. Information about hub sites for AT&T is not known.
- *Switching Centers:* Switching centers route traffic where it needs to go allowing telephones and cellular phones to communicate with each other. Switching

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[38] Verizon. (April 3, 2020). [Letter to the California Public Utilities Commission]. Retrieved from https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M333/K021/333021248.PDF
[39] Verizon. 2020.

centers have built in backup generators and batteries.[40,41] There are no switching centers located in San Francisco.

- *Deployables:* In the event of an emergency where cell sites are down or there is no power to the cell sites, the communications providers would deploy a fleet of COWs (cell on wheels), COLTs (cell on light truck), and GOATs (generator on a truck) to augment the network when needed; however, network capacity may be reduced with these solutions. These assets are strategically staged throughout Northern California, but none are located inside San Francisco. Deployables may provide a temporary redundant communication network, or in the case of GOATs, provide temporary power to restore the network. Backup generators rely on fuel deliveries after the initial supply runs out. AT&T has approximately 500-600 generators throughout the state with a fueling plan. AT&T participates in the California Fuel Set Aside Program and has its own agreements with fuel suppliers. Verizon also has an unknown number of generators geographically distributed throughout California.
- *RADIAX:* Underground BART and MUNI stations in San Francisco have cable that runs through the tunnels and acts as a linear cell site in BART and MUNI tunnels for all carriers. The volume of people using this cell site often creates a capacity issue; it will be exacerbated in a disaster. Expansion of the cable and cell site is anticipated through a contract with SFMTA.

Broadband Internet: Residential and business computers and other devices are connected to the internet through hardwired or wireless connections with subscriptions to an internet service provider. In San Francisco, the largest internet service providers are Xfinity/Comcast and AT&T. Internet connection is provided by cable, DSL, and increasingly fiber networks. Only Comcast was interviewed about its internet service for this project.

- *Fiber:* The entire Bay Area is served on a redundant fiber centralized radio access network (C-RAN) backbone loop that circles the Bay. Communications can flow in both directions on the route, so if fiber is cut in one location, data can route the other way.

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[40] AT&T. (April 3, 2020). [Letter to the California Public Utilities Commission]. Retrieved from https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M333/K160/333160807.PDF
[41] Verizon. 2020.

- *Headends and Hubs:* The fiber network enters San Francisco via multiple entry points and runs through headends located in the Mission and West side of the City. A headend is a centralized facility for receiving and processing television signals for distribution over a cable TV system, which also includes equipment for broadband and VoIP services.[42] Fiber for wireless, internet and cable TV are all located in the same conduit. Hubs distribute optical signals from headends throughout the service area.

  All of Comcast's California headend and hub locations have either backup battery or generators, and in most cases, both.[43] The battery backup systems typically have the capacity to operate for approximately four to 12 hours. Generators can continue to provide power as long as they can be safely refueled. Comcast strives to refuel when the fuel level reaches 50 percent, which typically occurs after approximately 24 hours of operation.[44]

- *Nodes:* Nodes convert the optical signals from hubs to electric (radio frequency) signals for distribution over coaxial cable.[45] Nodes serve about 500 to 1,000 customers each. From the nodes, fiber cables and/or hybrid fiber-coaxial (HFC) go to individual homes and businesses. Between the headends and a subscriber's home is approximately 15,000 network components that each rely on power.[46] These devices are equipped with battery backup that can run for 4 to 24 hours without power, but few of them have permanent backup generators.

  Each node requires power to function. All nodes have battery backup and some have backup generators, which can run continuously as long as they can be safely refueled.

  As internet capacity demands increase, Comcast is serving fewer customers per node and is extending fiber deeper into the neighborhoods. Because of City ordinances, nodes and backup power supply must be placed on private property that Comcast doesn't own. If the building is red tagged in an earthquake,

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[42] Comcast. (April 3, 2020). [Letter to California Public Utilities Commission]. Retrieved from https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M333/K045/333045570.PDF
[43] Comcast. 2020.
[44] Comcast. 2020.
[45] Comcast. 2020.
[46] Comcast. (November 18, 2019). [Letter to California Public Utilities Commission]. Retrieved from https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/News_Room/NewsUpdates/2019/Nov.%2018%202019%20Comcast%20Response%20to%20President%20Batjer%20Nov.%2013%20Letter.pdf

Comcast may not have access to backup power and restoration could be delayed.

- *Collocation and Data Centers:* Every telecom company is linked together at a collocation and data center at 200 Paul St in San Francisco where traffic can be handed off between the communication providers. Data centers, which store communications data, are generally located on the Peninsula and in the South Bay, rather than in San Francisco.[47] However, more than 25% are in high liquefaction probability areas.

System Upgrade and Disaster Planning Efforts

Department of Technology

In recent years, the Department of Technology has upgraded city phone service to voice over IP (VoIP), replaced the public safety radio system with an 800 MHz radio system that allows all public safety departments to communicate with one another, expanded fiber service to all city buildings, and established a backup datacenter for the cloud in Rancho Cordova. The Department of Technology has procured wireless mobile trailers with satellite communications that can be used during an emergency when cellular or fiber communications are unavailable.

Verizon

Verizon has made significant investment on improvements to the wireless network in San Francisco with a focus on building out the capacity of the network and boosting the network with small cell sites. Network improvements include:

- Small cell site densification and capacity improvement
- In-building distributed antenna systems (DAS) that amplify and distribute the signal in buildings
- Fiber path diversity
- Cell site relocations
- Permanent Generator additions
- Production of Verizon's 4GLTE eFemto solutions
- MCT (Mobile Connectivity Trailer) and Satellite Backhaul eFemtos for emergency use -- trailers with satellite dish, self-contained generator. Creates blanket coverage of 4G LTE and/or internet in area without coverage. Mobile

[47] A. Wein and D. Witkowski. 2019

connectivity trailer in position at fires sites for fire fighters to use data and make calls. Provide Wi-Fi for other network customers to make Wi-Fi calls.

Large events often provide an opportunity for wireless operators to expand the network to ensure adequate capacity for crowds of people. During the Bay Area's hosting of the Super Bowl in 2016, Verizon was able to access many utility poles to expand the network of small cell sites and macro cell sites. Verizon has also obtained more permits for generators at macro sites in recent years, doubling capacity to 14% of sites. This coverage of backup generators remains one of the lowest in the country according to Verizon.

AT&T

AT&T is constantly reinvesting in the system, upgrading its network, and expanding capacity to meet demand. AT&T is adding five macrosites in Golden Gate Park at Kezar, Beach Chalet, and three sites out of the public realm in anticipation of post-disaster staging and to expand coverage in the park. AT&T is planning to expand its fleet of fixed and portable generators that can be deployed to wireline and wireless sites when power is lost.[48]

Comcast

Comcast is also in a constant process of upgrading its network to meet expanding demands. Since 2014, Comcast has added a number of diverse, redundant fiber routes throughout the network. Comcast's technology has transitioned to be more fiber-based, with increasing functionality migrating to the cloud, thus reducing the need for active electronics in the systems in the field. Comcast's CRAN backbone fiber loop capacity has been expanded significantly, which reduces risk of outages in the network.

Since 2015, Comcast has been upgrading its power infrastructure and generator capabilities across the State of California. This increases reliability during a power outage and improves back-up power capabilities to both facility-based powering platforms and outside plant-based powering capabilities. Generators have been strategically placed across the power infrastructures footprint and are supported by numerous third-party resources that can provide facility-based power generators within

[48] AT&T (November 18, 2019). [Letter to California Public Utilities Commission]. Retrieved from https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/News_Room/NewsUpdates/2019/20191118%20ATTs%20Response%20to%20Pres.%20Batjer's%20Letter%20[PUBLIC%20VERSION].pdf

a one-hour response time, depending on traffic, road conditions and whether it is safe to do so.

In 2017, Comcast procured a mobile hub site, which will facilitate restoration of a hub site in less than 24 hours should a catastrophic event take place that destroys or greatly damages one of the hub facilities. Comcast has also added battery backup and generators at hub sites.

Comcast has a nationwide third-party fuel provider that can be utilized in an emergency. It would bring fuel from outside the region by truck. The service performed expertly during recent events in California. This is a major element of ensuring back-up power capabilities.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

Department of Technology

The primary data center in San Francisco is critical for operations. The data center is housed in a building that can withstand shaking a strong earthquake. If the building or data racks in the primary data center are damaged, the backup data center in Rancho Cordova will be operational for those business systems that have a disaster recovery system in the primary data center. The cables, fiber lines and towers should be operable in this scenario. Rancho Cordova is equipped with a satellite phone, and some staff will be sent there. Two separate cable paths to Rancho Cordova provide redundancy. DTIS expects all IT services to be back up within 10 hours, and has a prioritization schedule for restoring key services. Municipal financial systems and GIS will be immediate needs in disaster recovery that must be restored quickly.

2019 PSPS Outages

During the PG&E initiated Public Safety Power Shutoffs in 2019, cell service, internet-based landlines and internet systems went down in many places that lost power. Communications companies deployed temporary generators to many sites, but were often unable to access sites that were located on private buildings or within fire evacuation zones.

Fuel for backup generators in communication towers is stored in various locations across the city. Department of Technology is now working to establish a dedicated fuel reserve that will allow the radio towers to be operational for 10 days.

Cellular Network - Verizon and AT&T

In the event of an earthquake, cellular network functionality will depend on power availability and physical damage to infrastructure. Cell sites, hubs, fiber network and internet service all rely on power to operate and have been damaged by ground failure hazards (landslide, liquefaction and/or fault offset) and/or fire in past earthquakes.[49]

Many macro cell sites are located on private buildings. If the buildings are damaged, the cell sites may also be damaged. Access to sites on private property after an event could be a challenge, especially if the building is red tagged. Operators will bring in mobile assets such as Satellite COWs or COLTs to restore coverage when infrastructure is damaged. These can typically be in place within 6-12 hours, depending on safe access.

Macro cell sites that are not damaged but lose power will stay in operation until their battery backup systems fail in 2-6 hours. Once batteries run out, sites that have on-site standby generators (as noted above, about 14% of Verizon sites in the City; unknown number of AT&T sites) will remain operational for up to 72 hours or longer with refueling. Refueling requires safe access to the sites. Temporary generators can be deployed to some cell sites without permanent generators where safe and feasible. Not all macro cell sites can take a mobile generator because of where they are located – sites on rooftops for example. In such a scenario, operators would do an assessment of the network in the area and boost coverage at neighboring cell sites where possible to compensate for sites that have lost power, and assess where it may be feasible and safe to deploy COWs or COLTs. AT&T is currently doing an internal analysis of backup power capabilities at all its macro sites, and intends to increase backup power solutions in critical areas across the state.

Small cell sites are typically located on power poles. If the poles are damaged, the cell sites may also be damaged. Small cell sites do not have backup battery capability. However, small cell sites are added to the network to increase capacity, so loss of these sites will decrease data speeds and may decrease overall capacity of the network in that area, but coverage will be maintained.

[49] A. Wein and D. Witkowski. 2019.

Operators are constantly adding small cell sites throughout the city to improve capacity of the network. To obtain a small cell site permit, SFPUC requires operators replace the concrete foundation of the power poles, improving the likelihood that these sites will survive an earthquake. AT&T is also implementing FirstNet, a national broadband network for public safety, which will require AT&T to touch 90% of the existing poles. This work is improving the reliability of the network in the event of an earthquake and paving the way for many other upgrades to the network.

Hub locations, which aggregate data from small cell sites to send to switching centers via the fiber network, are also dependent on power. All four of Verizon's hubs have significant battery backup; however, only two are allowed to have permanent backup generators. Some of the hub sites may be damaged by liquefaction.

While some portions of the fiber network may experience damage due to liquefaction, redundancy in the system may limit the impact of this damage. Switching centers are not located in San Francisco and their performance in this scenario earthquake is not known.

Broadband Internet - Comcast

The biggest issue for Comcast in the San Andreas scenario event will be liquefaction damage to poles and underground cables. However, because Comcast began as a residential service provider in San Francisco, it currently does not have robust assets in the Financial District and SOMA where widespread liquefaction is expected. As node sites are serving fewer and fewer customers and fiber is pushing deeper into neighborhoods; consequently, whole system is becoming more reliable and less likely for an earthquake to cause widespread impact.

Most Comcast crews reside in the East Bay and equipment for repairs are staged along the Peninsula and in San Jose. Access to the City for restoration activities is a significant concern for Comcast, as well as other communication service providers. Comcast has two yards in San Francisco that contain some equipment and supplies for restoration.

In the event of damages and equipment failure from power outages, some capacity can be restored to the system through battery power and permanent backup generators installed at cell sites. Additional backup power can be provided by portable generators brought in from outside the city.

Demand Surge

Demand on the communication system has been shown to surge in the immediate post-disaster phase as users try to check in with family and friends and make calls for emergency services. Delays in reporting post-earthquake fires will result in fire spread.[50] The demand can exceed even the pre-event design capacity of the network. The Haywired model suggests that initial demand may increase up to ten times more than the network design capacity.[51] This demand surge further limits the ability of customers to access the network. Demand surge is expected to decline in the days after the earthquake. Instructions to limit phone calls to emergency reporting only can also limit the immediate post-disaster demand placed on the network.

Hayward Fault

Significant service disruption is not anticipated for San Francisco in the Hayward fault scenario. Damage to the fiber network outside San Francisco due to liquefaction or fault displacement could affect service delivery in San Francisco (123 fiber optic routes cross the Hayward fault in locations of anticipated significant fault displacement[52]); however, diversity and redundancy of the fiber routes within San Francisco should provide some protection from service disruption.

Because power is so critical to communication systems, any loss of power in the region could result in diminished cell service once onsite battery backups run out. Likely disruption to the fuel system and Bay Area refineries in this scenario will hamper the ability of communication providers to refuel generators and restore service before power is restored.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 7 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 7** reflects the current, existing performance in the Restoration Timeline in **Figure 9** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is

[50] A. Wein and D. Witkowski. 2019.
[51] A. Wein and D. Witkowski. 2019.
[52] Jones, J.L., et al. 2019.

moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 7: COMMUNICATION SYSTEM RESTORATION TIMELINES

	City Communications - Department of Technology	Cellular Network – AT&T and Verizon	Broadband Internet - Comcast
0 Hours	Initial disruption will likely be severe, however depending on time of day, systems may be restored very quickly. Data center will be back up immediately either locally or from backup in Rancho Cordova.	*AT&T and Verizon's goal is low disruption in the* immediate *post-disaster phase.* Actual initial disruption is likely to be severe due to potential damage to the Distributed Antenna System (DAS) headend, hubs, the fiber network, cell sites, and power grid. Loss of power will result in 50% loss of capacity in the network after 4-12 hours of battery backup because of lack of permanent generators. Temporary generators will be deployed to some sites where feasible and where they have permission to do so. Road access will be critical.	Initial disruption may be severe due to damage to the fiber network and utility poles, and loss of power. Within 24 hours, Comcast will be starting assessment and repairs, if conditions allow crews to get to San Francisco. Temporary Wi-Fi will likely be established at priority locations identified by the city such as city hall and emergency shelters. Customers with power and connectivity may start to have some services restored. Comcast will work to identify housing for approximately 30-40 restoration crews from outside the area, including setting up an RV park for employees if a suitable location can be identified.
72 Hours	*Department of Technology's goal is to restore critical communication systems within 10 hours. Other systems will take 72 hours or longer depending on which systems are in the disaster recovery site.*	Verizon's *goal is full restoration by 72 hours.* Actual restoration time depends on power restoration, fiber and water damage, or other damage to physical infrastructure.	Depending on damage and conditions, Comcast will likely have the distribution system back up and running within 72 hours. Comcast may run temporary above ground fiber cables and use deployables to speed

	City Communications - Department of Technology	Cellular Network – AT&T and Verizon	Broadband Internet - Comcast
72 Hours (cont.)	Actual restoration time will depend on availability of technicians. Many employees do not live in San Francisco. If technicians can't get into the city and if communication is lost that lets repairs happen remotely, then Department of Technology will need to rely on resources already within the city through mutual aid from other cities or private companies with employees in the city. A major challenge in restoration is how to communicate between city departments and support mutual aid.	By 72 hours, providers will try to provide enough coverage for everyone to make calls and texts, but not streaming data (i.e. coverage but not capacity). This will involve all options at their disposal: generators, COWs/COLTS, network optimization, etc. Verizon will provide additional capacity by 72 hours in priority areas such as, EOCs, hospitals, shelters, evacuation areas, and dispatch centers, where feasible If power is available, providers may focus on installing temporary microwave solutions to restore fiber and get full restoration within 24-48 hours. Road access is a critical need for this solution.	restoration of the network. Comcast may need assistance from the City to identify paths for temporary cables. Equipment may be tacked to buildings as a temporary measure. When poles are restored, equipment will be moved onto the poles. Comcast will prioritize restoring service to customers with undamaged buildings that have been inspected by the City. Where it is safe to do so, Comcast will bring in generators and a mobile hub site, if needed. Comcast contracts with a fuel vendor that will refill generators where it is safe to do so and is guaranteed to provide fuel, including from out of state if necessary. If roads are impassable, Comcast plans to identify a location where boats can deliver fuel. Restoration could be delayed if crews are not provided access to cordoned areas.
2 Weeks	Full restoration anticipated within 2 weeks	Disruption will be low by two weeks if there is no significant gas or water line damage that prevent access to assets and power is restored.	It will take many more months to restore service to neighborhoods that have been damaged and buildings need to be rebuilt. Unlike cell service, internet service requires physical connection to a building.

	City Communications - Department of Technology	Cellular Network – AT&T and Verizon	Broadband Internet – Comcast
2 Months		Full restoration anticipated by 2 months, given power is restored and with the possibility that some rebuild areas may take longer. Temporary restoration will be made where feasible while permanent infrastructure is replaced.	Full restoration of the network is expected within two months, to the extent buildings are functioning, is anticipated.
6 Months			
1 Year			
3 Years			

Hayward Fault Scenario

Communications will generally experience low disruption in the Hayward fault scenario. Collocated water and natural gas pipelines damaged by liquefaction may hinder repair of fiber optic cables. Repair of communications assets may be more challenging in this scenario because road damage in the East Bay will make accessing sites more difficult. The USGS Haywired study estimates that communications in San Francisco will be fully restored within a week in this scenario.[53]

Level of Confidence

All the communications operators are confident in their understanding of the performance of their systems based on experience in past disasters, preparing for special events like the 2016 Super Bowl and 2019 PSPS event, as well scenario plans and recent exercises.

System Interdependencies

The following table describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

[53] Jones, J.L., et al., 2019

TABLE 8: COMMUNICATION SYSTEM DEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – The restoration of the communications system is coupled with electric power. Except for Department of Technology, few back generators exist for critical communications components. Once battery backup runs out, cell sites will not operate.
Natural Gas	Moderate – Collocated natural gas pipelines damaged by liquefaction may hinder repair of fiber optic cables. Damaged gas lines can also result in precautionary power shutoffs. In certain locations, Comcast relies on natural gas-powered generators.
Water	Moderate – Data centers rely on water for cooling. Collocated water pipelines damaged by liquefaction may hinder repair of fiber optic cables
Wastewater	None
Communications	Significant – Communications providers rely on other providers to operate the fiber network.
Highways and Local Roads	Significant – Roads are required to provide access to crews and equipment to restore network.
Fuel	Significant – Battery backup will help continue operations in the initial hours, followed by backup generators where they are available. Diesel fuel will be needed to resupply generators; however, some operators have local fuel reserves or have hydrogen fuel generators.
Transit	None – Crew and equipment needed for repair and restoration will need to travel with trucks by road. Other staff can largely work remotely if transportation is limited.
Solid Waste	None
Airport	None
Port	Moderate - Comcast plans to deliver personnel, fuel and equipment by water if needed, and may seek options to house crews on ships. Department of Technology has plans to utilize the Port for post-disaster operations. Other operators do not rely on the Port.
Fire Suppression (EFWS)	Low – Immediate fire suppression will reduce damage to assets.

Actions to Speed Restoration

San Francisco should prioritize fuel distribution to generators at City radio sites and data centers to maintain vital information systems.

City radio communication sites will require fuel for generators to continue to operate when there is a long-term power outage. Fuel delivery should be prioritized to these sites to maintain public safety communication systems.

Communication providers should identify locations to add permanent generators at more cell sites and nodes and co-locate cell sites with building solar and battery systems.

Macro cell sites and nodes in San Francisco tend to have 4 to 12 hours of back up battery power before generators are needed to continue operating. Few cell sites in San Francisco (e.g. 14% for Verizon, unknown number for AT&T) have permanent backup generators, one of the lowest penetration rates in the country. Small cell sites (antennas on top of utility poles) do not have battery backup or generators. Placing generators for small cell sites is difficult in San Francisco because they take up space in the public right of way, are not aesthetically pleasing, need to be protected from public access, and must be kept away from entryways and air intakes of buildings. Additionally, some site leases on buildings will not allow for placement of permanent or temporary backup generators due to potential placement of units and the fumes they could emit (e.g. limited space will only allow for generator to be placed near air intakes to residential or commercial buildings).

Where safe to do so, temporary generators can be rolled out in an emergency, but they are often parked outside of San Francisco and bringing them into the city will take additional time due to road access limitations. Placement of temporary generators is also limited to locations that are accessible by crews, protected from the public and that can be permitted. Communication will be significantly impacted by cell sites that lack generators. Communications providers should work with the City of San Francisco to identify those macro cell sites and other facilities that are feasible to add permanent generators or link into building solar and battery systems to expand the availability of cell sites following an earthquake.

Mobile service communication providers should develop agreements to provide emergency mobile wireless to priority locations in the City within a specified time.

Commercial providers have truck and trailer mounted wireless equipment that can be moved to key locations in the City to re-establish wireless communications; however, none is located within city limits. The City should develop agreements with commercial providers to ensure this equipment is in the City and identify key locations where it should be deployed such as city hall and emergency shelters.

Develop a common and flexible identifier for critical communications personnel to ensure access to cordoned areas when safe for service restoration activities.

Developing a common and flexible identifier will help facilitate access to closed or cordoned areas for personnel who are not emergency responders but have critical immediate post-disaster roles in performing damage assessment, inspections, and immediate repairs of critical assets within San Francisco. Communications providers are not typically considered essential emergency responders. In recent disasters, communications repair crews have been denied access to cordoned areas or closed streets. Ensuring that commutations providers and their vendors have immediate access to these areas, when safe, will ensure faster restoration of service. Communications providers also have temporary assets, such as COWS, COLTS and GOATS that may need to be placed in cordoned areas. Providing a letter on official company letterhead or memo stating that specified communications company personnel and identified vendors may be granted access to closed roads as other disaster service workers would avoid having to call and request access for each road/site that needs to be visited.

Identify staging locations for personnel supporting communications restoration.

Large numbers of restoration crews will be required by private communications providers to inspect and repair cell sites, fiber lines and other communications infrastructure. In recent disasters elsewhere, RV parks have served as staging areas; however, few existing locations within San Francisco will provide adequate space to pursue this option. Partnership between the City and other business owners to pre-identify parking lots and equipment storage locations that can be used by communication providers could help speed recovery and restoration of vital services. Other private lifeline providers will also have this issue and this strategy should be coordinated with those providers as well.

Identify ways to ensure communications providers and other lifeline operators coordinate restoration activities.

Communications providers are not usually considered utilities and do not participate in the City's EOC. However, communications assets are located on SFMTA utility poles and co-located with other utilities below the street. Restoration activities and street clearance needs to be coordinated between all major utility and service providers. The faster these parties can be brought into common physical space after a disaster, the faster restoration can begin. The Lifelines Council should explore what the post-disaster coordination process will be between member lifeline organizations and how and when it will be activated.

Highways and Local Roads

Highways, bridges and roadways facilitate residents, workers and visitors traveling within San Francisco and throughout the Bay Area, which supports economic activity, goods movement, and quality of life. Roadways are used by vehicles, bicycles, pedestrians and transit services. In an emergency, roads are critical for moving supplies, materials, equipment and workers to support response and recovery.

Highways and Local Roads

Operators: Caltrans, Golden Gate Bridge Highway and Transportation District, Public Works

At A Glance

Key Findings

- The road network will take more than a year to be fully restored because of the number of road sections that need to be demolished and rebuilt or impacted by damaged underground utilities, especially in liquefaction areas.
- Caltrans and Golden Gate Bridge have retrofitted freeways and bridges to provide a minimum level of regional travel within hours of an earthquake.
- Local roads will be flowing despite detours and ongoing construction within a few days to a few weeks.
- The road network depends on power, telecom and fuel to operate. Users also rely heavily on transit until the freeways and bridges reopen. Restoration of local roads is highly dependent on restoration of underground utilities.
- Personnel critical for immediate post-disaster inspections and repairs increasingly live outside San Francisco. Depending on time of day of the event, initial inspections and restoration could be constrained by staffing resources until access across the Bay is established.
- San Francisco has limited access points and few freight traffic routes that can handle heavy vehicles for delivery of recovery critical supplies and equipment.
- Some Caltrans owned surface streets in San Francisco will be high priority for debris removal and clearance for San Francisco but are secondary priority for Caltrans, which has regional priorities for post0disaster debris removal.

Actions to Speed Restoration

- San Francisco should work with Caltrans and GGBHTD to identify protocols for granting access to bridges for repair crews.
- SFO should improve the reliability of priority utility systems in an earthquake.
- SFMTA and SF Public Works should designate freight traffic routes as disaster recovery critical supply routes and protect them from damage in an earthquake.
- Caltrans should delegate responsibility for clearing local priority state routes to local jurisdictions in an emergency.

Restoration Performance Goals

Bay Bridge and State Highways

Caltrans has established the following performance standards for its elevated assets, including Bay Crossings and freeway structures:

- **Lifeline performance standard:** The asset is deemed highly critical for the immediate movement of emergency equipment and supplies into or through the region. The asset may still suffer some damage, but will be easily repairable and immediately usable by emergency responders after a Maximum Credible Earthquake (MCE) event earthquake (approximately M8.3 on the San Andreas Fault), but will likely be closed to general traffic. The lifeline routes create a continuous link around and across the Bay. They include The Bay Bridge and Benicia-Martinez Bridge, I-280, I-680, CA-24, CA-116/12 between US 101 and I-80, I-238/580 east of I-880 and US 101 south of I-280 in San Jose and north of the Golden Gate Bridge.
- **Serviceable standard:** The asset will suffer damage, but can be restored in relatively short period (about 6 months). The remaining five Bay crossings (Antioch, Carquinez, Dumbarton, Richmond-San Rafael, and San Mateo-Hayward bridges) are designed to this standard, as are other major bridges on Caltrans-maintained routes.
- **Non-Collapse standard:** The asset will not collapse, but will have to be demolished. Most elevated freeway structures, overcrossings and interchanges are designed to this standard. Detours could quickly be established around these structures.

Figure 11 illustrates the performance standards for major Bay Area Caltrans assets.

Golden Gate Bridge

Once the Golden Gate Bridge seismic retrofit program is complete, the bridge and its approaches will provide for serviceability and functionality after the maximum credible event (MCE). The District's seismic design performance goal is to provide for serviceability and functionality of the bridge after the maximum credible earthquake, with only limited repair.

Local Roads

Public Works seeks to restore surface transportation as soon as possible following an earthquake, however Public Works has not yet adopted specific performance goals for surface roads or bridges for which the City is responsible.

System Restoration Timelines

The service restoration timeline shown in **Figure 10** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

SERVICE DISRUPTION LEVELS

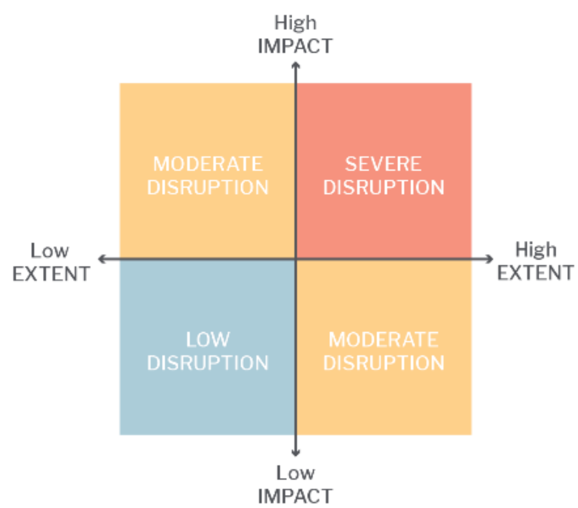
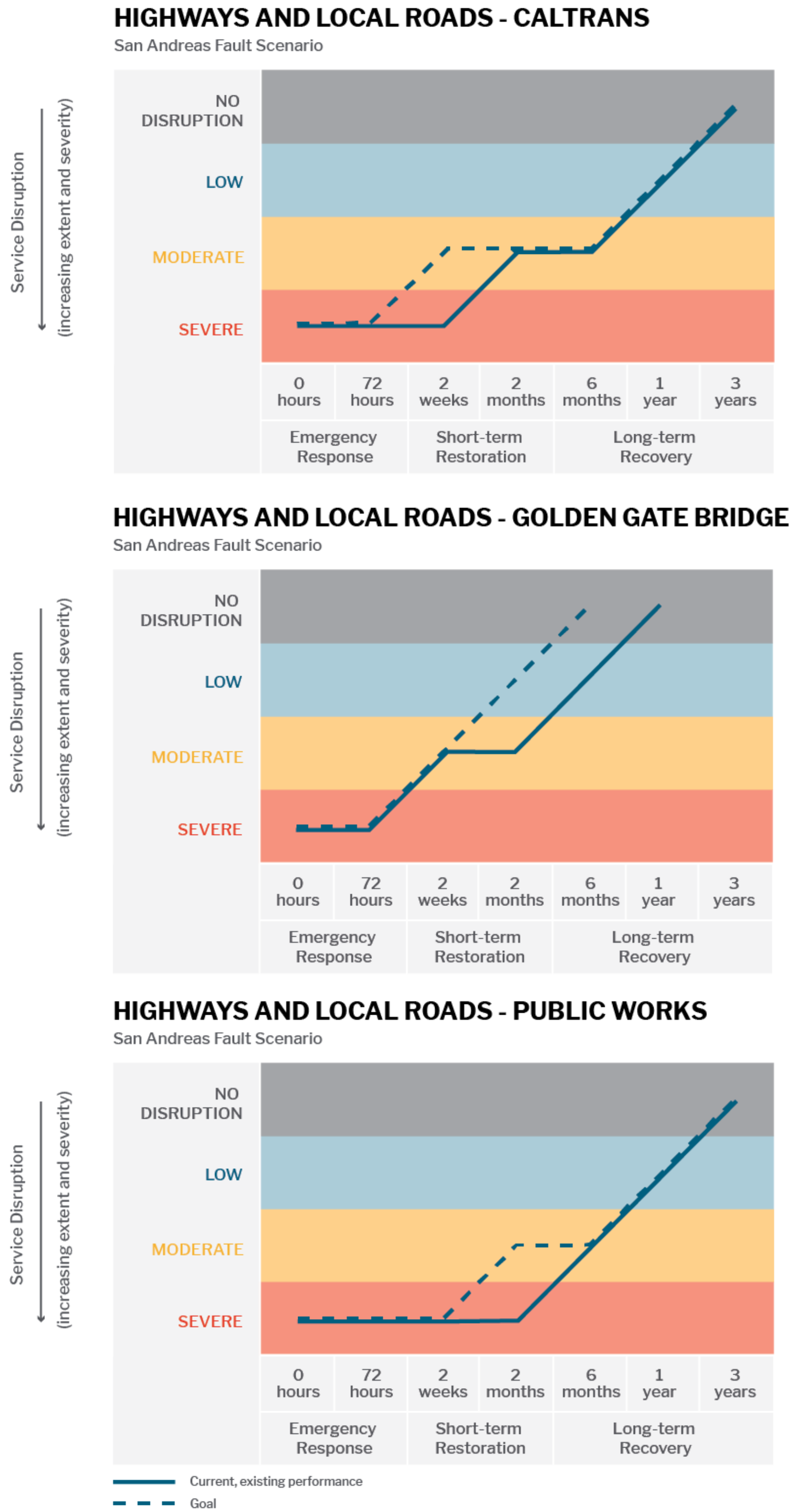


FIGURE 10: HIGHWAYS AND LOCAL ROADS SYSTEM RESTORATION TIMELINES



Sector Overview

The greater Bay Area is served by over 1,400 miles of state highways and another 20,000 miles of local roadways, as well as seven Bay crossings. **Figure 11** shows the major freeways and highways in the region as well as the major surface streets within the City and County of San Francisco.

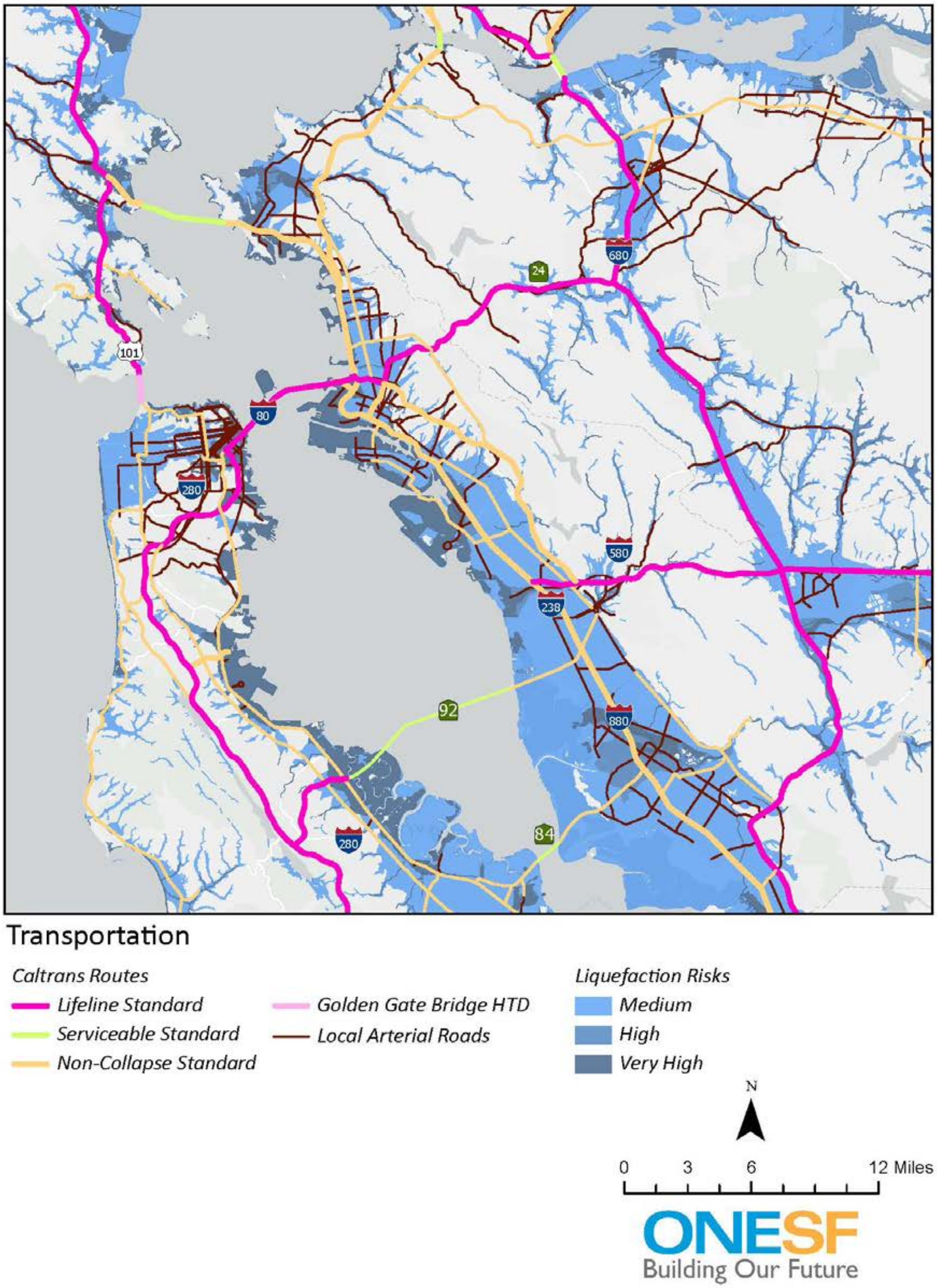
Due to its unique geography, San Francisco can only be accessed by a few key roads. The Bay Bridge is the only direct route to the East Bay, serving an average 278,000 vehicles a day.[54] US-101 and I-280 provide primary access to San Mateo County and points south; both corridors include numerous bridges and elevated freeway structures. Southern access is also provided on surface roads that include US-1, CA-35, and CA-82. The Golden Gate Bridge provides access to Marin County and points north, serving an average 113,000 vehicles a day.

Caltrans owns and operates these state and federal highways and interstates, as well as the Bay crossings, except for the Golden Gate Bridge. The Golden Gate Bridge is owned and operated by the Golden Bridge Highway Transportation District (GGBHTD). Spanning 1.7 miles from abutment to abutment, the Golden Gate Bridge is made up of six separate structures. Presidio Parkway, formerly known as Doyle Drive, is the southern access road to the bridge and is owned and operated by Caltrans. A new seismically safe approach structure was completed in 2015.

The San Francisco Department of Public Works owns, maintains and inspects approximately 13,000 blocks of local roads, 92 bridge structures (including vehicular bridges, pedestrian bridges, and movable bridges), and 370 road structures (including retaining walls and tunnels). Public Works maintains components above the deck for local bridges and inspects bridges owned by Caltrans within City limits. These bridges include parts of city streets that span over freeways and freeway bridges that span over city streets. Caltrans is responsible for inspecting its freeway viaducts and connector ramps. Public Works also inspects and maintains components above the road deck of a number of bridges over the Caltrain right-of-way. The bridges are under the jurisdiction of the Peninsula Corridor Joint Powers Board (PCJPB) that operates Caltrain.

[54] California Department of Transportation. "Traffic Census Program". Accessed February 22, 2019. http://dot.ca.gov/trafficops/census/ (2017 Traffic Volumes: Annual Average Daily Traffic)

FIGURE 11: HIGHWAYS AND LOCAL ROADS SYSTEM MAP



System Upgrade and Disaster Planning Efforts

Bay Bridge and State Highways

Several Bay Area highways and bridges experienced catastrophic failures in the Loma Prieta earthquake. The most notable damaged structures were the Bay Bridge, the Embarcadero and Central freeways in San Francisco and the Cypress Freeway in Oakland, as well as closure of Highway 17 over the Santa Cruz Mountains for 33 days due to landslide damage.[55] Since that time, Caltrans has spent over $12 billion statewide to seismically strengthen and prevent collapse of 2,200 of its 12,000 bridges and overpasses statewide.[56]

In 2013, Caltrans and the Bay Area Toll Authority completed all planned retrofits of its elevated freeway structures and the seven state owned bay crossings, including replacement of the eastern span of the Bay Bridge. Even as this statewide retrofit program is completed, Caltrans continues to learn from earthquakes across the state and update design standards. These learnings will be applied as Caltrans has the opportunity to further modify its structures.

Golden Gate Bridge

While the Golden Gate Bridge suffered no damage in the Loma Prieta earthquake, a vulnerability study following the earthquake concluded that a closer and larger earthquake could cause severe damage to the Main Suspension Bridge and other bridge structures, and would pose a substantial risk of collapse to the San Francisco and Marin approach viaducts and the Fort Point Arch.[57] A three-phase retrofit program began in 1996 with Phase 1 addressing the Marin (north) Approach Viaduct, Phase 2 addressing the San Francisco (south) Approach Viaduct, San Francisco (south) Anchorage Housing, Port Point Arch and Pylons S1 and S2, and Phase 3A addressing the North Anchorage Housing. Phase 3B, the final phase, to retrofit the Main Suspension Span Bridge, is currently in final design phases Construction will take approximately 5 years once it

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[55] Ca Dept of Conservation Division of Mines and Geology. 1990. "The Loma Prieta (Santa Cruz Mountains) California, Earthquake of 17 October 1989". Retrieved from http://www.co.contra-costa.ca.us/DocumentCenter/View/34132/CGS-1990--SP-104-Loma-Prieta.

[56] Ca Dept. of Transportation. "Seismic Retrofit Program". Accessed February 22, 2019. http://www.dot.ca.gov/hq/paffairs/about/retrofit.htm.

[57] Golden Gate Bridge, Highway and Transportation District. "Overview of Golden Gate Bridge Seismic Retrofit Construction Project". Accessed October 19, 2018. http://goldengatebridge.org/projects/retrofit.php.

begins. In 2015, Caltrans completed the Presidio Parkway project, a seismically safe replacement of Doyle Drive, the southern access road to the bridge.

Local Roads

Beginning in the mid-1990's, following the Loma Prieta earthquake, City-owned bridges were seismically analyzed and, if necessary, retrofitted to meet the standards applicable at the time. Public Works is in the process of developing a plan to identify the most important bridges within the City and perform a new seismic analysis to make sure that these structures meet current seismic design standards. The following seismic improvement work has been completed or is underway for City-owned bridges:

- Seismic retrofit design for Islais Creek Bridge is currently underway, with construction anticipated to begin in early 2020. This project will bring the bridge up to current seismic design standards.
- The Third Street Bridge is scheduled for rehabilitation work to be completed in April 2020 to sustain the integrity of the bridge and to address corrosion issues and extend the useful life of the bridge.[58]
- In 2016, the 23rd St Bridge and Paul Avenue Bridge were replaced and the abutments retrofitted by Peninsula Corridor Joint Powers Board (PCJPB) that operates Caltrain as part of its San Francisco Roadway Bridges Project after they were determined to be seismically deficient.
- The historic Fourth Street Bridge was seismically retrofitted in 2005. The retrofit included the integration of the new Third Street Light Rail that reestablished rail service between San Francisco's downtown and key points along the Bayshore Corridor.

Public Works is also evaluating establishing a post-earthquake team with bridge engineering experience to immediately inspect high priority bridges within the City after a seismic event.

In the mid-2000's battery backup systems (BBS) were installed by SFMTA on traffic signals at 70 key intersections to ensure they would remain functional in power outages. However, due to lack of continuing funding for battery replacement and ongoing maintenance, these systems became non-functional after several years. New funding secured by SFMTA revived the BBS at the 70 intersections with newer technology that allows the batteries to be switched out more easily. Ongoing funding is needed to

[58] San Francisco Department of Public Works. "Third Street Bridge Rehabilitation Project" Accessed April 22, 2020. http://www.sfpublicworks.org/ThirdStreetBridge.

replace batteries when they reach the end of their life. The batteries typically last for about 2 hours until they are drained. SFMTA has a limited set of spare batteries that can be swapped out for dead batteries that can then be recharged at another location that has power. Due to the limited number of spare batteries and short duration of charge, these batteries will only serve a short period and are not a feasible alternative for long outages. Solar panels on power poles do not provide enough power to recharge batteries; they must be recharged by electric power when it is available. Portable generators are also not a feasible alternative for charging batteries because of safety and security concerns with generators in the public right of way.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

The San Andreas Fault scenario will have the greatest impact on the local roads and highways within the City and County of San Francisco. This is not the worst-case scenario for the regional road network. Streets in the liquefaction zone in the eastern portion of the city could suffer damage due to liquefaction in this scenario, especially if pipes break or fail. In the Loma Prieta earthquake, most streets were damaged because of failing infrastructure, including sewer, water and gas pipe breaks. The City expects the possibility of some significant damage to its local bridges, which may result in closure of these bridges and the roadway (or waterway) below. However, San Francisco does not expect collapse since they were likely retrofitted to an equivalent of the Caltrans "non-collapse" standard.

The Bay Bridge and regional lifeline routes will remain operational in this scenario, but will initially be closed to general traffic for inspections in the first 72 hours. The Oakland Touchdown to the Bay Bridge will experience liquefaction damage that will likely be temporarily repaired within the first 72 hours. The West Approach was retrofitted as part of the Bay Bridge replacement project and is unlikely to sustain significant damage in this scenario earthquake.[59] Even as these routes are closed to general traffic, emergency vehicles will be granted access by the CHP where possible. Other critical personnel may be granted access as well by coordinating with the Caltrans Emergency Operations Center.

[59] Ca Dept. of Transportation. "The San Francisco Bay Bridge Seismic Safety Projects: West Approach". Accessed April 22, 2020. https://www.baybridgeinfo.org/projects/west-approach

While the Bridges and Interstates are initially closed for inspections, the San Jose Avenue (and Mission Street) connectivity to El Camino Real (CA-82); Bayshore Boulevard; and Sloat Boulevard/Great Highway's connectivity to Skyline Boulevard (CA-35) will become major entry points to the City. I-280 is designed to Caltrans' lifeline standard and will likely be shut down for inspection in the initial aftermath of an earthquake. US 101 North and the Waldo Tunnel will likely be closed due to landslides, limiting travel out of the City on the Golden Gate Bridge for a potentially long period of time.

Local roads will experience liquefaction and damage from broken underground utilities. Debris from damaged buildings may also close local roads initially. While some roads will be blocked due to liquefaction, utility damage or debris, the local road network is highly redundant and alternate routes will be possible to most locations until Public Works is able to assess damage and clear debris on key routes.

Hayward Fault Scenario

The Hayward Fault scenario will have the greatest impact on the regional transportation network. The bridges and overpasses on the major regional interstate routes of 880, 580 and 80 are mostly designed to non-collapse standard and many will likely need to be replaced. 880 in Oakland carries the highest volume of traffic in the region, with most trucking and supplies coming into the region through 880/80 to and from the Port of Oakland. 580 in Oakland, 80 through San Pablo, CA Routes 13 and 24 in Oakland, and the Richmond Parkway connecting 580 and 80 all cross the Hayward Fault in areas where significant displacement is likely.[60] Additionally, there are 37 highway, 127 secondary and 424 surface street crossings of the Hayward fault in Contra Costa and Alameda counties.[61]

Interstate 680 is designated a lifeline route by Caltrans that should perform well in a large earthquake. The Carquinez Bridge replacement project on the 680 corridor was completed in 2003 and will also perform well, but it is not designed to the lifeline performance standard. Interstate 680/CA-24 will be the best viable route to access the Bay Bridge if Interstate 580, 80 and 880 are damaged, however the Caldecott Tunnel will likely sustain fault rupture damage in the Hayward scenario. The Bay Bridge is also designed to a lifeline performance standard and will be operational immediately after an earthquake; however, the bridge will be initially closed for inspection even as emergency

[60] Jones, J.L., et al. 2019.
[61] Jones, J.L. et al. 2019.

vehicles are allowed to continue to use the bridge. There will also likely be liquefaction and buckling damage to the eastern approach that may impact the ability of vehicles to access the bridge, but that could be potentially temporarily repaired within the first 72 hours after this event.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 9 describes the existing level of service disruption for the assets and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 9** reflects the current, existing performance in the Restoration Timeline in **Figure 10** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 9: HIGHWAYS AND LOCAL ROADS RESTORATION TIMELINE

	Bay Bridge and State Highways*	Golden Gate Bridge	City-Owned Roads and Bridges
0 Hours	Activate EOC, launch damage assessment, close damaged roads, establish traffic control and inspect bridges. Close Bay Bridge and interstates to general traffic for damage inspection while maintaining access for emergency vehicles and other priority uses. The first 72 hours will be difficult to manage, with many road closures.	Immediately close the Golden Gate Bridge for damage inspection, with the goal of completing inspections within 12-24 hours. People on the bridge during the earthquake will likely be asked to abandon their cars and walk off the bridge. Abandoned cars will later be towed to a secure location for owner reclamation. Inspections will begin as vehicles are being towed.	All Public Works staff report to their assigned mobilization area. Deploy Windshield Inspection Teams within 4-8 hours to assess road damages and debris on all primary and secondary routes and critical facilities to determine which roads are passable and which need debris clearance and repairs.
72 Hours	Plan route recovery, perform quick paving operations and	Caltrans is responsible for inspection of Presidio	Complete windshield survey and prioritize routes for

	Bay Bridge and State Highways*	Golden Gate Bridge	City-Owned Roads and Bridges
72 Hours (cont.)	establish detours around damaged structures. For areas with limited access, establish priorities for buses, carpool, and emergency vehicles. Even if bridges and overpasses are not damaged, the approaches may not be accessible because of freeway damage. Work quickly to identify detours around them. The Eastern Bay Bridge Touchdown may require temporary repairs to mitigate liquefaction damage that will be completed within 72 hours. The focus of the initial damage assessment and reopening efforts will be on interstate freeways and toll bridges. State owned surface roads will be assessed and cleared as resources allow and priority is identified. Bay Bridge may reopen to general traffic within 72 hours.	Parkway approaches from the south. Initiate needed repairs for the bridge following completion of damage inspection. The Bridge continues to be open to emergency response vehicles and some controlled evacuation traffic. US 101 South and the Waldo Tunnel (in Marin County) will likely be closed due to landslides, limiting travel into the City on the Golden Gate Bridge, potentially for an extended period of time. Alexander Ave in Marin County is a possible alternate route onto the Bridge.	debris clearance and emergency repairs within 72 hours if staff resources are available and major roads are passable. The future goal is for windshield survey to be completed within 48 hours. Clear debris and make priority roads safe and passable. Most major roads should be cleared by 72 hours. Initiate repairs, depending on resources and available contractors.
2 Weeks	Stabilize traffic patterns.	Continue to perform repairs on the road surface and joints. The bridge may not be fully open to general traffic yet, but a few lanes should be open for emergency vehicles. Use by the public may be restricted to certain days/times.	Continue to clear debris, perform repairs and making roads safe and passable. Most major roads should be cleared.
2 Months	Initiate repair of damaged facilities.	Open the Bridge to general traffic, but some lane closures for repairs may remain.	Start to make permanent repairs to roads that are easier to repair; however,

	Bay Bridge and State Highways*	Golden Gate Bridge	City-Owned Roads and Bridges
2 Months (cont.)			construction will close roads, so impact remains severe. Alternate routes will be established for construction on major arterials. Repairs to roads depend on repairs to underground construction. Prequalifying contractors will speed repairs and more restore service more quickly.
6 Months	Establish permanent detours around facilities that need to be repaired and replaced.	Some repairs may still be ongoing, but disruption may be limited to closed lanes at night or other limited periods.	Some repairs are complete and some damaged roads will be reopened that had minor infrastructure damage.
1 Year	Only severe damage that will take more than 1 year to repair will remain impacted, especially if San Francisco takes the opportunity to remove freeways that cut through neighborhoods. Within the City, this level of damage is most likely on US 101. Overall impact is low at this point because interim traffic management solutions will be implemented, and people will have adjusted travel patterns.	The Golden Gate Bridge will be fully restored to normal operations.	Some repairs may remain, but most roads are reopened
3 Years	All damages are repaired and the road network will be fully restored to normal operations.		Local roads will be close to normal, but roadways are never completed and they are always being repaired and upgraded.

*Worst case scenario for Caltrans highway system is Hayward fault earthquake.

Hayward Fault Scenario

For the regional roads and bridges, the initial response phase will be the same. However, the Hayward fault scenario is more significant for Caltrans because of significant anticipated damage to critical regional highways, I-880, I-80 and I-580. The bridges and overpasses on these routes are mostly designed to non-collapse standard and many will likely need to be replaced. Freeways that cross the fault may also experience significant damage. The Bay Bridge and lifeline routes will be operational in both scenarios.

Fuel access is a greater concern in the Hayward fault scenario, as well as availability of workers. Many laborers live in the East Bay or even farther east and depend on bridges to cross the Bay. The Golden Gate Bridge will likely only receive minor damage in the Hayward fault scenario. It may be closed for the initial 12-24 hours for inspection; however, it is anticipated to be open to the public within 72 hours.

For City-owned roads, there will be less road damage due to liquefaction, less damage to underground utilities and less debris that would otherwise cause road closures.

Level of Confidence

Caltrans bases its impact assessment and restoration estimates on extensive network modeling that included hazard and damage modelling performed for the seismic retrofit program, as well as learning from other disasters across the state and the world. Caltrans regularly works with researchers to identify and implement the latest technical advances.

The GGBHTD bases its impact assessment and restoration estimates on the performance objectives of its seismic retrofit program as well as the USGS Haywired scenario[62], ABAG Cascading Failures report[63], the Bay Area Earthquake Plan and lessons from past disasters.

Public works bases most of its understanding of impacts and restoration estimates on experience in the Loma Prieta earthquake and seismic assessments of the local bridges.

System Interdependencies

Power, telecom and fuel are the primary interdependencies for operating the road network. Users will also rely heavily on transit until the freeways and bridges reopen. Restoration of local roads is highly dependent on restoration of underground utilities. The table below describes the dependence of roads and highways on all other lifeline systems and is shaded according to the degree of dependence.

[62] Detweiler, S.T., and Wein, A.M., eds. 2018.
[63] ABAG. 2014.

Table 10 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 10: HIGHWAY AND ROAD SYSTEM DEPENDENCIES

Sector	Extent of Dependence on Sector
Electric Power	Significant – Signals, controls sign, cameras, ramp meters, pump stations, and Caltrans EOC (has backup power) and Transportation Management Center rely on electricity.
Natural Gas	Significant – Damage to gas pipes will limit ability to restore surface streets. Natural gas powers asphalt plants; low for regional highways and bridges.
Water	Significant – Damage to water pipes will limit ability to surface streets; low for regional highways and bridges.
Wastewater	Significant – Damage to wastewater pipes will limit ability to restore surface streets; low for regional highways and bridges.
Communications	Significant – Damage to fiber network will limit ability to restore surface streets.
Highways and Local Roads	Significant – Traffic can't get on and off highway system without local roads and local traffic depends on Caltrans clearing highways and state owned surface streets.
Fuel	Significant – Most vehicles and construction equipment rely on fuel.
Transit	Significant – Transit will be important for managing displaced traffic and getting personnel into the city.
Solid Waste	Low – Only to the extent that solid waste collection will impact debris clearance operations.
Airport	Moderate – Caltrans may use the airport to deliver supplies and personnel; low for Public Works and Golden Gate Bridge.
Port	Moderate – Caltrans may deliver supplies and personnel via ferries. May be able to establish ferry landings where we don't have them right now at Redwood City, Larkspur and Oakland to help with traffic handling.

Sector	Extent of Dependence on Sector
Fire Suppression (EFWS)	Moderate – Damage to EFWS pipes will limit ability to restore surface streets.

Actions to Speed Restoration

San Francisco should work with Caltrans and GGBHTD to identify protocols for granting access to bridges for repair crews.

Granting access to bridges for personnel who are not emergency responders but have critical immediate post disaster roles in performing damage assessment, inspections, and immediate repairs of critical assets within San Francisco is essential to speedy restoration. Personnel critical for immediate post-disaster inspections and repairs increasingly live outside San Francisco or the Peninsula. Depending on time of day of the event, initial inspections and restoration could be constrained by staffing resources until access across the Bay is established.

Transportation inspection, maintenance and repair crews rely heavily on the regional road network or transit systems to get to the San Francisco to perform their work if the event occurs outside of normal work hours. 38% of Public Works' 1,567-member staff must cross of bridge to get to work, including 83% (25 of 30) street inspectors and 50% (10 of 20) engineers. 75% of Golden Gate Bridge District's personnel must cross a bridge to access either the north or south end of the Golden Gate Bridge. Caltrans has a maintenance station in San Francisco and contractors working on nearby projects that can respond immediately to the event, but additional Caltrans crews, emergency contractors and mutual aid resources will need to be brought in from outside the City. It is not only transportation agency staff that will need to cross the bridge to perform damage assessment, inspections and initiate repairs, personnel from every lifeline provider, both public and private will need to transport their personnel, many of whom don't live in San Francisco, into the City in the immediate post disaster phase. Some of these personnel could be transported by ferry, but many of them rely on work trucks and need to haul equipment and materials that require vehicular access to the City.

Because the Bay Bridge is designed to lifeline performance standard, these personnel could be granted access to the Bay Bridge and Golden Gate Bridge. However, damage to bridge access routes may still make Bay crossings challenging. Bridge access will be controlled by the CHP. Agencies that wish to have their priority personnel have access to the bridge immediately will need to coordinate among Caltrans, GGBHTD and EOCs in San Francisco, Marin and Alameda Counties. Ultimately, bridge access will be up to the judgement of the CHP officer at the bridge. Many public employees have Disaster Service worker identification that will help identify them to CHP officers. However, private lifeline companies, particularly communications companies, are unlikely to have disaster service worker identification and are less likely to have representatives in local EOCs who can highlight the needs of their personnel to access the bridge. Ultimately, San Francisco's efforts to preserve and expand affordable and workforce housing options within the City are critical to ensuring that these critical responders can continue to live within San Francisco and be available to respond to emergencies.

SFMTA and SF Public Works should designate freight traffic routes as disaster recovery critical supply routes and protect them from damage in an earthquake.

San Francisco has limited access points and few freight traffic routes that can the handle heavy vehicles for delivery of recovery critical supplies and equipment. Freight traffic routes connect industrial and commercial areas and the regional and state freeway system.[64] Immediately after an earthquake, a functioning road network is critical for movement of emergency vehicles and personnel, damage assessment of critical facilities and resumption of critical services.

San Francisco's Emergency Route Reopening Guide[65] depends on emergency personnel to navigate damaged or blocked streets for themselves before a complete picture of roadway status is available in the immediate 72 hours after an event with the assumption that if one street is blocked an alternate road will be available. While surface roads are highly redundant in this geographically small city, the performance of nearby streets is also highly correlated; damage or debris on one street is likely to mean damage and debris on nearby streets.

Within the first 4 to 8 hours, Public Works will coordinate deployment of Windshield Inspection Teams to assess road damages and debris on all primary and secondary routes and critical facilities to determine which roads are passable and which need debris clearance and repairs. This information will be used to identify routes that are

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[64] City and County of San Francisco, General Plan Transportation Element. Retrieved from https://generalplan.sfplanning.org/I4_Transportation.htm
[65] City and County of San Francisco, Department of Emergency Management. 2018.

blocked or damaged, but reopening and repair is prioritized based on operational objectives.

The San Francisco Municipal Transportation Authority (SFMTA) designates only a few routes in San Francisco as freight traffic routes that are candidates for handling the large trucks and equipment necessary for initiating recovery of the City. These freight traffic routes are important to facilitate removal of debris, transport equipment and material for repairs and rebuilding, and delivery of food, fuel and other supplies. These routes are designed for higher loads and bigger vehicles and most vehicles using these roads cannot use alternate roads for delivery into and within the City. Freight traffic routes should be protected from utility damage and building debris that would result in prolonged closure of these critical routes. The Transportation Branch of the EOC is led by SFMTA and responsible for finding the detour, staff, and equipment needed to provide transportation from point A to B when the usual route, people and equipment is not available. Public Works role will be prioritizing and opening the roads themselves. Reinstating the supply chain will be the shared responsibility of these departments.

To increase the likelihood that these routes will be functional and accessible after an earthquake, the following actions should also be taken:

- Develop signs indicating routes that are designated for use by emergency personnel during an emergency and educate motorists that if they find themselves on a disaster response route during an emergency, to exit the route as soon as possible to make way for first responder personnel. See British Columbia Disaster Response Routes as an example.[66]
- Pre-register and provide access to contractors involved in post-disaster inspections and repairs and manage access on critical supply routes to prevent bottlenecks of people and resources waiting for permission to travel over roadways closed to the public or entering restricted areas. Best practices on this strategy can be found in the Crisis Event Response and Recovery Access Framework developed by DHS.[67]

[66] Government of British Columbia. “Disaster Response Routes”. Accessed May 1, 2019. https://www2.gov.bc.ca/gov/content/transportation/driving-and-cycling/traveller-information/routes-and-driving-conditions/disaster-response-routes.

[67] U.S. Department of Homeland Security. “Crisis Event Response and Recovery Access”. Accessed May 1, 2019. https://www.dhs.gov/publication/crisis-event-response-and-recovery-access.

- Map significant utilities below critical supply routes to identify locations that would likely need repair after a disaster and develop a strategy to upgrade or relocate critical utilities or components, if possible.
- Prioritize seismic retrofit of buildings along critical supply routes to reduce the likelihood of damaged buildings blocking routes.

Caltrans should delegate responsibility for clearing local priority state routes to local jurisdictions in an emergency.

Through a delegated service agreement, Public Works is responsible for the normal maintenance and inspection of most state highways within San Francisco. However, in a disaster Caltrans is fully responsible for post-earthquake inspection and debris clearance of all its assets. While all Caltrans roads within San Francisco are high priority routes for debris clearance for San Francisco, these routes are secondary priority for Caltrans which will focus its initial efforts on inspecting and clearing Bay crossings and interstate highways in support of regional priorities. In an emergency, San Francisco will likely not wait for Caltrans to begin debris clearance on these roads, however federal reimbursement for these in a presidentially declared disaster could be at risk. To ensure immediate clearance of all high priority state highways within the City of San Francisco and ensure reimbursement for this emergency work, Caltrans should delegate responsibility for clearing priority state routes to local jurisdictions while Caltrans is focused on clearing its interstate highways and major bridges.

Following completion of highway inspections, Caltrans should work with local government through the EOC to identify local priorities for debris clearance and repairs of state highways. As its resources allows, Caltrans can also provide mutual aid to local governments to help remove debris from non-state highways.

Additional restoration actions

- SFMTA should secure funding to ensure battery replacement and maintenance of existing battery backup system for traffic signals at 70 intersections and expand the program to additional priority intersections.
- Speeding windshield surveys of local roads is key to improving the restoration of the road network. Public Works can develop risk models that predict likely road closures before an earthquake and use PGA based triggers to initiate and prioritize road inspections based on likely damage to utilities and buildings. Inspections should also be prioritized for access to critical facilities like hospitals, police and fire, and PG&E and SFPUC assets.

- To improve department coordination and speed damage data collection, Public Works should work with SFPUC, SFMTA and other lifeline operators to provide a mechanism for inspectors performing windshield surveys and damage assessments to provide information on damage of other systems as they come across it during their own inspections.
- To enhance the availability of local staff to perform inspections, Public Works should train alternative staff, such as MTA's PCOs, that live in SF on street inspection procedures and activate the public to send information on condition of their streets through 311. Usage of drones or helicopters from outside agencies could also speed assessments.
- All Public Works vehicles in the southeast portion of San Francisco are in the 12th Street garage where there is high liquefaction potential. A satellite yard could improve response time.
- In the initial 72 hours, Public Works will also be gathering information about available contractors to do emergency repairs. If these contractors were prequalified before the event, it could help speed the process.
- Public Works will need to communicate the state of the roads with other sectors and City agencies to prioritize repairs; however, the windshield survey teams relies on cell phones and tablets and does not have radios that are part of the City's new 800mHz system. Windshield survey teams should be provided with 800mHz radios to assist with communications of road conditions to other sectors and city agencies.
- All 311 reports on roadway damage will go through the Public Works Department Operations Center and staff will need to confirm the reports and identify the difference between potholes and sinkholes. Sinkholes are an indication of sewer pipe or other utility damage. This information will be forward to SFPUC for inspection of their pipes.
- Public Works relies on two granite rock asphalt plants located in Redwood City and South San Francisco which may be damaged and road access to the plants limited. These plants also rely on natural gas, which may have a long restoration timeline. There will also be high competition from other cities for these supplies. Public Works is working on a public private partnership to get an asphalt plant within City limits on the Pier 94 backlands. Evaluation of this pier is needed to understand if it will survive an earthquake. Additional asphalt production capacity is a good thing for the City, however it is likely that the conditions which may shut

off production at the plants in Redwood City and South San Francisco are also likely to shut off a facility within San Francisco.

- While the Golden Gate Bridge expects to be immediately operational, landslides on US 101 may restrict access into the Waldo Tunnel and San Francisco, cutting of a major transportation route in and out of San Francisco and a key link in Caltrans' local lifeline routes. Caltrans should assess the landslide risk along this section of US 101 and perform any necessary remediation to prevent landslides that would shut down this route in the scenario event.
- San Francisco residents will also need to move around the City following an earthquake. To the extent that San Francisco is encouraging alternative mobility options such as walking and biking today to reduce congestion and greenhouse gas emissions, this will also relieve pressure on the road network in a post disaster situation where priority access will be given to emergency vehicles, repair crews, and buses or other mass transit. The ability to recharge or fuel vehicles in the immediate post disaster phase could also be challenging, so relying on these basic forms of transportation will speed San Francisco's recovery and provide a minimum level of mobility for able bodied residents.
- San Francisco should work with the Metropolitan Transportation Commission and other County Operational Areas to better understand how local transportation priorities will be reconciled with regional transportation priorities.

Potable Water

The San Francisco water system, operated by SFPUC, serves 2.7 million residential, commercial, and industrial customers in the Bay Area. Approximately one-third of the delivered water goes to San Francisco and the remaining two-thirds is delivered to 27 wholesale agencies in Alameda, Santa Clara, and San Mateo counties. The system is comprised of the Hetch Hetchy Source, a regional system, and an in-city system.

Potable Water

Operator: SFPUC

At A Glance

Key Findings

- Water service could be severely disrupted for the first 72 hours with moderate disruption after two weeks following a major earthquake. Within two months, most pipe breaks will be repaired and most buildings will have water service, except in high liquefaction areas. Full restoration is expected within 6 months.
- The water system is highly dependent on water delivery, wastewater, and EFWS and has significant dependencies on communications, highways and local roads, power, natural gas, fuel, and transit. The water system is also dependent on ferries for employee transport.
- The $4.8 billion Water System Improvement Program (WSIP) upgraded dams, tunnels, treatment facilities, pipelines, pump stations, reservoirs and tanks to enhance the seismic reliability of some primary facilities of the regional water transmission system between Hetch Hetchy and the terminal reservoirs, but some local failures are still expected.
- Some, but not all, distribution pipes have been hardened and there will be significant breakage of smaller distribution pipes that deliver water from the reservoirs to customers.
- San Andreas scenario will have a greater impact on the in-city system. The Hayward scenario will shake the regional system harder, but the system has been designed to meet minimum water service delivery goals following the design earthquake scenarios.

Actions to Speed Restoration

- SFPUC should analyze the seismic reliability and expected restoration time of the in-city water distribution system and develop an upgrade strategy.
- SFPUC should identify key facilities that should be prioritized by PG&E for power restoration.
- SFPUC should stockpile critical spare parts needed for emergencies.
- SFPUC should work with lifeline sectors co-located in city streets to coordinate post-earthquake emergency response and restoration work.

Restoration Performance Goals

In 2017, SFPUC adopted the following seismic reliability level of service goals for the regional and in-city water systems.[68] These goals are an update to level of service goals adopted in 2008. In addition to seismic reliability goals, SFPUC has adopted level of service goals for water quality, delivery reliability, water supply, environmental stewardship, and economic, environmental and social sustainability. The goals are primarily being met through implementation of the Water System Improvement Program (WSIP).

Regional seismic reliability:

- Design water system improvements to meet current seismic standards, and over time regularly evaluate the ability of the system to meet current seismic standards.
- Deliver basic service to the three regions in the service area (East/South Bay, Peninsula, and San Francisco) within 24 hours after a maximum credible earthquake on the San Andreas, Hayward or Calaveras faults. Basic service is defined as average winter-month usage of 229 million gallons per day (mgd). The performance objective will provide delivery to at least 70% of the turnouts in each region, with 104, 44, and 81 mgd delivered to the East/South Bay, Peninsula, and San Francisco, respectively.
- Restore facilities to meet average-day demand of up to 300 mgd within 30 days after a major earthquake.

In-city seismic reliability:

- *Storage:* Maintain seismically reliable storage to provide at least two days average demand plus minimum two hours fire suppression at three hydrants (5,000 gallons per minute combined flow) in each pressure zone.
- *Fire Suppression:* In conjunction with the Emergency Firefighting Water System (EFWS), within one hour of a major earthquake, provide at least 50% anticipated water demand from post-seismic fires in each of 46 Fire Response Areas, and at least 90% citywide average water demand from post-seismic fires. See the chapter on EFWS in this report for more detail about the performance goals for the EFWS system.

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[68] San Francisco Public Utilities Commission. 2017. "San Francisco Water System Level of Service: Goals and Objectives". Accessed August 8, 2019. https://sfwater.org/Modules/ShowDocument.aspx?documentid=11729

- *Water Supply Restoration:* Provide water to support flushing, bathing/cleaning, and consumption if boiled or disinfected.
    - Within 24 hours, pressurize limited network of critical transmission mains (≥ 12-inch diameter) that serve critical care facilities.
    - Within 72 hours, pressurize limited network of critical secondary distribution system pipelines (<12-inch diameter).
    - Within 7 days, disinfect and restore to potable service a limited network of critical transmission and distribution mains.
    - Within 90 days, restore the secondary distribution system to potable service.

System Restoration Timeline

The service restoration timeline shown in **Figure 12** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

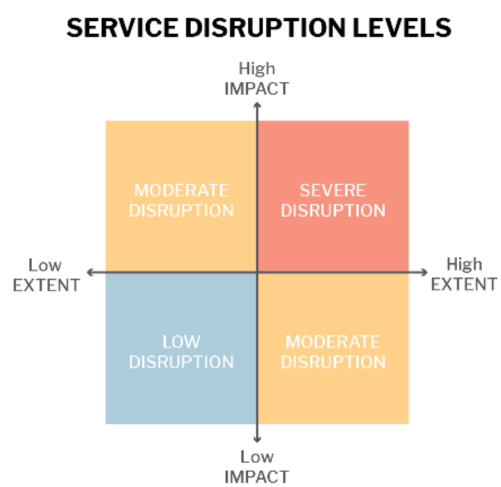
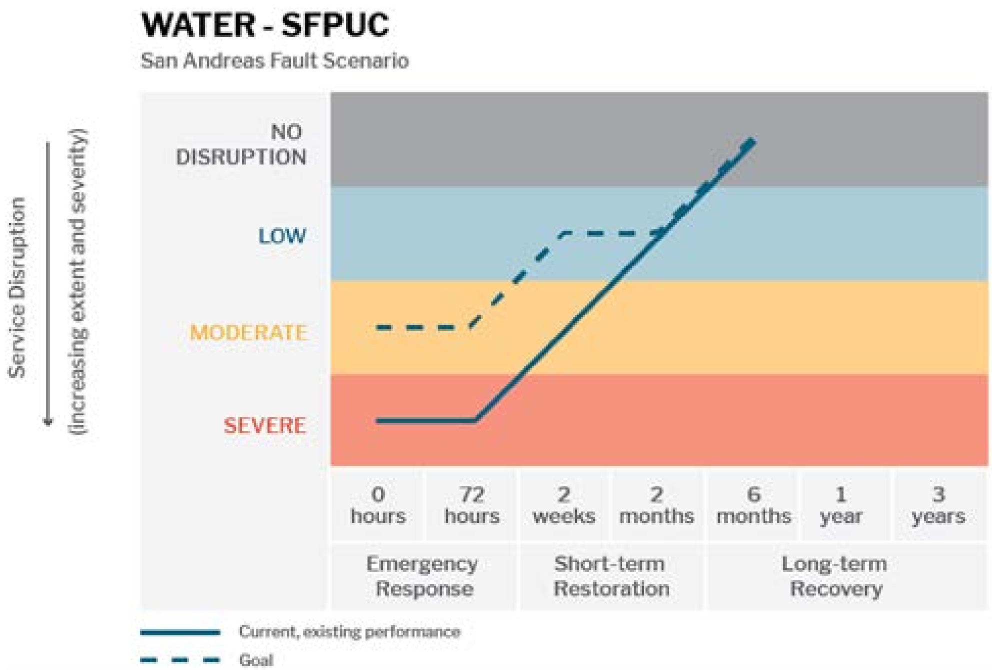


FIGURE 12: WATER SYSTEM RESTORATION TIMELINE



Sector Overview

Hetch Hetchy Source: The Hetch Hetchy watershed, located in Yosemite National Park, is the major source of water for all of San Francisco's water needs.[69] Spring snowmelt runs down the Tuolumne River and fills Hetch Hetchy, Reservoir. The surface water in the reservoir is treated, but not filtered because it is of such high quality. The Hetch Hetchy reservoir provides 85% of SFPUC water and an additional 15% comes from the Alameda and Peninsula watersheds through five reservoirs: Calaveras, San Antonio, Crystal Springs, San Andreas and Pilarcitos. Increasingly, groundwater and recycled water also provide water to the City of San Francisco.[70]

Regional Water System: From Hetch Hetchy Reservoir, water flows by gravity through the Canyon and Mountain tunnels via hydroelectric generation systems on the western

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[69] San Francisco Public Utilities Commission. "WSIP Overview". Accessed August 8, 2019. https://sfwater.org/index.aspx?page=115.

[70] San Francisco Public Utilities Commission. 2013. "City and County of San Francisco Comments on the State Water Resources Control Board Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay-Sacramento/San Joaquin Delta Estuary: San Joaquin River Flows and Southern Delta Water Quality". http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/dsedoc/sanfranciscocity.pdf

slope of the Sierra Nevada which produce about 1.7 billion kilowatt hours per year, enough to meet 20% of San Francisco's electricity needs.[71] After flowing through the powerhouses, the water is treated and transported via the 167-mile Hetch Hetchy aqueduct through the Central Valley. Near the City of Fremont, the aqueduct splits into five pipelines and a tunnel. All five pipelines cross the Hayward fault. Three pipelines cross under the Bay south of the Dumbarton Bridge and the remaining two travel south around the Bay. All five pipelines meet up again near the City of Palo Alto. The aqueduct terminates at the Pulgas Water Temple, where chloramine disinfectant is removed from the water before flowing into Upper Crystal Springs Reservoir. While most of the Hetch Hetchy water is delivered to customers at turnouts all along the aqueduct, some of the water is stored for later treatment and delivery in San Antonio and Crystal Springs Reservoirs. Stored water and local run-off in these regional reservoirs, combined with water from Calaveras Reservoir, are treated at two local filtration plants, and blended with the Hetch Hetchy water in the transmission system.

In-City Water (CDD) System: The CDD distribution system is comprised of 12 potable water reservoirs and nine storage tanks providing 412 million gallons of water storage capacity within San Francisco, approximately 4 to 5 day water supply for the City. Two additional reservoirs, Lake Merced and Lake Honda are maintained solely for emergency supply. 1,300 miles of pipeline, 17 pump stations, 8 hydro-pneumatic stations, 17 chlorination stations, 24 pressure reducing and 12,000 manually operated valves distribute potable water to 180,000-metered customers in San Francisco.

Regional transmission mains from Hetch Hetchy, Sunol Valley Water Treatment Plant and Harry Tracy Water Treatment Plant discharge into one or more of three groups of terminal storage reservoirs within San Francisco: University Mound (North and South), Merced Manor, and Sunset (North and South). Two of these reservoirs, University Mound and Merced Manor Reservoir, are at elevations low enough to receive water directly from Hetch Hetchy sources. The Sunset Reservoir is at a higher elevation, so water must be pumped to it via the Lake Merced Pump Station, Alemany Pump Station, or Baden Pump Station. The system includes 17 pump stations of varying capacities to supply reservoirs and tanks at higher elevations.

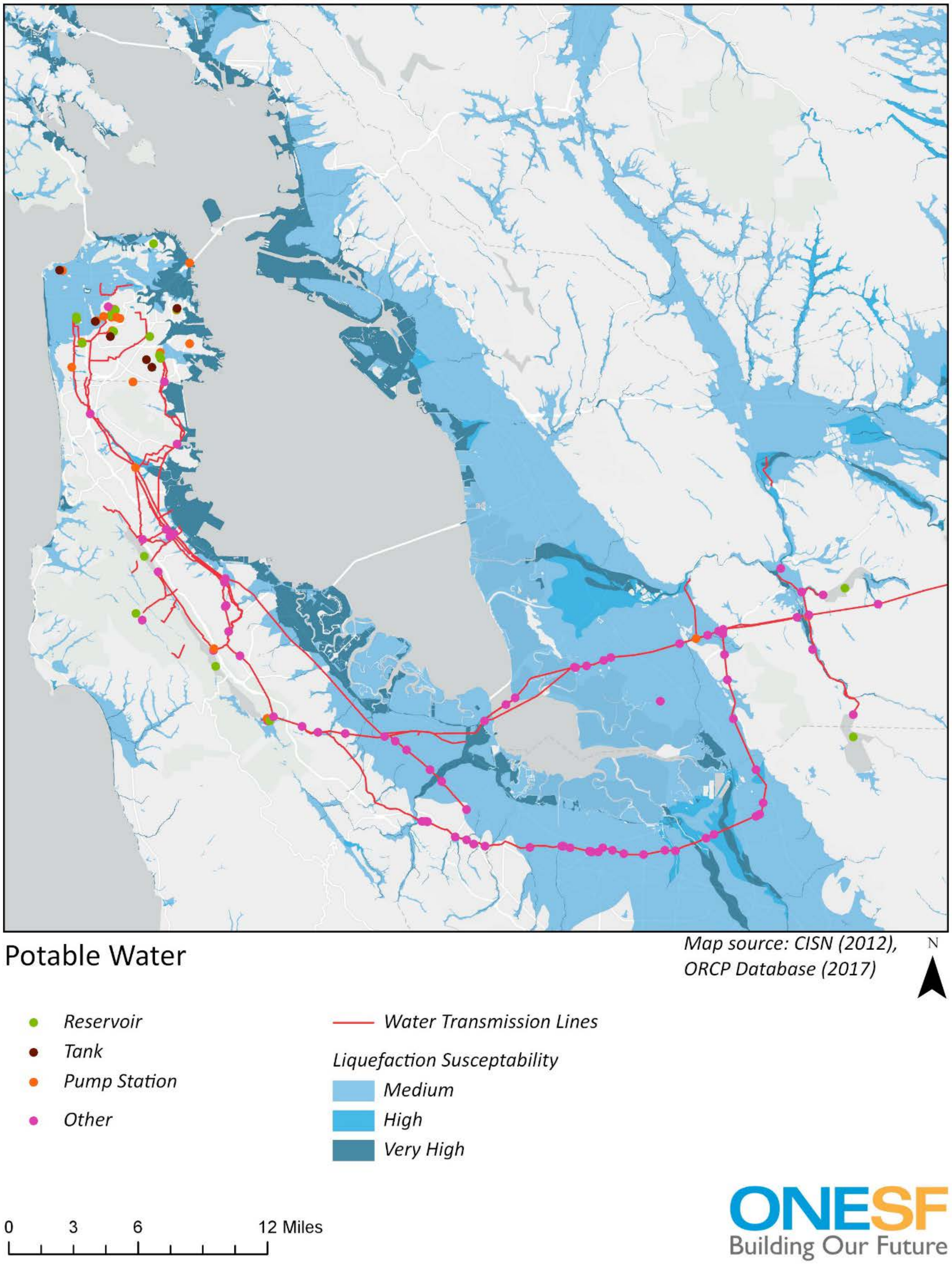
CDD is generally divided into three primary systems that are associated with the University Mound Reservoirs, Sunset Reservoirs and Merced Manor Reservoir. To provide normal water pressure to customers at varying elevations throughout the city,

[71] Wikipedia. 2019. “Hetch Hetchy”. Accessed August 8, 2019. https://en.wikipedia.org/wiki/Hetch_Hetchy#The_Hetch_Hetchy_Project

water flows from the three primary pressure zone systems into multiple pressure zones throughout the city.

These assets are displayed in the system map seen in **Figure 2**.

FIGURE 13: POTABLE WATER SYSTEM MAP



System Upgrade and Disaster Planning Efforts

SFPUC’s seismic improvement efforts have been primarily focused on reliably delivering far away Hetch Hetchy water into San Francisco and the other parts of the region, as well as hardening local water treatment plants that serve locally stored water and installing new groundwater wells within San Francisco, served by the system through the Water System Improvement Program (WSIP). WSIP is a $4.8 billion-dollar, multi-year capital program to upgrade the SFPUC's regional and local water systems, including upgrading dams, tunnels, treatment facilities, pipelines, pump stations, reservoirs and tanks. The program delivers capital improvements that enhance the SFPUC's ability to provide reliable, affordable, high quality drinking water in an environmentally sustainable manner to 2.7 million people in the greater Bay Area. The program consists of 87 projects - 35 local projects located within San Francisco and 52 regional projects, spread over seven counties from the Sierra foothills to San Francisco.

The WSIP objectives include:

- Improve the system to provide high-quality water that reliably meets all current and foreseeable local, State, and Federal requirements.
- Reduce vulnerability of the water system to damage from earthquakes.
- Increase system reliability to deliver water by providing the redundancy needed to accommodate outages.
- Provide improvements related to water supply/drought protection.
- Enhance sustainability through improvements that optimize protection of the natural and human environment.

The current forecasted date to complete the overall WSIP is December 2021. As of August 2019, the WSIP is essentially complete, and is in final close-out stage. The program is funded by a bond measure that was approved by San Francisco voters in November 2002 and will be paid for by both retail customers in San Francisco and 26 wholesale customers that serve Alameda, San Mateo and Santa Clara counties.

As the WSIP nears completion, improving the seismic reliability of the system that distributes that water to San Francisco residents and business is becoming a higher priority. Toward that end, SFPUC is aiming to install, renew and replace distribution system pipes and service connections for the 1,230 miles of mains in the system at a rate of 15 miles per year. The program is projected to cost $600 million through 2029.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

In this scenario, it is expected that the regional water delivery system and storage reservoirs will be able to deliver winter water demand to at least 70 percent of regional turn-outs within 24 hours of the earthquake. However, water distribution out of the reservoirs is more vulnerable to disruption due to damaged pipes and loss of power. From limited modeling of distribution pipeline breaks in a major earthquake, a significant number of pipeline breaks are expected, especially in areas of liquefaction. Some larger local transmission and distribution lines have been hardened; but smaller distribution pipes may have significant damage. Pump stations will likely perform well because of WSIP upgrades. Redundancies have also been added to the system through the WSIP program. Primary facilities have been hardened, but not all back-up secondary facilities have been hardened because they can be repaired.

In the Loma Prieta earthquake, the distribution system wasn't heavily impacted except in the Marina where there were 200-300 pipeline breaks. The rest of the system only experienced a handful of breaks. There was some local transmission system damage as well. Water was restored to all customers in the Marina in three days. All the pipes that failed in San Francisco in the Loma Prieta earthquake were cast iron. Steel pipes have also been shown to fail in past earthquakes.[72] Sixty percent of San Francisco's in-city water pipes are cast iron, 30% are ductile iron and 10% are welded steel. It was also observed in Lom Prieta and the 2014 Napa earthquakes that pipes were damaged in places not subject to ground failure. In some cases, damage may have resulted from ground strain associated with surface wave passage.

Hayward Fault

Because the regional transmission pipelines cross the Hayward fault, they are most vulnerable to damage in this scenario, however these pipelines have been hardened to resist damage. The local distribution system may sustain some localized damage and pipeline breaks in areas that liquefy.

[72] Detweiler, S.T., and Wein, A.M., eds. 2018.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 11 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 11** reflects the current, existing performance in the Restoration Timeline in **Figure 12** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 11: WATER SYSTEM RESTORATION TIMELINE

	Potable Water - SFPUC
0 Hours	*Goal is to achieve seismically reliable distribution pipes that will not fail (moderate disruption).* Many local distribution pipes will break, especially in liquefaction areas. The focus of the first 24 hours will be on providing adequate firefighting pressure and supply for both potable and EFWS systems, maintaining storage, assessing damage, isolating system, rerouting water, and isolating main breaks that are flooding buildings.
72 Hours	*Goal is to pressurize limited a network of critical transmission mains (≥12-inch diameter) that serve critical care facilities within 24 hours and pressurize a limited network of critical secondary distribution system pipelines (<12-inch diameter) within 72 hours (moderate disruption).. Boil water advisory may be in effect if contamination to reservoirs or pipelines.* In the first few days, many SFPUC resources will go toward ensuring the EFWS is fully functional for post-earthquake firefighting and isolating major breaks. Repairs for the water system won't be a priority for first 24 hours, but repairs will begin on major pipelines immediately after firefighting demands are met.
2 Weeks	*Goal is to disinfect and restore to potable service a limited network of critical transmission and distribution mains within seven days (low disruption).* Pipe repairs will be under way as fires are extinguished, if there is access to the streets. Trying to find critical repair parts in competition with other water systems may be a challenge.
2 Months	*Goal is 3 months for complete restoration and repair. There will still be some leaks remaining, but the system will be fully functional.*

	Potable Water – SFPUC
2 Months (cont.)	Most pipe breaks will be repaired and most buildings will have water service if their building can receive it. Areas of significant liquefaction or where streets remain closed may not have water service restored.
6 Months	Full restoration expected citywide.
1 Year	
3 Years	

Hayward Fault Scenario

The Hayward fault will shake the regional system harder, but it has been designed for this and will have minimal damage. Transmission lines have been hardened with redundant lines and can be repair quickly. The local system will experience significantly fewer pipe breaks than under the San Andreas scenario due to fewer areas of liquefaction. A HAZUS analysis was performed for the USGS HayWired study with adjustments for repair crew availability and lifeline interaction. The study estimates that San Francisco water service will be at about 40% capacity immediately following a M7.0 on the Hayward fault, growing to 55% restored after 3 days considering repair crew availability and lifeline interaction, 67% after one week, and full restoration within a month.[73] The restoration time depends primarily on repair crew availability and a fuel management plan to refuel backup generators until normal power is restored in about one week.

Level of Confidence

SFPUC is highly confident in the performance of the water system due to significant modeling and analysis performed through WSIP. This assessment is also informed by extensive EFWS system modeling, institutional knowledge, as well as experience in the Loma Prieta earthquake. Understanding of the system is also informed by modelling the USGS Haywired earthquake scenario and SFPUC has used hydraulic modeling and GIS layers to consider outages and contingency planning options.

[73] Detweiler, S.T., and Wein, A.M., eds. 2018.

System Interdependencies

The local water supply system is interdependent with regional water delivery water, wastewater, and EFWS and has significant dependencies on communications, highways and local roads, power, natural gas, fuel, and transit. The water system is also dependent on the Port seawall and ferries for employee transport, and on natural gas to repair pipelines where they are co-located.

Table 12 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 12: WATER SYSTEM DEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – backup generators are available for all critical facilities with stored fuel for approximately 72 hours, however if additional fuel cannot be replenished, the water system will be unable to operate until power is restored (current PG&E estimate is 90% restoration within 5 days).
Natural Gas	Moderate – SFPUC does not rely on natural gas for operations; however, gas pipe leaks may prevent access to water pipes for repairs so that the timing of repairs to water lines may be dependent on timing of repairs to gas lines (as well as other subsurface utilities).
Water	Significant – Failures in the regional water system could affect supply to the in-city water distribution system.
Wastewater	Significant – If water pipes break near sewer pipe breaks, there can be water quality and contamination issues. Sinkholes from sewer pipe breaks could damage water pipes. Sewer pipe breaks may prevent access to water pipes for repairs so that the timing of water pipes may be dependent on timing of repairs to sewer lines (as well as other subsurface utilities). Undersized sewer pipes could result in flooding from firefighting water that limits access to damaged water pipes.
Sector	**Extent of dependence on sector**

Communications	Significant – For SCADA systems, which remotely monitor reservoir levels and operate pump stations. Communications is also critical between employees and dispatch. All trucks are equipped with 800 MHz and low band radios as backup.
Highways and Local Roads	Significant – Repair crews who live in the East Bay will need to travel into the city to perform inspections and repairs. Roads will be needed to deliver repair parts and equipment. Access to local roads is critical to repair damaged pipelines.
Fuel	Significant – SFPUC has about 72 hours of fuel supply for backup generators. Alemany, Lake Merced, Central, Pump Station #1 and Pump Station #2 have 76,500 gallons of stored fuel collectively. Pump stations and facilities keep their tanks full. Fuel stored at headquarters is dispensed to service vehicles.
Transit	Significant – Employees residing in the East Bay rely on transit to get to work.
Solid Waste	Moderate - Accessing damage pipes will not be possible until debris is removed from streets
Airport	None
Port	Moderate – Failure of the seawall will damage water pipes and pump stations to draw water for EFWS. Ferry terminals are critical for employees residing in the East Bay to get to San Francisco.
Fire Suppression (EFWS)	Significant – for firefighting. Street flooding from firewater may prevent access to water pipes for repairs.

Actions to Speed Restoration

SFPUC should analyze the seismic reliability and expected restoration time of the in-city water distribution system and develop an upgrade strategy.

The primary focus of SFPUC efforts to enhance seismic reliability have been on the regional system that delivers water from the Hetch Hetchy watershed and regional water treatment plants to storage reservoirs in San Francisco. The reliability of the system that delivers water from the in-City reservoirs to customers is less certain and understood. SFPUC has hardened some of the larger distribution pipelines and is working toward hardening more; however, the seismic reliability and restoration time of the system has not yet been analyzed in detail.

The model developed by USGS for the East Bay Municipal Utility District (EBMUD) as part of the Haywired study is a good example. In that model, there will be an estimated 4,294 pipe repairs in the EBMUD service area because of a M7.0 earthquake on the

Hayward fault, with 0.64 repairs per kilometer.[74] The model indicates that full system restoration for EBMUD will take 28 weeks (6 months), compared to 14 weeks (3.5 months) if all brittle cast iron pipe were replaced and all pumping stations had sufficient emergency fuel for generators. The average customer will be without water for six weeks.[75] Availability of parts, availability of transit and roads, limited access due to debris and damaged buildings could also delay restoration of service.

Currently, SFPUC is replacing older water mains throughout the City on an annual basis of 12-15 miles of pipeline per year.[76] SFPUC should update its pipe replacement prioritization analysis to include seismic analysis of the risk and consequence of failure of critical pipelines. In addition to speeding post-earthquake restoration of the city's drinking water, replacing vulnerable pipelines before an earthquake would augment the city's fire fighting capacity after an earthquake and reduce fire losses."

SFPUC should identify key facilities that should be prioritized by PG&E for power restoration.

SFPUC facilities have generators with fuel supply for several days at pumping stations, but will be challenged to continue operating once fuel supplies run out if power is not restored. Given the critical nature of functioning water system for citywide recovery, SFPUC should work with PG&E to understand power restoration of these key assets may be prioritized post-disaster. Better understanding the specific timeline for restoration of PG&E power to these key assets will allow SFPUC to ensure that adequate fuel for generators is available for the estimated outage period. The USGS Haywired study estimated that in a Hayward fault event, restoration of the water system could be sped by three weeks by having a fuel plan and generators at all pumping stations.[77]

SFPUC should stockpile critical spare parts needed for emergencies.

Restoration of the water system may be delayed due to challenges in quickly procuring parts needed for repairs. Many other water agencies in the region will also likely be vying for these critical resources. SFPUC could identify what parts are most likely to be

[74] Detweiler, S.T., and Wein, A.M., eds. 2018.
[75] Detweiler, S.T., and Wein, A.M., eds. 2018.
[76] Applied Technology Council (ATC). 2016. "Study of Options to Reduce Risk Post-Earthquake Fires in San Francisco." Prepared for the San Francisco Earthquake Safety Implementation Program (ESIP). Redwood City, Ca.
[77] Detweiler, S.T., and Wein, A.M., eds. 2018.

required for immediate post-disaster repairs and stockpile them locally. SFPUC currently stockpiles a minor supply of repair parts to replace about 3 miles of pipe, and has emergency contracts with suppliers. SFPUC will also need to analyze the costs and benefits of this strategy. Parts that are very expensive or likely to become obsolete in the near term, may not be beneficial to stockpile.

SFPUC should work with lifeline sectors co-located in city streets to coordinate post-earthquake emergency response and restoration work.

City streets, transit and buried infrastructure, including are often co-located in city streets. Buried infrastructure may include water, EFWS, wastewater, natural gas, electric power, and telecommunications, as well as underground components of the transit system and rails or located on city streets. When one or more of these systems are damaged, it affects the ability to inspect and repair other systems in the same location. In areas that experience liquefaction, this interdependency will be especially pronounced. Gas leaks, damaged power lines and sewer leaks will all have to be repaired before the water system can be accessed at a particular location. In addition, restoration activities need to be coordinated to reduce the number of times a street is opened, disrupting traffic and transit flow. Coordination between public and private sectors to sequence restoration below city streets can be challenging. The critical lifelines systems collocated in city streets should work together to develop coordination methods ahead of a disaster that can speed post-earthquake inspections and repairs.

Transit

The transit system includes SFMTA's Muni (buses, electric trolley buses, metro light rail, cable cars, and historic streetcars), BART, Caltrain commuter rail, and regional bus services provided by transit operators such as AC Transit, SamTrans, and Golden Gate Transit, as well as ferry service. Because of the fixed nature of rail lines and Muni's overhead catenary system, they are the focus of this transit restoration assessment. Caltrain commuter rail was not included in this assessment because of the limited service it provides to San Francisco (15,427 average weekday riders in San Francisco, compared to 180,000 BART average daily trips to and from San Francisco stations and an average weekday ridership of 173,500 on Muni Metro). Buses other than those operated by Muni were also not included in this assessment because they can largely operate whenever there are passable roads, depending on availability of fuel. Restoration of roads and the fuel system are covered in their respective sections.

Public Transit

Operators: BART, SFMTA

At A Glance

Key Findings

- While BART will immediately shut down for inspections after a major earthquake, basic service between downtown San Francisco and Oakland will likely be operational within 24 hours for the San Andreas or Hayward scenario events, allowing passengers to get across the Bay. Service within the core system will likely be operational within 1-2 weeks and full system restoration is expected within six months. Restoration times could be much longer for more severe earthquake ground motions.
- BART's Fremont line and Berkeley Hills Tunnel are not expected to be operational for many months after a major Hayward fault earthquake.
- Upgrades to BART track and stations in San Francisco (including Muni tunnel) and on Richmond and Concord lines have been completed; consequently, the risk of damage on these lines has been significantly reduced. On the Richmond line and service will therefore likely be restored quickly, but there will be no service on the Concord line if the Berkeley Hills Tunnel suffers offset of the Hayward fault.
- The only remaining retrofit in the BART Earthquake Safety Program is the Transbay Tube (to achieve operability in 500-year event and life safety in 1,000-year event). This retrofit will be completed by 2023. The Berkeley Hills Tunnel was not retrofitted for fault offset, although feasibility of doing so has been studied.
- SFMTA will be severely disrupted for several weeks, with rail service disrupted for two months or more in areas with significant damage. Full SFMTA system restoration is expected within one year.
- A diverse SFMTA transit fleet provides transportation redundancy around the city and bus operations are highly flexible.
- BART cannot operate without traction power and water for fire protection in tunnels and underground stations. SFMTA needs power for Muni and trolleys.

Key Findings (cont.)

- BART and SFMTA also have critical dependencies on communications, fuel, highways and local roads, and other transit operators. SFMTA also has significant transit assets that would be impacted by a seawall failure.

Actions to Speed Restoration

- BART and SFMTA should work with PG&E to better understand when power will be restored to components of the transit system.
- BART should work with SFPUC and EBMUD to better understand when water will be restored to the BART system.
- SFMTA should assess the feasibility of providing battery backup for critical traffic signals to ensure basic level of post-earthquake traffic flow.
- SFMTA should study resilience issues related to the overhead catenary systems.

Restoration Performance Goals

BART

BART has upgraded the system to meet the following seismic performance objectives:

- To provide life safety of the entire system by preventing collapse in a 500-year earthquake.
- To provide operability of the core system (From Daly City Yard to the West Portal of the Berkeley Hills Tunnel and from MacArthur to North Berkeley stations) within a short period of time after a median deterministic (i.e. best-estimate realization) earthquake resulting from any of the maximum-magnitude sources listed below.
- To provide “modified” operability from Orinda station to Concord station within a short period of time after a median deterministic Magnitude 7.25 Hayward fault event only.
- To provide operability for critical assets in a 500-year event and to provide life safety in a 1,000-year event.

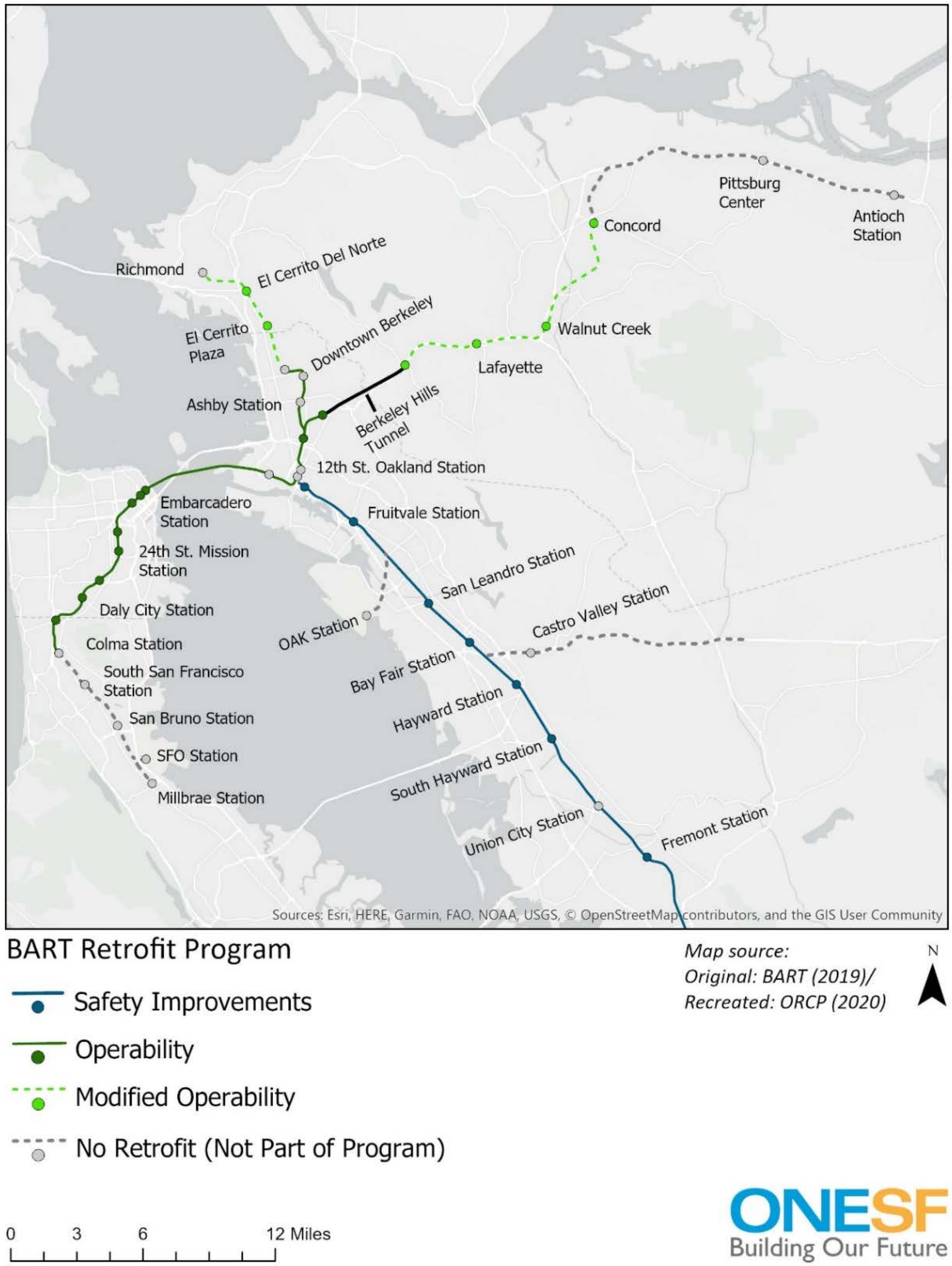
The following are the most significant maximum-magnitude earthquake sources used in BART’s deterministic Vulnerability Study and retrofit design criteria:

- Hayward Fault, Magnitude 7.25
- San Andreas, Magnitude 8.0

- Calaveras Fault, Magnitude 7.0
- Concord-Green Valley Fault, Magnitude 7.0

BART is nearing completion of the Earthquake Safety Program to meet these objectives. **Figure 14** shows the seismic performance objective of the BART retrofit program for individual components.

FIGURE 14: SEISMIC PERFORMANCE OBJECTIVES FOR BART RETROFIT PROGRAM



ONESF Building Our Future

BART extensions beyond Daly City Station, Fremont Station and Concord Station, and to Dublin/Pleasanton station, are newer and were designed to a higher seismic standard than the original system, close to the operability standard. They were not included in the Earthquake Safety Program.

SFMTA

It is SFMTA's goal to restore basic service citywide as quickly as possible following a major event, however no specific system restoration performance goals have yet been adopted by the SFMTA Board.

System Restoration Timelines and Considerations

The service restoration timelines shown in **Figure 15** represent the extent of service disruption experienced by the systems from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

SERVICE DISRUPTION LEVELS

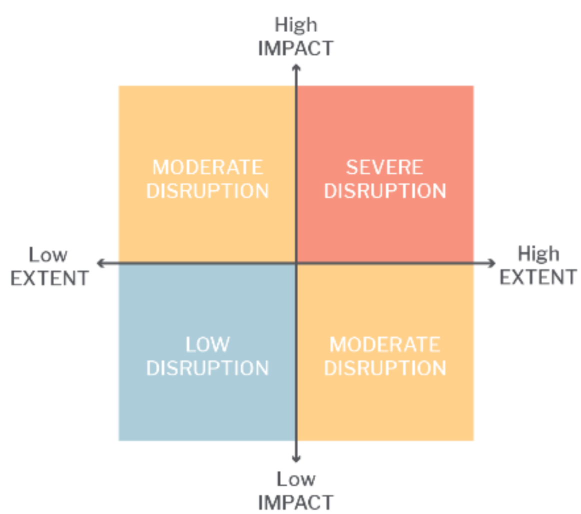
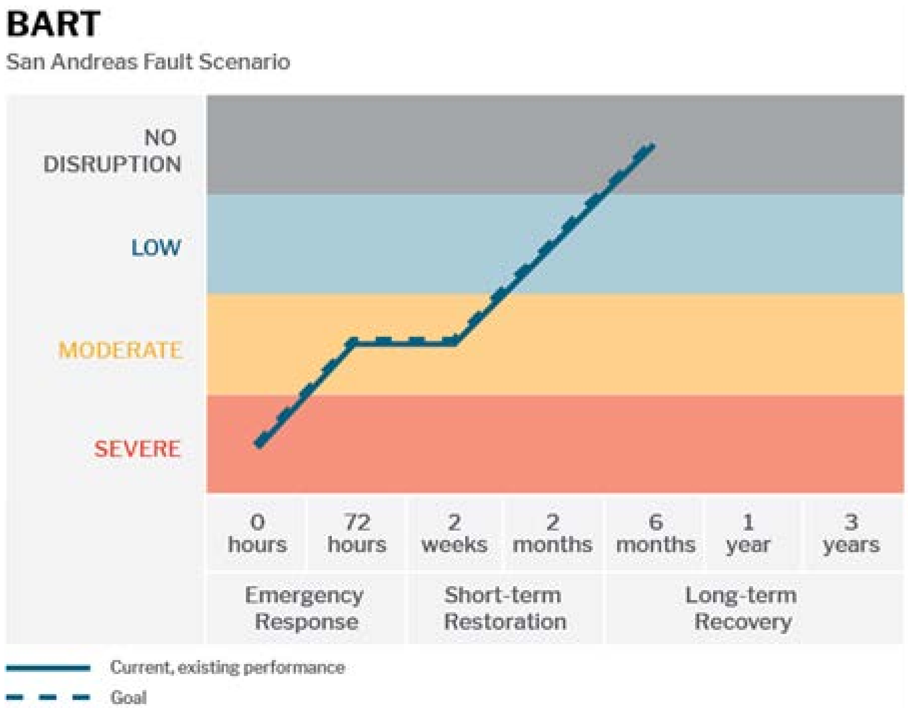
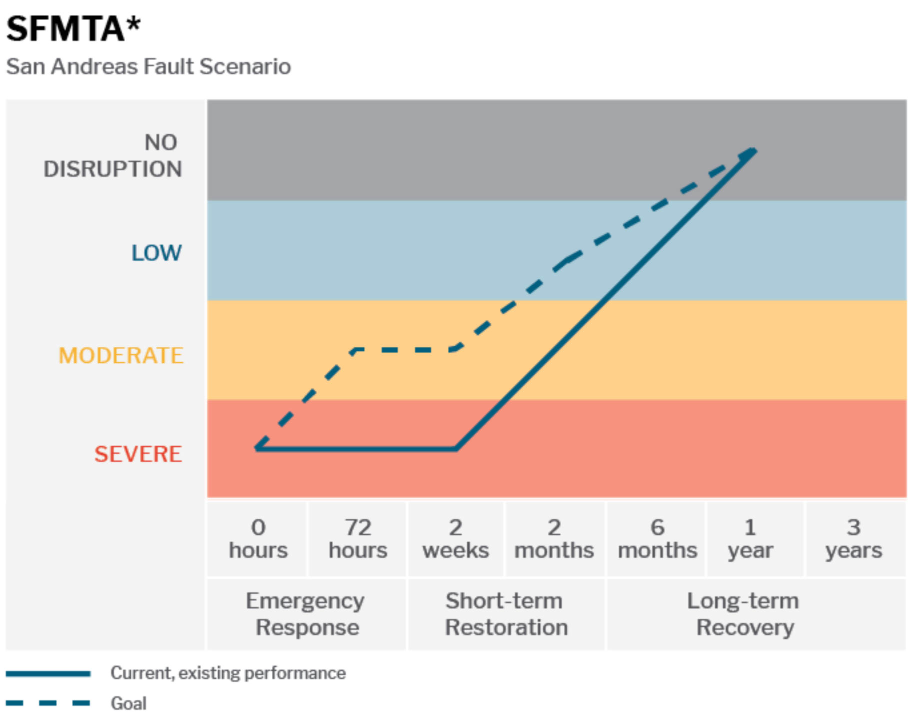


FIGURE 15: BARTAND SFMTA SYSTEM RESTORATION TIMELINES





*service restoration varies by mode

Sector Overview

BART

Bay Area Rapid Transit (BART) is a heavy rail elevated and subway system transit that connects San Francisco and Oakland with urban and suburban areas in Alameda, Contra Costa, and San Mateo counties. Currently the system is also being expanded to Santa Clara County with service to San Jose.

In 2018, BART served 126 million annual passengers and an average of 432,000 weekday passengers.[78] Embarcadero and Montgomery stations are the busiest in the BART system. In Fiscal Year 2017, over 180,000 trips were made to or from the four downtown stations each weekday. BART has an estimated 679 fleet vehicles.

Figure 16 illustrates BART and Muni Metro rail lines and stations, as well as Muni's overhead catenary system.

Stations: BART is served by 48 stations. Nineteen of the stations are at grade, 14 are elevated, and 15 are underground. BART operates eight below grade subway stations in San Francisco, located along the Market Street corridor, Mission Street and Interstate 280. San Francisco's four downtown stations (Embarcadero, Montgomery Street, Powell Street, and Civic Center/UN Plaza) are in the Market Street Tunnel and are shared with Muni Metro above. An additional four Muni-only stations (Van Ness, Church Street, West Portal, and Castro Street) are also located in the Market Street Tunnel and owned by BART.

Trackway: The current BART system has 112 miles of rail across six named and interlined rail lines. Twenty-seven miles of aerial track sit on guideways. BART also operates 10 miles of eBART track that extends the system from Pittsburg/Bay Point to Antioch. eBART tracks and trains are incompatible with those of the main BART system. An auxiliary transfer platform between Pittsburg/Bay Point and Pittsburg Center allows passengers to transfer between the BART system and eBART extension.

Rail cars: BART operates six types of electrically-operated, self-propelled rail cars. The eBART to Antioch extension trains are Diesel Multiple Unit (DMU). They are fueled by renewable diesel, an advanced biofuel produced from bio-based sources such as vegetable oil.

[78] BART. 2018. "BART 2018 Factsheet". Retrieved September 17, 2019. https://www.bart.gov/sites/default/files/docs/2018_BART%20Factsheet.pdf.

Berkeley Hills Tunnel and Transbay Tube: The Berkeley Hills Tunnel is a 3.2-mile long twin bore tunnel between Oakland and Orinda that crosses the Hayward Fault. The Transbay Tube is a 3.6-mile long tube at the bottom of the San Francisco Bay between West Oakland and Embarcadero stations.

Yards: The first maintenance yards built for the core BART system were in Richmond, Concord, and Hayward. In the late 1980's, an additional yard was added south of Daly City station. A yard will open at the planned Santa Clara station in 2026, upon completion of Phase II of the Silicon Valley BART Extension. The Coliseum–Oakland International Airport line utilizes the Doolittle Maintenance and Storage Facility as a car barn for the line's guideway trains. The eBART trains utilize a facility in Antioch for maintenance and service.

Central Control Facility: A Central Control Facility located near the Antioch station operates the eBART system and communicates with transit operations and maintenance personnel.[79] The facility is also linked to the Operations Control Center to allow synchronization of operations at the eBART Transfer Platform.

SFMTA

The San Francisco Municipal Transportation Agency (SFMTA), a department of the City and County of San Francisco, is responsible for the management of all ground transportation in the city, including oversight of the Municipal Railway (Muni), as well as bicycling, paratransit, parking, traffic, walking, and taxis. Established by voter mandate in 1999, the SFMTA aggregated multiple San Francisco city agencies, including the Taxi Commission, the Department of Parking and Traffic, and the Municipal Railway (Muni). Muni now has one of the most diverse transit fleets in the world and is the cleanest multimodal fleet in California. The San Francisco County Transportation Authority (SFCTA) projects a 40% increase in Muni ridership from 700,000 daily transit boardings in 2014 to 1,000,000 in 2040.[80] Muni operates the following transit services:

- **Motor Coaches (Buses)** operate on routes throughout the city that can be re-routed if needed. They carry about 45% of MTA's public transportation system riders. The motor coach fleet consists of roughly 610 vehicles and includes 32-foot, 40-foot and 60-foot buses. The fleet is being upgraded to biodiesel-electric

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[79] BART. 2018.
[80] SFMTA. 2017. "2017 SFMTA Facilities Framework". Retrieved from https://www.sfmta.com/sites/default/files/agendaitems/2017/6-16-17%20PAG%20Item%205%20-%20DRAFT%202017%20Facilities%20Framework.pdf

hybrid buses and electric trolleys. The hybrid buses operate using a blend of diesel and biodiesel.

- **Metro light rail** includes 71.5 miles of standard-gauge track, seven light rail lines, three tunnels, 12 subway stations, 25 surface stations, and 87 surface stops. The system has an average weekly ridership of 173,500 passengers, about 20% of total ridership. As of 2016, Muni Metro consisted of 151 light rail vehicles (LRVs).
- **Electric trolleys** operate on a fixed overhead line network that provides electric power. These 202 zero-emission vehicles carry about 30% of the public transportation system's riders and operate on local streets.
- **Cable cars** operate on three fixed routes and are hauled by a continuously moving cable located just below street level. Muni has 40 cable cars in its fleet.
- **Historic streetcars** operate on tracks along the roadway, with some track sections separated from regular auto traffic. Muni has 43 operational vehicles. Streetcars carry roughly, 21,000 passengers daily.

Muni Metro Stations: Muni Metro stations consist of two types: below grade subway stations and at grade surface stations. Subway stations consist of surface entrances and typically have two levels: a mezzanine concourse containing ticketing and passenger fare gates, and a lower level consisting of boarding platforms and transit system operation. In SFMTA/BART shared stations, BART operates on a third sublevel. At the surface, stations include elevated platforms, boarding islands, bus bulbs and curbside bus zones. Other regional transit services providers (e.g. Golden Gate Transit, SamTrans, AC Transit) also have boarding islands and curbside bus zones within San Francisco that are either stand-alone or jointly operated with SFMTA.

Muni Metro Fixed Guideway: Trackways consist of several critical functioning sub-assets such as the train control system, traction power system and switches. Trackways also include the track itself, which the LRVs and streetcars run on. Trackways span over 70 miles and support seven light rail lines. The trackway runs below ground in the subway along the Market Street corridor and other tunnels along the system. As the Metro lines extend towards outer service areas, the trackway runs at or above grade.

Tunnels: The SFMTA system includes several tunnels as well.

- The Market Street subway tunnel is owned by BART and discussed in that section.
- The Sunset Tunnel is used by the N Judah line and runs between Duboce & Noe Station at the eastern end and Carl & Cole Station at the western end.

- The Twin Peaks Tunnel is used by the K Ingleside/T Third Street, L Taraval, M Ocean View, and S Shuttle lines. The eastern entrance to the tunnel is located near Market and Castro Streets and the western entrance is located at the West Portal Station. The Forest Hill station is in the tunnel.
- The Central Subway project will extend the T Third Line from the 4th Street Caltrain Station to Chinatown with expected completion in 2021. Over one mile of the project's 1.7-mile alignment will be in dual subway tunnels. The project includes construction of four new stations:
  - 4th and Brannan Station at 4th and Brannan streets (street level)
  - Yerba Buena/Moscone Station at 4th and Folsom streets (subway)
  - Union Square/Market Street Station on Stockton Street at Union Square (subway)
  - Chinatown Station at Stockton and Washington streets (subway)

Yards and Shops: Muni Metro has three rail yards for storage and maintenance of light rail vehicles.

- The Curtis E. Green Light Rail Center, also known as the Green Yard, is located adjacent to Balboa Park Station and serves as the outbound terminus for the J Church, K Ingleside, and M Ocean View lines. The facility has repair facilities, an outdoor storage yard and larger car house structure.
- Muni Metro East is a newer facility opened in 2008 and is located along the Central Waterfront on Illinois and 25th streets in the Potrero Hill neighborhood, a block from the T Third Street Line. The 180,000 square foot maintenance facility with outdoor storage area is located next to Northern Container Terminal and the former Army Pier.
- The Cameron Beach Yard facility was originally a Market Street Railway facility has a separate car house. The yard has a body and paint shop, and houses Muni's F Line cars.

Muni also operates a number of yards for buses (electric trolley and moto coaches), cable cars, and historic streetcars.

- Burke facility is a warehouse that has recently been upgraded to serve as an overhead lines repair facility.
- Potrero and Presidio facilities serve as trolley coach facilities. Both facilities are currently undergoing renovation and seismic with completion expected by 2030.

In addition to direct vehicle maintenance, the Rail Vehicle Maintenance group maintains a full-service Machine Shop with two satellite locations, an electric motor Shop, a sheet metal shop, an electronic shop and HVAC repair shop. These support shops provide support to the rubber tire fleet, cable car infrastructure as well as light rail vehicles and historic vehicles.

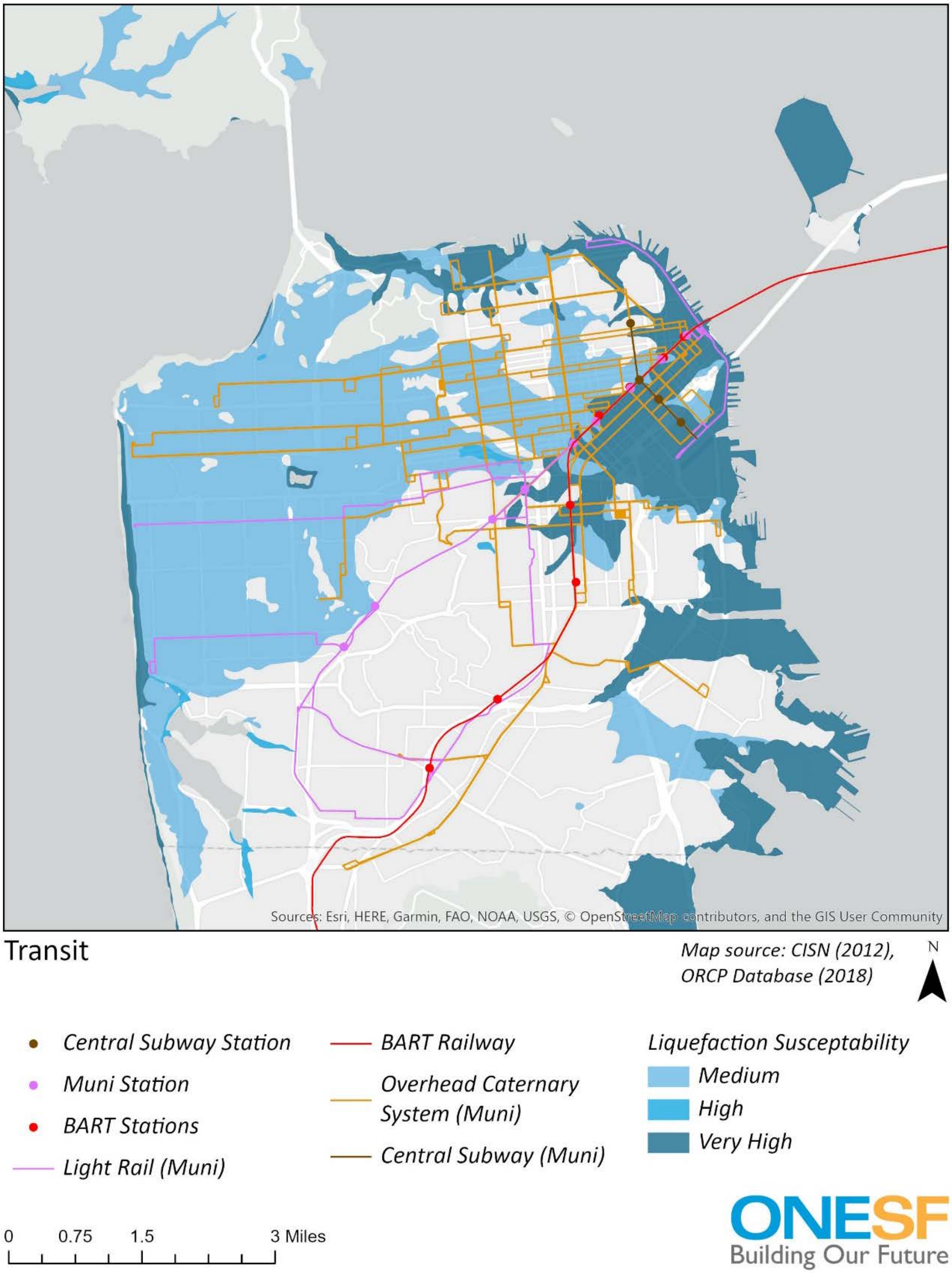
Signals: Over 1,200 traffic signals, signal communication systems, and related signal field hardware ensure the smooth operations of city streets and public transportation system.

Transportation Management Center and Operations Control Center: Completed in 2014, the Transportation Management Center (TMC) actively monitors traffic and manages transit from a central location at 1455 Market St.
The former Muni Operations Control Center, located near the West Portal Stations at Lenox Way, now serves as a redundant backup facility for the TMC.

Administration Building: The SFMTA's primary administrative offices are located at 1 South Van Ness Avenue in a building that was seismically retrofitted in 1989. It is expected that during a strong earthquake, the safety of occupants will be protected, but significant structural and nonstructural damage may occur. Repairs may be necessary before the building can be re-occupied, and in some cases, restoration may not be cost effective.

Fuel storage: SFMTA's stores approximately 177,000 gallons of diesel fuel across five locations and 80,000 gallons of renewable diesel at a single location. The SFMTA provides mutual assistance to San Francisco Police and Fire following emergencies. This fuel will be shared among those emergency responders and can be replenished once roadways are serviceable. Duration of initial fuel supplies before refueling depends on the immediate post-event emergency response needs.

FIGURE 16: TRANSIT SYSTEM MAP



System Upgrade and Disaster Planning Efforts

BART

Earthquake Safety Program

BART initiated the Earthquake Safety Program to ensure the safety of the public and BART employees and safeguard the public's significant investment in the system (currently valued at nearly $15 billion)[81] in the event of a likely, but significant earthquake. One of the first tasks for the Earthquake Safety Program, completed in 2002, was a system wide Vulnerability Study to assess how system components would perform during a major earthquake. The results of the study indicated that without strengthening, the system could be out of service for two years or more after a major earthquake.

The Earthquake Safety Program upgraded the entire system to ensure life safety and the core system so that it can return to operation shortly after a major earthquake. All BART rail line upgrades in San Francisco were completed by 2014. The four BART stations in the Market Street tunnel were determined to already meet the operability standard and no stations needed upgrades. BART also evaluated the four Muni-only stations (Van Ness, Church Street, West Portal, and Castro Street stations) in the Market Street tunnel, including the Muni Operations Control Center (OCC) at Muni West Portal Station for life-safety in the 500-year earthquake. The only Muni station that needed retrofit to achieve the life-safety standard was the Church Street station. The retrofit of that station is now

Loma Prieta earthquake

Within hours of the Loma Prieta earthquake, BART completed a full inspection of all BART stations and track. By beginning in Fremont, closest to the epicenter and working north, inspectors were able to quickly determine that there had been little damage and extensive inspection was not needed. BART completed repairs to all crucial system components and the system was functional within 12 hours of the earthquake. BART ran around the clock service for a month while the Bay Bridge was down and was critical for transporting people, food and services across the Bay. This event confirmed BART's critical role as the transportation backbone of the region and led to the creation of the Earthquake Safety Program so it would be able to serve that role with minimal interruption in the event of a much larger or closer earthquake than Loma Prieta.

[81] BART. "Earthquake Safety Program". Accessed July 7, 2020. https://www.bart.gov/about/projects/eqs#anchor1.

complete. No structural retrofit was needed for the OCC structure for life safety. However, the equipment, services and utilities within the structure were not evaluated by the BART Earthquake Safety Program, and this would probably have more bearing on whether the SFMTA OCC is immediately operational following a major earthquake.

Since 2014, BART has finished upgrades to track and stations on the Fremont, Richmond and Concord lines, procured more generators to help run stations in the event of power loss, and made upgrades to electrical systems and train control systems for the whole system. BART also now utilizes an earthquake early warning system to slow and stop trains ahead of earthquake shaking.

The only remaining retrofit in the Earthquake Safety Program is the Transbay Tube.[82] The Transbay Tube currently meets the operability goal in a 500-year earthquake; however, additional retrofit is underway to provide life safety in the event of a very large 1,000-year earthquake. The retrofit is expected to be completed in Fall 2023.

The Berkeley Hills Tunnel was not retrofitted as part of the program, although a feasibility study was performed to evaluate various retrofit and replacement concepts.

To date, the following retrofit projects have been completed as part of the Earthquake Safety Program:

- Bay Fair, Concord, Daly City, El Cerrito Plaza, El Cerrito Del Norte, Fremont, Hayward, Lafayette, Lake Merritt, MacArthur, Orinda, Pleasant Hill/Contra Costa Center, Rockridge, San Leandro, South Hayward, Walnut Creek, Coliseum, Fruitvale and West Oakland stations
- SFMTA Muni Church Street Station (owned by BART)
- Parking structures at Concord, Daly City, El Cerrito del Norte, Hayward, Pleasant Hill/Contra Costa Centre and Walnut Creek stations
- Elevated structures in cities of: Albany, Berkeley, Concord, Daly City, El Cerrito, Fremont, Hayward, Lafayette, Oakland, Orinda, Pleasant Hill, San Francisco, San Leandro, Union City and Walnut Creek
- Transbay Tube soil densification in Port of Oakland, Oakland Transition Structure strengthening and San Francisco transition structure seismic joints retrofit
- Miscellaneous structures in Oakland, San Francisco, Daly City, Concord, El Cerrito, and Walnut Creek

[82] BART. "Transbay Tube Retrofit". Accessed July 7, 2020. https://www.bart.gov/about/projects/eqs/retrofit.

- OKS Rail Spur, to store the Transbay Tube retrofit work train

Oakland Emergency Generator Project

This generator project will not be sufficient to support normal train operations in the event of a power failure but it will allow for auxiliary systems to be powered. The project also replaces and upgrades an aging emergency back-up generator at BART's Central Operations Control Center.

SFMTA

Since 2014, SFMTA has upgraded the following systems and facilities:

- Advanced Train Control System (ATCS): The ATCS system, which operates in the Market Street tunnel, is designed to fail safe, bringing all vehicles to a safe stop in the event of a system failure. In the event of system loss due to an earthquake, but where power remains in place, operators can continue to operate in the Market Street tunnel in manual mode. This reduces capacity of the tunnel by approximately 30%. ATCS is not critical to restoring operations to the Market Street tunnel; however, operating speeds and capacity would be reduced moderately. The ATCS system will be completely replaced in the Market Street tunnel by 2025, which will improve the ease of system restoration following a major earthquake, shortening the window from months to weeks.
- Updated radio system: The radio system used by the SFMTA is shared with Police and Fire, and has substantial redundancy built into its design. The Radio system can operate on the surface for approximately 100 hours on backup battery power, and all radio communication facilities are equipped with a generator that can continue to run with regular replenishment of fuel after this period. The only exception to this is the subway, which will lose radio coverage once its batteries fail after approximately 10 hours and will not be restored until re-connected to electrical power.
- Rail replacement in many areas
- Structurally reinforced Twin Peaks Tunnel which serves the K, L, M and S-Shuttle lines
- Structural retrofit of the Sunset Tunnel portal retaining walls and their foundations
- Blue light phone system – emergency independent communication system in tunnels, radio, Public Announcement Public Display System (PAPDS) – allows communication to riders from Central Control

- Fleet replacement: the SFMTA recently completed a full replacement of the entire motor coach fleet, which dramatically improved fleet reliability. This will be critical following a major earthquake when maintenance facilities may be operating at a reduced capacity. Muni is currently replacing 151 legacy light rail vehicles, which are also expected to operate five times longer before requiring maintenance. This replacement will be complete by the end of 2025.
- Muni is in the final year of the replacement of the Trolley fleet, which improved the battery range of the fleet. These vehicles can now travel between two and three miles off wire reliably. This will improve immediate post-earthquake response (previously, vehicles could travel only several hundred feet before dying). This also means that vehicles can be used on routes where Muni has not achieved full overhead restoration: operators can de-wire for segments without restored power, and re-wire in areas with active overhead to continue the route and re-charge the battery. This will reduce the recovery of service window even while recovery of infrastructure continues.
- SFMTA has installed the Traffic Signal Battery Backup System (SBBS) to restore power to 70 key intersections when the electric system is damaged in a disaster.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

BART

BART's Seismic Risk Analysis[83] completed for the Earthquake Safety Program, included a magnitude 8.0 earthquake rupturing the North Coast northern and North Coast southern segments, a scenario that is slightly worse than the one used in this study. Because BART uses probabilistic analysis for its retrofit evaluations and design, rather than scenarios, it is difficult to confirm operability, rather than simply safety, for elements of the system in San Francisco and San Mateo County. For the purposes of its responses for this study, BART assumed that the San Andreas scenario represents an earthquake intermediate between BART's operability design earthquake and BART's safety level design earthquake, and that some components will be damaged.

The core BART system (Daly City Yard to the west portal of the Berkeley Hills Tunnel and from MacArthur to North Berkeley stations) is likely to remain operational in this scenario. Service between Daly City through Berkeley Hills Tunnel to Concord and

[83] BART Chronological #001563

possibly to Richmond Station will also remain operational in this scenario because there will be no fault displacement across the alignment, provided power and water are functioning. However, there may be damage to structures near the Daly City station that will cut off access to SFO and the Daly City Yard, as the San Andreas scenario motions appear slightly greater than the operability design earthquake motions in this area. There may also be sufficient damage to the Fremont line to cause it to close for some time.

SFMTA

The SFMTA has not performed a detailed earthquake impact analysis on its entire system; however, it has conducted assessments off its tunnels and several critical buildings. With respect to surface transit, it is expected that liquefaction will damage many rail lines, especially in the Market Street corridor and Embarcadero. Trolleys and cable cars will also likely be inoperable in sections of the city immediately following an earthquake.

Below ground, BART has retrofitted the shared Muni/BART stations in the Market Street Tunnel for operability in a major earthquake. Life-safety evaluations of the four Muni-only stations in the tunnel showed that only the Church Street Muni station required upgrades. It is expected that the scenario earthquake could result in damage to these stations and rail lines in tunnels not shared by BART.

The SFMTA examined seismic vulnerabilities in the Muni tunnels and related structures culminating in the Muni Tunnel Seismic Vulnerability Study[84]. The Study noted the vulnerability of the old Eureka Valley Station originally built as part of the Twin Peaks Tunnel as well as the portion of the tunnel just east of West Portal Station which has a 140-foot-long unreinforced brick arch. The Sunset Tunnel itself were found to have no seismic deficiencies but the east and west portal retaining walls were found to be seismically vulnerable. The areas of deficiencies found in the Twin Peaks Tunnel and Sunset Tunnel portals above required retrofit; the retrofit work was completed as part of track-related projects (Twin Peaks Tunnel Trackway Improvement Project, N-Line Sunset Tunnel Trackway Improvement Project).

There are 70 critical intersections in the City with Transit Signal Battery Backup Systems. The remaining 1,170 traffic signals do not have battery backup systems and loss of power will result in many signals being out. More than 10 substations within the

[84] Prepared by Anil Verma Associates, Inc. February 29, 2012.

City distribute PUC power for the catenary system and those will likely be without power.

The SFMTA's primary administrative offices may sustain significant structural and nonstructural damage but transit system operability is not be contingent on restoration of this office building. The SFMTA's Transportation Management Center is expected to continue largely unimpeded, and the legacy Central Control, located at West Portal, is outfitted as a back-up location in the event of an emergency.

The core of SFMTA service is rubber tire, which will begin regular operations as soon as roadways are passable. Immediate post-earthquake service calls for operation of the Owl network. In the days and weeks following, light rail and trolley infrastructure would be inspected for damage and re-opened as permitted. Primary concerns for these modes are as follows:

- The SFMTA light rail yards (Green and Muni Metro) are accessible by street-level trackways, which are expected to experience moderate damage in a major earthquake. Re-opening these critical pathways will be a high priority and will be essential for restoring any light rail service. Muni Metro East traffic must cross the 4^{th} Street Bridge over the Mission Creek Channel to access the rest of the light rail system. Restoration of this bridge post-earthquake will be critical.
- The SFMTA trolley yards (Potrero and Presidio Divisions) are both well past their useful lives and are not expected to remain functional following a major earthquake. Potrero Division is slated for a full rebuild, which should be complete by 2025. Presidio Division will undergo a rebuild by 2030. The loss of either of these divisions will determine the speed of recovery of the trolley network as these vehicles can't be maintained in motor coach yards.

Hayward Fault

BART

BART's Seismic Risk Analysis included a magnitude 7.0 earthquake on the Hayward fault with a rupture from Richmond to Fremont that is roughly equivalent to the Hayward fault scenario in this study. This scenario represents an earthquake intermediate between BART's operability design earthquake and BART's safety level design earthquake.

A major earthquake on the Hayward fault has the greatest impact on the BART system overall. Significant damage is expected to the Fremont line and Berkeley Hills Tunnel, which will take months or years to repair. Retrofit of the Berkeley Hills Tunnel is likely to be so costly and disruptive because it crosses the Hayward fault, that replacement after an event would likely be a better option. The San Francisco stations and the Richmond line will likely be operational within 24 hours of this scenario earthquake.

SFMTA

There will be fewer infrastructure impacts for SFMTA in the Hayward fault scenario. SFMTA has underground storage fuel tanks at all its motor coach facilities to keep buses running initially, but resupply will be important after several days and is likely to be disrupted due to impacts to the regional fuel and transportation systems. The primary impact to Muni service is likely to be related to disruptions to the lives of operations-critical staff. A large percentage of Muni staff live in the East Bay, which is expected to suffer more serious damage under this scenario. Major disruptions to housing and infrastructure that result in displacement or to regional transportation systems will negatively affect the ability of operations and maintenance staff to reliably reach SFMTA facilities for work. Long-term staff attrition that depresses the ability to operate and maintain the Transit system could be substantial and long lasting.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 13 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 13** reflects the current, existing performance in the Restoration Timeline in **Figure 15** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 13: TRANSIT SYTEM RESTORATION TIMELINE

	Transit - BART	Transit - SFMTA
0 Hours	The BART Operations Control Center will be operational immediately and the Emergency Operations Center will be operational as soon as possible. All train operations will be immediately shut down for inspections. Assuming inspectors can report to work in a timely manner; initial visual inspections of the system will be completed in approximately 12 hours. These inspections will be prioritized based on likely locations of damage and critical assets needed to restore basic service, for example focusing on resuming Transbay service between downtown San Francisco and Oakland, and leaving inspections of outer service areas until later. Damage is expected to be minimal in the core system from Daly City to Richmond and Concord because it was retrofitted to an operability standard. The Berkeley Hills Tunnel will likely be operational in this scenario. The remainder of the system was retrofitted to a safety standard and may experience significant damage. The Fremont Line and Millbrae line south of Daly City may be significantly damaged.	SFMTA will follow the earthquake protocol immediately following a major event, which stops all train traffic until the infrastructure can be certified safe and evacuates the tunnel of passengers and personnel in the event of visible damage. Parking Control Officers (PCOs) will immediately be distributed to help with traffic management where signals are down. Overhead lines crews will be dispatched to repair dropped power lines. Bus routes may continue to operate in limited capacity where roads are passable. Many PCOs, operations and maintenance workers do not live in San Francisco, so continued operations will depend on their ability to travel into the city if the event occurs outside normal work hours.
72 Hours	Depending on damage and availability of power and water, limited service from Downtown San Francisco through the Transbay Tube to West Oakland will likely be operational again within 24 hours, and possibly through to Richmond and Concord. A detailed inspection and damage assessment of the wider system will likely take several days to weeks.	*Goal is* moderate *disruption.* By 72 hours, the regional transportation system should be sufficiently operating to allow inspection and repair crews to get to San Francisco. Track maintenance teams will inspect tunnel trackways and the trackways immediately adjacent to the maintenance yards to determine the scale of damage. Light rail service will remain suspended until both overhead and track is inspected and determined to be intact. Limited bus service, equivalent to OWL service, will be running by 72 hours.

	Transit – BART	Transit – SFMTA
72 Hours (cont.)		Traffic signals depend on power and will need visual inspection of underground conduit before they can be returned to service.
2 Weeks	Depending on availability of power and water, service in and out of San Francisco should be fully operational. Service will gradually be expanded out to the entire core system and the core system should be fully restored within 1-2 weeks. Electrical and telecom will likely be back in service, but water may not be. The Fremont Line and Millbrae/SFO lines south of Daly City station may have significant damage and may still be out of service.	*Goal is moderate disruption with rail service* restored *in areas that didn't experience major damage.* Restoration of trunk transit lines that suffered damage will be prioritized. Transit service will be expanded as permitted from the core OWL service to include more lines. Focus will continue to be on surface motor coach service during this period.
2 Months	Repairs to stations and rail lines with significant damage will be ongoing, with more of the system opening for service over time. Service within the core system will be expanding with more frequent service and faster speeds as repairs are completed.	*Goal is low disruption. This goal could be achieved with construction of the new seismically safe trolley yards and overhead lines facility. Restoration of these facilities depends on power restoration.* Rail service will be restored on segments where major damage has not occurred or where damage has been repaired; however, service beyond locations of major damage may take several months to restore.
6 Months	Repairs to stations and rail line with significant damage, such as those retrofitted to the safety standard, will be completed within about six months. BART service will be full restored to normal by six months.	Nearly all trolley service should be restored, presuming maintenance facilities have survived. Significant rail service restoration is also a goal by this point. All but major total infrastructure failure should be repaired by this point.
1 Year		If both trolley yards are significantly damaged, as is likely in this scenario, trolley coach service would take more than a year to restore.
3 Years		Reconstruction of damaged buildings and facilities will take three or more years to complete.

Hayward Fault Scenario

BART

The Hayward fault scenario is a worst-case scenario for the BART system overall. As with the San Andreas scenario, the Operations Control Center and Emergency operations center will be operational immediately, but BART will shut down all train operations immediately after the event to initiate inspections. The Richmond and Concord lines are expected to be operable once inspections are completed; however, fault offset is expected in the Berkeley Hills Tunnel that will require many months of repair. This scenario will also result in significant damage to the Fremont line and parts of the Richmond line that may require many months to repair. The Dublin/Pleasanton and Antioch lines are not expected to receive major damage, but they will be disconnected from the core system due to damages on the Fremont line and Berkeley Hills Tunnel, respectively. Basic service could be restored in and out of San Francisco within 24 hours following inspections, depending on damage and availability of power and water from either the San Francisco or Oakland sides of the Transbay Tube. By 72 hours post event, basic service in and out of San Francisco will be operating with low disruption and there will be no disruption to the core system by two weeks after the event. Damage to the Warm Springs line and Berkeley Hills Tunnel may take many months to repair and full restoration of service may take six months to a year.

SFMTA

SFMTA will experience moderate damage from this event. Operations running on fixed rail and overhead power will initially be shut down for inspections. Within 72 hours, the system will be running with moderate disruption while damaged components are repairs. Most damage is expected to be minor except in liquefaction areas. SFMTA expects low disruption by two weeks and full restoration within two months; however, service beyond locations of major damage may take several months to restore. Major damage may occur in areas of liquefaction. Power disruption, fuel availability and workers being able to travel from the East Bay is also a significant concern for continued operability of the system in this scenario.

Level of Confidence

BART

BART has moderately high confidence in the restoration performance of its system due to the comprehensive evaluation that was performed of BART components in the Systemwide Seismic Vulnerability Study[85], BART Seismic Vulnerability Study[86] and Seismic Risk Analysis[87] completed in 2002 and the resulting retrofit design and construction that was completed for the Earthquake Safety Program. The Seismic Risk Analysis developed earthquake ground motions, fragilities, retrofit options and other key inputs to a System Earthquake Risk Analysis (SERA) model and used Monte Carlo simulation to run the model 100 times on each of the 15,078 components of the model, varying earthquake forces and component behavior randomly with the standard deviations defined in the model. The results are a statistical distribution of outcomes that are described in term of the expected (mean), minimum, maximum, 16th percentile and 84th percentile estimates.

After completion of the retrofit designs, BART updated its fragility data based on the design analyses generated to improve the accuracy and confidence level of structural behavior of the retrofitted structures in the SERA model, allowing better near real time predictions of earthquake damage. BART currently has an effort underway to update fragilities for structures not addressed in the BART Earthquake Safety Program, thereby creating a complete set of fragilities for the entire system. Nevertheless, there is still considerable uncertainty inherent in prediction of earthquake effects, and BART, being an essentially non-redundant linear system, can be greatly impacted by only a few unexpected failures.

SFMTA

SFMTA has confidence in the restoration performance of its buildings because of the analysis and retrofits performed in the Market Street Tunnel as part of BART's Earthquake Safety Program, its own assessment of many of its buildings and its Continuity of Operations Plan (COOP), which includes an order of restoration plan. Trackway outside of the Market Street Tunnel and other equipment have not yet been assessed for seismic vulnerability.

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[85] BART Chronological #001722
[86] BART Chronological #001584
[87] BART Chronological #001563

System Interdependencies

BART cannot operate without traction power and water for fire protection in the Transbay Tube, tunnels, and underground stations. BART and SFMTA also have critical dependencies on communications, fuel, highways and local roads, and other transit operators. SFMTA also has significant transit assets that would be impacted by a seawall failure.

Table 14 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 14: TRANSIT SYSTEM DEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – BART and SFMTA operations are dependent on electric power, except for non-electric Muni buses. Traction power is necessary to power BART trains. PG&E has upgraded all power connections to the BART system to ensure continued operations once power is restored. BART has redundant power feeds on the east and west end of the Transbay Tube; if power feed is out on one side, the feed from the other side can provide enough power to move trains through the Tube. BART also has multiple power feeds in the system and has flexibility to pull power from other sections of the traction power supply system to if not all power feeds are operating. BART's Oakland Generator Project will provide light and pumping in the Transbay Tube and allow trains to exit the Tube in the event of a power outage, but it will not provide enough power to run normal train operations if power is out.
Natural Gas	None.
Water	Significant – BART cannot operate without water for fire protection in the Transbay Tube, all tunnels and underground stations. For above ground stations, a fire watch may be posted to allow continued operation; however, this is not an option for underground stations. EBMUD and SFPUC provide water at the east and west ends of the Transbay Tube, respectively. If water is out at only one end

Sector	Extent of dependence on sector
	of the Tube, service from the other end can provide enough water for trains to continue operating. SFMTA is not reliant on water for operations.
Wastewater	None.
Communications	Significant – Transit systems rely on SCADA and radio systems to operate. BART has no redundancy for radio operations for train operators. Cellular service may serve as back up communications to radio in emergency. BART's EOC/Operations Center has backup generators to ensure uninterrupted operations. SFMTA does not rely on external communications providers.
Highways and Local Roads	Significant – Road access is critical to perform system inspections and repairs. Station agents, train operators and maintenance crews rely on roads in order to reach their respective work stations, and passengers rely on roads to reach BART and Muni stations.
Fuel	Significant – BART relies on diesel fuel for eBART between the Pittsburg Bay Point and Antioch stations. BART's Operations Center and Emergency Operations Center have fuel for backup generators for 48 hours. SFMTA uses biodiesel for buses. BART and SFMTA requires fuel for maintenance and patrol vehicles.
Transit	Significant – SFMTA and BART workforce relies on transit to get to work and many passengers rely on transit-to-transit connections in their daily commutes.
Solid Waste	None.
Airport	Low – Transit systems don't normally don't transport a significant share of airport customers to the airports; if the airports are non-operational after an earthquake, the transit connections won't be needed. Neither BART nor SFMTA rely on the airports to support their respective operations.
Port	Significant – Transit is not dependent on the Port function, but some significant transit assets are located within Port property and rely on the seawall for asset protection.
Fire Suppression (EFWS)	Low – Fire suppression to prevent damage to transit systems.

Actions to Speed Restoration

BART and SFMTA should work with PG&E to better understand when power will be restored to components of the transit system.

PG&E has upgraded all power connections to BART so they should be functional in an earthquake. This will minimize the need to repair those connections, but BART will still be unable to operate until traction power is restored to the system. BART has redundant power feeds on the east and west end of the Transbay Tube; if a power feed is out on one side, the feed from the other side can provide enough power to move trains through the Tube. BART also has flexibility to pull power from other sections of the traction power supply system to if not all power feeds are operating. During the October 2019 Public Safety Power Shutoffs (PSPS), BART continued operations with minimal disruptions even as 700,000 Bay Area customers lost power.[88] Generators were brought in to provide station power at several locations. There are also vendors who have generators that could provide traction power, but few of these generators exist nationwide and availability will depend on demand and what other incidents are happening. The likelihood of obtaining such a generator quickly enough is low.

SFMTA relies on power supplied by SFPUC through PG&E distribution lines. A power outage would ground a large percentage of the Muni fleet. As mandated by the California Air Resources Board, SFMTA plans to have a 100% electric motor coach fleet by 2035, which means that the electricity disruptions that currently affect SFMTA trains and trolleys will also affect the motor coach fleet in the future. As part of this effort a consultant report is being developed that reviews SFMTA's transition away from hybrid diesel vehicles and towards an all-electric fleet. One of the goals of that report is to ensure that SFMTA maintains an adequate emergency operations fleet in the event of a natural disaster, however, an emergency fleet is not a fully operational fleet.

As a critical transportation backbone for the city and region, BART and SFMTA should work with PG&E to better understand expected time for power restoration to these systems following an earthquake and address any vulnerabilities identified to ensure that resumption of transit service is not hampered by power outages.

[88] BART. 2019. "BART expects no disruptions if PG&E shuts off power to prevent wildfires". October 8, 2019. Retrieved from https://www.bart.gov/news/articles/2019/news20190830-1.

BART should work with SFPUC and EBMUD to better understand when water will be restored to the BART system.

BART cannot operate without water for fire protection in all tunnels and underground stations. For above ground stations, a fire watch may be posted to allow continued operation; however, his is not an option for underground stations. EBMUD and SFPUC provide water at the east and west ends of the Transbay Tube, respectively. BART does not have a good understanding of the seismic vulnerability of the water connections between SFPUC and BART. The restoration of BART in downtown San Francisco and downtown Oakland depends on timely restoration of water service. BART should work closely with SFPUC and EBMUD to better understand water restoration to these systems following an earthquake and address any vulnerabilities identified. Note: EBMUD was not within the scope of this project because it does not serve customers in San Francisco.

SFMTA should assess the feasibility of providing battery backup for critical traffic signals to ensure basic level of post-earthquake traffic flow.

Most traffic signals do not have battery backup and loss of power will result in many signals immediately losing function after an earthquake. Parking Control Officers (PCOs) will immediately be distributed to help with traffic management where signals are down. The SFMTA has already funded and installed a TSBBS system for 70 intersections, but additional intersections have not been funded. Funding is also needed for future battery replacement. SFMTA should assess the feasibility of providing battery backup power for additional critical traffic signals to ensure a basic level of traffic flow post-earthquake.

SFMTA should study resilience issues related to the overhead catenary systems.

SFMTA's overhead catenary system that power much of its fleet are old and their resilience to earthquakes is unknown. Overhead Muni power lines could drop or sag in an earthquake, creating hazards for response crews including fire, especially if at night when visibility is low. The overhead lines are a unique system with their own Muni repair crews.

Natural Gas

Natural gas provides fuel for cooking and heating buildings. Compressed natural gas is also used to fuel some vehicles.

Natural Gas

Operator: PG&E

At A Glance...

Key Findings

- Full restoration of the natural gas system can take up to six months because of the time it will take to integrity test the lines prior to repressurizing and number of qualified personnel required to relight pilot lights.
- If the gas transmission system is damaged and cannot feed San Francisco, compressed natural gas trucks and feed gas directly into the distribution system.
- Natural gas restoration can happen quickly with large numbers of crews to relight pilot lights.
- Natural gas is primarily dependent on electric power and communications for remote operation of gas shut-off valves. The road network is critical to access manual gas shut-off valves and repair damaged pipes. Repair of natural gas pipes is highly dependent on restoration of other underground utilities.

Actions to Speed Restoration

- San Francisco Department of Building Inspection should require all new buildings to be fully electric.
- San Francisco Department of Building Inspection should require electrification of existing buildings with gas shut-off valves as an interim measure.

Restoration Performance Goal

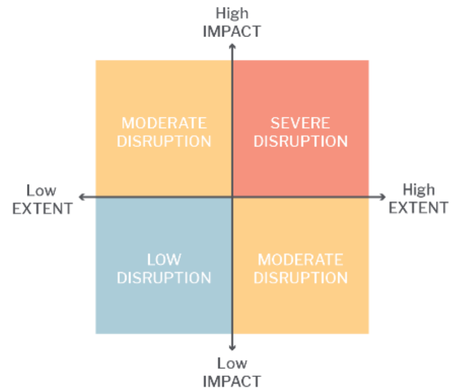
PG&E has not yet developed formal restoration performance goals for the natural gas system.

System Restoration Timeline

The service restoration timeline shown in **Figure 17** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

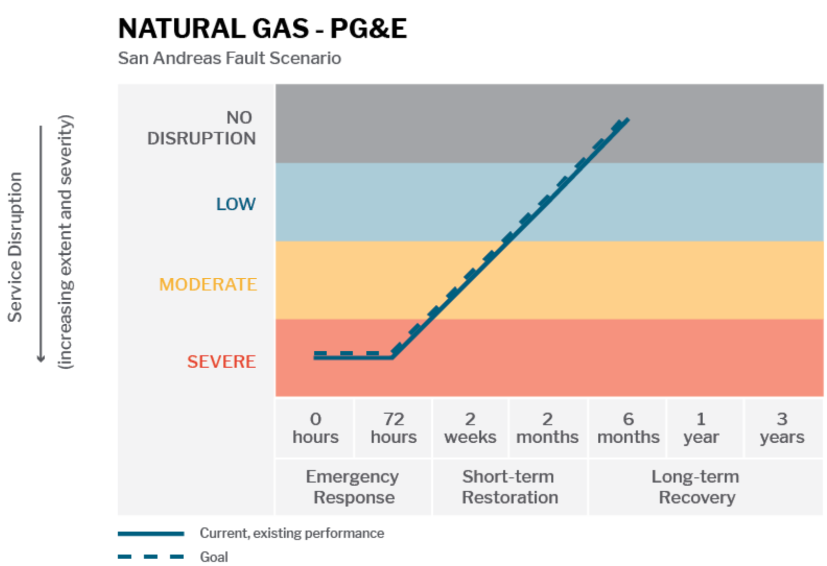
SERVICE DISRUPTION LEVELS



The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

FIGURE 17: NATURAL GAS SYSTEM RESTORATION TIMELINE



Sector Overview

The natural gas system consists of four major components: production, interstate transmission, intrastate and local transmission, distribution, and service lines. These are displayed in the system map seen in **Figure 18**.

Production: Most of the natural gas used in California comes from out-of-state natural gas basins. In 2017, California customers received 38% of their natural gas supply from basins located in the Southwest, 27% from Canada, 27% from the Rocky Mountains, and 8% from basins located within California.[89] Natural gas processing plants separate hydrocarbon gas liquids, nonhydrocarbon gases, and water from the natural gas to make it safe for delivery into the interstate transmission system. PG&E does not own any natural gas production facilities.

Interstate Transmission: Transmission pipelines carry natural gas across long distances, usually to and from compressors or to distribution centers or storage facilities. Transmission lines are large steel pipes (10" to 42" in diameter) that are federally regulated. They carry gas at a pressure of approximately 60-900 psi. Natural gas is delivered into California from producing and processing areas via the interstate natural gas pipeline system to storage facilities and distribution centers where natural gas is delivered to local distribution companies, such as PG&E. [90]

Intrastate and Local Transmission: PG&E delivers natural gas across its service area through high pressure transmission lines, often called the backbone system. Natural gas on the backbone pipeline system is then delivered into the distribution pipeline systems, to natural gas storage fields and directly to some large customers, such as power plants. There are no gas storage facilities or power plants located in San Francisco. Three 19 to 30-inch diameter PG&E transmission lines deliver natural gas up the Peninsula into the City of San Francisco. A fourth PG&E transmission line delivers natural gas from Oakland to a master gas service meter on Treasure Island via submarine pipeline. Compressor stations boost the pressure that is lost through the friction of the natural gas moving through pipes.

Distribution: Natural gas moves from the transmission system to lower pressure distribution lines or mains that range from 2 to 24 inches in diameter. Mains are located

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[89] California Public Utilities Commission. “Natural Gas and California”. Accessed June 2, 2020. https://www.cpuc.ca.gov/natural_gas/.
[90] California Public Utilities Commission. 2020.

beneath nearly every surface street in San Francisco. As gas moves through the distribution system, regulators control the flow from higher to lower pressures.

Service Lines: Service lines connect distribution lines to meters at homes and businesses. When the gas passes through the gas meter, a regulator further reduces the pressure for distribution within the home. Most natural gas customers are residences and small commercial businesses that use natural gas for heating and cooking. Some fleet vehicle owners rely on compressed natural gas delivered by PG&E for their vehicles.

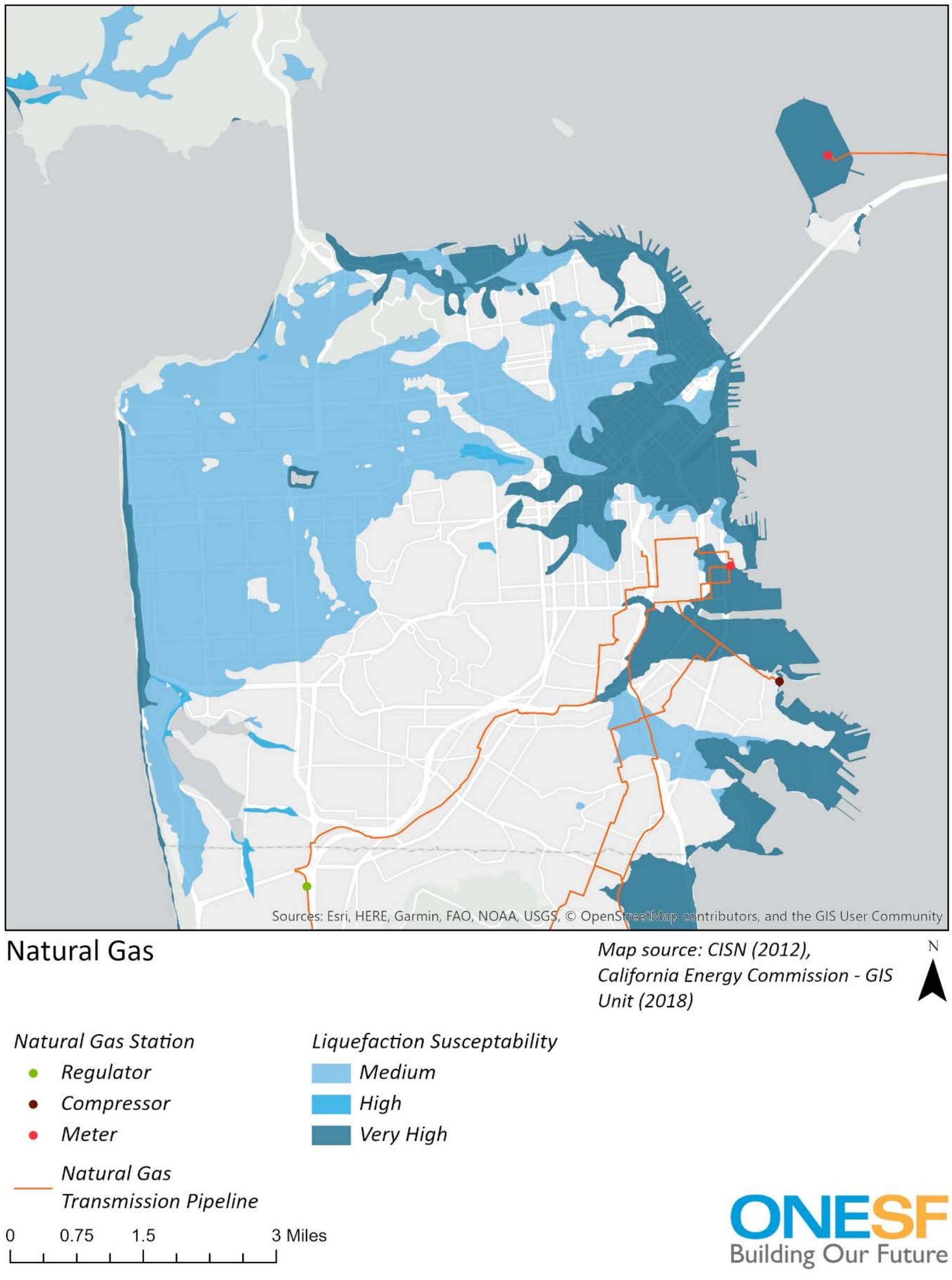
Natural Gas on Treasure Island and Yerba Buena Island

The existing natural gas distribution system on Treasure Island is owned by the Navy and the responsibility of the Treasure Island Development Authority (TIDA) through a cooperative agreement. The system is supplied with gas by PG&E and maintained by the San Francisco Public Utilities Commission (SFPUC) as part of a Utility Service Agreement between TIDA and SFPUC. SFPUC in turn administers a relationship with the SF Public Works to perform regular inspection, maintenance and repair of the existing system. SFPUC also administers the master meter service connection relationship with PG&E.

Redevelopment is underway on Treasure Island and the existing system is being replaced with a new system serving new development in a phased construction approach. As existing buildings and streets are demolished, service is being capped off. Some still-occupied existing buildings whose service has been capped off are being transferred to electrical or propane service during this process. During this period of transition, there will be two separate gas service systems on the island.

Following redevelopment, a new natural gas distribution system serving Treasure Island with a new primary on-island gas regulator station will serve the island. The new distribution system will be owned and maintained by PG&E. The existing natural gas system on Yerba Buena Island has been capped off and no longer serves the island. Following redevelopment, a new gas distribution system will again serve Yerba Buena Island.

FIGURE 18: NATURAL GAS SYSTEM MAP



ONESF
Building Our Future

System Upgrade and Disaster Planning Efforts

In 2010, a PG&E intrastate transmission pipeline in San Bruno rupture and exploded, killing eight people. Because of the rupture, the National Transportation Safety Board (NTSB) issued a number of recommendations to State and federal administrations and institutions to improve the safety of pipeline networks as well as to upgrade the integrity management program and emergency response system.[91] In response to these recommendations, PG&E developed the Pipeline Safety Enhancement Plan to modernize its gas transmissions operations. As a result of this plan, PG&E:

- Tested and replaced all its 2,270 miles of brittle cast iron and pre-1940 steel transmission pipes in its service area with stronger and more seismically resilient material. PG&E has also upgraded all cast iron distribution pipes in its system with a more earthquake-resistant design.
- Studied and mitigated San Andreas and Hayward fault crossings for main local transmission lines feeding San Francisco through PG&E's Fault Crossing Program, which characterizes active faults where they intersect with transmission pipelines and mitigates the impact if an event were to occur. Two additional lower pressure transmission lines are currently planned to be mitigated within the 2019 Gas Transmission and Storage rate case period.
- Overhauled its Gas Control Center in San Ramon and can now monitor and control the gas system across its entire service area, including 6,750 miles of transmission lines and 42,000 miles of smaller distribution pipes.
- Installed 235 remote and automated shutoff valves on its gas transmission lines across its Northern California service territory. These valves eliminate the need for an employee to travel to the site to manually open or close the valve. Remote control valves can be operated remotely from PG&E's new Gas Control Center when significant drops in pressure and/or increased flows at the valve location are detected. Automatic gas shutoff valves have also been installed in densely populated areas and where transmission lines cross major faults. The automatic shutoff valves have been designed to close automatically when local sensors at the valve site detect a possible pipe rupture. Automatic shutoff valves can also be operated remotely from PG&E's Gas Control Center. In San Francisco,

[91] National Transportation Safety Board. 2011. "Pacific Gas and Electric Company Natural Gas Transmission Pipeline Rupture and Fire San Bruno, California September 9, 2010". Washington D.C. August 30, 2011. Retrieved from https://www.aga.org/sites/default/files/legacy-assets/our-issues/safety/pipleinesafety/Technicalreports/Documents/Final%20Report%20of%20NTSB%20San%20Bruno%20Accident%20Investigation.pdf

automatic shutoff valves have been installed on the three transmission lines serving the city;

- Updated the PG&E Gas Emergency Response Plan (GERP) to reflect industry best practices;
- Implemented data management systems intended to ensure its pipeline records are traceable, verifiable and complete; and
- Created a First Responders Safety website, which provides secure access to maps and information about natural gas transmission lines, natural gas storage facilities, and shut-off valves for police, firefighters and Emergency Medical Technicians (EMTs).

Expected Impacts of an Earthquake

San Andreas Fault Scenario

Gas transmission pipelines are generally resistant to earthquake damage and are expected to continue working after an earthquake. However, damage in one or more transmission lines could result in a pressure loss and diminished gas service, depending on weather, day of week, location of damage and other factors.[92]

Gas distribution and service pipelines underlie nearly every street in San Francisco, with connections to nearly every building. Buried pipes can break and cause fires, as has happened in nearly every major earthquake.[93] Pipes located near steep hillsides and liquefaction areas are most at risk of damage. Damage to buildings can also rupture gas service connections to those buildings or appliance connections within a building such as connections to water heaters, stoves or furnaces. Ruptured gas pipelines can create fires if ignited, and those fires could burn until the fuel supply is exhausted. Ignitions from these natural gas sources typically account for about 25 percent of the total number of fire-following-earthquake ignitions.[94] There will be an estimated 68 to 120 total fire ignitions in this scenario, resulting in 11 to 28 million square feet of burned building floor area.[95] In the Loma Prieta earthquake, natural gas pipeline rupture was

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[92] ABAG. 2014.
[93] Applied Technology Council (ATC). 2017. "Study of Options to Reduce Post-Earthquake Fires in San Francisco."
[94] Detweiler, S.T., and Wein, A.M., eds, 2018.
[95] Applied Technology Council (ATC), 2010. "Here to Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco, Potential Earthquake Impacts." ATC 52-1 report, prepared for the San Francisco Department of Building Inspection under the Community Action Plan for Seismic Safety (CAPSS) Project. Redwood City, Ca. https://sfgov.org/esip/sites/default/files/FileCenter/Documents/9752-atc521a.pdf

responsible for some of the 36 post-earthquake fires that broke out in the Marina District. It took about 30 days to repair these pipelines.

Hayward Fault

The Hayward Fault scenario will have greater impact on transmission and distribution pipelines in the East Bay rather than in San Francisco, except for Treasure Island, which will have a similar level of impact to the distribution system as the San Andreas scenario. Some distribution and service pipelines could rupture particularly in liquefaction and landslide zones in San Francisco, but the number will be far fewer. There will be an estimated 27 to 47 gas related fire ignitions in this scenario, resulting in 3 to 11 million square feet of burnt building floor area.[96] An estimated 25 percent of these ignitions may be natural gas related.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 15 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 15** reflects the current, existing performance in the Restoration Timeline in **Figure 17** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

[96] ATC. 2010.

TABLE 15: NATURAL GAS RESTORATION TIMELINE

	Natural Gas - PG&E
0 Hours	Automatic and remote gas safety valves will shut off gas flow when drops in pressure are detected. Pipelines may rupture due to liquefaction. Many customers will lose service and customers may proactively shut-off gas as a precaution. Damage to buildings may result in damage to the customer owned gas lines and meters and appliance connections. Fires can ignite when pipes and connections are damaged. In the event of a significant earthquake, the Gas Emergency Center (GEC) in San Ramon would activate along with the PG&E Emergency Operations Center (EOC) in San Francisco or Vacaville, and local Operations Emergency Centers (OECs).
72 Hours	Inspection and repair will be underway with restoration focused on transmission lines and the highest priority customers such as hospitals, with attention to residential customers later. When gas transmission pipelines have been inspected and all corrective action have been completed, the pressure can be restored and valves reopened. The restoration time will depend on the extent of pipeline damage, likely taking one day to a week or more.
2 Weeks	Damage assessments will be completed and repairs underway. Integrity testing will be underway to allow pressurizing the lines. Support from PG&E resources and other utilities outside the region will have arrived and relighting pilot lighting will be underway. Pilot lights must be manually turned back on at each service location and depend on access and personnel. Ability to restore system will depend on availability of material, equipment and ability to move people. Sewage line breaks will impact ability to restore the system.
2 Months	Most customers with available connections will have service. Pilot relights will largely be completed and service will be returned to many customers, depending on homes and businesses being able to receive service.
6 Months	Full restoration is expected citywide.
1 Year	
3 Years	

Hayward Fault Scenario

The initial response will be the same in the Hayward fault scenario, however there will be fewer automatic or remote shut-offs in this scenario and fewer pipe ruptures. Some buildings owners may still turn off their gas at the meter, but there will be significantly fewer pilot relights needed than in the San Andreas scenario. Studies estimate that in San Francisco, 50% of gas service will be restored in nine days and restoration will be

90% complete in about a month in a Hayward Fault scenario.[97] The restoration time for the transmission system is expected to be similar or less than the San Andreas scenario.

Level of Confidence

PG&E's confidence in its restoration assumptions is based on recent system upgrades, emergency and contingency plans it has developed, significant system modeling and recent experience with disaster service restoration. PG&E combines a suite of USGS ShakeMaps scenarios with its System Earthquake Risk Assessment (SERA) vulnerability model to establish likely damage of components in the system. This model is used to design its system upgrade plan and as post-disaster decision support tool to determine where damage likely occurred. PG&E also has significant experience in disaster response and service restoration within its service area and through mutual aid to disasters outside its service area.

System Interdependencies

The operation of remote gas shut-off valves in the natural gas system is dependent on electric power and communications. Regulating stations, compressors and meters also rely on electric power and communications for SCADA systems. The road network is critical for access to manual gas shut-off valves and for repairing damaged natural gas pipes. Repair of natural gas pipes is highly dependent on restoration of other underground utilities.

Table 16 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

The operation of remote gas shut-off valves in the natural gas system is dependent on electric power and communications. Regulating stations, compressors and meters also rely on electric power and communications for SCADA systems, however most facilities have battery backup. The road network is critical for access to manual gas shut-off

[97] Almufti and Willford, 2013. "REDi Rating System: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings." Retrieved from https://www.arup.com/perspectives/publications/research/section/redi-rating-system.

valves and for repairing damaged natural gas pipes. Repair of natural gas pipes is highly dependent on restoration of other underground utilities.

TABLE 16: NATURAL GAS SYSTEM DEPENDENCE ON OTHER SECTORS

Sector	Extent of dependence on sector
Electric Power	Significant – Automatic and remote natural gas shut-off valves rely on electricity; however, they have battery backup power to operate in the case of an electric outage. The vast majority of gas regulation and control equipment are not affected by power outages as they are mechanical devices that are powered by pressure in the gas system. Loss of natural gas system could increase power usage for heating and cooking, especially in wintertime.
Natural Gas	None
Water	Moderate – Damage to water pipes will limit ability to repair natural gas pipes.
Wastewater	Moderate – Damage to wastewater pipes will limit ability to repair natural gas pipes.
Communications	Moderate – Communications are required to manage the Gas Control Center and activate remote control shutoff valves. Automatic shutoff valves are programmed locally and do not require communication to operate.
Highways and Local Roads	Significant – Roads are critical for access to manual shut-off valves, repair of ruptured pipes and delivery of supplies and equipment. Compressed Natural Gas (CNG) fueling stations for vehicles will have limited capacity for the extent of a natural gas outage and rationing may be necessary.
Fuel	Significant – Fuel is needed for backup generators
Transit	None
Solid Waste	None
Airport	None
Port	Low – For delivery of supplies
Firefighting Water (EFWS)	None

Actions to Speed Restoration

San Francisco Department of Building Inspection should require all new buildings to be fully electric.

Natural gas restoration following a major earthquake is estimated to take up to six months, compared to less than two weeks for full electricity restoration. Buildings damaged in earthquakes can rupture the gas connection to the building and gas appliances not connected with flexible pipes can also rupture, causing fires. Natural gas pipe breaks in buildings are expected to be responsible for most of the natural gas related fire ignitions in earthquakes.[98] If all post-earthquake gas related fire ignitions were prevented, ignitions might be reduced up to 25% and post-earthquake fire losses could be reduced by as much as $2 billion.[99]

Moving from natural gas for heating and cooking to electric sources can improve restoration times and reduce likelihood of fire following earthquake ignitions while also reducing greenhouse gas emissions. Electrified buildings may also be better able to take advantage of on-site solar energy stored in batteries, allowing near continuous operation of critical building functions following an earthquake (see associated recommendation in **Electric Power** summary).

To meet the City's Greenhouse Gas Reduction targets, reduce the potential for gas related post-earthquake fires and speed restoration of building functionality, San Francisco Department of Building Inspection should immediately require all new buildings to be fully electric with no gas service.

San Francisco Department of Building Inspection should require electrification of existing buildings with gas shut-off valves as an interim measure.

To reduce the likelihood of post-earthquake gas related ignitions and speed restoration of building functionality in existing buildings, San Francisco Department of Building Inspection, Department of the Environment and SFPUC Power Enterprise should work with PG&E to develop a program to require electrification of existing buildings by a specific date, at time of sale, or during significant alteration. The program should identify which neighborhoods are most at risk from conflagrations resulting from gas-related ignitions following earthquakes and prioritize electrification in the riskiest

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[98] ATC. 2010.
[99] ATC. 2017.

neighborhoods. Mitigation measure are most effective at a neighborhood scale because of potential for fire spread beyond the initial ignition. Dense, older neighborhoods, those in liquefaction areas, and high-rise buildings are generally at the greatest risk for post-earthquake fires. Incentives should also be considered for electrification of recovery critical facilities; such as medical buildings, schools, grocery stores, etc. and homes that serve vulnerable populations

As an interim measure for neighborhoods that are not the highest priority for electrification, San Francisco should require gas shut-off valves on all existing buildings. To date, PG&E has not encouraged customers to install shut-off valves on their meters and has chosen not to install them on the PG&E owned side of the meter.[100] One concern with gas shut-off valves is that following an earthquake, PG&E will need to manually restore gas service to every building in which the gas was shut off by inspecting the meter, restoring gas service and accessing the inside of buildings to relight the pilot light. This is labor intensive and could delay restoration of gas service citywide. Residents sheltering in place may need to obtain alternate methods of heating and cooking and could become displaced. However, restoration times can be sped up with additional personnel. To be effective, gas shut-off valves must be installed on a critical mass of buildings. In a dense neighborhood, there will be little benefit from preventing ignitions on a small number of buildings.[101]

Thirteen Bay Area cities and three counties as well as Los Angeles currently require automatic gas shut-off valves at the time of sale or during significant renovations.[102] For example, Contra Costa County requires approved seismic gas shut-off valves (motion sensitive) or excess flow gas shut-off valves (non-motion sensitive) to be installed downstream of the gas meter on all new construction, when a property is sold or undergoes significant renovation. The City of Berkeley provides free automatic shut-off valves to community members who attend disaster readiness training. Following the 1995 Kobe earthquake, the gas industry in Japan encouraged installation of these valves.[103]

[100] ATC. 2017.
[101] ATC. 2017.
[102] ATC. 2017.
[103] Detweiler, S.T., and Wein, A.M., eds. 2018.

Wastewater

Photo: Monteray Mechanical Co./Website

San Francisco's combined sewer system, owned and operated by the San Francisco Public Utilities Commission (SFPUC), treats on average 65 million gallons of wastewater daily during dry conditions and as much as 575 million gallons of combined sewer and stormwater daily during wet weather conditions. The collection system is largely gravity driven, using an interconnected web of combined sewers, tunnels, and transport/storage boxes to intercept, store, and convey combined sewer flows to one of three treatment facilities. Where gravity isn't sufficient to move this water around the system, or where weather conditions require the use of different facilities, force mains and pumping stations move wastewater to the treatment facilities. Following treatment to nationally permitted standards, effluent is discharged offshore either to the Pacific Ocean or the Bay.

Wastewater

Operator: SFPUC

At A Glance...

Key Findings

- Full restoration of the wastewater system may take three years due to damage to the collection system. As the water system is restored, wastewater volumes will increase, which may exceed the capacity of the damaged collection system until collectors and mains are repaired.
- Even damaged pipelines can convey some flow and even if many pipes are broken, flow can travel through the street until it reaches the next inlet.
- The wastewater system has significant dependencies on electric power, water, communications, highways and roads, and fuel for vehicles and generators. Transit for employees and natural gas for boilers are also important.
- None of the treatment plants and very few of the pump stations have redundant power. Although wastewater flows can move by gravity through parts of the system without electric power, wastewater cannot be lifted into the treatment plants or processed within the plants.
- Phase 1 of the Sewer System Improvement Program consists of 70 projects to be completed by 2026 totaling approximately $3 billion.
- Most sewer repairs are done by private contractors and Public Works, with no guarantee they will prioritize wastewater system repairs after an earthquake.

Actions to Speed Restoration

- SFPUC should develop service level agreements and MOUs to ensure adequate staffing for post-disaster evaluations and emergency repairs.
- SFPUC should communicate power restoration needs of treatment plants and pumps to PG&E.
- SFPUC should characterize its needs and impact to the pumps and treatment plants of lengthy power outages, and work with PG&E to prioritize restoration of power accordingly.
- SFPUC should adopt and implement measures to achieve performance goals pertaining to restoration of the wastewater collection system.
- SFPUC should develop a coordinated plan and public messaging for handling biological waste when toilets won't flush.

Restoration Performance Goals

SFPUC has adopted the following seismic reliability level of service goal as part of the Sewer System Improvement Program (SSIP): Dry weather primary treatment, with disinfection, will be online within 72 hours of a major earthquake.

Achieving this goal requires designing critical and new facilities to withstand M7.8 San Andreas Fault and M7.1 Hayward Fault events. Other objectives pertaining to this goal include reducing the number of overflow discharges, providing pumping plant redundancy for force mains, providing electrical redundancy at treatment facilities and pump stations, and providing redundant pumps.

It should be noted that the 72-hour restoration goal pertains to restoration of the treatment plants, not the collection system that conveys waste from homes, business and storm drains. Once water for flushing, showers and sinks returns to service, damage to the collection system and in-building plumbing will affect the system's ability to move wastewater to the treatment plants. The resulting conditions may present sanitation and public health challenges. Consequently, it would be valuable for SFPUC to develop additional restoration goals focused on customer use and collection.

In addition, the restoration timeline is predicated on a dry season event. Given the City's combined wastewater-stormwater system, rainfall can have a significant effect on wastewater storage and treatment. If the earthquake were to occur during the rainy season, it is possible that there would not be enough capacity to store untreated wastewater until wastewater treatment could resume and discharges of untreated wastewater into the Bay would be very likely. SFPUC would have to notify the Environmental Protection Agency and/or Regional Water Board about the discharges. The addition of stormwater runoff to the effluent would help mitigate negative environmental effects due to dilution.

System Restoration Timeline

The service restoration timeline shown in **Figure 19** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

SERVICE DISRUPTION LEVELS

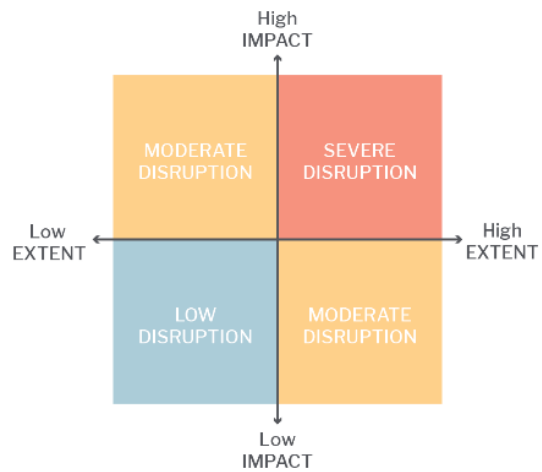
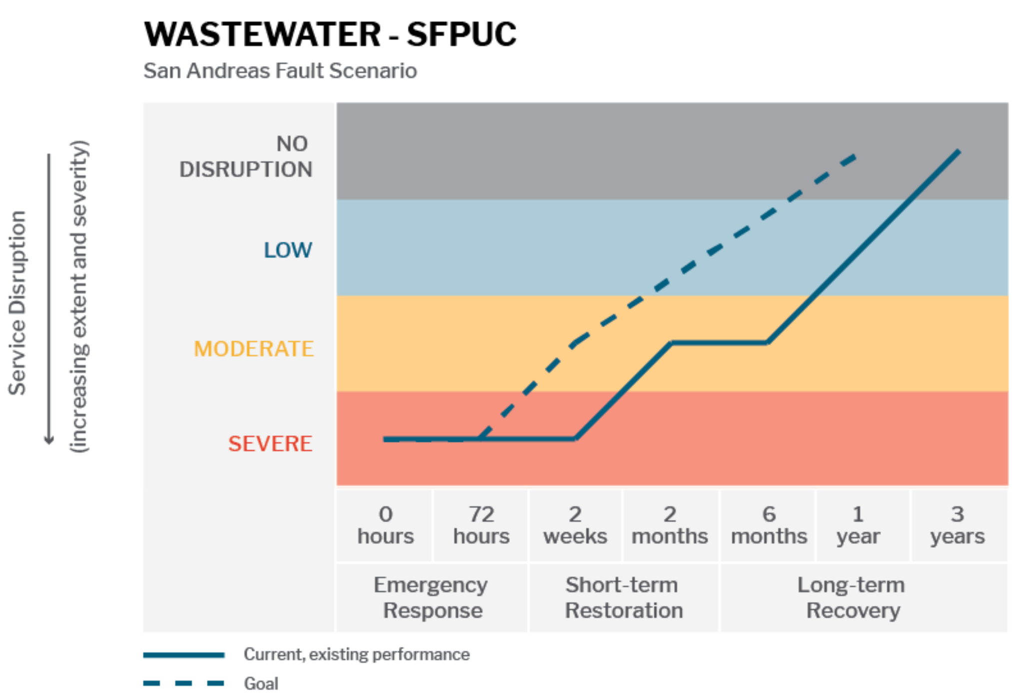


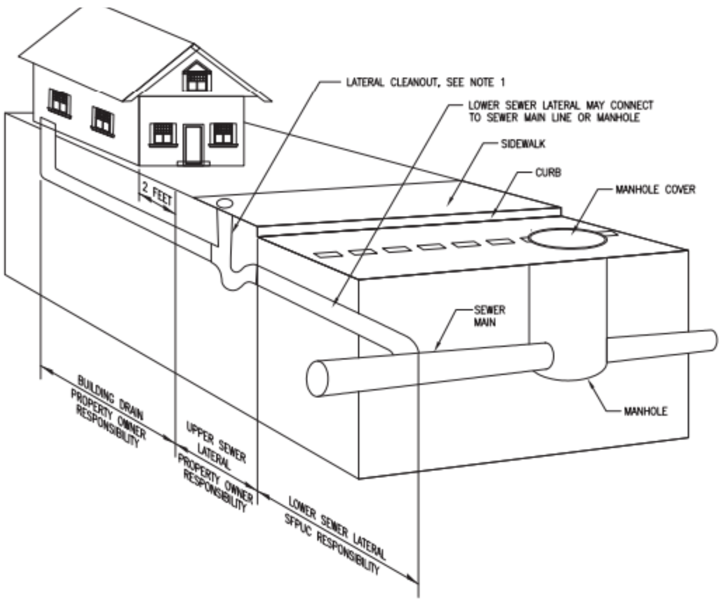
FIGURE 19: WASTEWATER SYSTEM RESTORATION TIMELINE



Sector Overview

The combined sewer system is composed of five components that are spread across the. These components, except for laterals, are shown in **Figure 20**. The system map is shown in **Figure 21.**

FIGURE 20: COMPONENTS OF THE COMBINED SEWER SYSTEM



Sewer laterals: Connect plumbing within a building to the sewer main in the street. Building owners are responsible for maintenance of the sewer lateral from the building to the main. SFPUC is responsible for the structural integrity of the lower lateral from the trap and vent located in the sidewalk to the sewer main. The graphic above demonstrates the way wastewater enters the system from the buildings and the respective areas of responsibility.

Combined sewer mains and tunnels: Conveys sewage from buildings and stormwater runoff to treatment plants. Sewer laterals connect buildings to sewer mains, which run beneath streets. Property owners own the pipe from the building to the cleanout at the sidewalk and SFPUC owns the lateral from the cleanout to the connection with the sewer main. Because of the topography of the city, water flows through most of the sewer pipes using gravity. SFPUC owns and operates about 1,900 miles of sewer mains and laterals beneath city streets.

Pump stations: Predominantly located along the Pacific coast or adjacent to the Bay with a few exceptions, and discharge via pressurized force mains. The system includes over two dozen pump stations.

Force mains: Typically buried conduits used when gravity flow is not sufficient to move combined sewer flows through a sewer. They link pump stations to other parts of the collection system or deliver combined wastewater to treatment facilities.

Transport/storage boxes: Encircle the City along its coastline and are part of the collection system. They can also store combined sewer and stormwater flows in wet weather events. The transport/storage structures provide treatment equivalent to primary treatment. Flows can be discharged from the transport/storage boxes through outfalls directly to the bay or ocean when treatment plants reach capacity.

Treatment facilities: Receive combined sewer flows from the system for treatment and discharge into the San Francisco Bay or Pacific Ocean.[104]

The Southeast Treatment Plant is in Bayview/Hunters Point, and serves the east side of the City. It is San Francisco's largest wastewater facility, treating on average 53 million gallons per day (MGD) in dry weather and 250 MGD in wet weather.

The Oceanside Treatment Plant, is located near the Pacific Ocean and the San Francisco Zoo, and serves the west side of the City. Oceanside Plant treats on average 12.4 MGD during dry weather and 65 MGD in wet weather.

[104] SFPUC. "San Francisco's Wastewater Treatment Facilities". 2014. Retrieved from https://sfwater.org/modules/showdocument.aspx?documentid=5801

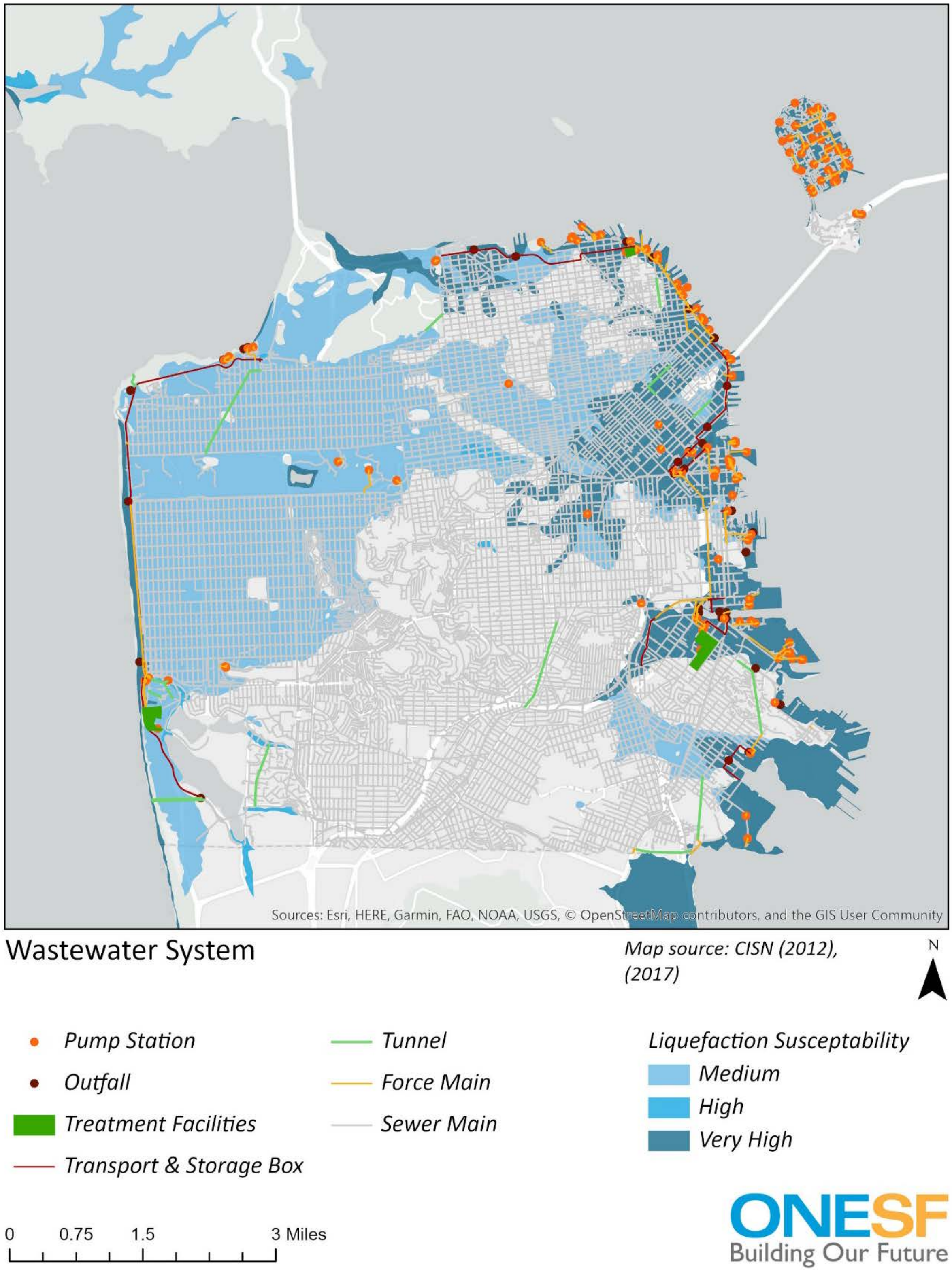
OCEANSIDE TREATMENT PLANT

The North Point Wet Weather facility, is located near Fisherman's Wharf but is used only for wet days (approximately 30 times a year). It can treat up to 150 MGD.

NORTH POINT WET WEATHER FACILITY

Because San Francisco has a combined system, heavy rains can lead to permitted combined sewer discharges directly (without passing through a treatment plant) into the bay and ocean with equivalent of primary treatment. In addition, when the system reaches capacity during large storm events, localized street flooding can occur. Rising seas and more intense and frequent storms can overwhelm the system, leading to more frequent direct discharges and street flooding.

FIGURE 21: WASTEWATER SYSTEM MAP



System Upgrade and Disaster Planning Efforts

SFPUC developed the Sewer System Improvement Program (SSIP) because routine repairs are no longer enough to keep pace with the aging and seismically vulnerable infrastructure. Phase 1 of the program consists of 70 projects to be completed by 2026 totaling approximately $3 billion. Twenty-six of the projects have been completed to date (December 2019)

The biggest projects that are scheduled to be completed in Phase 1, includes the following projects totaling approximately $2.5 billion.

- Collection system upgrades (various),
- 250 MGD Headworks Facility at the Southeast Plant, and
- Biosolids Digester Facility, also at the Southeast Plant.

SOUTHEAST TREATMENT PLANT

Other Phase 1 projects include Oceanside Treatment Plant upgrades, North Point Wet Weather Facility upgrades, North Point Outfall Rehabilitation, and Southeast Area upgrades. Half of the secondary clarifiers were upgraded and a redundant section of the force main was constructed for the Northshore pump station as backup to a leaky section of the pipe.

The Lateral Asset Management Program strategically addresses the condition of sewer laterals. The Collection System Asset Management Program is a risk-based approach to sewer replacement planning. The program uses condition assessment to replace mains at the end of their useful life. Since 2012 the CSAMP has replaced 109 miles of the highest risk sewers. The annual goal for sewer replacement is 15 miles. There are 1,000 miles of mains, and at the current rate, it will take 67 years to replace all the mains. Risk prioritization is based on the likelihood and consequence of failure. The SFPUC inspects about 100 miles of mains annually.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

Sewer pipes are segmented to accommodate movement and even damaged pipes can convey some flow. Still, many sewer mains will likely be damaged in this scenario, making it difficult to move flow to the treatment plants. In places with heavy damage, as in liquefaction areas, the street may be used to convey flows to the next inlet. Much of the system flows by gravity and doesn't require power, but pump stations are still required to move flow to higher elevations. Very few pump stations have backup power from generators to move wastewater. None of the stationary or mobile backup generators will provide enough power to run the pumps at full capacity; the primary purpose of the generators is to provide basic services such as lights, fire suppression and HVAC. SFPUC Wastewater Enterprise is planning to purchase at least one 400kW generator soon; additionally, all the pump stations can be hardwired to a generator large enough to run the pumps at full capacity, but such a generator would need to be rented or borrowed for the largest pump stations.

Damage to the water system will significantly decrease wastewater flows from domestic water use (toilets, sinks, showers, laundry, etc.) in the immediate post-disaster period. Damage to the wastewater collection system may prevent adequate collection of the wastewater flows that do occur. In locations where there is damage to the water and/or wastewater systems, the City may instruct Residents may be instructed to tag and bag human waste or dispose of it by burying it on site, however specific plans have not yet been developed to address this issue.

Effluent that reaches a treatment plant will likely be statically discharged without secondary treatment if there is no power. The treatment plants do not have back-up power. If it's not raining, combined sewage can be stored in the system via the Transport/Storage structures and the North Point Wet Weather Facility. Because of this storage capacity, SFPUC has never had to discharge without treatment in an earthquake scenario. While chemical spills at treatment plants are also a concern in earthquakes, the chemical tanks at Southeast and Oceanside treatment plants are designed to current seismic standards and chemical spills are less likely.

TRANSPORT/STORAGE STRUCTURE

Any blockage or damage of the plumbing system up to the cleanout at the curb will have to be repaired by the building owner before wastewater can flow out of the building. Buildings that sustain structural damage or are in liquefaction are likely to have damaged pipes within the building and buildings in liquefaction areas are likely to have damage to the outflow pipe or trap.

If the lateral were damaged, wastewater would come to the surface at the cleanout and then flow into the gutter and then into a nearby storm drain inlet, where it would return to the system. SFPUC can check the cleanout and identify the damage, but it is up to the building owner to make the repairs. Damage to laterals and mains could result in flow and ponding of wastewater on the surface in numerous locations. Wastewater flows may not be moving out of buildings until water service is restored, so damage to the lateral may not be apparent until flows begin moving.

Many employees live in the East Bay and far East Bay and returning to work in a timely manner could be challenging for many of them, depending on the condition of their homes and functionality of the transportation system. SFPUC does anticipate that there will be enough crews in the city or on the Peninsula to cover the initial response shifts until East Bay employees arrive.

Hayward Fault

SFPUC doesn't anticipate widespread damage to the system in this scenario, due to reduced risk of liquefaction. While the collection system may be damaged, significant damage is not expected at the wastewater treatment plants. Power outages would affect the treatment plant's ability to operate. Delivery of chemicals by truck to the treatment plants could be an issue, as most chemical shipments come from Southern California and Richmond through a service contract. Employee access to San Francisco from the East Bay will also be an issue in this scenario.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 17 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 17** reflects the current, existing performance in the Restoration Timeline in **Figure 19** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 17: WASTEWATER SERVICE DISTRUPTION TIMELINE

	Wastewater - SFPUC
0 Hours	Following an earthquake, SFPUC will shut down the system and perform an immediate conditions assessment to determine where main breaks have occurred through windshield surveys, as road access allows. Information coming in to the City's Emergency Operations Center and the PUC's Department Operations Center would also be collected. PUC crews would pull manhole covers and check flows in the mains to determine whether the mains were operating properly. SFPUC's draft Emergency Operations Plan for wastewater calls for dispatch of wastewater staff for inspection of facilities where shaking intensity reached MMI 6 or greater.
72 Hours	*Goal is for dry weather primary treatment, with disinfection, to be online within 72 hours. This goal will be achieved after completion of SSIP program in 15-20 years.* Within a relatively short period of time, priorities for repairing damaged mains would be established. This prioritization would be done in coordination with the Department of Public Works, given that the larger mains tend to be in the larger and busier streets. Bypass pumps to work around breaks in the mains would also be installed while repairs are ongoing. SFPUC would use its own crews, supplemented by contractors, for the assessment, pumping, and repair activities. Repairs to important sewer mains will begin. Flows will start moving around the city where there is no damage and water service has been restored, and primary treatment will be online.
2 Weeks	*Goal is for moderate system wide restoration at 2 weeks.* Flows will be moving through the collection system, sewage will be partially treated and will be discharging (not fully treated). Wastewater may flow over the streets or otherwise not be collected and transported properly. Digesters, force mains, and pump stations may still be out of service until power is restored (at around 1 week). Public health would be at risk where flows are traveling over land.
2 Months	At this period there will be enough digesters running to run dry weather operations. Repairs to laterals would begin as repairs to the mains are completed. As requested by building owners, SFPUC can check cleanouts and identify damage. Building owners will undertake repairs of the lateral to the cleanout, which is their responsibility. However, the pace at which these repairs occur will be dependent on the owner's resources, insurance settlements, availability of contractors, and other factors beyond SFPUC's control.
6 Months	Given the tens of thousands of buildings and thousands of miles of laterals that could possibly require repair, the timeline for restoration of the collection system (and therefore proper use by the customers) could take many months. Buildings in heavily damaged areas or where owner responsibility repairs have not yet been made, may not have service.
1 Year	*Goal is for full restoration of collection and treatment systems within one year.* Restoration will continue with more of the heavily damaged areas returning to service.

	Wastewater – SFPUC
3 Years	Full restoration of collection and treatment system may take up to three years, depending on extent of damage and restoration of building plumbing and laterals.

Hayward Fault Scenario

Inspections and conditions assessments will be triggered in areas with shaking intensity MMI 6 and greater, but there is likely to be limited system damage or customer impact.

Level of Confidence

SFPUC has high confidence in the performance of the treatment system based on modeling completed for SSIP. Disaster scenarios, past earthquakes, other recent disasters, daily operations and maintenance activities, and capabilities of the staff who know the system inform its understanding of how the system will perform in future earthquakes.

System Interdependencies

The wastewater system has significant dependencies on electric power, water, communications, highways and roads, and fuel for vehicles and generators. Transit for employees and natural gas for boilers are also important for the wastewater system.

Table 18 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 18: WASTEWATER SYSTEM DEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – Without electric power, wastewater cannot be conveyed to the treatment plants or processed within the plants and flows could be statically discharged to the Bay or Pacific Ocean without treatment. Very few of the pump stations and none of the wastewater treatment plants have any redundant power. The Oceanside Plant can switch between dual power feeds from two different PG&E substations with PG&E approval.
Natural Gas	Moderate – For fueling boilers used to heat the digesters. Keeping digesters at the right temperature is important to ensure complete digestion of solids and compliance with regulatory requirements for biosolids disposal. In addition, if treatment process isn't completed, solids cannot be transported for disposal
Water	Significant – Restoration of wastewater system is dependent on restoration of the water system that provide flow to the system– a person cannot flush a toilet, or run sinks or showers without water. At the same time, lack of water service initially will reduce demand on the system while repair work is underway. Water is also used to cool the larger pumps and for fire response at Southeast Treatment Plant.
Wastewater	None
Communications	Significant – SFPUC's SCADA system controls operation of the pump stations
Highways and Local Roads	Significant – For chemical delivery, employee movement, access to pipes for maintenance and repair
Fuel	Significant – For fleet vehicles and generators
Transit	Moderate – For employees to return to work
Solid Waste	Moderate – Accessing damage pipes will not be possible until debris is removed from streets
Airport	None
Port	Moderate – For employees to return to work
Firefighting Water (EFWS)	Low – EFWS service at Northpoint (wet weather). SE and Oceanside not served by EFWS. Have own high-pressure system at Southeast treatment plant. Pump stations don't have dedicated fire treatment.

Actions to Speed Restoration

SFPUC should develop service level agreements and MOUs to ensure adequate staffing for post-disaster evaluations and emergency repairs.

Seventy five percent of crews who perform maintenance and repairs to the gravity sewer system are private contractors who may also work for the SFPUC Water Enterprise. The remaining 25% of crews work for Public Works. Without a dedicated sewer repair crews, SFPUC may be forced to compete with other departments for labor to perform emergency inspections and repairs. Availability of crews in an emergency that affects water and streets as well should be evaluated and contingency plans developed. SFPUC should develop service level agreements and MOUs with Public Works and private contractors to ensure adequate staffing for post-disaster evaluations and emergency repairs.

SFPUC should communicate power restoration needs of treatment plants and pumps to PG&E.

Most of the pump stations and all the wastewater treatment plants do not have back-up power. Power demand of the treatment plants is too large to carry on a backup generator. None of the backup generators for the pump stations will provide enough power to run the pumps at full capacity, although some can provide limited pumping; the primary purpose of the generators is to provide basic services such as lights, fire suppression and HVAC. Without power, wastewater will move by gravity only where possible and may be discharged directly to the bay or ocean. The system has some capacity to store effluent in the storage/transport boxes for up to 72 hours with primary treatment. The period will be less if an earthquake occurs during wet weather. Once the storage boxes are full, undisinfected effluent will begin to discharge to the Bay or Ocean in violation of National Pollutant Discharge Elimination System (NPDES) permit requirements. SFPUC should characterize its needs and impact to the pumps and treatment plants of lengthy power outages, and work with PG&E to prioritize restoration of power accordingly.

SFPUC should adopt and implement measures to achieve performance goals pertaining to restoration of the wastewater collection system.

The restoration performance goals that have been adopted by SFPUC to date pertain to the storage and treatment of wastewater in dry weather conditions, not the ability of customers to flush their toilets and move wastewater from buildings to treatment plants. Given the fact that the people in the city are more likely to be aware of, and immediately affected by, the collection system, SFPUC should consider adopting a second performance goal for this aspect of the system. In addition, it should address restoration expectations and issues pertaining to an earthquake occurring during wet weather.

SFPUC should develop a coordinated plan and public messaging for handling biological waste when toilets won't flush.

When toilets cannot be flushed due to lack of running water, damage to building plumbing system, or damage to the wastewater collection system, people may be forced to use alternative methods of waste removal while sheltering at home. This possibility, along with leaks and breaks that could lead to surface flows and pooling of wastewater in the streets, will create poor sanitary and public health conditions. Alternative waste disposal options may include instructing residents to tag and bag human waste, disposing of it by burying it on site or installing portable toilets throughout affected neighborhoods. The City needs to develop a coordinated strategy and public messaging around handling biological waste when toilets won't flush. The adopted timeline for restoration of the collection system could provide a framework for assessing the scope and duration of the problem. This effort should be coordinated between the Department of Emergency Management, SFPUC, Department of Public Health, and Recology, among other organizations.

Solid Waste

Photo Source: Recology

Recology Inc. is a regional resource recovery company headquartered in San Francisco that owns the Recology operating facilities serving the City of San Francisco. Recology San Francisco is the exclusive refuse (recyclables, compostables and trash) and primary construction and demolition debris processing and hauling company operating recycling plants, San Francisco's Household Hazardous Waste Facility, and performing long-haul trucking operations for material to Recology's out of region compost and landfill facilities. Recology Golden Gate and Sunset Scavenger are San Francisco's collection companies.

Solid Waste

Operator: Recology

At A Glance...

Key Findings

- Refuse collection will be restored as truck fuel is available and roads traversable. However, the sorting of recyclables could take a year to be fully restored primarily because of likely damage to the Recycle Central facility located at Pier 96.
- Recology has significant dependencies on natural gas and fuel, the Port, highways and local roads, and transit for its operations.
- Post-disaster fuel availability could significantly restrict municipal solid waste collection operations.
- Damage to Pier 96 could significantly restrict post-disaster recycling operations and overload the San Francisco Transfer Station.
- Recology personnel increasingly live outside San Francisco. Depending on time of day of the event, municipal solid waste collection could be constrained by staffing resources until access across the Bay is established.
- Recology's capacity to store municipal solid waste is limited to about three days before it must begin transferring it out of the City to the landfills, composting facilities, and recyclers.

Actions to Speed Restoration

- Recology should increase its understanding of post-disaster fuel availability and the regional prioritization process to enable better planning for post-disaster fuel needs.
- Port of San Francisco should complete a vulnerability study to determine the likelihood that Pier 96 will be operational after the scenario earthquake and determine alternate recycling collection and debris processing locations.
- Recology should explore alternative methods for waste transfer, such as activation of the existing rail spur and connection to the rail line which would reduce likelihood of surpassing Recology's waste storage capacity.
- Large building owners should consider establishing a redundant power source for refuse compactors for commercial buildings.

Restoration Performance Goals

Recology's immediate post-earthquake goal is to provide emergency refuse collection service at the City's direction, share resources such as equipment and labor with partner City agencies, while working to repair, replace, or rebuild infrastructure and equipment as quickly as possible, to meet our obligations to the City and County of San Francisco, and our contracts with Federal and State properties located in San Francisco.

System Restoration Timeline

The service restoration timeline shown in **Figure 22** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

SERVICE DISRUPTION LEVELS

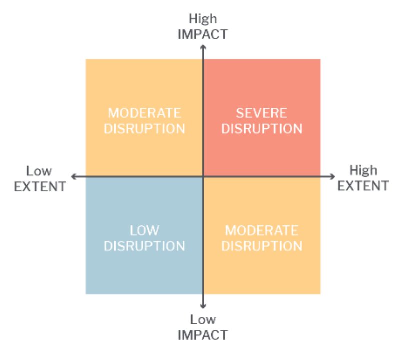
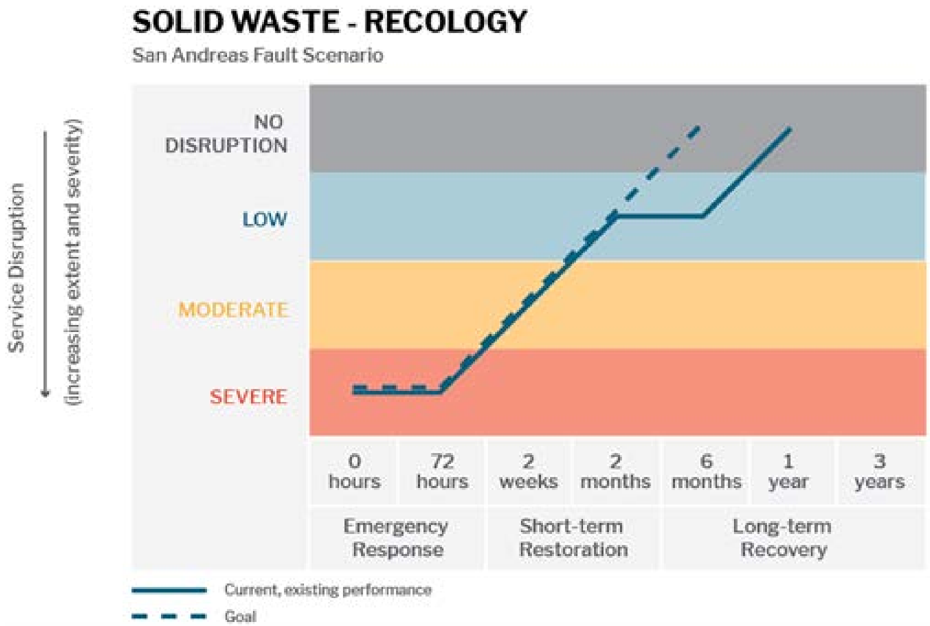


FIGURE 22: SOLID WASTE SYSTEM RESTORATION TIMELINE



Sector Overview

Recology Inc. is a regional resource recovery company headquartered in San Francisco that has been servicing the City for nearly 100 years. With this historic relationship, Recology's commitment to the City of San Francisco goes beyond its contractual obligations and intends to serve San Francisco in whatever capacity it can following an earthquake. Recology Inc. owns the Recology operating companies that serve the City of San Francisco. Recology San Francisco is the processing and hauling company that operates the recycling plants, San Francisco's Household Hazardous Waste (HHW) Facility, and performs the long-haul trucking operation of material to Recology's out of region compost and landfill facilities. Recology Golden Gate and Sunset Scavenger are San Francisco's collection companies. The solid waste system for San Francisco is shown in **Figure 23**.

Sunset Scavenger and Recology Golden Gate operate 320 route trucks that collect materials from businesses and residents in San Francisco with a source separation collection system. This system consists of blue bins for recyclable materials, green bins for compostables, and black bins for trash. Materials from the black and green bins, as well as construction and demolition material (C&D), are delivered to the Transfer Station on the border of Brisbane and San Francisco at 501 Tunnel Ave. The 75-acre facility is permitted to receive up to 5,000 tons per day and performs the following functions:

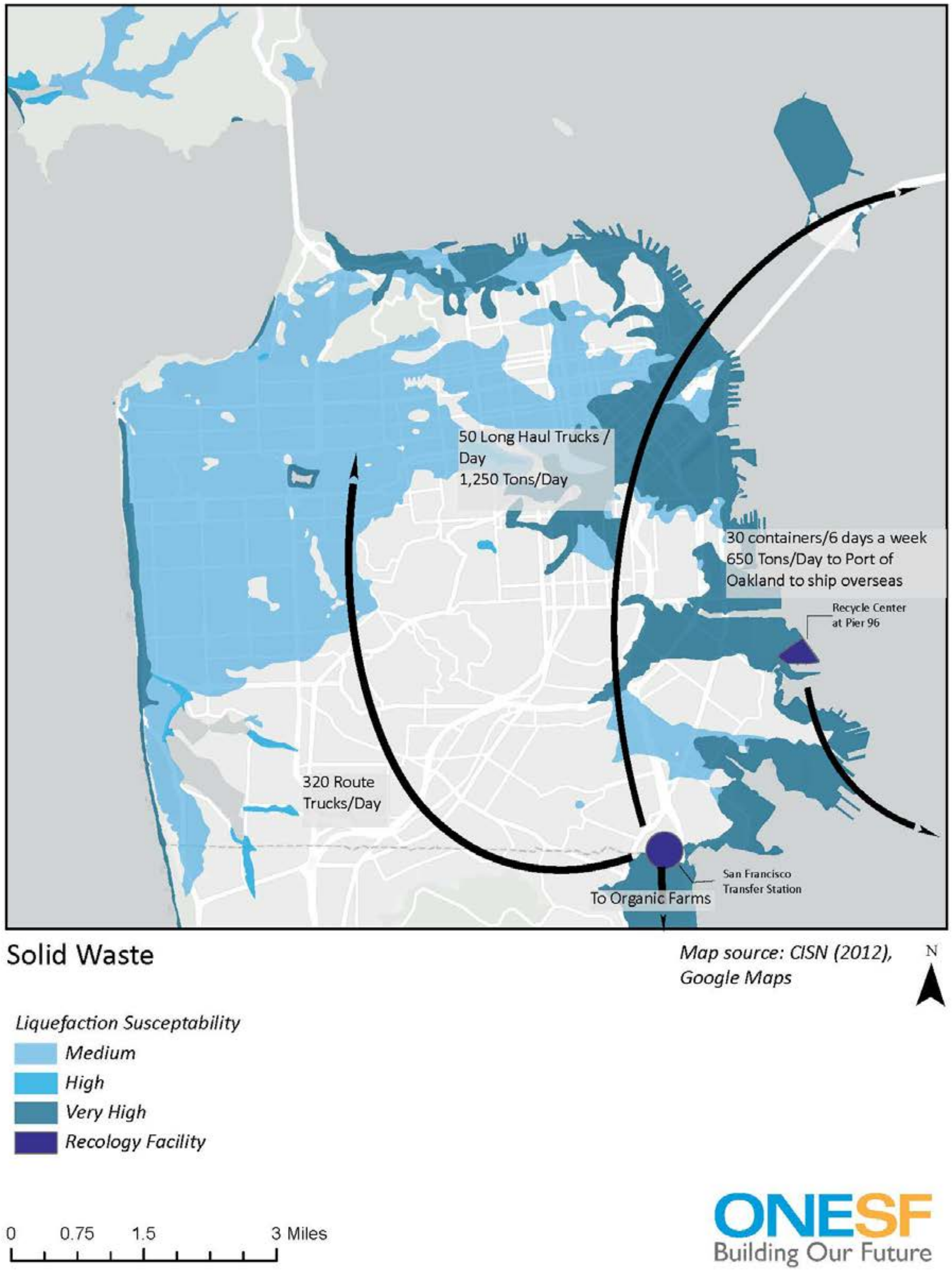
- Receiving municipal solid waste (MSW) (refuse) from City collection routes and shipping this material to landfill;
- Receiving commercial and residential compostables to the West Wing Organics Facility and shipping this material to composting facilities;
- Receiving C&D material collected within San Francisco or self-hauled to the facility and sorting this material into separate streams of recyclable material (wood, metals, inerts, etc.);
- Receiving HHW from San Francisco residents and small businesses and sorting this waste into 36 separate waste streams for shipment to off-site hazardous waste facilities outside the Bay Area.

50 long haul vehicles transfer 1,200 tons a day of trash from the Transfer Station to the landfill in Dixon and 750 tons of organics to a compost facility in Stanislaus County.

650 tons a day from the City's blue bins and commercial office routes are delivered to Recology's Recycle Central operation at Pier 96 where it is sorted, containerized and delivered by truck to the Port of Oakland for shipment overseas to recycle purchasers. More than 30 large containers are shipped 6 days a week from this facility. Recycle Central facility employs 175 employees and currently receives 400 trucks trips per day. The facility is permitted to receive up to 2,100 tons per day and has an 840 maximum vehicle trips per day limitation.

The HHW Facility receives approximately 500 tons per year of non-electronic HHW and has a maximum permitted storage capacity of 14,285 gallons (approx. 220 55-gallon drums). The HHW Facility is staffed by 17 specially trained hazardous waste technicians and typically ships 50-60 55-gallon drums of HHW offsite every two weeks.

FIGURE 23: SOLID WASTE SYSTEM MAP



System Upgrade and Disaster Planning Efforts

Construction of the new West Wing organics facility at 501 Tunnel Ave was completed in November 2018 and was designed to current seismic codes. It is also located on the portion of the site that is on solid rock. Solar panels on the West Wing can be used to power operations during the day. Recology also installed a backup generator for the West Wing and has installed a second generator for CNG and LNG fueling systems. The installation of a third backup generator for the dispatch facility was completed in December 2019. The foundation pads for the generators are robust and expected to perform well in an earthquake. The generators run on diesel and are tested regularly.

In order to meet San Francisco's zero waste goals[105] and handle projected future demand, Recology is proposing to construct a new construction and demolition material recovery facility adjacent to existing the Integrated Material Recovery Facility (IMRF) with upgraded equipment at 501 Tunnel. . This will free up space at 501 Tunnel Ave for a new trash processing facility to capture additional organics (compostables) and recyclables from the trash (black bin) stream to advance the City toward its goal of zero waste.

Recology has undertaken significant emergency response planning in recent years with all its operating companies. Each company has an emergency management team that initiates disaster response and draws on corporate resources as needed. Emergency response plans are exercised every year and Recology has emergency operations plans for each zone in which it operates.

Recology, Inc. identifies resources that can be drawn upon in the case of emergency (mutual aid between the operating companies). Emergency response plans are exercised every year using an earthquake scenario (in this region), but the earthquake fault or magnitude is not specified. In a disaster Recology subsidiaries will all form EOCs and determine how to share resources and support operations. Recology is currently planning an exercise where business recovery (from Recology and community perspective) is the primary objective.

[105]SF Environment. 2018. *"Mayor London Breed Announces Significant Efforts to Reduce Greenhouse Gas Emissions in San Francisco."* Retrieved from https://sfenvironment.org/press-release/mayor-london-breed-announces-significant-efforts-to-reduce-greenhouse-gas-emissions-in-san-francisco

Expected Impacts of an Earthquake

San Andreas Fault Scenario

The San Andreas earthquake scenario is the most severe for Recology. The core operating infrastructure of the West Wing, C&D facility, HHW Facility and iMRF at 501 Tunnel Ave will not be heavily impacted because these facilities are newer and built on rock. These facilities are located on the portion of the site that is in the City of San Francisco and is primarily on rock. The portion of the site located in San Mateo County contains the administrative offices, maintenance office, and dispatch center, which are in the City of Brisbane and on land that is potentially liquefiable. Recology's recycling plant at Pier 96 is likely to suffer significant damage in this scenario because of the age of the pier and its location in a very high liquefaction hazard zone, however a vulnerability analysis has not been performed on the pier. Pier 96 is also vulnerable to flooding in large storms and sea level rise. In an earthquake where Pier 96 is no longer usable, all recyclable and C&D materials will be delivered to the San Francisco Transfer Station. This situation has the potential to overwhelm the 501 Tunnel facility.

Hayward Fault

The Hayward Fault scenario is not expected to significantly impact Recology's facilities in San Francisco. Loss of fuel is considered more likely in this scenario because of likely damage to the region's refineries. Natural gas transmission pipelines are considered at less risk in this scenario.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 19 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 19** reflects the current, existing performance in the Restoration Timeline in **Figure 22** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 19: SOLID WASTE RESTORATION TIMELINE

	Solid Waste - Recology
0 Hours	Recology has identified locations in the four quadrants of the city where routes trucks will convene immediately after a disaster to activate their emergency response plan if they are out on their routes. C&D material from post-earthquake debris removal activities can be temporarily staged at these locations until it can be processed, recycled or reused. Freeways and bridges are the primary access to SF. If those arteries are down, it will severely impact Recology's ability to service the City and move materials out of the Transfer Station and Recycle Central on to their final destinations. Depending on the time of day of the earthquake, workers from outside San Francisco or the Peninsula may have difficulty. Workforce availability depends on time of day. Availability of local roads will determine Recology's ability to maintain its normal collection schedule.
72 Hours	Recology's primary obligation in the first 72 hours will be on continuing to provide refuse collection for hospitals, shelters and other high priority facilities based on the City's recommendations. Recology also has heavy equipment which can be utilized at the direction of the appropriate City agencies for clearing roads and debris removal. Initially, residential refuse collection will not be the focus. Fuel availability may begin to become a significant challenge at this point if the natural gas or fuel pipelines are not operational.
2 Weeks	Recology will try to restart its normal collection routes, depending on fuel availability. Any delay beyond two weeks will start to become a public health emergency, especially if sewers are down and solid waste needs to be bagged.
2 Months	Recology will gradually be restoring normal service as more roads become passable and plans are made for relocating Recycle Central from Pier 96.
6 Months	Residential and business refuse and C&D collection will be back to normal, but diversion of recyclables may not be the same if Pier 96 is damaged. Recology will work to restore service as quickly as possible before debris and HHW accumulate and becomes a public health issue. Recology's goal is full restoration of service within 6 months. When Recology realizes its goal of consolidating all operations at 501 Tunnel Ave, it will be better positioned to meet this service restoration goal.
1 Year	Within a year, any damaged facilities will likely be repaired or replaced.
3 Years	

*H*ayward Fault Scenario

In a Hayward Fault scenario, Recology's 501 Tunnel facilities and Pier 96 will likely be undamaged and there is unlikely to be significant debris within San Francisco that will inhibit normal waste collection. Recology may send crews to respond to other locations that are more severely damaged.

77% percent of Recology's workers that service San Francisco live outside of the city and depend on bridges or transit to get to work. Long haul trucks that deliver waste to the Dixon landfill could also have transportation challenges if bridges are closed. The Port of Oakland is likely to experience liquefaction in this scenario that will disrupt operations and will impact the shipping of recyclables.

Recology has combined natural gas and diesel fuel on hand for four days of normal operations. Natural gas supply is considered less likely to be damaged in this scenario, but if the Kinder Morgan pipeline is damaged, operations will likely become severely disrupted after its diesel supply runs out. Rationing plans could stretch the available fuel a little longer. LNG deliveries for long haul trucks will be disrupted to the extent that the transportation network is operational to allow for continued fuel deliveries. In this scenario, as soon as fuel becomes available, operations will be fully restored to normal.

HHW shipments off-site may be highly impacted in this scenario due to the distant location of the majority of receiving hazardous waste facilities.

Level of Confidence

Recology has a high degree of confidence in the restoration timelines because of its experiences in past earthquakes and other disasters and its recent disaster planning exercises; however, modelling or analysis has not been performed to verify its assumptions.

System Interdependencies

Recology has significant dependencies on natural gas, fuel, the Port, highways and local roads, and transit for its operations. Recology is also dependent on telecommunications, and water and wastewater infrastructure for its operations. The table below describes the dependence of roads and highways on all other lifeline systems and is shaded according to the degree of dependence.

Table 20 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;

- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 20: SOLID WASTE SYSTEM INTERDEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – Recology depends on electricity to run its sorting lines for recyclables and C&D materials. The sorting lines do not have backup generators and it would be difficult to purchase one with enough capacity. Recology could consider leasing a generator that would be stored offsite and delivered in case of emergency. Dispatch can be done manually and electricity wouldn't affect ability to deliver service. Residents and business also rely on electricity to preserve food. Loss of power contributes to an increased volume of municipal solid waste and public health challenges.
Natural Gas	Significant – Half of Recology's route trucks run on CNG.
Water	Low – Used for dust control, truck washing, and sanitary, but not critical to operations.
Wastewater	Low – for flushing toilets, and truck hopper and container washing.
Communications	Moderate – Dispatch depends on telecommunications, but it can be done manually and all the trucks have radios for backup communication
Highways and Local Roads	Significant - Freeways and bridges are the primary access to San Francisco for workers, LNG fuel delivery, and HHW off-site shipments. If those arteries are down, it will severely affect Recology's ability to service the City.
Fuel	Significant – Half of Recology's route trucks use diesel fuel
Transit	None – Negligible number of employees use public transit to get to work
Solid Waste	None
Airport	None
Port	Significant – Recycle Central is located on Pier 96, owned by the Port of San Francisco.
Firefighting Water (EFWS)	None

Actions to Speed Restoration

Recology should increase its understanding of post-disaster fuel availability and the regional prioritization process to enable better planning for post-disaster fuel needs

Post-disaster fuel availability could significantly restrict municipal solid waste collection operations. The likely loss of fuel in this or the Hayward fault scenario is the biggest post-earthquake concern for Recology. Recology is one of the biggest consumers of diesel fuel on the Peninsula which is used for 50% of its route fleet vehicles. This fuel is purchased from Golden Gate Petroleum and Flyers, which receives fuel deliveries from the North Bay refineries at Kinder Morgan's Brisbane Terminal. The remaining 50% of Recology's fleet is fueled by compressed natural gas (CNG) that is delivered by natural gas pipeline traveling up the Peninsula and compressed on site. Combined, Recology has approximately two days of fuel supply on hand for its fleet vehicles. If either natural gas or diesel fuel is not available, Recology will ration its fuel and prioritize waste collection to priority customers like hospitals and first responders. However, public health priorities will mean that refuse, especially compostables and trash, will need to be collected as soon as possible after an earthquake. These priorities will be determined in conversation with the City of San Francisco after an earthquake.

A portion of Recology's long haul vehicles use LNG fuel, which is delivered by truck from the Midwest. LNG delivery could be disrupted depending on accessibility of the transportation network. There is about three days of LNG stored on site with some redundant bio-diesel trucks that can be called into service to replace LNG trucks as supplies dwindle.

Port of San Francisco should complete a vulnerability study to determine the likelihood that Pier 96 will be operational after the scenario earthquake and determine alternate recycling collection and debris processing locations

Damage to Pier 96 could significantly restrict post-disaster recycling operations and overload the San Francisco Transfer Station. Recology's 200,000 square-foot recycling, sorting, and baling facility that processes 650 tons of recyclables is located on Pier 96, owned by the Port of San Francisco. Recology plans to construct a new construction and demolition (C&D) material recovery facility adjacent to the IMRF at 501 Tunnel Ave. In the event of an earthquake, the C&D facility would be used to process much of San

Francisco's recyclables displaced from Pier 96 and may be used to process disaster debris as well.

77% Percent of Recology's workforce lives outside San Francisco or the Peninsula. If an earthquake occurs outside of normal work hours, there could be delays getting workers into the City if the regional transportation network is down. Recology workers do not rely on personal service vehicles or tools and equipment; therefore, they can easily be transported by road, transit or ferry. Additional workers available through mutual aid may also need to be transported into San Francisco but coordination with the City could facilitate transportation of these workers from outside the County in partnership with Caltrans, BART, and WETA.

Recology should explore alternative methods for waste transfer, such as activation of the existing rail spur and connection to the rail line which would reduce likelihood of surpassing Recology's waste storage capacity

Recology's capacity to store solid waste (refuse and C&D) is limited to about three days before it must begin transferring it out of the City to the landfills, composting facilities, and recyclers. Since Recology's capacity to store solid waste within San Francisco is limited to about three days, there is a real need to quickly re-establish road access out of the City for Recology's long haul trucks. Alternate transfer mechanisms by sea or rail are possible, but are not currently established. This option would also need additional equipment, such as rail cars, and to support a process for loading these alternative transfer options. If a transfer mechanism cannot be identified after a few days, solid waste collections will be put on hold. There are concerns about Caltrans ability to clear the major state routes like 101, Bay Bridge, Golden Gate Bridge, 35, 92, El Camino Real and those that run through the city. These roadways need to be prioritized for reopening as soon as possible.

Large building owners should consider establishing a redundant power source for refuse compactors for commercial buildings

Refuse compactors are used by many large facilities and multi-family properties to manage the frequency of refuse collection. Recology offers stationary and self-contained compactors to its large commercial clients to handle large amounts of recyclables, compostables, and trash, as well as manage odor and space. Compactors reduce the frequency with which Recology needs to collect refuse from these facilities. However, these compactors rely on electricity and this load is generally not planned for when sizing on-site emergency backup generators. Nonfunctioning compactors will mean a faster buildup of refuse and exacerbating public health challenges.

Port

Photo: Donald Ogg/Flickr

The Port of San Francisco is responsible for the 7.5 miles of San Francisco waterfront adjacent to San Francisco Bay from Aquatic Park in the north to Heron's Head Park to the south.[106] Port maritime and water-dependent uses stretch along the entire waterfront. Port property is a complex mix of piers, structures, seawall, and open land, and is home to more than 500 tenants.

[106] Port of San Francisco. 2016. "Port of San Francisco 2016-2021 Strategic Plan". Retrieved from https://sfport.com/sites/default/files/StrategicPlan_8-5-16.pdf

Port

Operator: Port of San Francisco

At A Glance...

Key Findings

- The Port is leading the Waterfront Resilience Program to improve the resilience of the waterfront to seismic and flood events. Currently, the seismic risks could result in damage and disruption to waterfront assets and services, including:
  - Significant lateral spreading along portions the waterfront that will damage the Embarcadero Roadway and Promenade, the transportation and utility infrastructure that use the Embarcadero corridor, the buildings that sit on top of the Embarcadero Seawall and access to maritime facilities including ferries and waterborne emergency services.
  - Regional ferry and port operations could be severely impacted for many years. Within two months, temporary repairs and relocated operations will reduce disruption. Full Port restoration is not expected for 2-4 years due to extensive repairs and reconstruction of shoreline structures, wharves, and older piers; ferry operations will resume more quickly.
- While the Downtown Ferry Terminal Expansion Project is designed to an essential facilities standard, a strong earthquake is expected to damage access to older ferry landings or the utilities and systems that they rely on. For example, there may be a gap between ferry services and the Embarcadero Roadway and Promenade that makes it difficult to travel across the Embarcadero corridor to the water. Ferry operations may be disrupted for a short period (days or weeks) while temporary access is constructed, permanent repairs the Seawall, Embarcadero Roadway, Promenade, and utilities may take several years.
- The seismic vulnerability of the southern waterfront has not yet been assessed, but many of the landfill pier structures (Pier 80, Pier 94/96) are important for emergency response, experienced liquefaction in Loma Prieta, and are likely to experience damage and disruption in larger earthquakes.
- While the Port may be able to maintain operations for a limited amount of time without access to other lifeline sectors, if utilities such as water, power and wastewater are not restored within 72 hours Port operations will be disrupted.

Actions to Speed Restoration

- The Port should evaluate potential seismic upgrades to Pier 1 and a plan to upgrade Pier 50 or relocate these operations to support the Port's role in waterfront restoration.
- The Port, the Department of Emergency Management and the ferry operators should evaluate the impact of a major earthquake on ferry operations and the expected timeline for restoration of service.
- The Port should identify additional resources, partnerships, projects, policies and actions necessary to continue to reduce the risk of seawall failure.
- The Port should perform a seismic vulnerability assessment of southern waterfront with particular focus on piers that are important to the City's post-disaster response.
- The Port should develop Memoranda of Understanding (MOUs) with Resource agencies responsible for permitting along the shoreline to expedite post-disaster construction.

Restoration Performance Goals

The Port of San Francisco has not yet developed performance goals for restoration of Port operations, but it recognizes the need to do so and to identify the resources needed to achieve the goals. The Waterfront Resilience Program and the Port's Chief Harbor Engineer will set performance goals for individual facilities in the northern waterfront that could inform development of a system wide performance goal. A seismic assessment study of the southern waterfront like that performed for the northern waterfront in 2016 is also being scoped.

System Restoration Timeline

The service restoration timeline shown in **Figure 24** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

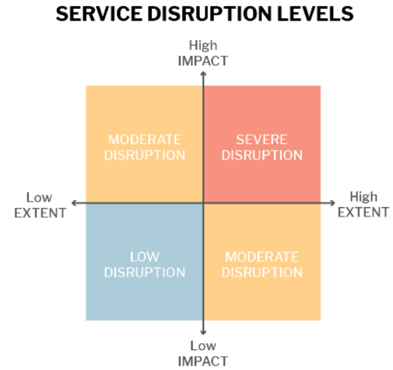
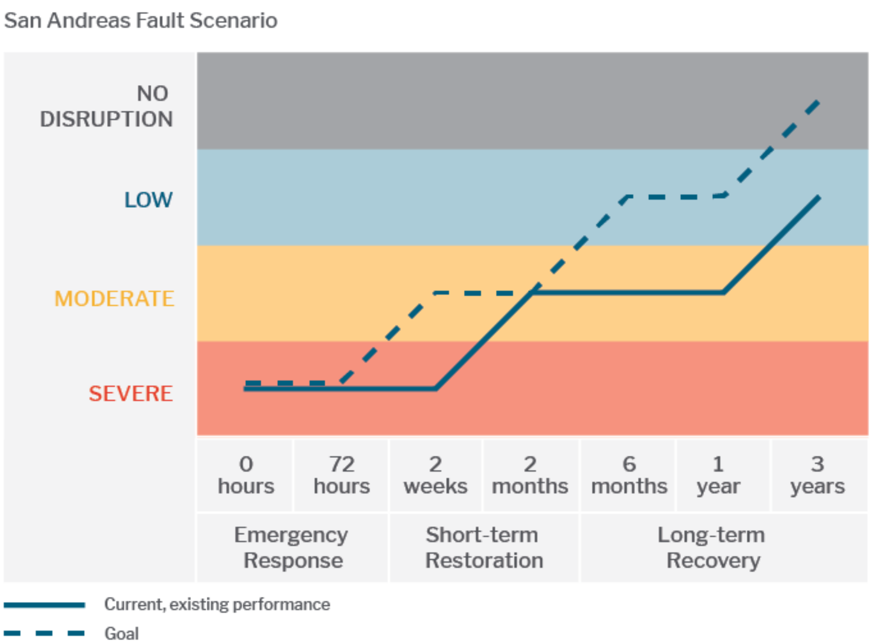


FIGURE 24: PORT RESTORATION TIMELINE



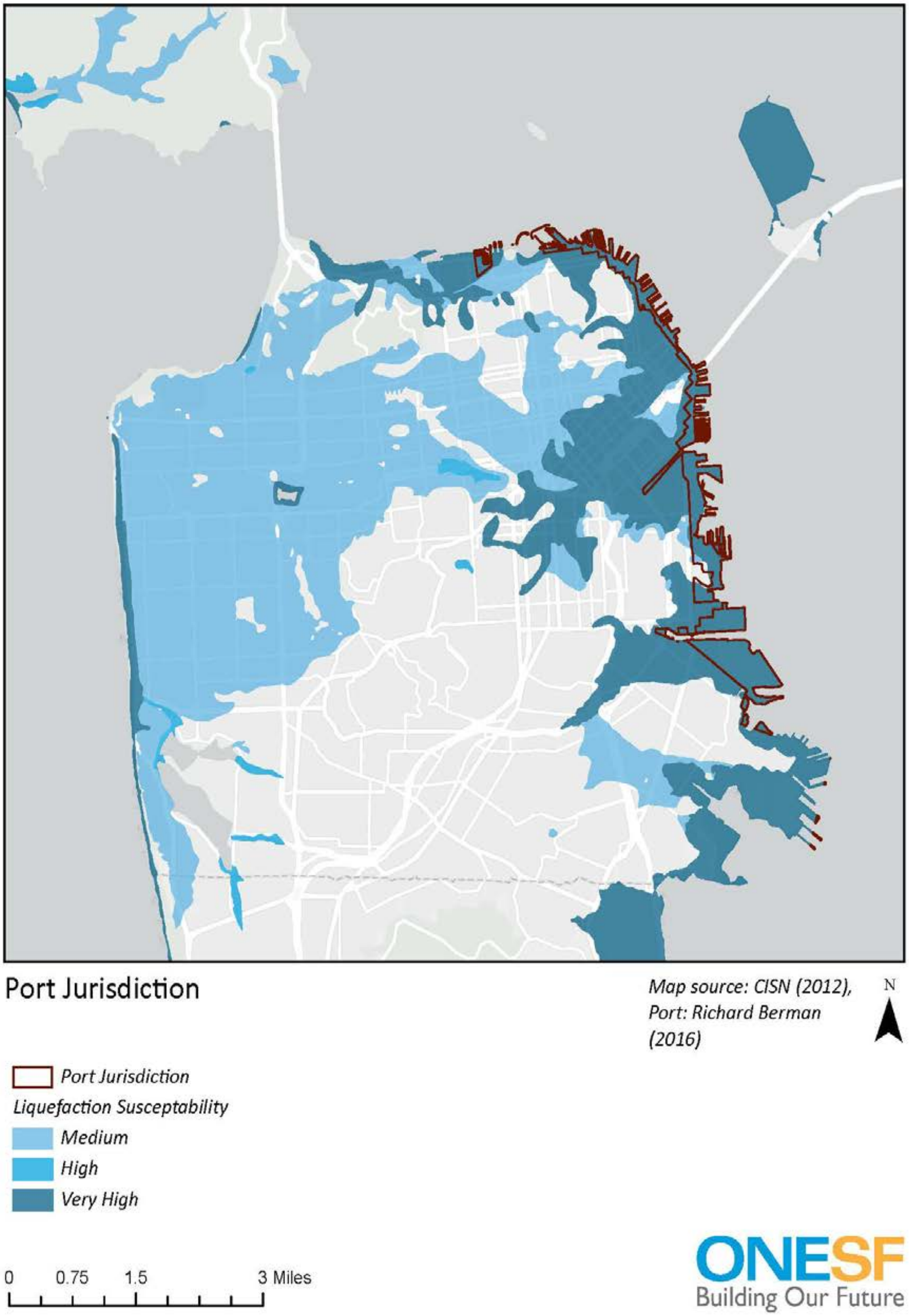
Sector Overview

In the northern waterfront, most of the piers, bulkhead buildings, the Embarcadero Seawall, and waterfront structures along the Embarcadero were built before World War II and together comprise the Embarcadero Historic District which is listed on the National Register of Historic Places. Port lands support a number of uses, including ferry and cruise ship operations, large and small businesses, public access, maritime and industrial uses, some of the most well used public open spaces and public access areas and natural and urban shoreline areas. The Port is home to many of San Francisco's leading tourist attractions, including the Ferry Building, Oracle Park, the Exploratorium, Alcatraz Landing, Pier 39, Fisherman's Wharf, Hyde Street Pier, Oracle Park and the new Chase Center. These amenities draw more than 24 million visitors annually to the Port's northern waterfront.

The Embarcadero Seawall is the foundation of over three miles of the northern waterfront from Fisherman's Wharf to just beyond Oracle Park. The seawall forms the city's shoreline in this location and supports the Port's finger piers and over $100 billion in assets and yearly economic activity within the long-term flood exposure area. The Embarcadero Seawall provides flood protection to over 500 acres of downtown San Francisco and regional transportation systems, including the BART and Muni Metro underground transit networks. The seawall also supports critical emergency response and recovery areas on the Embarcadero. The Embarcadero Roadway and Promenade already experiences periodic flooding, which will get more frequent and severe due to rising sea levels.

To the south, the waterfront includes some of San Francisco's last remaining industrial land, Port deep berth cargo maritime facilities, rail yard, and many large and small businesses. There are also parks, open spaces, public access areas and some of the Port's last remaining natural areas. Some of the more prominent uses include the Recology Recycle Central at Pier 96, the Roll-on/Roll-off (RORO) terminal at Pier 80, a bulk material terminal at Pier 92 and Port maintenance operations at Pier 50. There are many new developments that are being built south of Mission Creek. These include mixed use developments such as Mission Rock, Pier 70 and India Basin, the Chase Center, new parks, medical and research facilities and residential development that is in Mission Bay. The jurisdiction of these assets is displayed in the system map seen in **Figure 25**.

FIGURE 25: PORT JURISDICTION MAP



ONESF
Building Our Future

System Upgrade and Disaster Planning Efforts

Waterfront Resilience Program

The Waterfront Resilience Program is the Port's comprehensive program to protect San Francisco's bayside waterfront from hazards, including earthquake, flooding and sea level rise. The Program includes the Embarcadero Seawall Program and Flood Resiliency Study being conducted jointly by the Port and U.S. Army Corps of Engineers (USACE).

Embarcadero Seawall Program

The Port is leading the Embarcadero Seawall Program, a citywide effort to strengthen the three-mile Embarcadero Seawall from earthquake, flooding, and sea level rise risks.[107] The Embarcadero Seawall makes up the San Francisco shoreline from Fisherman's Wharf to Mission Creek. The Program is currently in the planning stage, following an extensive Multi-hazard Risk Assessment. Critical life safety projects are estimated for completion by 2026. San Francisco voters passed a $425 million general obligation bond (Prop. A) in November 2018 with 82% of the vote to fund needed critical life safety improvements. The Port is pursuing local, state, federal and private funding sources to fully fund the reduction of risk along the Embarcadero Seawall and associated infrastructure, anticipated to cost up to $5 billion.

USACE/Port Flood Study

The USACE and the Port have partnered to study flood risk along San Francisco's bayside shoreline.[108] The USACE/Port Flood Study area encompass the full 7.5 miles of Port property, beginning just north of the Port's jurisdiction at Aquatic Park and ending just south of Heron's Head Park at the Port's southern boundary. The approximately three to ten-year study will identify vulnerabilities and recommend strategies to reduce current and future flood risks. While the mandate for this study is only coastal flooding, the Port is working with USACE to include the seismic risk reduction benefits that may be coincident with implementing a flood mitigation solution built to current seismic codes.

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[107] Port of San Francisco. "Embarcadero Seawall Program Overview." Accessed May 28, 2019. https://www.sfseawall.com/seawall-program.
[108] Port of San Francisco. "U.S. Army Corps of Engineers/Port of San Francisco San Francisco Waterfront Flood Resiliency Study." Accessed May 28, 2019. https://www.sfseawall.com/-flood-study.

Resilience Projects

The Port has undertaken a number of efforts to improve the resilience of the San Francisco waterfront.

- The Downtown Ferry Terminal Expansion Project is currently under construction and includes three new ferry gates and a new plaza south of the Ferry Building.[109] The structure is designed to current essential facility standards (operational during 475-year return period and repairable in the maximum considered earthquake). The plaza structure is designed to accommodate the expected seawall movement of two feet in 1906 and as much as seven feet in a maximum considered earthquake.
- Public Works recently led a design-build contract for Fire Station 35 at Pier 22.5, which requires the new pier facility with bunkhouse to be constructed on a float.[110] This is the first pier along the San Francisco waterfront that utilizes floats for a permanently occupied structure, and could inform options for future adaptations along the waterfront. Floats have the advantage of being resistant to sea level rise, while also being mostly isolated from seismic shaking.
- As part of the Embarcadero Seawall Program, the Port is conducting a Multi-Hazard Risk Assessment (MHRA) of the northern waterfront to understand and quantify the risk to assets and services in this area of the City to earthquake and flood events, including sea level rise. This work includes analysis of potential damage to marine structures, buildings, and infrastructure along the Embarcadero including disaster response assets and ferry landings from Fisherman's Wharf to Oracle Park. The MHRA will be published in Summer 2020.
- As an immediate follow-on action to the MHRA, the Port and the Department of Emergency Management are planning a series of disaster response exercises to inform City, regional and state/federal emergency planners of the expected earthquake damages to the waterfront. The purpose of these exercises is to better understand how earthquake damages should inform emergency response plans and the investments the Port and City should make to facilitate disaster response using 2018 Proposition A funding. For example, ferry landing access, utilities and equipment may be damaged at multiple locations in a large earthquake. The Embarcadero Seawall is projected to move up to three feet

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[109] Port of San Francisco. "Downtown San Francisco Ferry Terminal Expansion." Accessed May 28, 2019. https://sfport.com/downtown-ferry-terminal-expansion.
[110] San Francisco Public Works. "Fire Station No. 35." Accessed May 28, 2019. https://sfpublicworks.org/fire-station-35.

towards the Bay and subside in a 1906 type of event in several locations. This movement will cause damage to the shoreline, the Embarcadero Roadway and bulkhead buildings, causing debris which may also impede access to marine facilities. Following an earthquake, debris removal and steel plates may be needed to provide access to ferry landings and landing equipment may require significant repairs to be operable.

Southern Waterfront

The seismic vulnerability of the southern waterfront has not yet been assessed. However, the landfill pier structures (such as Piers 50, 70, 80, 94/96) are believed to be vulnerable to disruption and damage in an earthquake. These piers generally have a low risk to life safety because they consist primarily of lightly populated industrial facilities and wide expanses of asphalt and other hardscape used for heavy equipment operations and storage of materials. However, San Francisco's emergency response plans, including those involving debris management, FEMA supplies and fuel logistics, rely heavily on these facilities to be operational for restoration of other city functions. Unlike the northern waterfront where the Embarcadero Seawall is a similar condition from Fisherman's Wharf to Mission Creek making up the San Francisco shoreline, the southern waterfront sites need to be evaluated individually to better understand their vulnerability and the consequences of disruption and damage. A vulnerability study like that performed for the Embarcadero Seawall in 2016 is being scoped with the southern waterfront's unique conditions being factored in to how to proceed to best understand the performance of the shoreline, assets and services in the southern waterfront.

Seismic Design and Retrofits

New Port facilities are designed according to the Port of San Francisco Building Code, which uses two-thirds of the Maximum Considered Earthquake (MCE) as the basis for life safety performance. New buildings and existing structures where usage is changed require that the structure be built or modified to comply with current codes. Several Port historic resources have been seismically retrofit, including Pier 1, Piers 1.5-3-5, the Exploratorium (Pier 15), and the Ferry Building. These seismic retrofits were designed before the lateral spread risk to the Embarcadero Seawall was identified.

Port facilities built or modified before 1973 (when building codes adopted seismic design requirements) that have not undergone a change of use, comply with the building code in effect at the time of construction. In many cases, such as for the hundred-year-old piers, seismic forces were not considered in the design at all. Rather, lateral force design was based on wind loads and vessel berthing loads. About 20 historic piers without seismic upgrades have low allowable occupancies (i.e. warehouse storage, parking, and light industrial).

Building Occupancy Resumption Program (BORP)

The Port contracts with engineering consultants through San Francisco's Building Occupancy Resumption Program (BORP) to inspect its prioritized buildings and facilities following a significant earthquake. These engineers have agreed to initiate damage evaluations within 72 hours of the event. The Port also empowers its own engineers to inspect the remaining Port facilities after an event. Following a magnitude 4.4 earthquake near Berkeley in January 2018, the Port tested its inspection program by dispatching its own engineers to inspect piers. The test was also useful in uncovering routine maintenance issues that needed to be addressed.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

Until the risk associated with the Embarcadero Seawall is reduced, the San Andreas Fault scenario contemplated in this study could result in significant lateral spreading ranging from one to three feet along the waterfront, depending upon the location.[111] This lateral spreading may create damage and disruption of the Embarcadero Roadway and Promenade and damage the transportation and utility infrastructure that runs along the Embarcadero corridor. Many of the bulkhead buildings and wharves that sit directly on top of the Embarcadero Seawall may also be damaged or fail, creating life safety risks for tenants and visitors inside and outside of the buildings. Most of the piers will still be usable, with some damage. However, bulkhead damage will initially cut off access to many of the piers. Unretrofitted sheds sitting atop the piers will likely be damaged as well. Many Port facilities, including Piers 1 (Port headquarters) and 50 (Port maintenance) which also serve at the Department Emergency Operations Centers, may be unsafe to occupy because of this damage.

Regional Port operations like ferries, bar pilots, tugs, and the cruise ship terminal may be severely impacted for a year or more. Temporary access and/or temporary facilities may allow these operations to commence more quickly. Some gates of the Downtown Ferry

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[111] *Under a 975-year event, lateral spreading along the Embarcadero Seawall could exceed 7 feet in some locations.* CH2M/ARCADIS/Fugro. 2020. "Embarcadero Seawall Program Earthquake Hazard & Geotechnical Assessment Report" (page 12-2 & Figure 13.3-2d.
April 2020). Developed for the Port of San Francisco.

Terminal (Gates E, F, and G) may be out of service for up to several weeks due to displacement of the seawall and damage to nearby buildings potentially restricting access, particularly to Gate G.

Piers on the southern waterfront not within the Embarcadero Seawall Program are also older and potentially vulnerable to earthquake damage, but engineering evaluations have not yet been performed on these piers. However, Port engineers expect that cargo piers in the southern waterfront (i.e. Pier 80, Pier 94/96) may be significantly damaged in large earthquake events due to liquefaction induced settlement and lateral spreading.

Hayward Fault

The Hayward Fault scenario is expected to result in lower ground motions along the San Francisco waterfront and a reduced likelihood that the Embarcadero Seawall will experience lateral spreading, however, liquefaction of the Embarcadero fill is expected. Consequently, the Hayward fault scenario will have a more moderate impact on Port operations. Some piers and buildings may be damaged, especially bulkhead wharves and buildings along the Seawall. The Southern Waterfront is exposed to high liquefaction hazard in this scenario[112] and damage is expected to landfill piers, as well as the Embarcadero. Port operations may be substantially affected until temporary repairs can be made followed by permanent repairs. Impacts to Port operations will likely be primarily driven by loss of access, power and water needed for the Port to maintain operations.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 21 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 21** reflects the current, existing performance in the Restoration Timeline in **Figure 24** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

[112] Jones, J.L., et al. 2019.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 21: PORT RESTORATION TIMELINE

	Port of San Francisco
0 Hours	Initially the Port, including all ferry terminals and Pier 1 (Port Headquarters) and Pier 50 (Port Maintenance Facilities), will be shut down for inspections. These piers also serve as the Port's Department Emergency Operations Centers (DEOC).
72 Hours	Inspection of the ferry terminals by Port engineering staff will be completed within 72 hours. The ferry terminals will remain out of operation prior to inspection. After inspections, a limited number of ferry terminals will be operable; others are likely to be damaged or have access constraints. Windshield inspections of other Port facilities will largely be completed and detailed inspections will be initiated. Most of the Port is still shut down as a precaution. Unsafe facilities will be tagged and need to be fenced off. It is anticipated that over 50% of the Port's facilities will be unsafe to occupy. Pier 50 and Pier 1 will likely remain closed due to damage to the bulkhead wharf that may keep the pier inaccessible for a period of time. The Port will identify an upland location for emergency operations. While the Port may be able to maintain operations for a limited amount of time without access to other lifeline sectors, if sectors such as water, power and wastewater are not restored within 72 hours Port operations will be disrupted.
2 Weeks	*Goal is for moderate disruption at this point, where work arounds like ramps, gangways, or steel plates are in place to access ferry terminals or other Port facilities. Debris that restricts access to operable facilities has been removed.* Some detailed inspections will still be ongoing. Where major failures occur, operations will need to be relocated. Focus will be on inspection, design of repairs for structures with minor damage, and removing debris from these structures. Except for Gates E, F and possibly G, the downtown ferry terminals will remain out of operation. Alternate ferry landings may be utilized to resume regional ferry service.
2 Months	Emergency repairs to shore buildings, planning for permanent repairs, and debris clearance will continue. Emergency repairs to marine facilities, which require specialized equipment and crews to complete, will be getting started. Some commerce will begin at repaired facilities. Operations formerly located in severely damaged facilities will have been relocated and overall Port operations will again commence in limited capacity. The Port will relocate available recovery assets and equipment from damaged areas to upland locations. The Port will seek an alternate office location for department operations, if Pier 1 and Pier 50 remain inaccessible.

	Port of San Francisco
2 Months (cont.)	Design of facilities to bridge the gap from the Embarcadero to the ferry terminals over the damaged seawall will be initiated.
6 Months	*Goal is for low disruption at this point with debris removal to be complete. Some lingering, more challenging repairs may remain, but Port has minimal disruption overall. Where significant damage occurred to structures, temporary accommodations have been made to continue operations (the new normal).* Emergency repairs to shore building structures will likely be complete. Port offices will be relocated to temporary facilities. Where minor damage occurred to marine structures, repairs would likely be continuing. Typical marine construction takes 1 to 3 years for completion of a single facility, but demand for marine construction equipment may cause delays. More commerce has started at s repaired facilities.
1 Year	*Goal is for low disruption at this point with construction of challenging repairs to be under way with minor repairs complete.* Repairs to Pier 1 will be complete and the Port will move back to its headquarters. Port maintenance facilities at Pier 50 will be repaired or relocated. Commerce at other repaired facilities is defining a "new normal". Facilities with minor damage have completed repairs, however, major or challenging repairs or seismic upgrades will likely be in the design or permit phase or beginning construction. It is likely that available marine contractors will be occupied with other high-value repairs in the region such as oil terminals.
3 Years	*Goal is for full Port restoration where construction of major or challenging repairs are completed.* Commerce back to a "new normal". Repairs to severely damaged (but not collapsed) piers, wharves, and damaged buildings is complete Planning to remove or replace collapsed piers, wharves, and other structures is underway, spanning till 5 years from the event

Hayward Fault Scenario

The Port will sustain moderate damage including some liquefaction and lateral spreading in high hazard areas of the Seawall. The Port, including ferry terminals, will be shut down for inspections in the first 72 hours with emergency repairs initiated within two weeks. By two months, the design of permanent repairs will be under way and temporary repairs, such as ramps gangways, or plates which would provide temporary access to a facility will be initiated by Port maintenance personnel. Regular commercial operations at facilities requiring repairs will be relocated. By six months, the design of repairs will be complete and contracting for repairs will begin. Operations that were relocated will be up and running. Construction of repairs will be underway within a year with construction completed within three years.

Level of Confidence

The Port has confidence in the assessment of its system, primarily based on the Seawall Program and related studies, as well as the performance of pier and wharf structures in earthquakes around the world. The Port's participation in the ASCE 61 Committee (Seismic Design of Piers and Wharves) provides additional insight on the seismic response of pier and wharf structures from subject matter experts.

System Interdependencies

The dependence on other lifeline sectors for the Port is initially limited; however, restoration efforts are significantly hindered after 72 hours if power, water, wastewater and fuel are not restored.

Table 22 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 22: PORT SYSTEM INTERDEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – Electricity is required for normal commercial operations. Backups will last approximately 72 hours.
Natural Gas	Moderate – Port buildings and tenants rely on natural gas for pace conditioning and cooking.
Water	Significant – Port buildings, tenants, parks, open space areas and maritime berths rely on SFPUC water delivered by Port facilities.
Wastewater	Significant – Port buildings, tenants, parks, open space areas and maritime berths rely on SFPUC water delivered by Port facilities.
Communications	Moderate – Port buildings and tenants rely on communications for operation. The Port also has a law enforcement and security role that relies on communications.

Sector	Extent of dependence on sector
Highways and Local Roads	Moderate – Port employees, tenants and visitors rely on local roads and highways to get to and from the Port and deliver supplies and equipment needed for Port operation.
Fuel	Significant – The Port relies on fuel for vehicles and boats the support maintenance and operations and security.
Transit	Moderate - Port employees, tenants and visitors rely on buses, Muni, Bart and ferries to get to and from the Port and deliver supplies and equipment needed for Port operation.
Solid Waste	Moderate - Port buildings, tenants, parks, open space areas and maritime berths rely on solid waste collection by Recology for operation.
Airport	None
Port	None
Firefighting Water(EFWS)	Moderate – Port buildings, tenants, parks, open space areas and maritime berths rely on fire protection to suppress post-earthquake fires on Port property.

Actions to Speed Restoration

The Port should evaluate potential seismic upgrades to Pier 1 and a plan to upgrade Pier 50 or relocate these operations to support the Port's role in waterfront restoration.

The Port's headquarters and DEOC is in the Pier 1 bulkhead and shed, which may be damaged by lateral spreading and Seawall movement. Pier 50 is home to the Port's Maintenance Facility, including all the maintenance staff and equipment who will support initial inspection activities, emergency repairs and some longer-term repairs. Pier 50 also serves as an alternate DEOC and may also be closed due to damage to the bulkhead wharf making the pier inaccessible for a period of time. The Port should evaluate potential seismic upgrades to Pier 1 and a plan to upgrade Pier 50 or relocate these vital personnel and operations to support the Port's role in waterfront restoration.

The Port, the Department of Emergency Management and the ferry operators should evaluate the impact of a major earthquake on ferry operations and the expected timeline for restoration of service.

The focus of this study is on the permanent, physical infrastructure owned and operated by the Port of San Francisco. However, the regional ferry transportation system, which relies on Port infrastructure, are a critical component of the region's post-disaster emergency transportation plans. A ferry restoration evaluation should be undertaken to assess the potential impact of a major earthquake on ferry operations and the expected timeline for restoration of service.

An estimated 250,000 people commute to work in San Francisco each day and a significant portion of this population will be relying on ferries to return home in the North and East Bay after an event. Consideration should be given to restoration times for the Bay Bridge, Golden Gate Bridge and BART, which may be faster than ferries following completion of retrofit of these assets. It is important that the regional ferry operators that own or lease ferry terminals, docks, gangways and tagging areas are included in this assessment, including Water Emergency Transportation Authority (WETA), Golden Gate Ferry, Blue and Gold, and other smaller operators. In San Francisco, most of these facilities are leased from the Port of San Francisco. However, the new waterside infrastructure at the Downtown Ferry Terminal will be owned by WETA. The results of the ferry restoration evaluation should inform updates to local and regional emergency plans focusing on post-disaster regional transportation.

The Port should identify additional resources, partnerships, projects, policies and actions necessary to continue to reduce the risk of seawall failure.

Over the last 5 years, the Port has made significant progress in understanding the risk to San Francisco and the region of failure of the Embarcadero Seawall. The program is currently in the planning stage, following an extensive Multi-hazard Risk Assessment. Addressing the risk of failure of the seawall is anticipated to cost up to $5 billion. A $425 million general obligation bond has been secured to fund the critical life safety and emergency response projects and is anticipated to be completed by 2026. However, the Port must continue to identify additional partnerships, programs, projects and identify the remaining funding needed to fully fund the reduction of risk along the Embarcadero Seawall and the Port's southern waterfront.

The Port should perform a seismic vulnerability assessment of southern waterfront with particular focus on piers that are important to the City's post-disaster response.

With its varied shoreline conditions, the Port's southern waterfront does not have a uniform condition that exists along the Embarcadero Seawall Program. This part of the waterfront is highly industrial and serves a number of important functions for San Francisco, especially in disaster recovery. A seismic vulnerability study has not yet been completed for the southern waterfront, but many of the piers and overwater structures are believed to be highly vulnerable to damage in an earthquake. The southern waterfront is also vulnerable to sea level rise. The Port is undertaking a seismic vulnerability assessment for the southern waterfront to help understand the expected damage and restoration times of these critical assets.

The Port should develop Memoranda of Understanding (MOUs) with Resource agencies responsible for permitting along the shoreline to expedite post-disaster construction.

The difficulty in restoration from the Port's perspective is the timeline for completion of any meaningful work on the waterfront. With a typical project construction timeline of two to four years, the Port will have difficulty reacting quickly to get marine contractors with appropriate equipment to commence the repairs. Consideration should be made prior to the next earthquake for the Port to put in place a MOU with the resource agencies such that habitat in-water work windows and/or the permitting process do not slow down the Port's ability to react to a disaster.

Airport

The San Francisco International Airport (SFO) is owned and operated by the City and County of San Francisco and served 57.8 million passengers in 2018. The Bay Area's largest airport, SFO offers non-stop flights to more than 49 international cities on 43 international carriers and connects non-stop with 85 cities in the U.S. on 12 domestic airlines. The Airport campus covers 4.4 million square feet, primarily located between the east side of U.S. Highway 101 and the San Francisco Bay, south of San Francisco in unincorporated San Mateo County. Some airport property, comprised of mostly habitat and some utilities, is also located to the west of US-101.

Airport

Operator: SFO

At A Glance

Key Findings

- Damage to utilities and runways may keep the Airport out of service for commercial aviation for six months or longer. After a year, the Airport will be operating at near capacity.
- While the Airport may not initially be ready to serve commercial passengers, it will serve emergency response. Some helicopter operations for emergency will be possible immediately if there is some fuel and serviceable roadways. Fixed wing aircraft may land on shorter segments of runway after a few months.
- The Airport cannot operate without fuel, power, communications and water. The reliability and restoration of these systems are also the greatest unknown for the Airport.
- Damage to the Kinder Morgan pipeline that provides jet fuel to SFO will shut down the airport, even if there is no facility damage on site. The Airport has roughly five days fuel supply on hand. There is currently no viable fuel delivery alternative to the pipeline to meet the airport's fuel demand.

Actions to Speed Restoration

- SFO should identify ways to improve the reliability of fuel delivery in the event of an emergency
- SFO should improve the reliability of priority utility systems in an earthquake.

Restoration Performance Goals

SFO has not developed performance goals for restoration of service; however, the Airport believes it would be useful to define minimum level of airport service.

System Restoration Timeline

The service restoration timeline shown in **Figure 26** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

The service disruption levels are defined as follows:

- Low: disruptions with low spatial extent and low impact;
- Moderate: disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Severe: disruptions with high spatial extent & high impact.

SERVICE DISRUPTION LEVELS

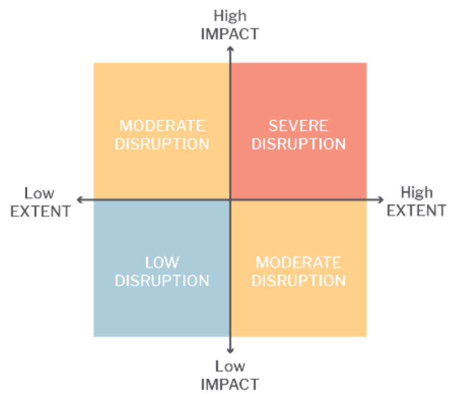
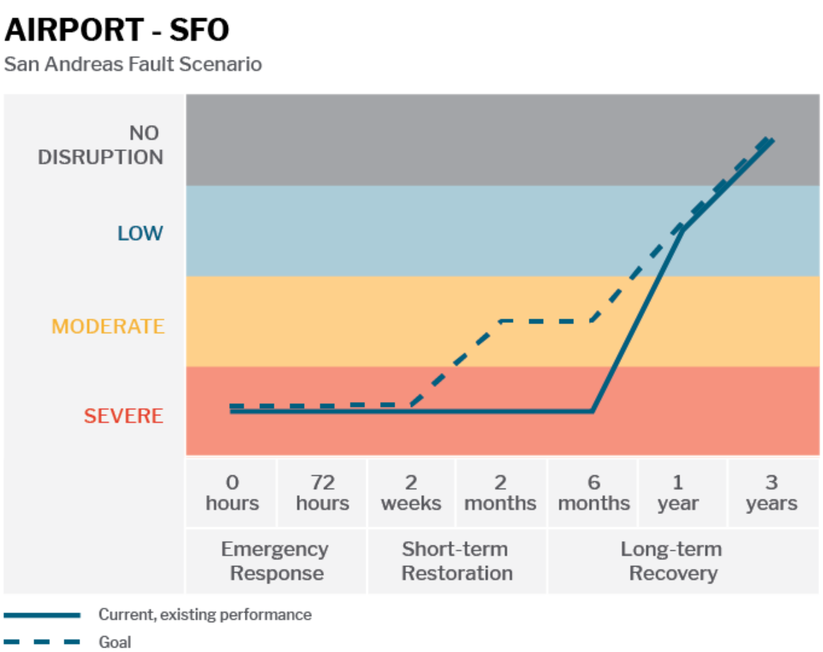


FIGURE 26: AIRPORT SYSTEM RESTORATION TIMELINE



Sector Overview

Airport infrastructure includes: four runways, 91 operational gates, four terminals, as well as 32 miles of roadways, seven parking garages, the AirTrain transit system, a rental car facility, leased cargo and maintenance facilities, a wastewater treatment plant, and more than 274 miles of pipelines, ducts, power, and pump stations for water, sewage, storm drainage, industrial waste, and gas, in addition to electrical and communications distribution systems. These assets are displayed in the system map seen in **Figure 27.**

Airfield: The SFO airfield consists of runways, taxiways, hardstands and service vehicle roadways. The airfield also has a storm drain and power distribution system, as well as communications copper and fiber optic infrastructure. Two parallel runways are oriented in the east-west direction and are intersected by two parallel runways in the north-south direction. Planes land and take off in parallel during good weather conditions. Two airfield lighting buildings feed the airport lighting system for the Airport Operations and Area (AOA). A shoreline protection system consisting of dikes, concrete seawalls, and interlocking vinyl sheet piles of various ages and construction types covers six of eight miles of the Airport's bayfront perimeter.

Air Traffic Control Tower: SFO's 221-foot air traffic control tower is located above Terminal 2. Construction of the new tower was completed in 2016 to replace the seismically unsafe tower built in 1983. Deconstruction of the former tower and two floors of the base structure below was completed in 2019. The bottom two levels of the space are being rebuilt to include a new public café and an outdoor observation deck along with an airline lounge and office space as well as an additional gate at Terminal 2.

Terminals: The Airport consists of three domestic terminals and one international terminal. The terminal buildings consist of several different structures with varying ages that will perform differently in an earthquake. As structures are renovated or replaced, they are brought up to the current seismic standards of the time.

Parking facilities: SFO's campus has several parking structures. The central garages and north and south international parking structures are located near the terminals. Three parking structures are located north of the terminal complexes, one for the Airport's workforce, one for the rental car fleet, and two for travelling customers. The Airport also has two large surface lots located in the west field area.

Roadways: 32 miles roadways, including some elevated structures owned by SFO to connect US-101 to the Airport. The upper level viaduct that fronts the domestic terminals (T1, T2, and T3) has been seismically retrofitted. Most of the inbound and outbound roadway structures from 101 were constructed in the late 1990's. It is not known whether the older ramps that served the Airport prior to the International Terminal Building development have been retrofitted.

Transit: A BART station is located at International Garage G. Tracks on elevated structures that feed into the station from the north and south directions, which provides some redundancy in the event of an earthquake. AirTrain operates two lines on elevated structures to transport passengers around the Airport. The Red Line connects all terminals, terminal garages, the hotel and the BART Station. The Blue Line connects the Rental Car Center with all terminals, terminal garages, the hotel and the BART Station.

Utilities: Two utility tunnels, one at the north end of the Airport campus and the other at the south end traverse below US-101 to deliver electrical power from SFPUC, water, data and communications services to the Airport. These two tunnels deliver utilities to the North and South Minimum Point of Entry (NMPOE and SMPOE) where SFO takes ownership of utility delivery to airport customers. A third utility tunnel under highway US-101 provides a third potable water feed from SFPUC to the Airport campus just north of the terminal complex.

Fuel: SFO currently receives on average 80,000 barrels or 3,600,000 gallons of jet fuel per day. During high demand months, the Airport may receive more than 88,000 barrels per day.

All SFO's fuel is delivered by a Kinder Morgan pipeline from the refineries located along the Carquinez Strait to the Airport via a tank farm and pumping station in Brisbane (Brisbane Terminal), eventually terminating at SFO's North Field Fuel Farm and a Shell storage facility located three quarters of a mile west of the Fuel Farm. (See **Fuel** summary for further discussion of the Kinder Morgan fuel system). The jet fuel pipeline has a capacity of shipping 92,400 barrels or 3,880,800 gallons per day and is the sole supply of jet fuel to the Airport. The primary providers of jet fuel for the Airport are PBF Energy, Chevron and Valero Energy.

At the Airport, SFO Fuel LLC owns the North Field Fuel Farm, which operates on a ground lease from SFO. The Fuel Farm has a storage capacity of 315,000 barrels, of which 285,000 are usable without drawing sediment into the tanks, providing the Airport with up to 3.2 days of storage, depending on deliveries and uplifts. SFO Fuel also leases 150,000 barrels of fuel storage from Kinder Morgan and 186,000 useable barrels from the Shell storage facility, providing an additional 2-3 days of storage, providing the airport with approximately five days of fuel storage in total. This additional capacity is normally used to ensure the Airport has supply if there are problems in the supply chain.

The airlines and SFO Fuel have individual contracts with jet fuel suppliers and Kinder Morgan. This allows them to manage their purchases and transportation logistics. Each airline purchases its aviation fuel from their suppliers and the suppliers batch these purchases together and ship them to SFO.

The Fuel Farm supplies fuel to the Airport's fuel hydrant system, which consists of a 24-inch pipeline that loops the Airport terminals and 13 fuel vaults. This pipeline and vaults are connected to lateral pipelines that serve 247 hydrant pits that allow hydrant carts to fuel aircraft. Aircraft can also be fueled via mobile fuel trucks capable of fueling aircraft from their onboard storage tanks.

If the fuel pipeline is damaged, neither the Brisbane Terminal nor the Airport, can currently accept barge deliveries of fuel. As SFO nears the capacity of the current pipeline, it is looking for alternative fuel delivery sources that will also improve reliability of fuel delivery in an earthquake. A barge facility may provide an efficient and cost-effective alternative means for supplying fuel to the Airport if the pipeline were out of service for a long period. The SFO Fuel Farm also has the capability of receiving over the road truck deliveries of approximately 4,000 barrels per day. This additional capacity is necessary in the summer months to supplement the pipeline delivery, which is at capacity.

Communications: The communications service from outside the Airport is delivered via the North and South Minimum Point of Entry (MPOE). From there, the Airport distributes communications services to the terminals and Airport tenants. SFO owns the entire communications infrastructure within the Airport campus. Internet and wireless services are purchased separately from wireless and data carriers (AT&T, Verizon, etc.) by each individual airline and the Airport. Local exchange telephone service emanates from the Colma and San Bruno central offices.

There are still segments of legacy copper that enter the Airport from the north along South Airport Boulevard and serve small portions of the terminals and select areas of the campus; however, that service will be phased out over time.

Electricity: SFO receives power from the San Francisco Public Utility Commission (SFPUC) distribution at two points – one in the south and one in the north. SFO transforms the power and distributes it to the entire Airport campus via its own power distribution facilities.

Natural Gas: Natural gas from PG&E comes in to the Airport via pipeline in the south and leaves to the north, but is separate from the utility tunnels. A hydrogen fueling complex compresses the natural gas to supply the Airport's CNG light duty vehicle fleet. There are two CNG stations at the Airport, one located on North McDonnell Road near San Bruno Avenue, the other at the south end of the Airport on South McDonnell Road near Millbrae Avenue.

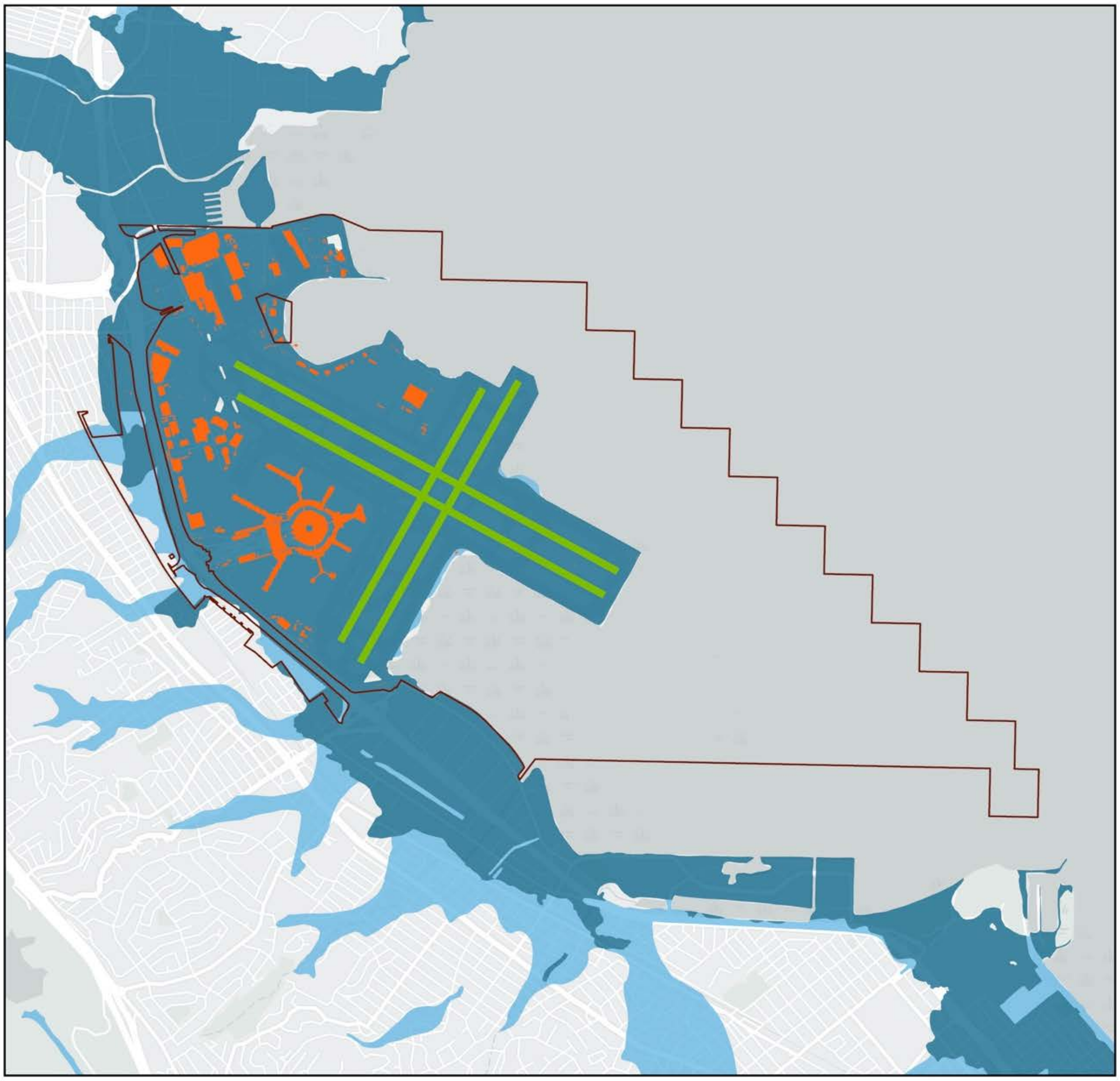
Water: SFO is served with water from SFPUC's regional system through the north, south and center utility tunnels and is connected to a distribution system owned by SFO that services the Airport campus.

Industrial Waste: The Mel Leong Treatment Plant (MLTP) also includes an industrial waste treatment plant, and a recycled water plant is currently under construction.

Wastewater: Sewage from SFO facilities is treated in the Mel Leong Treatment Plant (MLTP) in the North Field, which is operated and maintained by SFO. The Treatment Plant includes a collection system and treats sanitary wastewater from airplanes and Airport facilities, including terminal restrooms, hangars, restaurants, and shops. The industrial treatment plant includes a separate collection system and treats industrial wastewater from maintenance shops and vehicle washing, as well as first-flush storm water runoff from industrial areas. The chlorinated effluent from both plants is combined at a pumping station and discharged to the North Bayside System Unit (NBSU) pipeline, which transports treated wastewater to the South San Francisco and San Bruno Water Quality Control Plant for dechlorination prior to discharge to the lower San Francisco Bay.

Tenants: Once power, water, fuel and data services enter the airport property, it is the responsibility of SFO to distribute those services, as well as collect and treat wastewater, for all commercial tenants on the campus, including airlines, companies that serve the airlines, the on-site hotel, and concessions. Additionally, SFO provides utilities, power and data for the FAA and water, wastewater, power and telecom to the air traffic control tower. SFO is also the utility provider for the US Coast Guard, which owns a facility at North Field.

FIGURE 27: SFO AIRPORT MAP



SFO Airport

Map source: CISN (2012), ORCP Database (2017)

N

Property

Structures

Runway

Liquefaction Susceptibility

Medium

High

Very High

0 0.4 0.8 1.6 Miles

ONESF
Building Our Future

System Upgrade and Disaster Planning Efforts

SFO has undertaken a number of seismic improvement projects in recent years and the airport is rapidly expanding and developing. As old facilities are replaced, new facilities will be constructed to the latest seismic design standards. The following projects with seismic elements have been completed, or are currently underway.

- In 2016, the Air Traffic Control Tower was rebuilt to replace the former seismically vulnerable tower. The new 220-foot tower was designed to remain operational following a Design Level Earthquake (approximately a 475-year return period), and to provide safe passage and no collapse in a Maximum Considered Earthquake (approximately 2,500 year return period, equivalent to ground motions experienced in the 1906 earthquake).[113]
- A new International Terminal was constructed in 2000.[114] It is the largest building in the world built on base isolators. The five-story building was designed to the highest seismic safety requirements ever imposed on an American airport terminal so that it will remain operational in the event of a major earthquake.[115]
- Terminal 1 was built in the 1960's and is currently undergoing a $2.4 billion redevelopment that will be completed in 2023.[116] An earlier phase was completed in 2019. The project will bring the airport's oldest terminal to the latest seismic standards.
- Terminal 2 was originally built in 1954. The terminal was modernized and remodeled in 1983 to serve as an international terminal. It was closed in 2000 when construction of the new international terminal was completed. The terminal underwent another major renovation from 2008-2011 when it was converted back to a domestic terminal.[117] The latest renovation brought the

[113] Rafael Sabelli, Joe Maffei, Susendar Muthukumar, and Lawrence Burkett, 2017. "Tour de Force for San Francisco International Airport", Structure Magazine, January 2017. Retrieved from https://www.structuremag.org/?p=10863
[114] ABC7 News. 2011. "Seismic Engineering built into critical Bay Area facilities", March 15, 2011, Retrieved from https://abc7news.com/archive/8014820/
[115] "San Francisco International Airport – Structural Engineering", Skidmore, Owings & Merrill (SOM). Retrieved from https://www.som.com/projects/san_francisco_international_airport__structural_engineering
[116] SFO Airport. "Welcome to Harvey Milk Terminal 1". Accessed July 8, 2020. https://www.flysfo.com/about-sfo/airport-development/t1.
[117] SFO Airport. "Terminal 2", Accessed on July 8, 2020. https://flysfo.com/about-sfo/airport-development/t2.

terminal to essential facility seismic standards so it will remain operational in a major earthquake.

- Terminal 3 was constructed in 1981. In 2014, renovation of Boarding Area E was completed[118] and in 2015, renovations of Terminal 3 East were completed.[119] The Terminal 3 West retrofit project is in currently in the scoping phase.
- Replacement of Long Term Parking Garage 2, which has been designed according to current seismic life safety standards, was completed in 2019.[120]
- The AirTrain system is being upgraded and expanded to include two new stations at Long Term Parking Garage 2 and the hotel. The project includes retrofit and upgrades of Central Control Operations.[121]
- Fire House #3 was completely rebuilt in 2017 to essential facility standards, ensuring it will remain operational following a major earthquake. The facility is LEED Gold certified.

SFO is undergoing several other major capital improvements projects that do not directly address seismic resilience.

- The airport's utility infrastructure is undergoing a comprehensive overhaul to support increased demand, be more environmentally efficient and resilient to climate change. These projects include upgrading the wastewater system, fuel supply improvements, separating fire and domestic water systems, improve SFO and City of Millbrae water tie ins, upgrading substations, improving the Central Utility Plan, upgrading power distribution infrastructure, improving the shoreline protection system to protect against sea level rise and flooding, and adding a recycled water plant.[122] Seismic mitigation is not a component of this project.

[118] SFO Airport. "Terminal 3 Boarding Area E", Accessed on July 8, 2020. https://www.flysfo.com/about-sfo/airport-development/terminal-3-boarding-area-e.
[119] SFO Airport. "Terminal 3 East Concourse", Accessed on July 8, 2020. https://www.flysfo.com/about-sfo/airport-development/t3-east.
[120] SFO Airport. 2019. "SFO Celebrates Opening of New Long-Term Parking Garage with $18 Daily Rate Effective May 1st", April 15, 2019. Retrieved from https://www.flysfo.com/media/press-releases/sfo-celebrates-opening-new-long-term-parking-garage-18-daily-rate-effective-may
[121] SFO Airport. "AirTrain Extension & Improvements". Accessed on https://www.flysfo.com/airtrain-extension-improvements.
[122] SFO Airport. "Utilities", Accessed on July 8, 2020. https://www.flysfo.com/about-sfo/sfo-tomorrow/utilities

- The new SFO Business Center was opened in 2010 at 575 North McDonnell Way. The building is the new home for Airport Commission employees and is LEED Gold certified.[123]
- Construction of a new Grand Hyatt hotel at SFO was completed in 2019. The project was designed to current life safety seismic standards and is LEED Gold certified.[124]
- SFO is undertaking a project to rebuild the aging Shoreline Protection System to protect the airport from future flooding due to sea level rise.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

SFO may experience violent shaking in the San Andreas scenario earthquake. The soft soil on which the airport is built may amplify shaking and result in liquefaction. SFO airport is entirely constructed on fill of different ages and depths placed over marshlands.[125] Fill placed at different times may perform differently. Consolidation and slumping of the airfield is expected and will be more pronounced toward the Bay, with liquefaction-induced settlements ranging between 1 to 4 inches.[126] There may be lateral spreading where different layers of fill meet, as well as consolidation, cracking and vertical displacement. The North Field, Taxiway Lima, and Runway 19 are most susceptible to liquefaction damage.

Buildings have been built over time to different engineering standards and some will perform better than others. Performance will also depend on shaking intensity, duration, and direction of shaking. However, as the airport undergoes significant expansion and renewal, many of the airport key facilities, including the control tower and terminals, are being upgraded to the highest seismic standards and may be operational after an earthquake, but damage to utilities and runways may keep the airport out of service for commercial aviation for six months or longer. While the Airport may not initially be ready to serve commercial passengers, it will serve emergency response. Some helicopter

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[123] SFO Airport. 2010. "SFO Business Center Open for Business". July 28, 2010. Retrieved from https://www.flysfo.com/media/press-releases/sfo-business-center-open-business#:~:targetText=The%20building%2C%20located%20at%20575,Management%2C%20Finance%2C%20and%20Accounting.
[124] SFO Airport. 2010.
[125] Association of Bay Area Governments (ABAG), *'Preliminary Assessment of Earthquake-Induced Liquefaction Susceptibility at Five San Francisco Bay Area Airports"*, Fugro Consultants, Inc. May 2013, Retrieved from: http://resilience.abag.ca.gov/wp-content/documents/Cascading_Failures/Final_Liquefaction_Report_20130531.pdf
[126] ABAG. 2013.

operations for emergency will be possible immediately if there is some fuel and serviceable roadways. Shorter stretches of runways could be opened in an expedited manner to allow use by fixed wing aircraft and military flights after several months.

Damage to utility systems within the airport are also expected and repair may take several months. Utilities may fail at expansion joints and connections to buildings. Sensitive equipment such as transformers and pumps may be damaged. Pipelines may be damaged by ground movement, especially in areas with liquefaction and lateral spreading.

The airport is also dependent on BART and access from US-101 to the airport and external utilities, such as water, communications and power delivered to the Airport. Many of these systems will likely experience significant damage as well that will affect the restoration of airport service.

SFO will prioritize repairs and bring systems and facilities back online over time. Once the airport is open, it can start to phase in commercial passenger service.

Hayward Fault

SFO may experience strong shaking in the Hayward fault scenario earthquake. Liquefaction induced settlements in this scenario are expected in the range of 1 to 3 inches.[127] In addition to potential damage to airport facilities, buildings and runways, potential for damage to fuel distribution and SFPUC water transmission lines coming from the East Bay, is an additional concern in this scenario. The SFPUC's Hetch Hetchy Regional Water System has recently undergone a $4.8 billion upgrade to ensure reliability in a major earthquake (See Water Chapter). Overall, the impact of the Hayward Fault scenario on the airport is expected to be less than in the San Andreas scenario; however, any damage or disruption to the fuel refineries or Kinder Morgan pipeline will shut down the airport until fuel delivery via pipeline is restored.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 23 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 23** reflects the current, existing performance in the Restoration Timeline in

[127] ABAG. 2013.

Figure 26 above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 23: SFO AIRPORT RESTORATION TIMELINE

	Airport - SFO
0 Hours	Airport will immediately be shut down for damage assessments.
72 Hours	The focus in the first 72 hours will be on saving lives, emergency response, and damage assessments. The airport will remain closed to commercial aviation. Some emergency helicopter operations will be possible if there is some fuel and serviceable roadways.
2 Weeks	Inspections and damage assessments will be completed within two weeks. The airport will remain closed to commercial aviation. Some emergency helicopter operations will be possible if there is some fuel and serviceable roadways. It is not clear when fuel delivery via the refinery and pipeline system will be restored, but SFO estimates that it could be months in this scenario.
2 Months	*Goal is moderate disruption with commercial aviation returning to service.* The airport may be operating at 25% capacity by two months. Completing facility assessments, runway repair and business resumption are primary goals in this phase. With round the clock crews repairing the runways, shorter stretches of certain runways may be repaired by 2 months to allow use by fixed wing aircraft and military flights for emergency operations; however, other systems on site such as utilities may still not be operating. If the runways experience vertical displacement, they will need to be re-certified by the FAA, adding additional time to restoration.
6 Months	*Goal is moderate disruption with commercial aviation continuing to expand service.* From two to six months post-event, the airport will be gradually increasing capacity as liquefaction-damaged runways, utilities and buildings are repaired. Emergency operations will be prioritized and commercial aviation will restart as soon as possible, depending on road access to the airport and completion of repairs. The airport must also provide security and ensure runway safety before it can open for commercial flights.
1 Year	At one year, the airport will be operating at near capacity, with some facilities still under construction. Any significantly damaged facilities will be restored or rebuilt within 1-2 years.
3 Years	Full restoration is expected by 2 years, as damaged facilities are restored or rebuilt.

Hayward Fault Scenario

In the Hayward fault scenario, the airport will experience less damage to utilities, facilities and runways than in the San Andreas scenario. However, the airport anticipates significant damage to the Kinder Morgan pipeline in the East Bay that will shut down the airport for several months. Damage to refineries that shuts down fuel production is also a significant concern for the airport. The airport has approximately days of fuel supply on hand. Trucking fuel or other means of fuel delivery are not logistically possible because of the volume required. SFO can require airlines to tanker in fuel and require flights to make fuel stops, but most other airports don't have enough excess fuel supply or capacity to take the extra load. SFO could possibly run at 25-50% capacity with these adjustments. Once fuel delivery resumes, the airport can also return to operation.

Level of Confidence

SFO's confidence in its assessment of restoration performance is based on past earthquakes, scenario plans, an airfield liquefaction study, other reports, experience in the Loma Prieta earthquake, and examining other disaster impacts, such as Santa Cruz in Loma Prieta, Puerto Rico in Hurricane Maria, Napa earthquake and Hurricane Katrina in New Orleans.

System Interdependencies

SFO has significant dependencies on electric power, water, wastewater, communications, fuel, and highways and local roads for operations and access to the airport. SFO is also dependent on natural gas, transit and solid waste.

Table 24 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 24: SFO AIRPORT SYSTEM INDEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Significant – SFO cannot operate without power. The airport has significant power redundancy and emergency generation capabilities, but if these are not operational, loss of power would affect communications and flight operations.
Natural Gas	Moderate – The airport relies on natural gas for cooking, heating, and ground buses (CNG). Contract stipulates that supplies need to be trucked in within six hours if the pipeline is damaged, but that won't be possible in a disaster. If the pipeline is functional but the power is out, backup generators on site can compress the gas.
Water	Significant – Water is needed for fire suppression, restrooms, and aircraft.
Wastewater	Significant – SFO collects and treats its own wastewater and industrial waste on site. Treated water is transported offsite by pipeline to the South San Francisco and San Bruno Water Quality Control Plant for dechlorination prior to discharge to lower San Francisco Bay. If the treatment plants are damaged, or there is no power, untreated effluent will be discharged directly to the Bay, likely forcing the airport to close to prevent discharge to the Bay.
Communications	Significant – Communications are critical for air traffic control, aircraft operations, terminals and tenant operations. The airport cannot operate without communications.
Highways and Local Roads	Significant - Passengers and employees primarily rely on surface roads to access the airports.
Fuel	Significant – SFO is completely dependent on fuel delivery to the Fuel Farm for its operations. If the fuel pipelines are damaged, fuel can be shipped to Brisbane or Port of San Francisco via barge, but there is currently no infrastructure to transport the fuel from the barges to SFO. A fuel truck can only deliver about 4,000 barrels per day, making trucking fuel not a viable alternative in the event the pipeline is damaged to meet the airport's demand of 80,000 barrels per day. On-hand fuel supply and onboard aircraft tanker fuel could mitigate potential impacts for a short period.
Transit	Moderate – Many passengers and employees rely on SamTrans and BART to access the airport.
Solid Waste	Moderate – refuse (trash, recycling and organics) generated by the airport is transported by Recology to its facilities for sorting and disposal.
Airport	Low – SFO does not depend on other regional airports for operations. However, if SFO is shut down, other airports in the region may be able to accommodate some of SFO's traffic. Four of the five airports in the region that can handle large

Sector	Extent of dependence on sector
Airport (cont.)	aircraft will experience strong to violent shaking in the San Andreas and Hayward Scenario. Travis Air Force Base in Solano County may be the only airport in the region with a long enough runway for large aircraft that is not impacted by the scenario earthquakes.[128]
Port	None – The airport does not rely on the Port for operations.
Firefighting Water (EFWS)	None – The airport is located outside the area served by EFWS.

Actions to Speed Restoration

SFO should identify ways to improve the reliability of fuel delivery in an earthquake.

SFO is completely reliant on fuel delivered by Kinder Morgan pipeline for its operations. No viable alternative currently exists to substantially continue operations in the absence of the pipeline. Fuel can be shipped to Brisbane or Port of San Francisco by barge, but there is currently no infrastructure to transport the fuel from the barges to SFO.

SFO should first clarify with the California Energy Commission Fuel Set Aside Program what the process will be for distributing fuel in an emergency and what the priority will be for SFO to obtain fuel. In the longer term, SFO should evaluate the feasibility of developing a barge facility to provide redundant fuel delivery in case of pipeline or refinery damage.

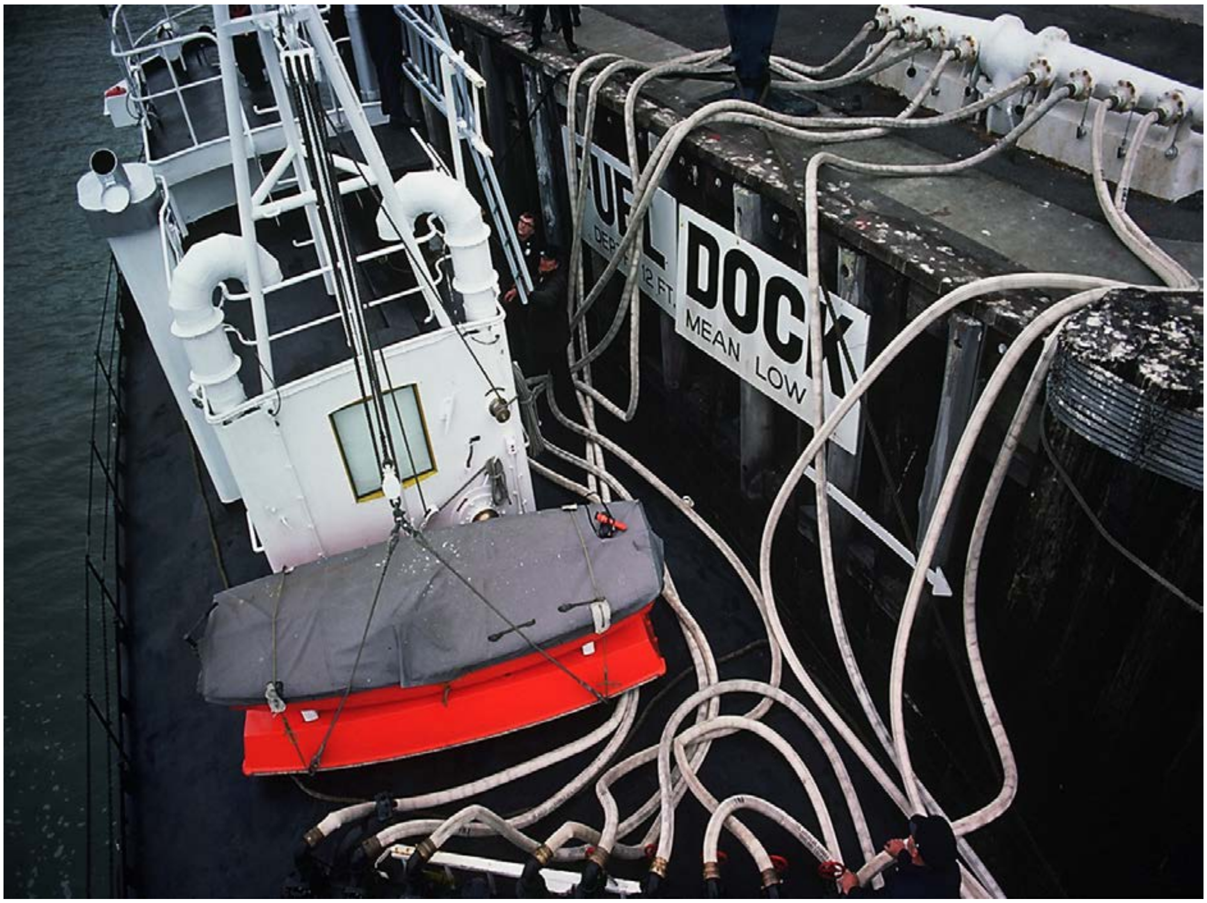
SFO should improve the reliability of priority utility systems in an earthquake.

A substantial impediment to reopening of the SFO is the functioning power. All other critical systems, including water, communications, transportation, and wastewater systems rely on power for operation. Water, power and communications are delivered on site by external providers and SFO transports treated sewage offsite for final dechlorination and discharge to the Bay. Passengers and workers must use either BART or local roads and freeways to access the airport. Within the airport campus, SFO owns and operates all these systems. The Airport needs to better understand the vulnerability

[128] ABAG. 2014.

of both the utilities it owns and those external services to damage in a major earthquake and take steps to improve the systems to help meet its restoration goals.

Firefighting Water (EFWS)



The Emergency Firefighting Water System (EFWS) is a high-pressure firefighting water system constructed in response to the Great Earthquake and Fire of 1906 to safeguard lives and property in the case of future earthquakes. The system provides a secondary high-pressure water supply system for fighting post-earthquake fires. The system is also routinely tapped to fight multi-alarm fire events even in the absence of an earthquake and can be called on as much as 30 times in a single year. If the EFWS were significantly disrupted in an earthquake, the risk of urban conflagrations that threaten life safety and property could be significant.

Firefighting Water (EFWS)

Operator: SFPUC

At A Glance…

Key Findings

- There may be some pipe breaks and leaks in the system in the scenario earthquake, but it will meet its level of service goals and be able to respond to the anticipated fires across the City.
- EFWS has significant dependencies on highway and local roads for access, and communication for remote operation of pumps and SCADA systems. EFWS is designed to run independently and manually without electricity or potable water. Multiple water sources are available, but backup generators for pumps will eventually need to be refueled until electricity is restored.
- Areas not currently well served by EFWS are served by the City's low-pressure water system for post-earthquake firefighting. Once the EFWS has been expanded to these neighborhoods with planned improvements, the neighborhoods will have access to the EFWS and City's low-pressure system to respond to fires.
- SFPUC is focusing future investment in three areas: system expansion to meet citywide level of service goals, expansion to serve new developments, and repairs and upgrades to the current system.

Actions to Speed Restoration

- SFPUC should complete studies and analysis, and implement capital projects to improve and expand the EFWS, emphasizing capital investments in areas of the City with limited access to the EFWS.

Restoration Performance Goal

The Level of Service Goal for the EFWS is that the system is 90% reliable in supplying water citywide for fire suppression after a magnitude 7.8 San Andreas fault earthquake.[129]

[129] AECOM/AGS. "CS-199 Planning Support Services for Auxiliary Water Supply System (AWSS): Project Report". SFPUC February, 2014. Retrieved from:https://sfwater.org/Modules/ShowDocument.aspx?documentid=5055

System Restoration Timeline

The service restoration timeline in **Figure 28** represents the extent of service disruption experienced by the system from the perspective of users in San Francisco at specified time points after the San Andreas earthquake. In setting the service disruption level for each time period, each system operator considered the measure of service loss appropriate for their system.

The solid line shows the expected restoration performance if an earthquake were to occur today. The dashed line shows the target performance, as defined by the system owner. Target performance considers existing plans for system upgrade and improvement that have not yet taken place.

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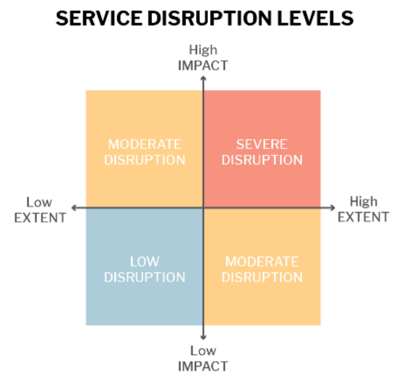
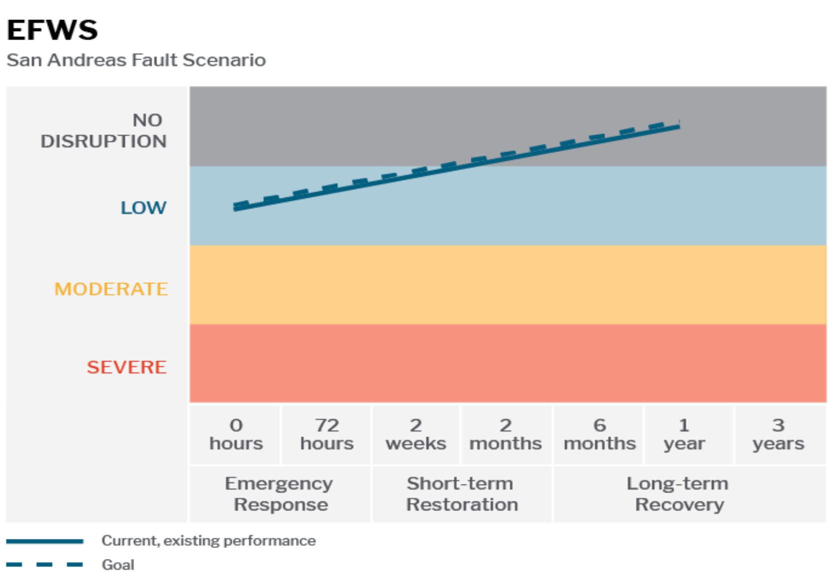


FIGURE 28: EFWS RESTORATION TIMELINE



Sector Overview

The EFWS is comprised of reservoirs, pump stations, manifolds, cisterns, and pipelines and tunnels: These assets are displayed in the system map seen in **Figure 29**.

Reservoirs: The primary water supply for the system comes from the Twin Peaks reservoir, with a storage capacity of 10.5 million gallons. The Ashbury and Jones Tanks provide an additional 500,000 gallons and 750,000 gallons of storage capacity, respectively. All three of the primary water sources for the EFWS are supplied with water from the SFPUC's Hetch Hetchy Regional Water System. The regional water system underwent $4.8 billion in seismic upgrade with a level of service goal to restore basic service within 24 hours after a major earthquake on the San Andreas, Hayward or Calaveras faults (see Potable Water chapter for further discussion).

Pump stations: The EFWS system has a secondary water source, the San Francisco Bay, which can be accessed via two pump stations (Pump Stations 1 &2) along the waterfront that are capable of pumping 10,000 gallons per minute of seawater at high pressure into the system. Both pump stations have onsite backup generators.

Manifolds: Additional water can be drawn from the Bay through five manifold connections where three fireboats can connect and deliver seawater into the system at a rate of 9,600 to 24,000 gallons per minute.

Cisterns: Approximately 200 independent underground cisterns located throughout the city can provide additional water for the system as a last resort. Sizing varies from 75,000 gallons to over 200,000 gallons with a total storage capacity of over 11 million gallons of water.

Pipelines and tunnels: 135 miles of underground pipelines and tunnels dedicated to emergency firefighting and motorized/manual valves facilitate transportation of this water across the city to the high-pressure fire hydrants used by SFFD.

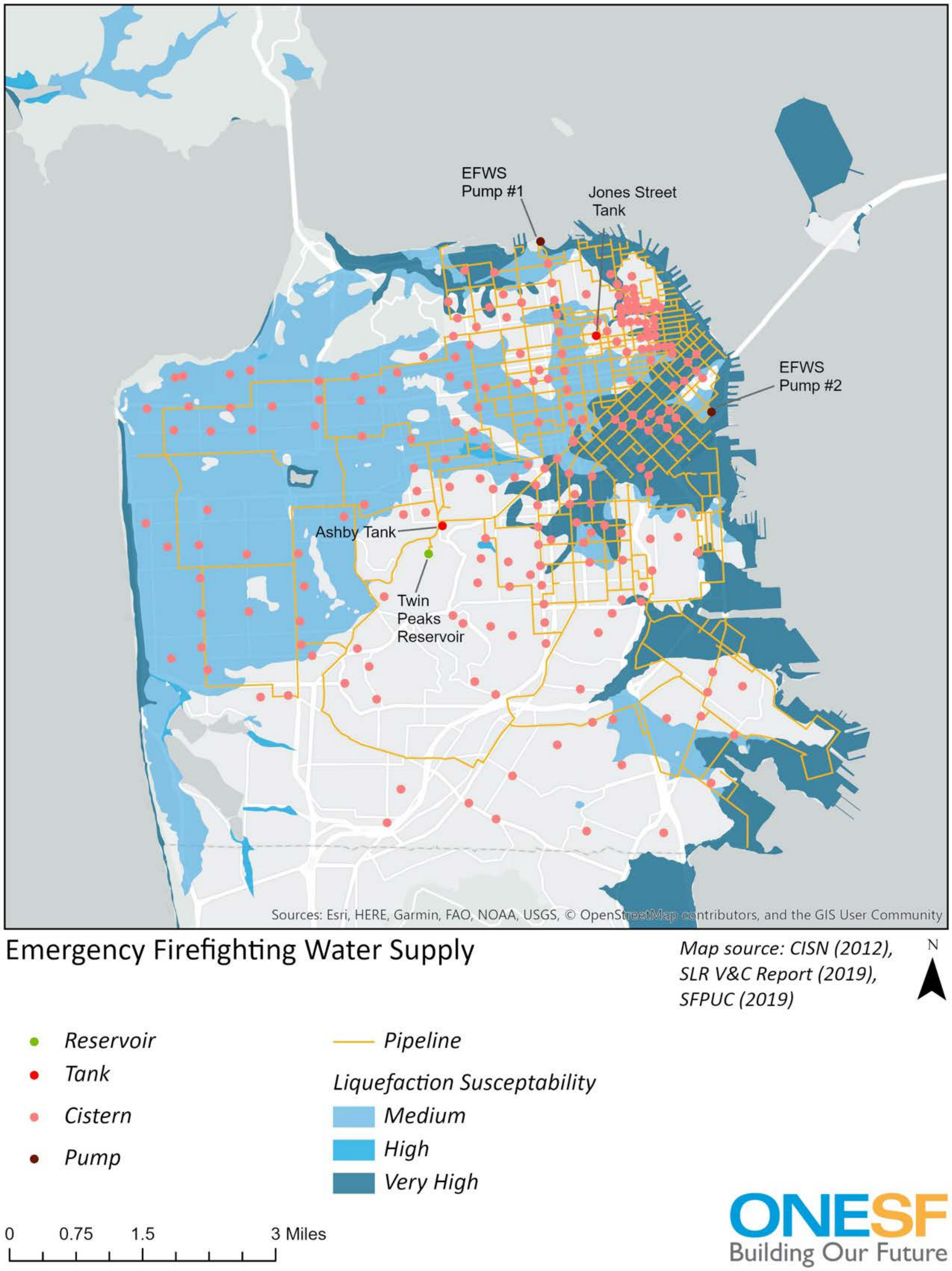
The EFWS has undergone expansions and improvements through several bond measures over the years. Today, the Eastside and Downtown are reliably and extensively covered by the system, but the Westside has lower reliability. Currently, SFPUC and SFFD are identifying extension alternatives in partnership with the public to increase Westside reliability.[130, 131]

Originally, the EFWS was constructed by Public Works and managed by SFFD. However, ownership transferred to SFPUC in 2010. Today, it is utilized by the SFFD and operated and maintained by the City Distribution Division (CDD) of SFPUC. As part of the transfer, a full assessment of all existing facilities was conducted.[132] The assessment showed that the 2010 EFWS would be about 47% reliable in terms of providing water citywide following a magnitude 7.8 earthquake on the San Andreas Fault. To address the deficiency, the City has issued two general obligation bonds known as the Earthquake Safety and Emergency Response (ESER) Bonds. Once fully completed, the projects implemented with the ESER 2010 bond funds will increase the citywide reliability score from 47% to 67%. The full completion of the projects implemented with the ESER 2014 bond funds will increase the citywide reliability score from 67% to 87%. Construction of additional recommended future projects will increase the citywide reliability score to 96%.

The EFWS has not been tested in an earthquake equivalent in size to the 1906 earthquake, which it was designed in response to. The largest earthquake the system has experienced is the 1989 Loma Prieta earthquake. In that event, the system suffered one 12-inch main break and four fire hydrant breaks in SOMA and two pipe leaks in the Marina and Mission district due to liquefaction and lateral spreading.[133] These breaks did not significantly affect the performance of the system. By comparison, the municipal water system suffered more significant damage with 69 main breaks and 54 service connection breaks in the Marina, demonstrated the importance and reliability of the EFWS system.

[130] AECOM/AGS. 2014.
[131]San Francisco Public Utilities Commission. “Assessment of Fire Suppression Options for Westside”. Public Presentation, 2012. Retrieved from https://onesanfrancisco.org/sites/default/files/2019-05/Agenda%20Item%204%20-%20AWSS%20Presentation.pdf
[132] AECOM/AGS. 2014.
[133] AECOM/AGS. 2014.

FIGURE 29: EFWS SYSTEM MAP



System Upgrade and Disaster Planning Efforts

Significant probabilistic analysis and hydraulic modeling has been performed on the EFWS system in recent years to inform decisions about needed upgrades to meet the system's level of service goals.[134] Since 2010, the ESER Bonds (ESER 2010 and ESER 2014) have provided $156.7 million to implement the necessary maintenance and capital improvements projects to improve seismic reliability and range of coverage, including:

- Critical reliability upgrades at the three primary water sources: Twin Peaks Reservoir, Ashbury Heights Tank and Jones Street Tank.
- Upgrades to Seawater Pump Station #1, which is one of the secondary sources of water for the system.
- Structural and seismic upgrades to Seawater Pump Station #2 began in late 2018 and are estimated to be complete in 2020.
- Construction of 30 new cisterns, 15 of which are in the Sunset and Richmond districts.
- Completion of six pipeline and tunnel projects, with seven more currently in planning, design or construction.

Future ESER funds will focus on improving coverage to the City with limited access to the EFWS and improving infrastructure in existing areas, such as upgrading manifolds that allow seawater to be pumped into the system from the Bay.

SFPUC utilizes earthquake resistant pipe for all new pipeline projects. The rigid pipes in the EFWS system are being replaced with ductile iron pipe systems that are substantially less prone to damage.

As new developments and population growth occur in San Francisco, the water required for firefighting to address post-earthquake fires may change. SFPUC is modeling the effects of new developments on EFWS capacity requirements, both within the new developments and in the City as a whole. The SFPUC and SFFD are working together to specify new EFWS piping and hydrants requirements for new developments. Additionally, developers are required to contribute financing towards pipelines or pump stations for the existing system or construct EFWS facilities for additional firefighting

[134] AECOM. '*Westside Emergency Firefighting Water System Options Analysis*". SFPUC January, 2018. Retrieved from: https://sfwater.org/modules/showdocument.aspx?documentid=11740; and CS-199 Planning Support Services for Emergency Firefighting Water System (EFWS) Project Report (2014). Retrieved from: https://sfwater.org/Modules/ShowDocument.aspx?documentid=5055

capacity. These requirements are specified in the Development Agreements approved by the Board of Supervisors for new, large development projects.

The SFPUC prioritizes water pipelines for replacement based on risk scores and condition assessments. San Francisco's Emergency Fire Water System (EFWS) is prioritized for expansion or replacement with seismically reliable pipelines based on post-seismic fire-fighting demand analysis. Expansion of EFWS to new developments within San Francisco, and replacement of older infrastructure, will take 30-50 years.

Expected Impacts of an Earthquake

San Andreas Fault Scenario

EFWS pipelines are vulnerable to damage from bending or pipe joint extension/compression, particularly in liquefaction zones. The SFPUC has performed pipe assessment analysis and EFWS pipelines will see some degree of breakage or failure, however, the system is expected to meet level of service goals if the scenario earthquake were to occur today.

Hayward Fault

The Hayward fault scenario will result in less liquefaction and lateral spreading than the San Andreas scenario and the system is expected to meet level of service goals if the scenario earthquake were to occur today.

System Restoration Timelines and Considerations

San Andreas Fault Scenario

Table 25 describes the existing level of service disruption for the asset and the restoration actions that each operator will take during the specified recovery period in the San Andreas Fault scenario. **Table 25** reflects the current, existing performance in the Restoration Timeline in **Figure 28** above. Each box in the table is colored to correspond to the expected service disruption levels, where red is severe disruption, orange is moderate disruption, blue is low disruption and gray is no disruption. Italicized text explains gaps between existing and goal performance for each restoration period.

These restoration assumptions should not be viewed as a predictive model of performance in a future earthquake or other disaster, but rather an indication of the types of restoration issues that will arise in this scenario.

TABLE 25: EFWS RESTORATION TIMELINE

	EFWS - SFPUC
0 Hours	The focus of the first 72 hours will be on fire response and making any critical repairs necessary to maintain system functionality. Debris clearance will also be important to allow fire personnel and equipment to access fires. In the first hour, the Fire Department will organize a fire command to assess which areas to target for firefighting and how to fight those fires. Estimates are that there may be as many as 70 simultaneous fire ignitions in this scenario, while firefighting will be impeded due to debris and damaged roads.[135] While the Fire Department is planning its response, SFPUC will be evaluating damage and functionality of the system and determining what components of the system need to be isolated to maintain adequate pressure. Some valves will need to be opened manually and some can be opened remotely. Once the system is running, crews will need to isolate the breaks and make any necessary immediate repairs. The time of day of the event will determine how many crews are immediately available to perform necessary operations. The gatemen required to operate critical valves and controls, all live in San Francisco or the Peninsula, except for one. Additionally, SFPUC is staffed 24/7 with plumbers, maintenance crews, and staff ready to deploy to key components to ensure they're functioning.
72 Hours	After immediate post-earthquake firefighting needs are met, SFPUC will focus repair efforts on restoring the municipal water first and then return to completing needed repairs to the EFWS system. The same crews serve the municipal and EFWS systems. If aftershocks cause any additional fires, staff will divert their attention to providing support to the SFFD to ensure firefighters have the water supply at the volumes and pressure they need to fight fires.
2 Weeks	
2 Months	
6 Months	
1 Year	The system will be fully restored within a year as needed long-term repairs are completed.
3 Years	

[135] Applied Technology Council (ATC). *'Here Today—Here Tomorrow: The Road to Earthquake Resilience in San Francisco. Potential Earthquake Impacts"* SF DBI, 2010 Retrieved from: https://sfgov.org/esip/sites/default/files/FileCenter/Documents/9753-atc521.pdf

Hayward Fault Scenario

As in the San Andreas scenario, the focus in the first 72 hours will be on making the system functional for any firefighting needs. Crews will then focus on restoring the municipal water supply system before returning to repairs needed to fully restore the EFWS system. Only minor, localized damages are expected in this scenario and restoration is expected within a few months.

Level of Confidence

SFPUC has high confidence in the EFWS based on experience in the Loma Prieta earthquake and probabilistic analysis, hydraulic modeling, reliability modeling and geotechnical analysis that has been performed on the system.

System Interdependencies

EFWS has significant dependencies on highway and local roads for access, and communication for remote operation of pumps and SCADA systems. EFWS is designed to run independently and manually without electricity or potable water. Multiple water sources are available, but backup generators for pumps will eventually need to be refueled until electricity is restored.

Table 26 describes the extent of this sector's dependence on other infrastructure sectors for post-disaster restoration, as well as any mitigations that have been taken to reduce the dependence. The extent of dependence is described as:

- Low = minimal reliance on sector;
- Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;
- Significant = large reliance on sector with limited backup available.

TABLE 26: EFWS DEPENDENCIES

Sector	Extent of dependence on sector
Electric Power	Moderate - EFWS pumping stations rely on electric power; however, both pumping stations have backup diesel generators in the event of a power outage. A two-stage turbine pump can be used to fill Twin Peaks Reservoir from Ashbury tank and can run on an emergency diesel engine in the event of a power outage.
Natural Gas	Moderate **-** SFPUC does not rely on natural gas for operations.
Water	Moderate - The EFWS system relies on access to water to operate; however, multiple sources of water are available. The primary source of water is the Hetch Hetchy Regional Water System, which feeds the reservoir and tanks that fill the system. The Hetch Hetchy Regional Water System underwent a $4.8 billion upgrade using a magnitude 7.8 earthquake as its level of service. There is sufficient supply to initiate firefighting efforts without reliance on an uninterrupted supply of water from the regional system. Eventually, though, the system will have to be replenished. A secondary source of water is the San Francisco Bay. Finally, there are approximately 200 cisterns throughout the city that hold water specifically for firefighting.
Wastewater	None
Communications	Moderate – Communications are critical for remote operation of Pump Station #1 and some valves. SCADA relies on microwave signals (redundant pathways are available). PS1 has a backup city copper telephone system. The SFPUC headquarters buildings has satellite internet that can control the valves. Valves can also be remotely controlled from several other locations. The pump stations can also be operated manually in case remote control is down due to the earthquake. All EFWS components that can be operated remotely can also be operated by a staff person at the specific location. Therefore, even if the SCADA system is down, all pump stations, valves, generators, and other key components can still be operated.
Highways and Local Roads	Significant – Local roads are critical for accessing facilities and manual valves. Pump Station #2 requires manual operation with access by local roads. In the immediate response phase, regional transportation is not critical. All but one of the gatemen required to operate valves and controls live in San Francisco or Peninsula. Additionally, SFPUC is staffed 24/7 with plumbers, maintenance crews, and other critical staff that will be able to take action immediately. Regional transportation will be required to relieve crews after the initial response phase.

Sector	Extent of dependence on sector
Fuel	Moderate - Diesel tanks at the pump stations provide 24-48 hours of supply (with 9,700 gallons at Pump Station #1 and 6,840 gallons at Pump Station #2). The City has contracts with fuel vendors to refill these tanks.
Transit	None
Solid Waste	None
Airport	None
Port	Significant - The intakes that supply seawater to the two pump stations and the five manifolds that the fireboats connect to pump seawater into the system may be damaged if the sea wall were to fail in an earthquake. The SFPUC is working with SFFD to undertake two projects to upgrade the manifolds at Fort Mason and at Pier 33 to make them more seismically resilient.
Firefighting Water (EFWS)	None

Actions to Speed Restoration

SFPUC should complete studies and analysis, and implement capital projects to improve and expand the EFWS, emphasizing capital investments in areas of the City with limited access to the EFWS.

Working collaboratively, the San Francisco Public Utilities Commission (SFPUC), San Francisco Fire Department (SFFD), and the San Francisco Public Works (SFPW) are completing studies and analysis, and implementing capital projects, to improve and expand the EFWS. For upcoming EFWS capital investments, the three agencies are placing an emphasis in areas of the City where there is limited access to the EFWS. One potential conceptual project includes over 13 miles of seismically resilient pipeline, connected to two new pump stations, to provide high-pressure fire suppression to western neighborhoods.

The three agencies completed a planning study in October 2013 to help maximize the likelihood that the EFWS will effectively provide the necessary firefighting capabilities after a major earthquake. Additionally, the agencies completed a study in 2018 analyzing options for high-pressure fire suppression for the Richmond and Sunset Districts. The results and recommendations from these two studies help to inform the selection of specific capital projects to be implemented. This selection process is led by the EFWS Management Oversight Committee, consisting of the Chief of the SFFD, the Director of SFPW, the General Manager of the SFPUC, and the Assistant General Manager of the Water Enterprise for the SFPUC.

Section 4 Updating the Project

The Restoration Project should be updated approximately every five years to document the progress made by lifeline operators in improving the resilience of lifeline systems and to reconsider the restoration goals set in the previous Project.

As discussed in **Section 1**, the Project used the model developed by Chang et al. and was the result of a structured interview process with each of the lifelines providers and a cross-sector workshop to compare and validate findings. This approach should guide future update processes.

Refine restoration timelines

Where possible, the general, qualitative findings in this project should be built upon to conduct detailed, quantitative modeling and develop more accurate restoration curves. However, privacy and security of lifeline data makes this kind of analysis challenging for third party researchers. Lifeline organizations could conduct this work themselves and share the results publicly.

Validate restoration performance goals

The restoration performance goals in this project were largely identified through judgement of the interviewees in each lifeline organization. In a few cases, lifeline organizations have adopted restoration performance goals. Restoration performance goals should reflect the performance expectations of the public, as well as what the lifelines can reasonably achieve. Future updates to the Project should validate the goals through a consensus-building process with City officials, lifeline providers and community stakeholders.

Restoration performance goals should also consider restoration and recovery goals identified in other city plans to understand public expectations for lifeline restoration. See **Appendix F** for summary of related published restoration goals.

Appendix A. Methodology

Overview

The Lifelines Restoration Performance Project adapted the methodology developed by for characterizing lifeline system resilience in earthquakes.[136] The approach utilized a structured interview process to illicit expert judgement from key members of each lifeline organization. The interviewees were asked to consider the physical performance of lifeline systems during two realistic but extreme earthquake scenarios: a magnitude 7.9 earthquake on the San Andreas Fault and a magnitude 7.0 earthquake on the Hayward Fault. These two scenarios provide the opportunity to examine the different effects of very near and more distant major earthquakes on San Francisco. Details about the selection of these scenarios is provided in **Appendix B**. Scenarios.

Expert interviews

Most of the data found in this report is the result of interviews with expert staff representing each of the lifeline sectors. The interviews involved people most knowledgeable about system's operations, emergency response, seismic performance and restoration processes. Each lifeline operator was interviewed independently. Interviews lasted approximately 1-2 hours and the questions were provided ahead of time. Interview questions were adapted from Chang et al. (2014) and were designed to illicit expert judgement about expected damage from the earthquake scenario, how the system would function in terms of its ability to provide service to customers within San Francisco at various time periods after an event, the interdependencies among systems, previous seismic upgrades completed for the system, and level of confidence in the responses. In an addition to the methodology from Chang, et al., we also asked

[136] Stephanie Chang et al. "Toward Disaster-Resilient Cities: Characterizing Resilience of Infrastructure Systems with Expert Judgments," Risk Analysis, Vol. 34, No. 3, 2014; DOI: 10.1111/risa.12133

interviewees to set performance goals in terms of desired system function at various time periods after an event. In a few situations, desired performance had been formally established in adopted service levels. Thinking about the experience of the user was a key focus of the interview questions. The interview questions used for this study are shown in **Appendix D**.

Interviewees were asked to inform their responses with as much data collection, modelling, experience in previous disasters, studies and information as the organization has developed to date. The types of information used to support these responses was documented. Detailed notes were taken during the interviews, which were provided back to the interviewees for validation. Additional research and follow up questions were used to clarify interview responses as needed.

Cross-Sector Workshop

A cross-sector workshop was organized to bring all the lifeline providers together to present draft findings from the interviews. Participants were divided into breakout sessions for key sectors to validate and revise the key findings, restoration goals and assumptions, and to identify key actions to speed restoration. A summary of the workshop is included in **Appendix E**.

Data Synthesis

Restoration Timelines

A key outcome of the interviews is a set a restoration timelines for each lifeline system that depicts an averaged citywide level of service disruption based on extent and impact at key time intervals following an earthquake. The time intervals were selected by reviewing common time intervals in city, state and national emergency response and recovery plans. Interviewees were asked to consider any measure of service disruption appropriate to their system in selection of service disruption levels.

The service disruption levels are defined as follows:

- Severe = disruptions with high spatial extent & high impact disruptions.
- Moderate = disruptions with low spatial extent & high impact, OR high spatial extent & low impact;
- Low = disruptions with low spatial extent and low impact;
- No disruption

Where,

- Extent = spatial reach of the disruption and proportion of people within the area that are affected.
- Impact = severity of consequences and the duration of the disruption. For example, complete loss of water supply is high impact (independent of how many people are affected), whereas a boil water advisory is low impact.

The restoration timelines were also enhanced through written descriptions of the impacts, consequences, and interdependencies for each sector. Much of this work is an update from the 2014 Lifelines Interdependencies Study[137] and will provide a way for us to dig into the details that underlie these charts.

Interdependencies

An interdependency matrix was also developed based on the responses of the interviews to describe how each lifeline depends on each of the other lifelines. The reliance or dependence was described as:

- None: no reliance on sector
- Low: Minimal reliance on sector
- Moderate: Large reliance on sector with significant backup available or moderate reliance on sector with no backup available
- Significant: Large reliance on sector with limited backup available

These descriptors were enhanced with descriptions of the nature of the dependency or reliance.

Actions to Speed Restorations

Sector specific and cross-cutting actions were identified that would speed the restoration of lifeline systems after an earthquake. These actions were identified based on issues identified during the interviews and in the cross-sector workshop.

[137] San Francisco Lifelines Council. 2014. Lifelines Interdependency Study I Report. City & County of San Francisco, Office of the City Administrator. April 17, 2014.

Appendix B. Scenarios

To conduct the Project, it was necessary to consider the physical performance of lifeline systems during an earthquake. This can be done in terms of defining the effects of an earthquake in probabilistic terms (e.g. the level of shaking that could be expected to occur with a 10 percent probability over a 50-year time period) or by defining a scenario event (a hypothetical earthquake defined by the location of a rupture along a particular fault and the magnitude of energy release). Two scenario earthquakes were selected for this evaluation because this approach lends itself more readily to a system-, city-, and region-wide application (as opposed to site-specific analysis). Earthquake scenarios help us better understand the impact an earthquake can have on our built and social environments. Officials and the public can use scenario information to act to reduce risk and change the negative outcomes highlighted by the scenario.

Scenario Selection

The scenarios selected for the Project are:

- A magnitude 7.9 earthquake on the San Andreas Fault (a repeat of the 1906 earthquake)
- A magnitude 7.0 on the Hayward Fault (equivalent to the USGS Haywired scenario)

The next earthquake to strike our region will not necessarily have the exact magnitude, location or fault rupture details of the selected scenarios, but they do represent scientifically reasonable earthquakes that can help us better plan and prepare for an actual event.

An earthquake on the San Andreas Fault will likely have a larger magnitude, and the proximity of the fault will translate to stronger shaking, more widespread liquefaction, and likely more damage within the city itself. An earthquake on the Hayward Fault will likely have a smaller magnitude, and its greater distance from San Francisco will mean somewhat less intense shaking and liquefaction for the city; but because so much of the city's infrastructure crosses the Hayward Fault, lifeline impacts will still be significant.

Together, the two scenarios represent a comprehensive evaluation of the possible impacts to San Francisco infrastructure on major faults likely to rupture in the region and provide the opportunity to examine the different effects of very near and more distant major earthquakes on San Francisco. The shake maps for both selected scenarios use average ground motions that do not account for all the variability inherent in complex earthquake faulting and local site conditions, and therefore shouldn't be used to predict damage to specific lifeline components.

These two scenarios, along with the Concord Fault scenario, also form the basis for the Association of Bay Area Governments' (ABAG's) regional lifelines interdependency study, which details regional system damages and consequences from infrastructure failure in the Bay Area.[138] The Hayward Fault scenario is the same one used by the U.S. Geological Survey (USGS) for the Haywired scenario report.[139]

Lifelines organizations were provided with a scenario overview document before the interview, which included a ground shaking intensity map for each scenario with a brief description of the likely associated damages and consequences (**Figure 30** and **Figure 31**), a liquefaction susceptibility map across the region (**Figure 32**), and a brief description of the damage experienced by these systems in the Loma Prieta earthquake.

San Andreas Fault Scenario

The San Andreas Fault scenario represents a likely worst-case event for San Francisco in terms of shaking intensity and damage within the city. It is approximately a repeat of the 1906 Great San Francisco earthquake. Damage to buildings and infrastructure in the surrounding region will also be significant. An earthquake on the San Andreas Fault will likely have a larger magnitude, and the proximity of the fault will translate to stronger shaking and likely more damage within the city itself.

In 2006, a detailed scenario was developed by a team of earthquake loss experts to develop a best estimate of the potential ground motions, building damage and losses,

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[138] ABAG. 2014.
[139] Detweiler, S.T., and Wein, A.M., eds. 2018.

and consequences if the 1906 were to happen with 2006 exposures of people and buildings.[140]The 2006 scenario also formed the basis for the Lifelines Council's 2014 Lifelines Interdependency Study.

Since this time, the U.S. Geological Survey (USGS) has updated its Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) with authoritative estimates of the magnitude, location, and time-averaged frequency of potentially damaging earthquakes in California.[141] The study revised the shake map scenario earthquakes, including the M7.9 San Andreas Fault scenario.[142] We have used the revised scenario shaking map for this Project (see **Figure 30**). While detailed damages and consequence information like that completed in 2006 has not been analyzed for this revised scenario, it represents the latest scientific information that can be used by lifeline operators to model and estimate damage and disruption to their own utility systems.

Other San Andreas Fault scenario shake maps are available and have been used by the City for various studies. Most notably, the SPUR[143] and CAPSS[144] studies have both used the smaller "expected" M7.2 San Andreas Fault scenario earthquake for their work. These studies focused primarily on building damage where damage will be apparent at lower levels of shaking. For the Lifeline Council's 2014 Interdependency Study, the Council agreed that the interdependencies among systems would be more visible with the larger M7.9 event.

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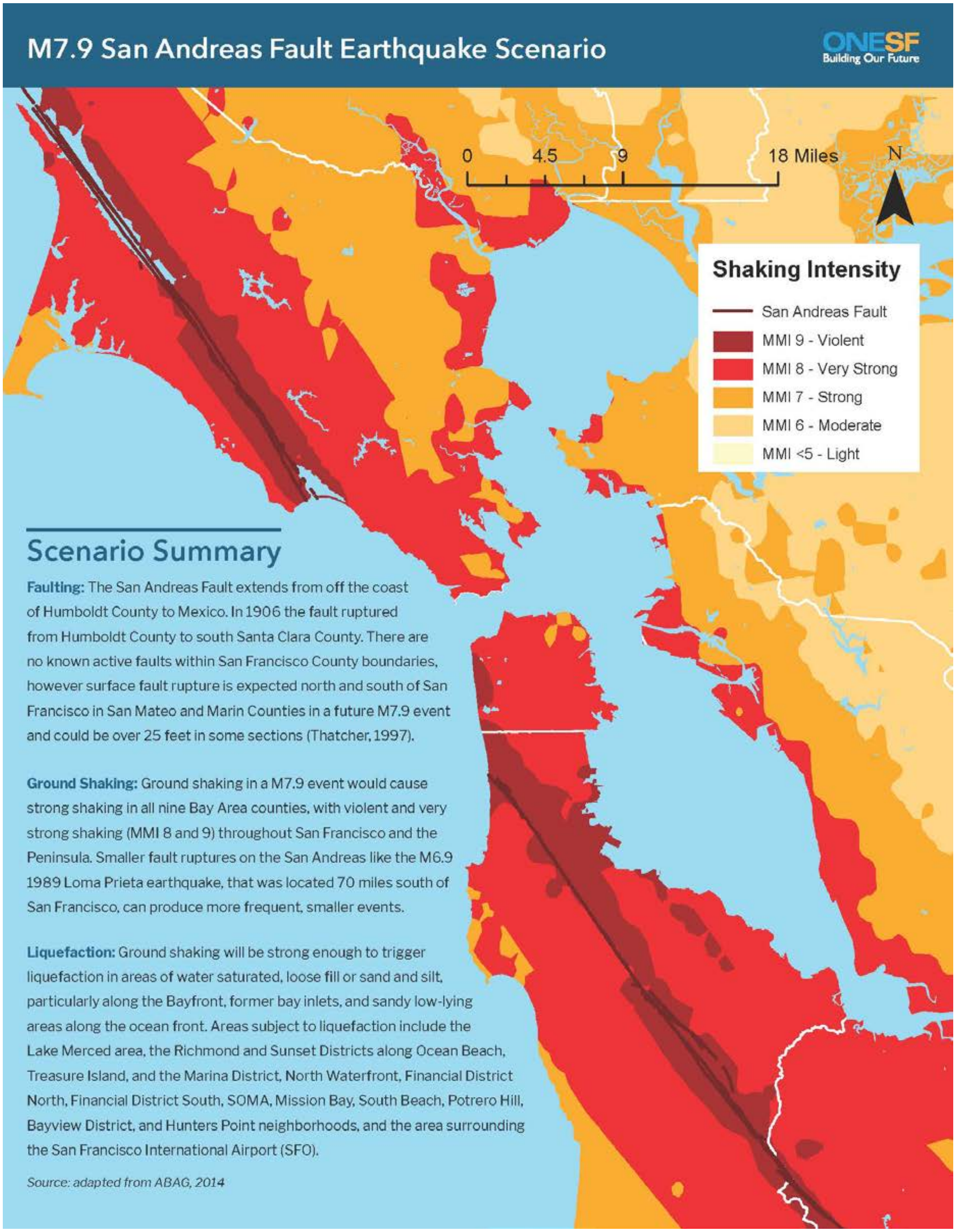
[140] Kircher, C.A., Seligson, H.A., Bouabid, J., and Morrow, G.C., 2006. When the Big One Strikes Again—Estimated Losses due to a Repeat of the 1906 San Francisco Earthquake. Earthquake Spectra: April 2006, Vol. 22, No. S2, pp. 297-339.
[141] Field, E.H., et al., 2013, Uniform California earthquake rupture forecast, version 3 (UCERF3)—The time-independent model: U.S. Geological Survey Open-File Report 2013–1165, 97 p., California Geological Survey Special Report 228, and Southern California Earthquake Center Publication 1792, http://pubs.usgs.gov/of/2013/1165/.
[142] CISN, 2012. Earthquake Planning Scenarios. California Integrated Seismic Network. Retrieved From: http://www.cisn.org/shakemap/nc/shake/about.html#scenario
[143] SPUR, 2009. The Resilient City: Defining what San Francisco needs from its seismic mitigation policies. SPUR. February 2009.
[144] ATC. 2010.

FIGURE 30: SAN ANDREAS MAGNITUDE 7.9 EARTHQUAKE SCENARIO



Hayward Fault Scenario

An earthquake on the Hayward Fault will likely a smaller magnitude, and its greater distance from San Francisco will mean less intense shaking for the city; but because major features of the infrastructure serving the city cross the Hayward Fault, lifeline impacts will be significant.

The HayWired earthquake scenario was developed by U.S. Geological Survey to model and study impacts on the San Francisco Bay area from a M7.0 earthquake occurring on the Hayward Fault on April 18, 2018.[145] The earthquake's epicenter is in Oakland with a rupture of 52 miles along the Hayward Fault (see **Figure 31**).

The HayWired study builds upon understanding of the last large earthquake on the Hayward Fault, which occurred in 1868. However, the study seeks to address the realization that modern urban infrastructures are made vulnerable by multiple layers of interdependencies among lifelines, with a major reliance on the Internet and telecommunications. This scenario considers as much as $50 billion in regional infrastructure strengthening investments that were motivated by the 1989 Loma Prieta earthquake.[146] This scenario also considers impacts from a sequence of aftershocks following the main earthquake, an often overlooked aspect that is an important component of the physical and emotional damage associated with large earthquakes extending into the days and months following.

Because of the location of the Hayward Fault, much of the major building and infrastructure damage is in the East Bay. However, this scenario has significant impacts on San Francisco's lifelines that cross the Hayward Fault, particularly water, fuel, electricity, and regional roads and transit.

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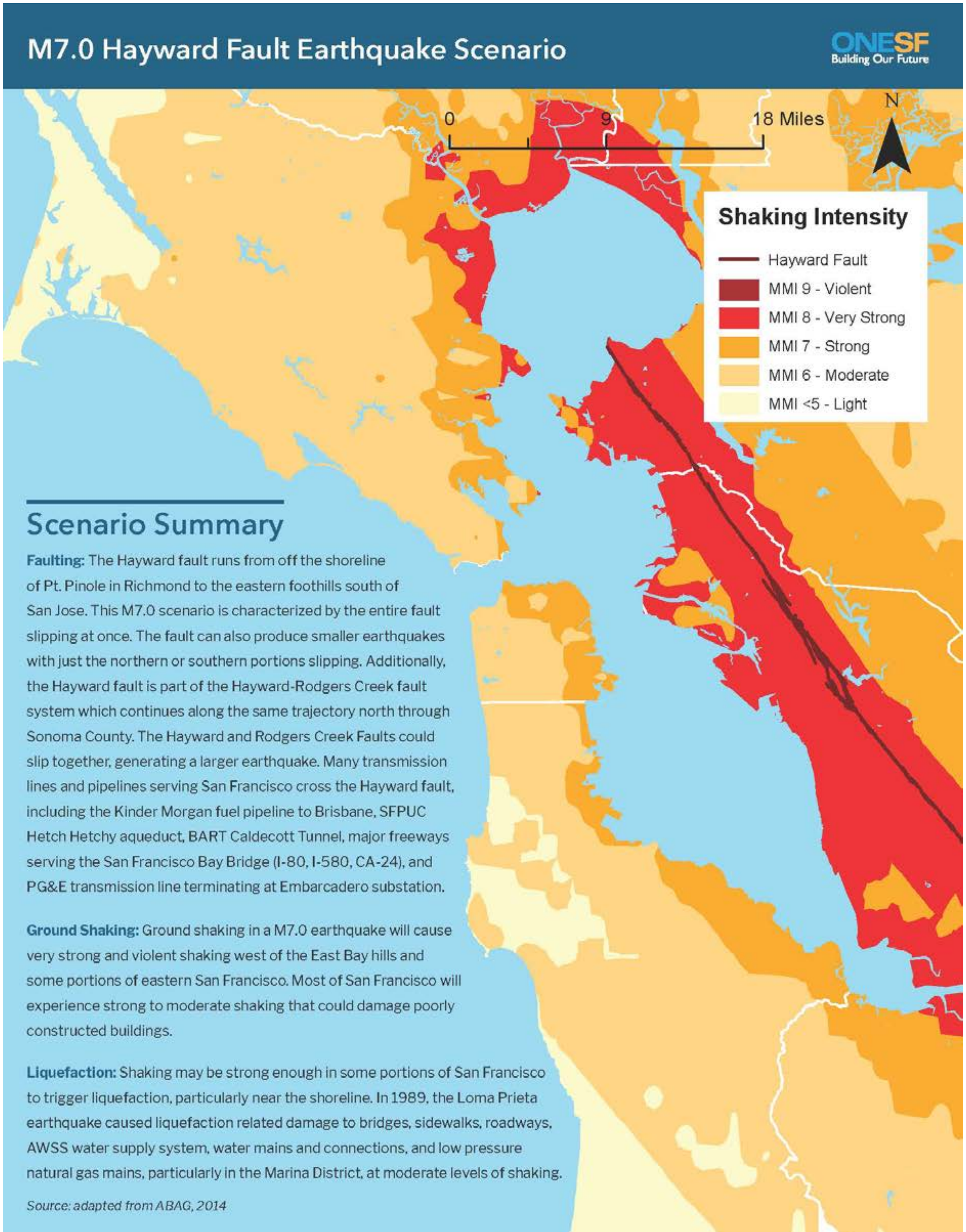
[145] Detweiler, S.T., and Wein, A.M., eds., 2017, The HayWired earthquake scenario—Earthquake hazards: U.S. Geological Survey Scientific Investigations Report 2017–5013–A–H, 126 p., https://doi.org/10.3133/sir20175013v1.

[146] KQED, 2014, 25 years after the Loma Prieta earthquake, are we safer?: KQED Science web page, accessed April 11, 2017, at https://ww2.kqed.org/science/2014/10/13/25-years-after-theloma-prieta-earthquake-are-we-safer/.

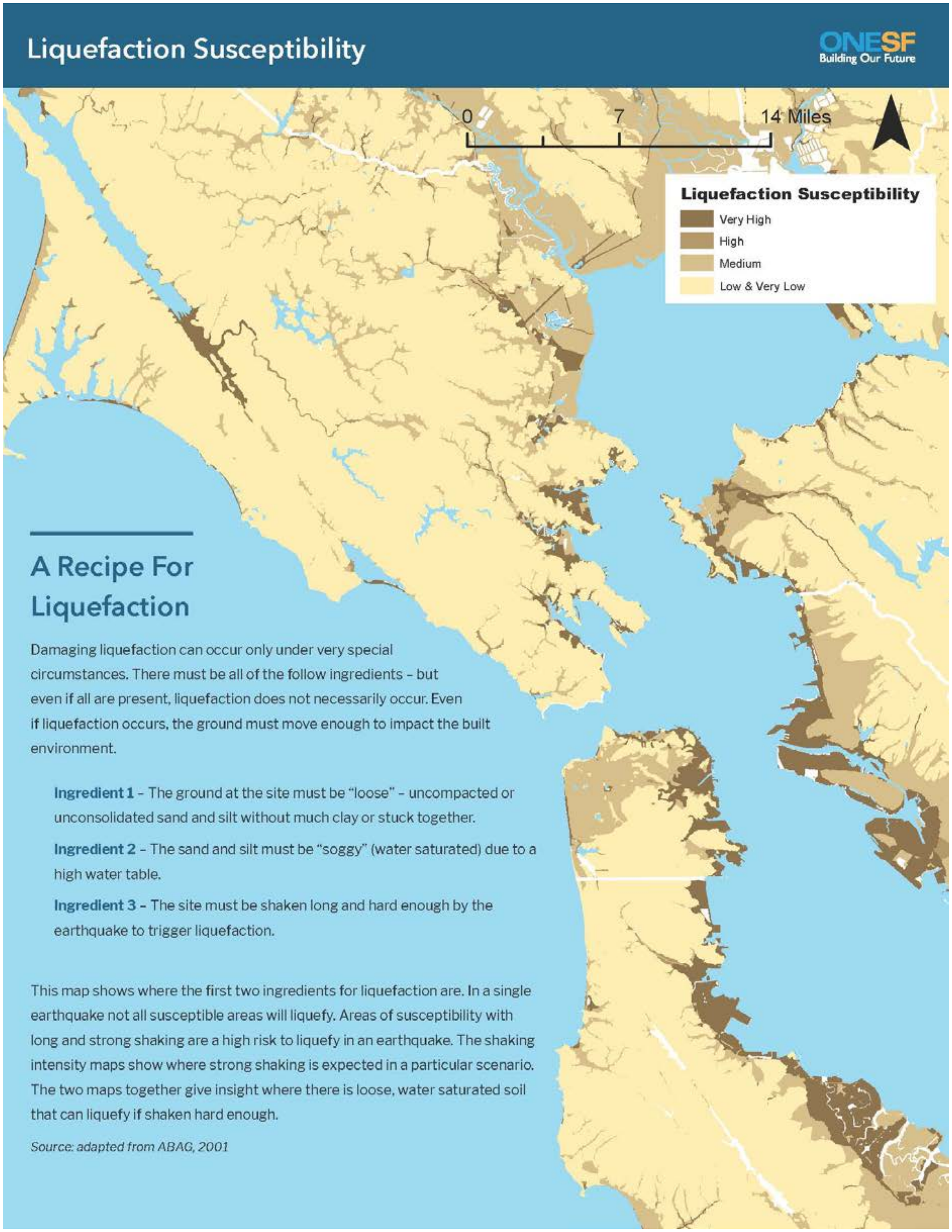
FIGURE 31: HAYWARD FAULT MAGNITUDE 7.0 EARTHQUAKE SCENARIO



Liquefaction

Liquefaction can be particularly damaging for buried and distributed infrastructure systems. A map of liquefaction susceptibility is shown for the entire Bay Area in **Figure 32**. This map depicts the areas that are likely to experience liquefaction, if shaken hard enough. Not all areas will liquefy in a particular earthquake**.** Areas with relatively higher liquefaction susceptibility may liquefy in moderate or stronger shaking, whereas area with less liquefaction susceptibility may only liquefy with stronger shaking.

FIGURE 32: LIQUEFACTION SUSCEPTIBILITY MAP



Appendix C. Related Plans and Studies

Related City of San Francisco Plans

The Project builds on a number of efforts to better understand performance of lifeline systems in the City and County of San Francisco. In particular, a critical recommendation from the 2014 Lifelines Interdependencies Study is to refine the current restoration timelines and develop common restoration standards for the performance of lifelines.

The Hazards and Climate Resilience Plan Strategy IN-1.05 calls for the Office of Resilience and Capital Planning to complete the Lifelines Restoration Performance Project and implement the recommendations of the Project.

The following initiatives in San Francisco's Resilience Strategy, known as Resilience SF, point to the need to complete this effort:

- Initiative 1.6: Actively coordinate for recovery with our private and public utilities
- Initiative 1.12: Continue Building and Upgrading Infrastructure
- Initiative 2.6: Repair, upgrade and protect our sewer systems
- Initiative 2.7: Water System Improvement Program
- Initiative 2.8: Repair, expand and improve auxiliary and portable water supply systems
- Initiative 2.9: Earthquake vulnerability study of the northern, waterfront seawall

The Safety Element of San Francisco's General Plan has several additional goals and policies that support the goals of this project:

- Policy 1.18: Identify and replace vulnerable infrastructure and critical service lifelines in high-risk areas

- Policy 1.2:1 Ensure plans are in place to support populations most at risk during breaks in lifelines
- Policy 1.5: Support development and amendments to buildings code requirements that meet City seismic performance goals. While the focus of Policy 1.5 is on building seismic performance, a recent ATC report (ATC-119) recommended performance goals for San Francisco's buildings and recognized that even the best built buildings cannot meet the established goals without the availability of key lifeline systems.[147]

Related Studies

This Restoration Project builds on the 2014 San Francisco Lifelines Interdependency Study, with the methodology primarily based on the work on Chang et al (2014), as described in **Appendix A**. We also build on the SPUR Resilient City Initiative (2009) which set performance targets for buildings and lifelines in San Francisco and estimated their existing performance.

We also reviewed other frameworks and methodologies for assessing lifelines performance and setting performance goals. The National Institute of Standards and Technology (NIST) Community Resilience Framework further built on the SPUR effort and developed detailed tables for the performance of various components of each lifeline system. The decision to try to include restoration performance goals was in part driven by the SPUR work and NIST guidance. We also drew from the Association of Bay Area Governments' 2014 *Cascading Failures: Earthquake Threats to Transportation and Utilities* report for potential impacts to regional lifeline systems.

Lifeline system restoration is becoming an increasingly important topic in the field of earthquake engineering and earthquake resilience. The most recent National Earthquake Hazards Reduction Program (NEHRP) reauthorization calls for FEMA and NIST to convene experts to recommend "options for improving the built environment and critical infrastructure to reflect performance goals stated in terms of post-earthquake re-occupancy and functional recovery time" (42 U.S.C. 7705(b); Senate Bill

[147] Applied Technology Council (ATC). 2019. Recommended Earthquake Performance Goals for San Francisco's Buildings (Draft). ATC 119 report, prepared for the San Francisco Office of Resilience and Capital Planning.

1768, 2018).[148] Contributing to that effort, the Earthquake Engineering Research Institute (EERI) developed a white paper outlining a potential framework for functional recovery. The framework proposes a definition for functional recovery and examines what is an acceptable functional recovery time, what strategies will make achieving the desired functional recovery time likely, and in what cases will planning strategies be needed to supplement design strategies. This project seeks to answers the same questions for lifelines serving San Francisco and complements the city's efforts to answer the same questions for the functional recovery of our buildings.

[148] Earthquake Engineering Research Institute (EERI). 2019. "Functional Recovery: A Conceptual Framework with Policy Options". Retrieved from https://www.eeri.org/wp-content/uploads/EERI-Functional-Recovery-Conceptual-Framework-White-Paper-201912.pdf

Appendix D. Interview Questions

System/Sector	
Interviewees	
Date	

The purpose of this interview is to gather information that will support the development a common operating picture for all lifeline sectors that serve San Francisco. We will set realistic goals for the restoration performance of lifelines following two major scenario earthquake events and understand how our lifelines would perform if one of these events were to happen today. The responses to these questions should be informed by as much data collection, modeling, and information as your organization has developed to date. This is an iterative process and we will continually update the assessment over time as we develop a deeper understanding of each of our systems. The outcome of this effort will be a set of detailed recommendations for how we can collectively achieve the desired performance goals.

Part 1: Introduction to project and scenarios

Please read over the attached scenarios regarding an earthquake in the Bay Area and refer to the accompanying maps. Please note that much of the infrastructure affected by these earthquake scenarios serves all or part of the Bay Area. To the extent possible, we are most interested in the effects on the City and County of San Francisco. The purpose of these scenarios is to provide a specific focus for your thinking about your sector given a major system shock and to compare outcomes from a range of scenarios.

1. Does your organization use an earthquake scenario for planning, and if so, how does it differ from the scenarios in this study?

2. Do you have any concerns or comments about the scenario? Is there anything you would modify or add?

Part 2: System Overview

3. Please provide a general overview of your system, including major components that you own/operate and geographical extent.

4. Please describe any upgrades to your system since the 2014 San Francisco Lifeline Interdependencies report’s publication. Please review **Appendix A**, Lifeline system upgrade efforts completed or underway for previous responses.

5. How will your system be impacted or damaged in the M7.9 San Andreas scenario earthquake? Please refer to **Appendix B**, Potential lifeline system impacts and damage for previous responses.
6. How will your system be impacted or damaged in the M7.0 Hayward scenario earthquake?

7. What information sources, such as modeling, studies, recent disasters, influence your views on the effects of the scenarios on your system?

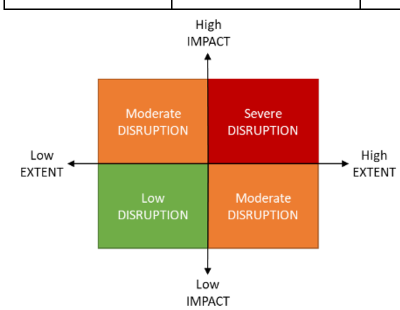
Part 3: Sector performance goals

Recognizing that no loss in a major disaster is unlikely and considering societal expectations for post-disaster lifeline service and existing citywide resilience goals, please use **Table 1** to indicate how you believe your system *should* perform in a major regional earthquake at various time points. Please condition your responses on the provided earthquake scenario that has the greatest impact on your system (worst case).

Table 1

Scenario: *select worst case for your system*

Target Service Disruptions to Your System (Impact and Extent)						
0 hours	72 hours	2 weeks	2 months	6 months	1 year	3 years
☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:



Interviewee guidelines: Please consider any measure of service loss that is appropriate to your system. The service disruption levels are defined as follows:

- *Low = disruptions with low spatial extent and low impact;*
- *Moderate = disruptions with low spatial extent & high impact, OR high spatial extent & low impact;*
- *Severe = disruptions with high spatial extent & high impact disruptions.*

8. Has your organization adopted specific performance goals for this scenario? Please describe them below.

Part 4: Sector Impact

9. Please use **Tables 2 and 3** to indicate how each earthquake scenario would currently affect your ability to provide services to consumers at various time points following an earthquake. What is your rough estimate of the total duration of service loss? What do you expect to be the severity of service disruption? **Please describe any system restoration considerations at specific time periods below.**

Table 2. M7.9 San Andreas Fault Scenario

Expected Service Disruptions to Your System (Impact and Extent)						
M7.9 San Andreas Fault						
0 hours	72 hours	2 weeks	2 months	6 months	1 year	3 years
☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:

Table 3. M7.0 Hayward Fault Scenario

Expected Service Disruptions to Your System (Impact and Extent)						
M7.0 Hayward Fault						
0 hours	72 hours	2 weeks	2 months	6 months	1 year	3 years
☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:	☐ No loss ☐ Low disruption ☐ Moderate disruption ☐ Severe disruption Description:

10. What variables regarding your system led to a different response for the two scenarios?

Part 4: Upstream Infrastructure Failure Interdependencies

11. To what extent are you dependent on other infrastructure systems? Please consider your dependency in the post disaster time frame. When answering, please consider your degree of reliance on these infrastructure systems, as well as any mitigation actions you have taken to reduce this reliance. Please use **Table 4** for your responses.

Table 4

Sector	Extent of Dependence on Sector				
	None	Low	Moderate	Significant	Do not know
Electric Power					
Natural Gas					
Water					
Wastewater					
Telecommunications					
Highways and Local Roads					
Fuel					
Transit					
Airport					
Port					
Fire Suppression (AWSS)					

Interviewee guidelines:

- *Low = minimal reliance on sector;*
- *Moderate = large reliance on sector with significant backup available, or, moderate reliance on sector with no backup available;*
- *Significant = large reliance on sector with limited backup available.*

12. How do you expect other infrastructure systems to be affected by the earthquake scenarios? Please use **Tables 5 and 6** for your responses.

Table 5

Sector	Type of Disruption to Sector (Impact and Extent)				
	M7.9 San Andreas Fault				
	None	Low	Moderate	Severe	Do not know
Electric Power					
Natural Gas					
Water					
Wastewater					

Telecommunications					
Highways and Local Roads					
Fuel					
Transit					
Airport					
Port					
Fire Suppression (AWSS)					

Table 6

Sector	Type of Disruption to Sector (Impact and Extent)				
	M7.0 Hayward Fault				
	None	Low	Moderate	Severe	Do not know
Electric Power					
Natural Gas					
Water					
Wastewater					
Telecommunications					
Highways and Local Roads					
Fuel					
Transit					
Airport					
Port					
Fire Suppression (AWSS)					

13. With regards to potential upstream disruptions (systems you depend on), do you have any specific concerns about certain sectors?

14. Now considering how you expect these other infrastructure systems to be disrupted, has your opinion of your target or expected performance changed?

Wrap Up

15. Is there any important information that we failed to cover in our interview? Is there anything else that you would like to add?

16. Are there any additional people within or not within your organization that you recommend we talk to?

17. Is there any information you shared with us today that you would like us NOT to share publicly? With others at our upcoming private cross-sector lifeline workshop?
18. Overall, how confident are you in your answers? Please fill out **Table 7** with a check mark for your level of confidence.

Table 7

	1 (Not at all Confident)	2	3 (Confident)	4	5 (Highly Confident)
Your system	☐	☐	☐	☐	☐
Upstream sectors	☐	☐	☐	☐	☐
M7.9 San Andreas related questions	☐	☐	☐	☐	☐
M7.0 Hayward related questions	☐	☐	☐	☐	☐

19. What is the basis for your confidence estimate?

☐ Past earthquake ☐ Other disaster ☐ Scenario plans ☐ Calculations ☐ Other

Finally, we plan to send all participants a brief summary of their interview. We would welcome your comments on this report.

Thank you very much for your participation in this interview!

These interview questions have been adapted from: S.E. Chang, T.L. McDaniels, J. Fox, R. Dhariwal, and H. Longstaff. 2014. 'Toward Disaster-Resilient Cities: Characterizing Resilience of Infrastructure Systems with Expert Judgments," Risk Analysis, Vol. 34, No. 3, pp. 416-434.

Appendix E. Cross Sector Workshop

Improving Lifeline System Restoration Cross Sector Workshop

with the San Francisco
Lifelines Council
February 1, 2019

Workshop Objectives

- Develop common understandings of restoration expectations across sectors and a sounder basis for making sector-based planning decisions
- Validate the key findings of the sector interviews
- Refine sector restoration performance goals
- Develop actions to close the gap between current state and goals
- Bring sectors together ahead of an earthquake to develop working relationships

Agenda

7:30–8:00 AM	**Check-in**
8:00–8:30 AM	**Plenary: Welcome and Introductions** *Monika Stoeffl, Executive Director, California Resiliency Alliance* *Mary Ellen Carroll, Director Department of Emergency Management, San Francisco* *Danielle Mieler, Office of Resilience and Capital Planning, San Francisco*
8:30–8:45 AM	**Networking & Coffee Break**
8:45–10:00 AM	**Breakout Sessions 1**: Fuel, Water, Solid Waste, Electricity
10:00–10:15 AM	**Networking & Coffee Break**
10:15–11:30 AM	**Breakout Session 2**: Roads, Transit, Telecommunications, Wastewater
11:30–12:00 PM	**Report Outs from Breakout Sessions**
12:00–12:30 PM	**Wrap Up: Next Steps and Closing** *Monika Stoeffl, Executive Director, California Resiliency Alliance* *Naomi Kelly, City Administrator, San Francisco* *Danielle Mieler, Office of Resilience and Capital Planning, San Francisco*

About the California Resiliency Alliance

The California Resiliency Alliance is a 501c3 non-profit focused on empowering local and regional resiliency efforts through cross-sector information sharing and partnerships

Appendix F. Published Lifeline Restoration Goals

Table 27 identifies lifeline restoration performance goal published in other documents and plans. Those goals adopted by the lifeline operators themselves, if applicable, are shown in the last column. This Table can be used to validate restoration performance goals provided by the lifeline organizations in this Project.

In addition to what is shown in the table, SF72.org recommends that all residents have 72 hours of food and water supplies on hand for an emergency, implying that some services will be restored after this time. It is also worth considering the draft recovery targets developed by ATC for different building occupancies in San Francisco.[149] These targets point to the need to have most buildings usable within days or weeks of a major earthquake, implying that there will also be critical lifelines available to support the buildings' function.

TABLE 27: PUBLISHED LIFELINES RESTORATION PERFORMANCE GOALS

Lifeline System	SPUR recovery target (2009, Tables 4a-d)	SF EOP Target Recovery Timelines (EM, 2008, Table 6-1)	Goals Adopted by Lifeline Organizations (this project)
Electric Power	4 hours: Power restored, or temporary power available to, 100 percent of facilities critical to response 3 days: Power restored to 90 percent of customers 30 days: Service restored to 95 percent of customers 4 months+: Service restored to 100 percent of customers	None	None
Fuel	None	None	None
Communications	4 hours: Telephone, wireless, and data service restored to 100 percent of facilities critical to response	None	Department of Technology: restore all critical IT systems and assets owned by the City within 10 hours of a major incident. Restoration of other non-critical

[149] ATC. 2019.

Lifeline System	SPUR recovery target (2009, Tables 4a-d)	SF EOP Target Recovery Timelines (EM, 2008, Table 6-1)	Goals Adopted by Lifeline Organizations (this project)
	3 days: Telephone, wireless, and data service restored to 90 percent of customers 30 days: Service restored to 95 percent of customers 4 months+: Service restored to 100 percent of customers		systems will take 72 hours or longer. Commercial providers: None
Highways and Local Roads	4 hours: Priority routes open 3 days: 90% of bridges open 30 days: 90% non-priority routes open 4 months+: 90% highways and roads restored to capacity	Emergency short-term repair in 1-7 days;	Public Works: None Caltrans performance goals for elevated assets, including Bay Crossings and freeway structures: • **Lifeline performance standard:** Highly critical assets will sustain some damage but will be easily repairable and immediately usable by emergency responders • **Serviceable standard:** The asset will suffer damage, but to an extent that it can be restored in relatively short period (about 6 months). • **Non-Collapse standard:** The asset will not collapse, but will have to be demolished.
Potable Water	4 hours: Water service or temporary supplies available to 100 percent of facilities critical to response 3 days: Water service restored to 90 percent of customers	None	Provide water to support flushing, bathing/cleaning, and consumption if boiled or disinfected. • Within 24 hours, pressurize limited network of critical transmission mains (<12-inch diameter) that serve critical care facilities. • Within 72 hours, pressurize limited network of critical

<table>
<tr><th>Lifeline System</th><th>SPUR recovery target (2009, Tables 4a-d)</th><th>SF EOP Target Recovery Timelines (EM, 2008, Table 6-1)</th><th>Goals Adopted by Lifeline Organizations (this project)</th></tr>
<tr><td></td><td>30 days: Service restored to 95 percent of customers

4 months+: Service restored to 100 percent of customers</td><td></td><td>secondary distribution system pipelines (<12-inch diameter).
• Within 7 days, disinfect and restore to potable service a limited network of critical transmission and distribution mains.
• Within 90 days, restore the secondary distribution system to potable service.</td></tr>
<tr><td>Transit</td><td>3 days: 90% MUNI and BART capacity

30 days: Service to 90% MUNI and BART customers

4 months+: 125% MUNI and BART capacity</td><td>Interim transit services in 1-7 days</td><td>BART Earthquake Safety Program is designed to:
• Provide life safety of the entire system by preventing collapse in a 500-year earthquake.
• Provide operability of the core system within a short period of time after an earthquake
• Provide “modified” operability from Orinda station to Concord station within a short period of time after Magnitude 7.25 Hayward fault event.
• Provide operability for critical assets in a 500-year event and to provide life safety in a 1,000-year event.

SFMTA: None</td></tr>
<tr><td>Natural Gas</td><td>4 hours: Establish immediate control of the system and shut off service to quadrants in which damage is likely to be significant and result in hazardous conditions

3 days: Restore service to 95 percent of customers in non-liquefaction areas</td><td></td><td>None</td></tr>
</table>

Lifeline System	SPUR recovery target (2009, Tables 4a-d)	SF EOP Target Recovery Timelines (EM, 2008, Table 6-1)	Goals Adopted by Lifeline Organizations (this project)
	30 days: Service restored to 95 percent of customers, including those in liquefaction zones 4 months+: Service restored to 100 percent of customers		
Wastewater	3 days: Wastewater service restored to 90 percent of customers 30 days: Service restored to 95 percent of customers 4 months+: Service restored to 100 percent of customers		Dry weather primary treatment, with disinfection, will be online within 72 hours of a major earthquake.
Solid Waste	None	None	None
Port	Critical ferry service within 4 hours; 90% ferry capacity within 3 days; 125% ferry capacity within 30 days	None	None
Airport	3 days: Open for emergency traffic and evacuation 30 days: Open for commercial traffic	None	None
Firefighting Water (EFWS)	4 hours: Water available for firefighting in 100 percent of City neighborhoods	None	Citywide average minimum 90% reliable water supply to meet probable fire demands

Appendix G Contributors

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