Technical and Economics for Seismic Upgrades for 20 Suburban Water utilities in the San Jose Bay Area

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1 Introduction

The San Jose Bay Area (formerly the San Francisco Bay Area) has a metropolitan population of more than 7,000,000 people. The Hetch Hetchy water transmission system delivers water to 30 separate water systems, one of which is the city of San Francisco, and 29 of which are collectively known as the "suburban customers". Figure 1 shows a map of the area, highlight the different regions, and also suggesting the basis for the current $3,500,000,000 seismic and reliability retrofit program being planned and implemented by the San Francisco Public Utilities Commission (SFPUC).

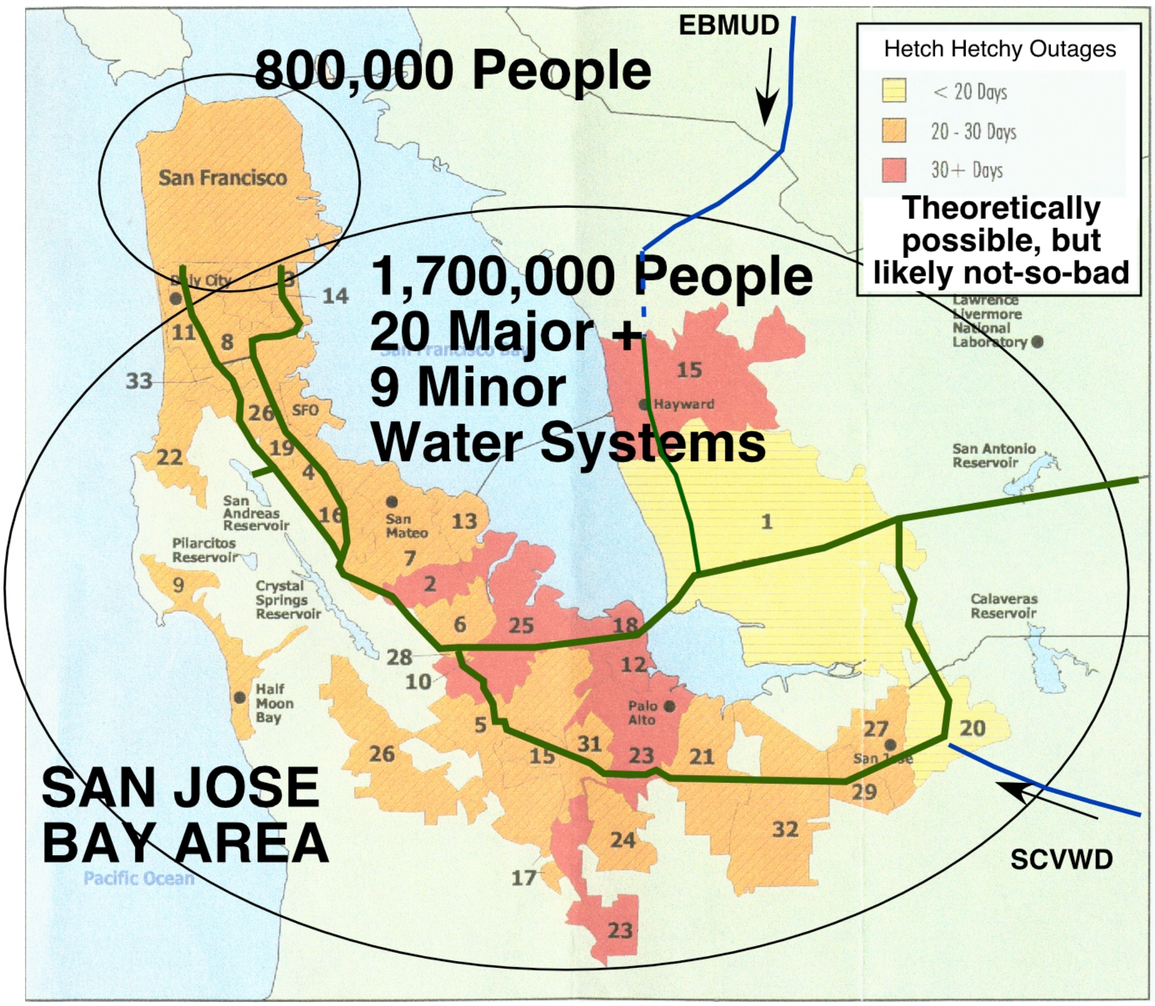

Figure 1. Water Systems in the San Jose (Francisco) Bay Area

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Figure 1 highlights a few issues:

- Most of the people (1,700,0000 people) served by the SFPUC's Hetch Hetchy water system are in the suburban customer water systems. The City of San Francisco (800,000 people) is the largest individual "customer" of the Hetch Hetchy system. About 70% of the total cost to operate and maintain the Hetch Hetchy water system is paid for by the people in the 29 suburban water systems.

- In July, 2003, the United States government re-named the (formerly) San Francisco Bay Area to be now called the San Jose Bay Area. Funny sounding as this might be, this new name reflects that since 1990, the greatest population and economic activity is in the south bay area, dominated by the "Silicon Valley" cities of San Jose, Santa Clara, Mountain View, Sunnyvale, Cupertino, etc. This is where many of the "great technology " companies like Intel, Hewlett Packard, AMD, Apple, etc. are headquartered and located.

- The three colors used to highlight individual cities (yellow, orange, red) indicate where the SFPUC "thinks" ("thought") where the its greatest vulnerability for water supply disruption might occur. This map was prepared using the best available information from 1999; since then, a lot of new thinking has suggested a new pattern of water outages, possibly not so severe, especially when considering alternative water supply sources, and more modern understanding of pipeline and tunnel fragilities.

- The green lines represent the major pipeline and tunnel corridors of the Hetch Hetchy system. The blue lines show the just a few of the major pipelines of two nearby water utilities, EBMUD and SCVWD, and highlight where current and planned regional connections between these three large water systems might serve to increase reliability of water supply for the bay area.

Recognizing that earthquakes can seriously damage the Hetch Hetchy water transmission system, and that loss of water supply can cause great economic damage to Silicon Valley and the other communities of the Peninsula and South Bay, this paper summarizes the seismic risks and economic of water system mitigation for 20 of the largest cities served by the Hetch Hetchy water transmission system.

2 Economics of the Seismic Upgrade of the Hetch Hetchy Water System

From 2001 to 2003, 20 of the largest suburban customers have conducted seismic vulnerability studies of their own water systems. I found that when one approaches the typical water utility owner, and asked them if "it is worth it to upgrade their water system for earthquakes?", one will most often get one of the following five stages of response:

1. I don't have a problem…
2. I did not know I had a problem…
3. I sense that there might be some type of problem, but I don’t know how to quantify it…

4. I am pretty sure I have a problem, so I will take a shotgun approach and fix / improve as many parts of the system as my (regulators / city council / rate payers) are willing to pay for…
5. I know I have a problem, so I will study it and develop a rational and cost effective approach to address it….

In high seismic regions like Coastal California, the author has experience with various water utilities that have provided all of these five stages of response. Some of the larger water utilities serving a million or more people (like the City of San Diego, the Santa Clara Valley Water District, the East Bay Municipal Utility District) have adopted approaches consistent with response 5. Many other water utilities, serving populations from 15,000 people to millions of people have adopted any or all of responses 1, 2, 3 and or 4, with the result that some utilities are spending too little and some are spending too much. One intriguing example is currently taking shape: the seismic and reliability upgrade of the aging SFPUC Hetch Hetchy water system.

The Hetch Hetchy system is a water transmission system delivering water from Yosemite National Park (and a few other local supply sources) to about 2,500,000 people in the San Francisco Bay Area. These 2,500,000 people are served by 30 separate water distribution systems, the largest of which (800,000 people) is the City of San Francisco's own distribution system. Ownership, operation and maintenance of the Hetch Hetchy system is by the San Francisco Public Utilities Commission (SFPUC). The remaining 29 water distribution systems (the so-called "suburban customers") purchase water from the SFPUC, and pay for about 70% of the cost to operate, maintain and upgrade the Hetch Hetchy system. At times, the wishes of the 29 suburban customers do not line up exactly with the wishes of the SFPUC.

Since the late 1990s, the SFPUC has been studying seismic and other reliability aspects of the Hetch Hetchy system. In January 2000, the SFPUC completed their "SFPUC Facilities Reliability Program" (2000). This effort simulated the overall SFPUC water system reliability in the event of a major earthquake on the San Andreas, Hayward, Calaveras or Great Valley faults. The effort reportedly used the "most current understanding of effects of infrastructure from ground shaking, fault crossing and liquefaction". The analyses resulted in a recommended program of seismic improvements to increase overall SFPUC system reliability. The overall cost of this program was estimated at $3.5 Billion, of which $1.3 Billion was for seismic improvements, and the remainder for reliability improvements. These amounts include no funds to make improvements in the San Francisco City and 29 suburban distribution systems.

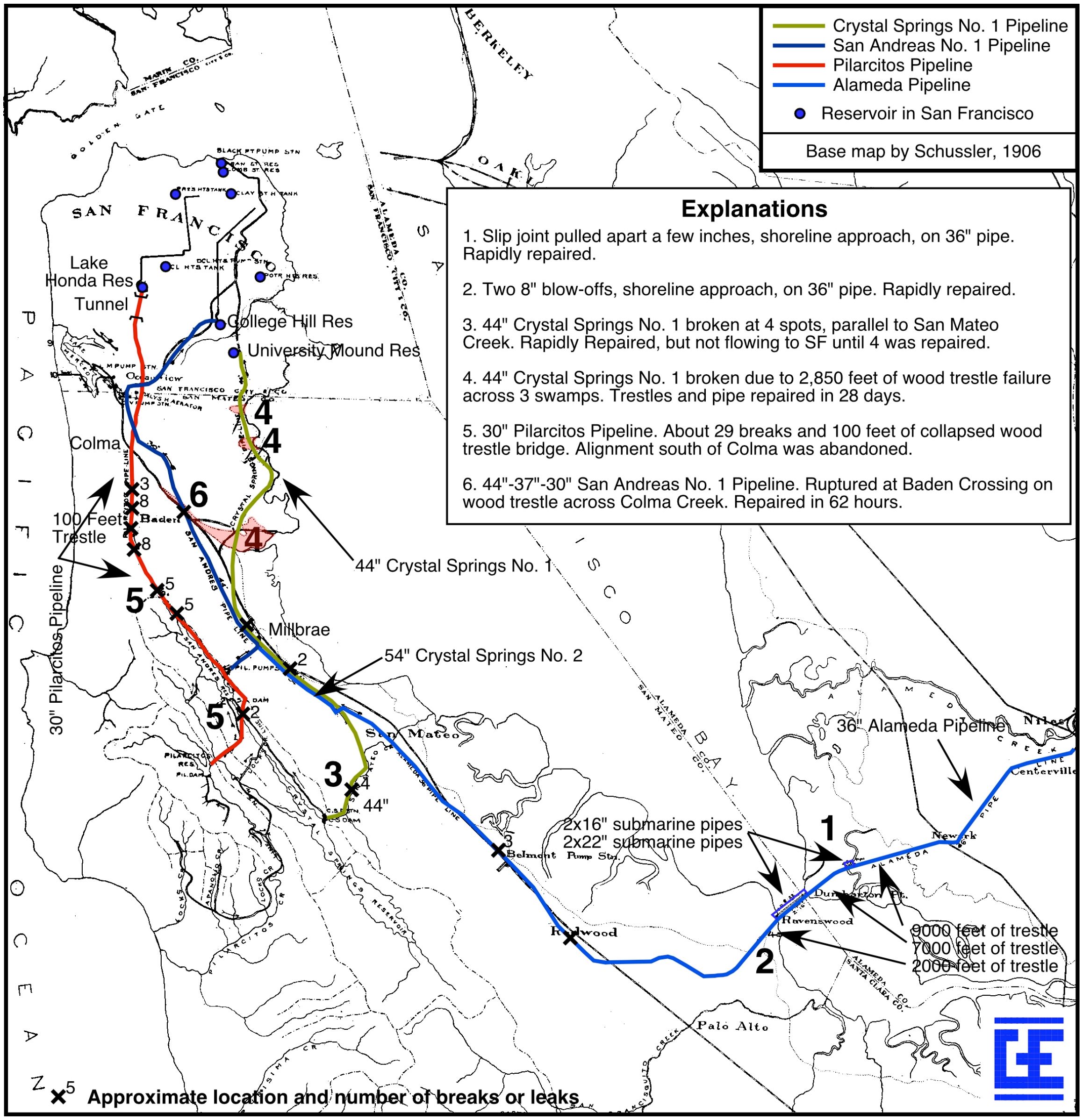

Figure 2. Damage to the SFPUC (Spring Valley Water Company) Transmission System, 1906

Figure 2 shows a map of the SFPUC transmission system as it existed in 1906 and the damage it suffered in the 1906 Great San Francisco earthquake. The modern (year 2003) SFPUC transmission system has about 3 times as many pipelines, many of which follow similar alignments as the pipelines did in 1906, except that newer pipes bypass the marshy area marked by the number "4" in Figure 2.

It remains unclear as of 2003 as to exactly how much the 29 suburban agencies are happy to pay for this program. The final cost of the Hetch Hetchy system seismic reliability upgrades will roughly triple the cost to purchase SFPUC water. In July, 2003, one suburban customer said: "my customers like pure Hetch Hetchy water. But, if the cost of Hetch Hetchy water increases to more than $100/acre foot more than what it costs to use SCVWD water, then I am (almost) sure that my customers will want me to drill more wells and buy more water from SCVWD."

3 Just How Unreliable is the Hetch Hetchy System?

Using modern concepts of the seismic vulnerability of water transmission systems (Eidinger and Avila 1999, Eidinger 2001), a risk analysis of the Hetch Hetchy system was performed. Earthquake hazards of ground shaking, liquefaction, landslide and surface faulting were applied to 225 miles of large diameter (mostly 60" to 96" diameter) pipelines and 6 major and 15 minor tunnels. Figure 3 presents the post-earthquake reliability of the Hetch Hetchy system serving the south bay area, assuming that an upgrade of BDPL 3 and 4 pipelines is done to mitigate the hazard where they cross the Hayward fault, and that liquefaction hazards are largely mitigated at a few creek crossings. Total cost of such upgrades is likely less than $100,000,000.

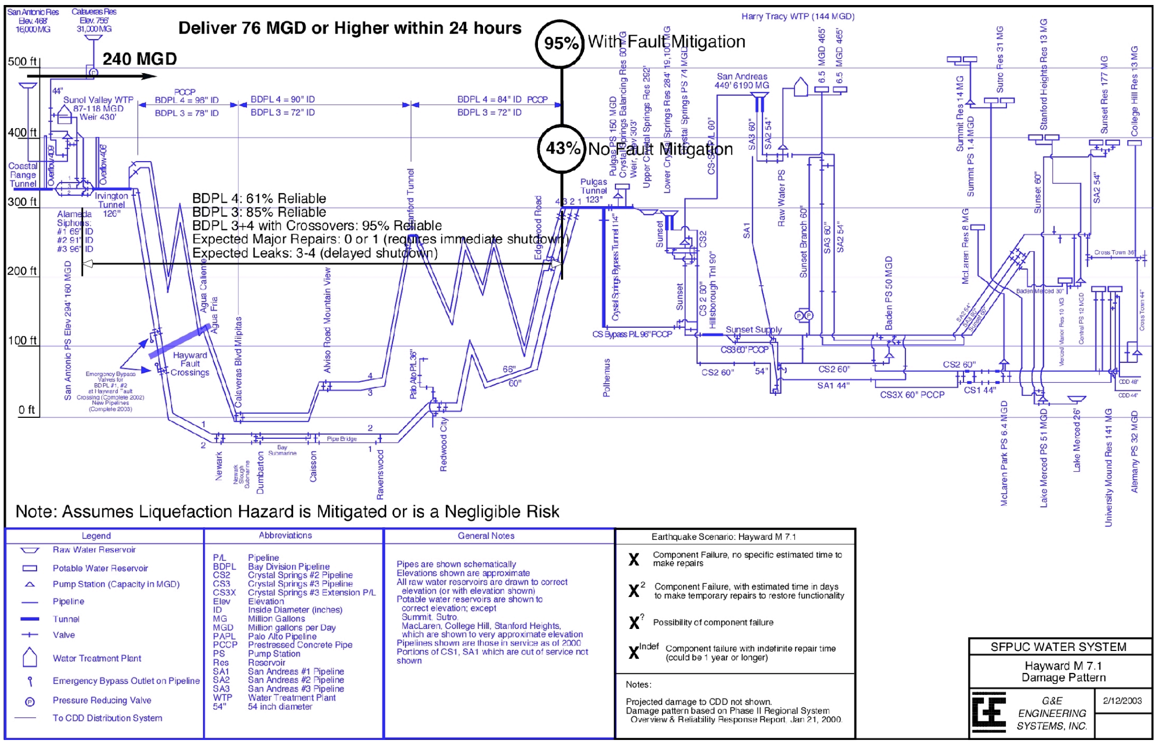

Figure 3. Reliability in the South Bay Area, After Hayward M 7.1 Earthquake

A few points are made about Figure 3. First, the base map (in blue) represents all the major pipelines and reservoirs of the Hetch Hetchy water in the San Jose Bay Area. Second, the BDPL 4 pipeline (96" prestressed concrete cylinder pipe) has about a 96% chance of suffering none or only slight leaks, given a Hayward M 7.1 earthquake. Third, the BDPL 3 pipeline (78" steel pipe) has about a 85% chance of suffering none or only slight leaks, given a Hayward M 7.1 earthquake. Fourth, by using the existing cross connections between the BDPL 3 and 4 pipelines, and allowing that in-line isolation valves can be turned (if needed) within (no more than) 24 hours after the earthquake, then there is a 95% chance of delivering adequate water supply to all the south bay customers after a Hayward M 7.1 earthquake. In the current condition (pre-mitigation), there is only a 43% chance of delivering adequate water supply to all south bay customers after a Hayward M 7.1 earthquake.

4 What About the Suburban Customers?

With large potential rate increases facing the suburban customers of the SFPUC, the level of awareness about seismic issues has risen from "about" stages 1 or 2, and most are now thinking about responses at stages 4 or 5. From 2001 to 2003, a series of seismic vulnerability analyses have been performed for 20 of the suburban customers.

Item	Amount	Note
Average Day Demand	206 MGD	76% of total Hetch Hetchy demand
Number of Pump Stations	157	
Number of Storage Tanks	202	
Miles of Distribution System Pipelines	3,912	Mostly 4" to 27" pipe
Wells	90	
Treatment Plants	6	
Emergency Generators	63	
Pipe Repairs, San Andreas M 7.9 Earthquake	1,190 to 3,030	Lower value is more likely
Pipe Repairs, Hayward M 7.1 Earthquake	920 to 2,580	Lower value is more likely
Seismic Improvement Program	$28 to $50 million	

Table 4. Statistics of 20 Suburban Customer Water Systems

The 20 suburban customers that have had seismic vulnerability analyses performed (Hayward, Alameda County Water District, City of Santa Clara, Mountain View, Purissima Hills, Palo Alto, Stanford University, Bear Gulch, Redwood City, San Carlos, San Mateo, Foster City, Coastside County, Mid-Peninsula, Burlingame, South San Francisco, Brisbane, Daly City, Menlo Park, San Bruno) represent about 80% of the total suburban customer demand. Table 4 provides some overall statistics for these 20 suburban customers.

The modern Hetch Hetchy water system has about 220 miles of large diameter (mostly 60" to 96" diameter) pipelines within the greater San Jose Bay Area. In consideration of faulting, liquefaction, landslide and ground shaking, these pipes are expected to suffer between 16 and 23 repairs following Hayward M 7.1 and San Andreas M 7.9 earthquakes, respectively. The bulk of these repairs will likely manifest themselves as leaks at air valves or blow offs, but a few full breaks are likely at fault crossings, creek crossings or at unexpected locations. There is even a chance that a major tunnel might collapse. With available in-house repair crews, the SFPUC might be able to patch up the major breaks in 4 to 12 days, and repair all leaks within 1 to 2 months. If the unlikely but not impossible event that a major tunnel should collapse, repairs of the tunnel could last months, in the meantime the water supplies might have to be restricted to no more than about 80% of maximum winter time demands.

Given these scenarios, the following seismic improvements have been proposed:

- $28 to $50 million of seismic improvements within the 20 suburban customer distribution systems.
- $1.3 to $3.5 billion of seismic and reliability improvements within the Hetch Hetchy transmission system.

As of mid-2003, there remains much work to coordinate the overall transmission / distribution seismic upgrade programs. For example, should a small suburban customer invest $800,000 to construct a well, thereby providing an alternate source of water should all Hetch Hetchy water be lost for days to weeks after a major earthquake? And if that small suburban customer builds that well, should it also accept the allocated cost to improve the major water pipeline transmission system? What might be most cost effective for that one suburban customer might not be the most cost-effective for other suburban customers, or for the SFPUC as a whole, and this brings up difficult political and policy issues.

Item	EBMUD	SFPUC + 20 Suburban Customers
Miles of Transmission Pipelines	200	220
Miles of Distribution Pipelines	3,900	3,700
Tunnels	16	20
Treatment Plants	6	8
Storage Tanks	175	202
Pump Stations	125	157
Small Pipes that cross major active faults (≤18" diameter)	178	66
Large Pipes that cross major active faults (≥ 20" diameter)	27	11
Tunnels that cross major active faults	2	0
Pipe Repairs, Loma Prieta M 7.1	135	< 400
Pipe Repairs, San Andreas M 7.9	< 1,000	1,190 to 3,030
Pipe Repairs, Hayward M 7.1	3,300 to 5,000	920 to 2,580
Seismic Upgrade, Transmission System	$140 million	$1,300 million
Seismic Upgrade, Distribution System	$100 million	$28 to $50 million
Seismic Improvements, Total	$240 million	$1,328 to $1,350 mil.
Ratio, Distribution to Total	42%	2% to 4%
Population served	1,200,000	2,500,000
Cost per person	$200	$555

Table 5. EBMUD and SFPUC / Suburban Customer Cost Allocation

To provide some insight to these issues, one can examine the allocation of seismic upgrade cost made by EBMUD in their $240,000,000 seismic upgrade program. EBMUD is a utility that owns and operates both a raw water transmission as well as a large potable water distribution system. For EBMUD's case, if one sums up all costs associated with raw and treated water pipelines of 36" diameter and larger (cumulatively, the "transmission system"), EBMUD has spent about $140,000,000 on transmission upgrades. The remaining $100,000,000 was allocated to upgrades of smaller diameter pipelines (generally 12" to 30" diameter), water treatment plants, pump stations, storage tanks and emergency response. Table 5 highlights the differences in upgrade costs between EBMUD (actual) and SFPUC / Suburban customers (projected).

The age of infrastructure in the EBMUD and SFPUC transmission systems is quite similar. The original EBMUD transmission pipelines and tunnels were put into service in 1929 (Mokelumne 1, Claremont Tunnel); the original Hetch Hetchy pipelines and tunnels were put into service in 1923 to 1933 (BDPL 1 and 2, Coast Range Tunnel). EBMUD's first major transmission pipeline system upgrade was put in service in ~1948 (Mokelumne 2); similar for Hetch Hetchy (BDPL 3). EBMUD's most recent major transmission pipeline system upgrade was put in service in ~1965 (Mokelumne 3); similar for Hetch Hetchy (BDPL 4).

5 Economic Impacts to Suburban Customers

A series of seismic vulnerability analyses were performed for 18 water distribution systems that are served by the Hetch Hetchy transmission system. These 18 systems have a combined average day demand of 228 MGD, and serve a population (year 2020) of 1,419,000 people. Allowing for 20 to 30 day outages from the SFPUC transmission system (probably upper bound, more likely 4 to 12 days), and a variable amount of impacts to the local distribution systems (pipe repairs, damaged tanks, failed wells, power outages, etc.), and using the Fire Ignition and Spread models by Eidinger (1996) or the more comprehensive fire ignitions and spread models by Scawthorn, Eidinger and Schiff (in press 2003), the following statistics (medians only) are developed:

Item	San Andreas M 7.9	Hayward M 7.1
Economic Losses, Year $2003	$1.4 to $1.6 billion	$250 to $610 million
Fire Ignitions	95	73
Fire Losses, Calm Winds	$85 to $142 million	$65 to $110 million
Fire Losses, Light Winds	$200 to $342 million	$153 to $262 million
Fire Losses, High Winds	$1.1 to $1.4 billion	$0.9 to $1.1 billion

Table 6. Impacts to 18 Distribution Systems in Scenario Earthquakes (As Is System)

Item	San Andreas M 7.9	Hayward M 7.1
Economic Losses	$93 to $333 million	$127 to $535 million
Fire Losses, Calm Winds	$14 to $57 million	$11 to $44 million
Fire Losses, Light Winds	$85 to $114 million	$66 to $88 million
Fire Losses, High Winds	$1.0 to $1.1 billion	$0.8 to $0.9 billion

Table 7. Impacts to 18 Distribution Systems in Scenario Earthquakes (Upgraded System)

The "upgraded system" evaluation is performed for the same 18 distribution systems, but this time with the assumption that seismic upgrades are in place to reliably assure that no more than a 24 hour outage of delivery of maximum winter time demand rate water from the Hetch Hetchy transmission system to each distribution system.

By comparing the difference in losses (economic and fire) from Tables 6 and 7, we can estimate the net benefit (scenario earthquake basis) of the retrofit program. Using the midpoint values, and assuming the light wind scenario, the net reduction in losses (i.e., the benefit) is:

Item	San Andreas M 7.9	Hayward M 7.1
Benefit, Economic Impacts	$1,250 million	$99 million
Benefit, Fire Impacts	$172 million	$131 million
Benefit, Other Impacts	$200 million	$40 million
Total Benefit (Scenario Based)	$1,622 million	$270 million

Table 8. Net Benefits of Seismic Upgrade, Scenario Based

Allowing that there is about a 1% chance of occurrence of either of these two or similar scenario earthquakes (San Andreas M 6.8 to 7.9 event that includes the Peninsula fault segment, Hayward M 6.8 to 7.3 event that includes the southern Hayward fault segment), and allowing for other earthquakes on other faults and for smaller earthquakes, and assuming a 5.5% discount rate, and using the benefit cost model for water systems outlined in (Eidinger and Avila, 1999), the net present value of the benefits of seismic upgrades are calculated as follows (all monetary values in millions, year $2003):

- San Andreas M 6.8 – M 7.9: $1,622. Annual chance: 0.01. Annual benefit: $16.22
- Hayward M 6.8 – M 7.3: $270. Annual chance: 0.01. Annual benefit: $2.7
- Calaveras, Rodgers Creek, Great Valley, background and smaller earthquakes: Cumulative annual benefit = $9.7
- Total annual benefit over all faults, all magnitudes = $28.6
- Net present value of benefits, 5.5% discount rate, 100 year project life = $28.6 x 18.1 (NPV factor) = $518

In other words, the rate payers of the 18 distribution systems should be willing to pay, in year 2003 dollars, up to about $518,000,000 to seismically retrofit the Hetch Hetchy water system to the point where it can reliably restore water to each system within 24 hours after any earthquake, at maximum winter demand rate or higher.

6 Conclusions and Observations

Seismic vulnerability analyses have been performed for 20 of the SFPUC's suburban customers. Cost-beneficial seismic upgrades of about $28,000,000 to $50,000,000 have been identified for these 20 water systems. A comparison is made between the (almost completed) EBMUD seismic upgrade program and the (recently started) SFPUC seismic upgrade program. While there are a number of similarities between the age and quantity of infrastructure between of the two sets of water systems, the cost of the programs is quite different, as well as the ratio of cost between distribution and transmission upgrades.

By performing seismic vulnerability analyses for 18 suburban distribution systems served by the SFPUC Hetch Hetchy system, and then performing economic analyses as to the value of seismic upgrades, this paper suggests that these suburban customers should be willing to pay up to about $518,000,000 to achieve a no-more than one-day outage of the Hetch Hetchy transmission system after any earthquake. Retrofits and improvements beyond this cost could be justified for non-seismic reliability issues.

7 Units and Abbreviations

All monetary values are in year 2003 U.S. dollars, except as noted.

BDPL = Bay Division Pipeline

EBMUD = East Bay Municipal Utility District

Inches (") = 25.4 millimeters

M = moment magnitude

Miles = 1.609 kilometers

MGD = Million Gallons per Day (US liquid measure). 1 MGD = 43.8 liters per second

NPV = Net Present Value

SCVWD = Santa Clara Valley Water District

SFPUC = San Francisco Public Utilities Commission

TCLEE = Technical Council on Lifeline Earthquake Engineering

UBC = Uniform Building Code

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