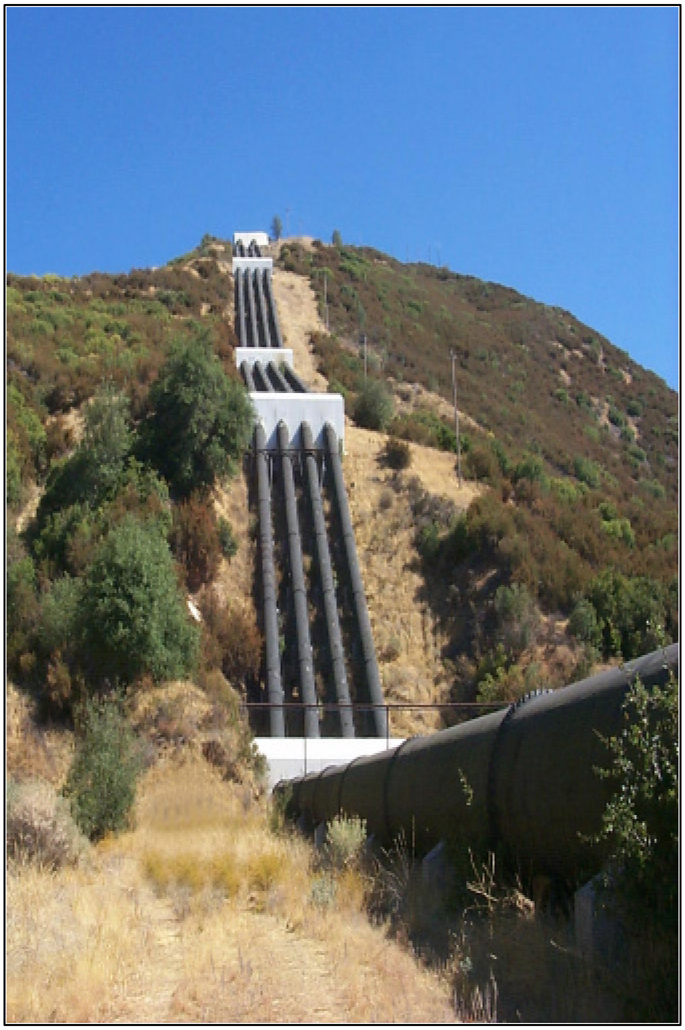

Hetch Hetchy Water and the Bay Area Economy

Bay Area Economic Forum

A Partnership of the Bay Area Council And the Association of Bay Area Governments

October 2002

BAY AREA COUNCIL

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FOREWORD

This report is an economic scenario analysis, and estimates the probable effects on the Bay Area economy of a major failure of the San Francisco Public Utility Commission's Hetch Hetchy water system, a key regional asset serving 2.4 Bay Area million residents and businesses in four counties. While it describes the design and operation of the Hetch Hetchy system and related issues affecting the availability of alternative supplies and regional water security, this report does not address issues concerning the system's governance or management.

This report has been prepared by the Bay Area Economic Forum as part of a continuing series of analyses of major components of the Bay Area's economic infrastructure, and of the public policy choices required to support the region's long-term competitiveness and growth. Its modeling and economic analysis were produced by Dr. David Sunding, Dr. David Zilberman, and Nicholas Brozovic of the University of California at Berkeley. Interviews and supporting research were conducted by Niels Erich. Technical and policy review was provided by members and representatives of the Bay Area Economic Forum's Board of Directors including Sunne Wright McPeak, President & CEO of the Bay Area Council, and Dr. Frederick Furlong of the Federal Reserve Bank of San Francisco.

The Bay Area Water Users Association provided a valuable regional perspective, and extensive technical review. The San Francisco Public Utilities Commission provided additional technical comments and materials. The Economic Forum is also indebted to Kevin Haroff of the law firm of Squire, Sanders & Dempsey, LLP, and Douglas Charlton of Charlton International for their insightful review and comments; and to the representatives of numerous water districts, regional organizations and private businesses who agreed to be interviewed for this report.

The Bay Area Economic Forum is a partnership of regional leaders representing business, government, universities, labor and the community, sponsored by the Bay Area Council and the Association of Bay Area Governments. A public-private partnership, the Economic Forum works to foster a dynamic and competitive economy in the Bay Area, through focused reports and analyses and by facilitating dialogue and action by regional leaders on key economic issues.

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EXECUTIVE SUMMARY

This report has been prepared as an economic scenario analysis, to determine the scale of potential costs to the Bay Area economy from a disruption of water supply from the San Francisco Public Utility Commission (referred to hereafter as the Hetch Hetchy system) in the event of a major earthquake. It concludes that the Bay Area economy is at major risk, due to the deteriorating condition and vulnerability of the Hetch Hetchy system to a major seismic event. The consequences for the region include the large scale shutdown of industries and commercial enterprises of all sizes and across a wide range of sectors, and the long-term loss of economic base due to the permanent closure or relocation of business outside the region.

The Hetch Hetchy System

San Francisco's Hetch Hetchy water system, completed in 1934, is a 167-mile, gravity-driven network of dams, reservoirs, tunnels, pump stations, aqueducts and pipelines that collects Tuolumne River runoff on federal land near the Yosemite Valley and transports it to the San Francisco Bay Area. The San Francisco Public Utilities Commission (SFPUC) manages and operates the Hetch Hetchy system. In 2000-01 SFPUC delivered nearly 260 million gallons of water per day (mgd) to retail customers in San Francisco, and to 29 wholesale buyers – cities, water districts, a public utility and other institutions – that supply communities in San Mateo, Santa Clara and Alameda Counties. Of that total amount, 85% was Hetch Hetchy water and 15% was from local sources. In all, SFPUC delivers water to a customer base of some 2.4 million people in the region.

San Francisco uses about one-third – 84 mgd – of SFPUC water. The other two-thirds – 175 mgd – is delivered to wholesale customers outside the city, represented by the Bay Area Water Users Association (BAWUA). Of the 29 BAWUA members, 18 are wholly dependent on Hetch Hetchy water, and another three are at least 75% dependent.

Business and institutional users account for 30% of water demand in the city of San Francisco (26 mgd) and 25% of demand in the BAWUA service territory (65 mgd). Key business and institutional users of SFPUC water include the computer, semiconductor, biotechnology, automotive, aerospace, electric utility, telecommunications, tourism and other sectors, plus schools and hospitals, and smaller businesses such as restaurants, glass and metal fabricators, beverage plants and food processors.

Strains to the System

The system's limited capacity, its age and its vulnerability to serious damage and service disruption in an earthquake, flood, fire or other catastrophic event, present major implications for the region's economy if not addressed. Specifically:

- Based on recent experience in droughts, SFPUC can only assure its customers a total supply of 239 mgd, and currently operates 21 mgd above that assured supply capacity. The current shortfall will grow to 64 mgd by 2030 and 71 mgd by 2050.

- Hetch-Hetchy's major dam, reservoir, pipeline, tunnel and pump station components are all at least nearly 50 years old, and many are 60-80 years old. Key structural assessments, maintenance and upgrades have been deferred for decades. Major components have no bypass capability in the event of failure.

- Hetch Hetchy crosses at least five active earthquake faults. Facilities located near these points of intersection are at risk of failure in the event of a major earthquake, an event considered likely in the next 30 years.

A failure of the Hetch Hetchy system caused by an earthquake or other catastrophic event could leave some customers without water for 10-30 days, and in some instances as long as 60 days. Alternative supplies will be limited. Many communities have only a few days of locally stored reserves in tanks and small reservoirs, most of which would be depleted within the first 48-72 hours of an emergency to meet the initial spike in demand for emergency services. Communities with groundwater wells could increase that output, but at the risk over time of excessively depleting common aquifers. The few interconnections that exist to other water systems are limited in capacity, and that water would, in most cases, require significant treatment at the industry level.

The Economic Cost

Business surveys conducted by the Bay Area Economic Forum and others indicate major impacts on manufacturing processes, output, sales, production schedules, employment and the reputation Bay Area firms enjoy as reliable suppliers to their customers. Faced with emergency and drinking water requirements for residential consumers commercial and industrial consumers will be assigned low priority for the allocation of scarce water supplies, magnifying the economic impact of a disruption. Industries that require pure or de-ionized water for rinsing, sterilizing, flushing and refrigeration would be particularly affected, due to the distinct characteristics of Hetch Hetchy water, but any commercial building drawing water from a city system reliant on SFPUC water would face closure within 2-3 days without water for drinking, fire control and sanitation.

Potential economic losses to the region from a water supply interruption total at least $28.7 billion for a major earthquake on the San Andreas Fault and $17.2 billion for a similar event on the Hayward Fault. Commercial and industrial losses alone are estimated to be at least $14.2 and $9.9 billion respectively. Residential welfare losses are estimated at $3.8 billion and $1.5 billion respectively. Incremental damage from lack of adequate water supply to suppress post-quake fires would likely total $10.7 billion and $5.8 billion respectively.

Business Losses	San Andreas Fault	Hayward Fault
Manufacturing	$4.35 billion	$3.45 billion
Wholesale/Retail	7.70 billion	5.60 billion
Professional/Scientific Technical	1.60 billion	.63 billion
Accommodations/Food Services	.54 billion	0.20 billion
Total Business Losses	**$14.2 billion**	**$9.9 billion**
Residential Losses	**$ 3.8 billion**	**$1.5 billion**
Fire Damage (water related)	**$10.7 billion**	**$5.8 billion**
TOTAL ESTIMATED LOSSES	**$28.7 billion**	**$17.2 billion**

In addition to quantifiable near-term damage, the Bay Area economy would suffer irreversible long-term damage due to the failure of many businesses to reopen because of losses incurred during a disruption, the permanent relocation of other businesses outside the region due to water security concerns, and the reluctance of new businesses to locate here for similar reasons. These permanent economic losses are difficult to estimate without more study, but would almost certainly be on a large scale.

Prevention vs. Cure

Unlike much of the region's building and transportation infrastructure, the Hetch Hetchy system has not been upgraded to current seismic standards. SFPUC has adopted a Capital Improvement Program (CIP) for the regional water system to improve flexibility and reliability – $2.9 billion for the regional system and $700 million within San Francisco, but with San Francisco paying $1.6 billion of the cost, reflecting its benefit from regional improvements. Projects would start in 2003 and, according to SFPUC, all are to be completed by 2016. Repayment of the bonds would be shared proportionately by ratepayers in the City and County of San Francisco and in BAWUA area communities. Average water rates would increase by an average 8.8% annually for suburban wholesale customers and 9.6% for residents and businesses in San Francisco through 2015 – a far lower cost, spread out over a longer time period, than the likely economic damage plus emergency system repairs in the midst of a crisis.

Future Vision

The improvements outlined in the SFPUC Capital Improvement Program are important to maintaining a reliable regional water system, irrespective of a major earthquake or future demand growth. The economic implications of an earthquake induced system failure, however, and the long lead time required for the CIP's completion, make immediate action to address these problems essential.

Beyond these immediate improvements, a broader regional discussion is required on longer-term issues relating to regional water security and the smarter use of water resources, including the blending of supplies, and improved interconnection and emergency coordination among Bay Area water systems.

The SFPUC system is a critical regional asset providing an essential service and commodity to the Bay Area economy. Its deteriorating condition places the regional economy and the welfare of millons of Bay Area residents at risk. Effecting the necessary repairs and improvements to assure Hetch Hetchy's continued reliability, and developing it as part of a larger, integrated water security strategy, is critical to the Bay Area's economic security, competitiveness and quality of life.

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1. An Engineering Marvel

The Hetch Hetchy system has accommodated Bay Area population and economic growth for nearly 70 years.

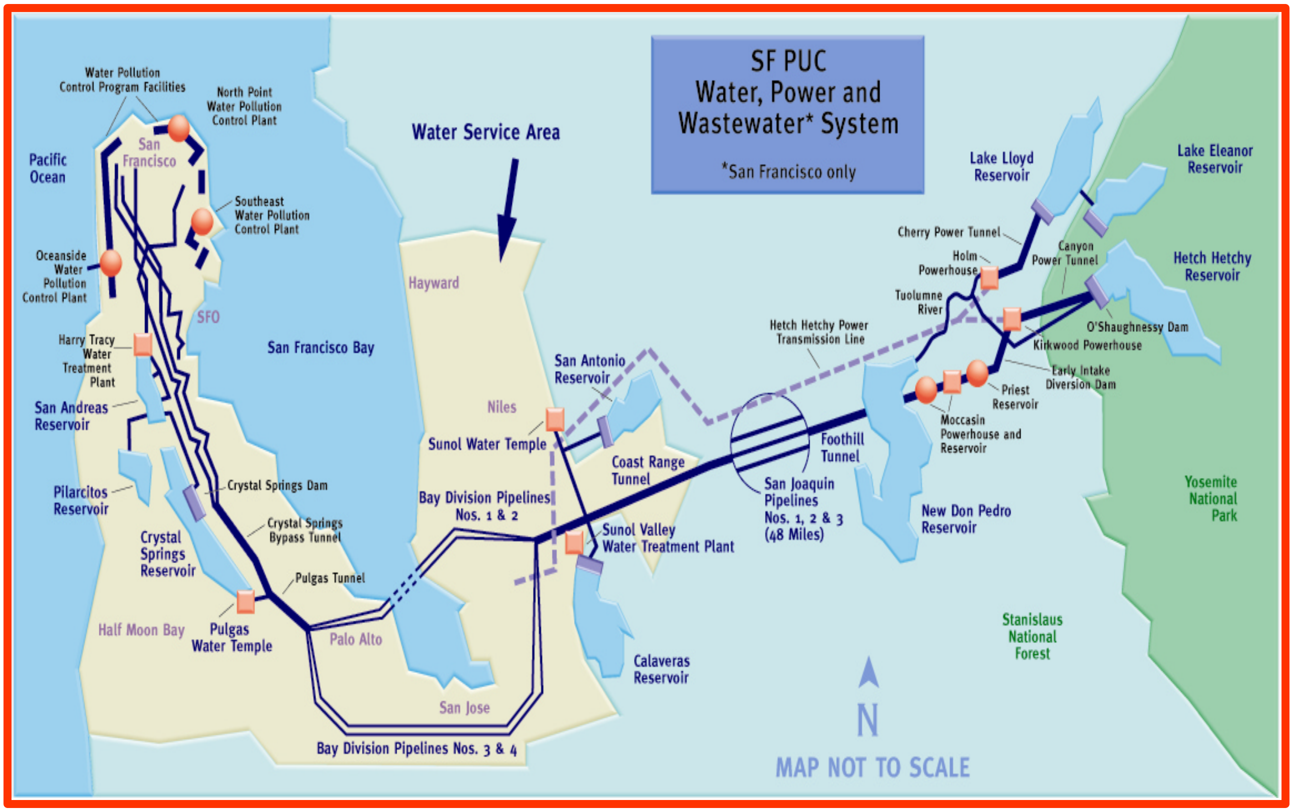
By any measure, construction of San Francisco's Hetch Hetchy water system – begun in 1914 and completed in 1934 – was a milestone engineering achievement. The system captures rain and snow melt runoff from the Tuolumne River near Yosemite National Park, and moves it mainly by gravity through a 167-mile series of tunnels, aqueducts, treatment plants and pipelines, to reservoirs and turnouts along its route through the South Bay, up the Peninsula and into San Francisco (*see Map 1*).

History

Initial plans for Hetch Hetchy grew out of concerns in the late 1800s that San Francisco was outgrowing its water supply. In the post-Gold Rush era the city had emerged as a West Coast center for commerce, trade and migration. By 1900, the Spring Valley Water Co., San Francisco's single private supplier of water, delivered about 2 million gallons per day (mgd) pumped from city and peninsula creeks, springs and wells, some of it stored in redwood-lined reservoirs. As the city continued to grow, demand was expected to soon exceed what Spring Valley Water could deliver.

A catastrophic event, the 1906 earthquake, forced the issue of a new water system. Most of the extensive damage during the quake was the result of fires from ruptured gas mains, and the lack of adequate water supplies or pressure to put them out. San Francisco set about building a system that would greatly expand the overall supply of water, and provide adequate local storage in the event of an emergency. Building the Hetch Hetchy system required an act of Congress, the 1913 Raker Act, granting San Francisco rights of way in Yosemite National Park and Stanislaus National Forest to build the Hetch Hetchy Dam and Reservoir on the Tuolumne River.

In 1930, San Francisco acquired the Spring Valley Water Co. and merged it with Hetch Hetchy under a public agency that is now the San Francisco Public Utilities Commission (SFPUC), to create essentially the system in place today. For ease of reference this study will refer to "the Hetch Hetchy system." While the Tuolumne River and Hetch Hetchy reservoir are its predominant water source, it should be noted that the SFPUC's regional system also draws on local sources for approximately 15% of its supply.



Map 1: SFPUC Regional Water System

A Changing Customer Base

Today the SFPUC supplies nearly 260 million gallons per day (mgd) to some 2.4 million customers in San Francisco, the Peninsula, South Bay and a portion of Alameda County. The system originally was planned to provide water to San Francisco and neighboring communities. Initially it served mainly San Francisco, but today the city only uses about a third of Hetch Hetchy water – some 84 mgd. The other two-thirds, 175 mgd, is delivered to 29 suburban water agencies and other large wholesale customers in more than 30 localities (*see Map 2*). These wholesale customers are represented in negotiations with SFPUC by the Bay Area Water Users Association (BAWUA).

BAWUA agencies rely on Hetch Hetchy for 66% of their total water supplies. Several large agencies – Alameda County Water District, Santa Clara, Milpitas, Sunnyvale and Daly City, for example – have diversified supplies. But 18 of the 29 suburban customers are wholly dependent on Hetch Hetchy for their water and another three are more than 75% dependent. Among the system's largest individual customers are the University of California San Francisco; Stanford University, Stanford Hospital and the Stanford Linear Accelerator; NASA Ames Research Center; and San Francisco International Airport.

Business and institutional users account for 30% of San Francisco water demand (26 mgd) and 25% of demand throughout the BAWUA service territory (65 mgd). Key business and institutional users of SFPUC water include the computer, semiconductor, biotechnology, automotive, aerospace, electric utility, telecommunications, tourism and other sectors, plus schools and hospitals, and smaller water-dependent businesses such as restaurants, glass and metal fabricators, beverage plants and food processors.

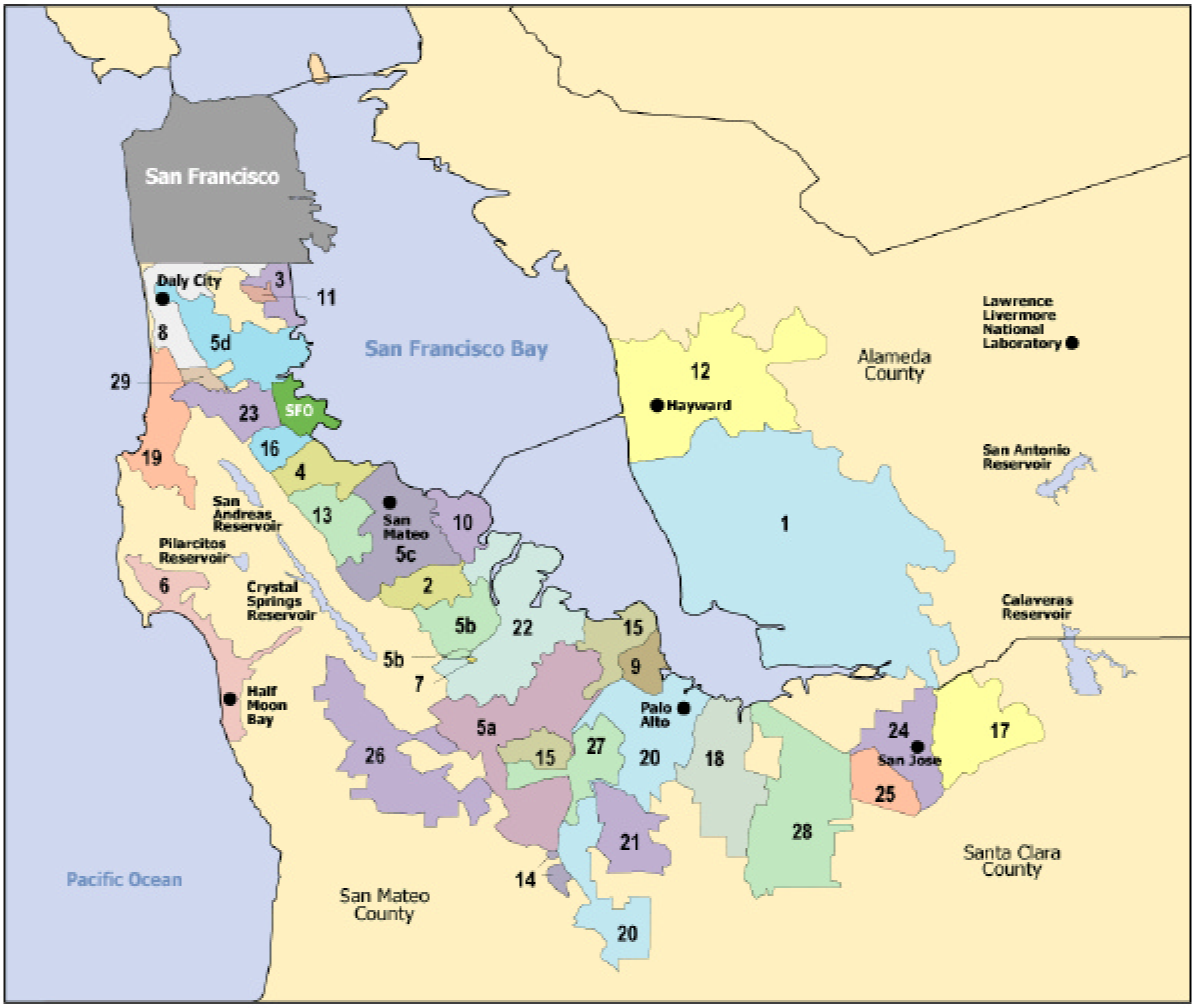
Over the last several decades, farm acreage on the Peninsula and in the South Bay has gradually been displaced by housing, commercial office complexes, hotels and manufacturing plants. This has contributed to a gradual net increase in water demand in support of added residents and jobs. Levels of activity that could, in the past, subsist on groundwater supplies have given way to uses that first required more efficient management of Bay Area aquifers, and then new South Bay connections with Hetch Hetchy to accommodate growth. It should be noted, however, that suburban purchases of SFPUC water fell during the 1986-92 drought, and still remain below 1985 levels despite a 15% growth in population, indicating sustained improvement in the efficiency of water use by suburban customers.

Water Quality

Its relatively high quality allows Hetch Hetchy water to avoid EPA filtration requirements. The Alameda County Water District (ACWD), which serves Fremont, Union City and Newark, blends most of its SFPUC supply with groundwater to mitigate groundwater hardness. Daly City also blends its well water with Hetch Hetchy supplies.

Communities that receive water from a combination of sources do not typically blend supplies, however, for several reasons. One is the historic growth and development of distinct zones, served by separate turnouts and pipes to separate sources, with little integration. Blending is also restricted by SFPUC's use of free chlorine as a disinfectant. Most suburban water agencies use chloraminates, a mix of ammonia and chlorine, to disinfect groundwater they pump directly from wells, as does SCVWD in the water it supplies to South Bay communities. If not closely controlled, blending water with these different disinfectants can produce an undesirable taste or odor. SFPUC plans to switch to chloramination in December 2003, clearing the way for suburban communities to consolidate water delivery zones and blend supplies to a greater extent.

Businesses requiring large amounts of water in their industrial processes generally prefer Hetch Hetchy water because it needs less pre-treatment and post-treatment. Semiconductor manufacturers, biotech and pharmaceutical companies, automobile plants, glass makers, aerospace manufacturers, medical laboratories and other businesses require pure or de-ionized water for rinsing, diluting, sterilizing, cooling and plating. After the water is used, depending on the process involved, wastewater may require post-treatment in order to be recycled for other on-site uses such as closed loop cooling or fire sprinkler systems, or for eventual discharge into local sewer systems. Up to 90% of water-related manufacturing costs are in pre-treatment and wastewater post-treatment filtration.



Agency No.	Agency Name	Agency No.	Agency Name
1	Alameda County Water District	13	Town of Hillsborough
2	Mid-Peninsula Water District	14	Los Trancos County Water District
3	City of Brisbane	15	City of Menlo Park
4	City of Burlingame	16	City of Millbrae
5a	Bear Gulch – Cal Water Service Co.	17	City of Milpitas
5b	City of San Carlos – Cal Water Service Co.	18	City of Mountain View
5c	City of San Mateo – Cal Water Service Co.	19	North Coast County Water District
		20	City of Palo Alto
5d	City of South San Francisco – Cal Water Service Co.	21	Purissima Hills Water District
		22	City of Redwood City
6	Coastside County Water District	23	City of San Bruno
7	Cordilleras Mutual Water Association	24	City of San Jose
8	City of Daly City	25	City of Santa Clara
9	City of East Palo Alto	26	Skyline County Water District
10	Estero Municipal Improvement District	27	Stanford University
11	Guadalupe Valley Municipal Improvement District	28	City of Sunnyvale
		29	Westborough Water District
12	City of Hayward		

Source: San Francisco Public Utilities Commission and the Bay Area Water Users Association.
Note: Lawrence Livermore National Laboratory is an associate member of the Bay Area Water Users Association

Most manufacturing and research facilities have treatment process controls that can be adjusted to accommodate water of varying hardness and chemical content, as long as there is adequate advance notice of a content change from SFPUC and the local water agency. Adjustment typically involves replacing filtration devices. If the facility has no onsite backup storage of pure water, there may be downtime during replacement, ranging from a few hours to a full day. Less pure water requires increased pretreatment and more frequent replacement of costly filters.

When water has higher amounts of particulate matter in it, more water is needed to perform the same operation. Over time this means higher water bills and, in cases where the additional water is discharged in the Bay, higher sewer charges and discharge taxes. Some operations are designed specifically around the assumption of a Hetch Hetchy water quality level and would have to retrofit if the water source changed for a sustained period.

For these reasons, blending and greater overall integration of regional water supplies is very limited. As a result, customers within zones supplied wholly by SFPUC are particularly dependent on the system.

2. Strains to the System

Demand has already outpaced Hetch Hetchy's assured supply capacity. As aging facilities continue to weaken and maintenance is deferred, the system is increasingly vulnerable to routine failures and natural disasters.

The 1976-77 and 1986-92 droughts in the Bay Area demonstrated the systems limits. Reservoirs reached record low levels. Residences and hotels installed low-pressure shower fixtures and low-flush toilets to conserve, and cut back on landscaping. Parks shifted to trees and plants requiring less water and maintenance. Golf courses began irrigating with reclaimed water. Restaurants provided drinking water by request only.

Based on conditions during the most recent drought period, SFPUC now has determined that the maximum quantity of water it can reliably deliver to its customer base is 239 mgd annually. However, actual demand in 2000-2001 was nearly 260 mgd, and it is generally understood that the SFPUC system is operating in excess of its assured supply capacity and approaching its actual delivery capacity.

Capacity

Total demand for Hetch Hetchy water is expected to grow to 303 mgd in 2030 and 310 mgd by 2050. Absent a significant expansion of the system, the shortfall relative to assured supply will therefore increase from 21 mgd presently to 64 mgd within 30 years and 71mgd within 50 years.

Present alternative sources won't cover the gap. Some water agencies (Daly City, for example) could increase groundwater output from wells, but most – particularly in the South Bay – draw from the same large underground aquifers at different points. Utilities must be careful to avoid drawing from those aquifers faster than they can be recharged, or water supplies and well pressure will be depleted. In some areas, taking too much water from wells can cause subsidence. State Water Project supplies are accessible through ACWD and SCVWD, but require costly treatment. Other long-term supply alternatives are discussed in detail in Chapter 5.

Age

All of the major Hetch Hetchy facility components are at least 46 years old. Some, including the Crystal Springs and San Andreas Dams and Reservoirs, pre-date Hetch Hetchy back to the 1870s. But the facilities of most concern include pipelines, tunnels, portals, supplemental reservoirs and dams built in the 1920s and 1930s along the 167-mile route, that intersect earthquake faults and have been weakened from years of water pressure, weather and ground movement.

Key sections of the Hetch Hetchy "backbone" have not been seismically retrofitted and braced. Some are made of original materials such as redwood, cast iron and concrete that are now corroded and not designed to bend rather than break with stress. Most facilities have little or no redundancy built into them so that in the event of a system failure, a tunnel, portal, pipeline or siphon cannot be bypassed and the failure quickly isolated and repaired without interrupting service.

While the system has received incremental repairs, parts have not undergone any structural assessment since the 1960s – much less comprehensive maintenance and repairs – because the entire system would have to be shut off upstream. There is no backup system through which to divert the water and keep it flowing to customers while this work is done. Even without any catastrophic event taking place, failure to reinforce, replace, maintain and modernize Hetch Hetchy will mean an increase in small failures; compounded problems when failure in one aging part of the system produces another failure somewhere else; wasted water; drops in pressure and added costs from leaks.

Beyond the technical constraints, a February 2000 report by the Office of the State Auditor criticized the level of deferred maintenance. It noted that, during 1990-2000, only 54 Hetch-Hetchy capital projects valued at $270 million were completed. "Given the size, complexity, age and declining condition of the Commission's water delivery system," the report concluded, "this project completion rate appears low." The report also pointed out that system upgrades and repairs growing out of damage from the 1989 Loma Prieta earthquake were not begun until 1994. It blamed high SFPUC executive staff turnover, inadequate management expertise and a lack of efficient procedures for awarding and executing large projects, among other factors.

Many of the organizational difficulties cited by the State Auditor appear on the way to being resolved under current SFPUC management. But the result over time has been a gradual weakening of the water system that makes it susceptible to frequent small failures, as well as to a critical failure following a major earthquake.

Vulnerability to Disaster

Hetch-Hetchy facilities cross at least five active earthquake faults: The San Andreas, Hayward, Calaveras and Greenville Faults, as well as the Great Valley Fault Zone. From a statistical standpoint, given the geology of the region, a major earthquake along at least one of these faults – ranging from 6.7 magnitude along the Great Valley zone to 7.9 along the San Andreas Fault – is considered 70% likely by the year 2030. Water system facilities at or near points of intersection with the five faults are at high risk of failure in the event of such an earthquake.

Since the September 11 terrorist attacks in New York and Washington, public officials must also take into account the possibility of sabotage to major pieces of regional infrastructure such as the Hetch Hetchy system. Generally, safeguards already in place or under consideration to address a natural catastrophic event (reinforcement of structures; new materials and technology; expanded system monitoring, valve shutoff and bypass capabilities, etc.) tend to serve the dual function of improving security, as does improved perimeter fencing, surveillance, patrols and other measures now under review and planning. It should be noted that a number of water agencies have formed the Bay Area Security Information Collaborative to exchange information and develop security strategies for protecting water system assets.

3. Emergency Scenarios

A prolonged Hetch Hetchy system failure would seriously compromise the Bay Area's water supply.

A January 2000 facilities reliability study done for SFPUC by consultants CH2M HILL, Olivia Chen Consultants, Montgomery Watson and EQE International, examines the likely impacts of major earthquakes along four different faults on the Hetch Hetchy system – both in terms of damage to the system and emergency response within the service area. All of the information in this section is based on findings contained in that study. Scenarios and conclusions contained in that document appear to be generally accepted as reasonable by water agencies, engineers, consultants and others who were interviewed for this analysis and not involved in preparation of the study itself.

The SFPUC study assumes four scenarios: a 7.9 earthquake on the San Andreas Fault, a 7.1 event on the Hayward Fault, a 6.8 event on the Calaveras Fault and a 6.7 quake in the Great Valley Fault Zone. Each of Hetch Hetchy's component facilities is rated for damage risk according to age, condition and proximity to fault areas. Each scenario would produce different results for SFPUC water customers in different areas.

After a 7.9 earthquake on the San Andreas Fault:

- Most critical pipelines, tunnels, bypasses, pumping stations, supply lines and feeder mains from Newark west and north up the Peninsula and into San Francisco, plus the Harry Tracy Water Treatment Plant, are assumed to fail.

- Peninsula and city customers are cut off from the Hetch Hetchy system, as are South Bay customers west of either Milpitas or Mountain View, depending on the extent of damage.

- Pressure in the gravity-driven system drops to that of the elevation of the furthest upstream failure, about 300 feet, making it difficult to move supplies that are stored or in the pipes beyond the break.

- Leaks systemwide exacerbate the pressure problem and diminish supplies.

- The intertie with the Santa Clara Valley Water District (SCVWD)at Milpitas may not be operational in this scenario, either because the SCVWD also sustains major damage or because it is upstream of the system failure; therefore it is not assumed to be a reliable source of backup supply.

After a 7.1 earthquake on the Hayward Fault:

- The San Antonio Pump Station and Sunol Valley Water Treatment Plant are damaged; the Alameda Siphons fail; the Irvington Tunnel west portal collapses; the Bay Division Pipelines (BDPLs) rupture.

- Pressure in the gravity-driven system drops to that of the elevation of the furthest upstream failure, again about 300 feet.

- South Bay customers served by turnouts from the BDPLs are wholly dependent on local storage; Peninsula and San Francisco systems are fully operational but cut off from further upstream Hetch Hetchy supplies pending evaluation and repairs.

- The Harry Tracy treatment plant is ramped up to its maximum flow rate of 144 mgd – enough to serve the Peninsula and city; but not enough if the BDPLs are partially operational and portions of the South Bay remain on the system; South Bay customers would at best receive 50% of demand.

- In this scenario, there is a greater possibility of direct damage to the SCVWD and the Milpitas intertie with SCVWD. Again, it is not viewed as a backup source of water supply.

After a 6.8 earthquake on the Calaveras Fault:

- The same facilities are considered to fail as with the Hayward Fault scenario, with the same impacts.

After a 6.7 earthquake in the Great Valley Fault Zone:

- The San Joaquin pipelines, Tesla Portal and Thomas Shaft disinfection stations and the Coast Range Tunnel are all assumed to incur major damage and fail.

- Leakage of high volumes of water cause a significant drop in system pressure downstream.

- The entire SFPUC system remains operational but, isolated from Hetch Hetchy supplies, it can only meet about half of normal demand; additional supplies available from SCVWD intertie.

In addition to Hetch Hetchy itself, local pipe failures are also possible in bayfront communities where the combination of loosely compacted, sandy soil and a high water table can cause liquefaction.

Supply/Demand/Repair Assumptions

In developing various scenarios, the study assumes average daily demand (ADD)of 260 mgd throughout Hetch Hetchy's service territory; local SFPUC reservoirs filled to a typical 65% of total capacity (East Bay and Peninsula), or 48 million gallons; and San Francisco city reservoirs filled to 80% of capacity, or 330 million gallons. Water supplies further upstream would most likely be unavailable after a downstream system failure. In addition, much of the supply in three upstream reservoirs – Lake Eleanor, Lake Lloyd and the New Don Pedro Reservoir – is held in reserve to meet downstream irrigation, water quality and fisheries requirements, and to provide hydroelectric power under contract to the Modesto and Turlock Irrigation Districts. Finally, it is assumed that downstream supplies of untreated water would not be pumped into the distribution system for health reasons.

In the first 24 hours following a catastrophic failure, ADD in directly impacted areas is expected to double, due to the increased needs of fire and emergency services. Consumption in the next three days is expected to drop to 30% of ADD in suburban areas and 50% in San Francisco, as rationing programs are put in place, increasing to 50% systemwide within 20 days as residents and businesses begin to recover and as facilities are repaired, and continuing to rise to full ADD again by 30 days.

The time required for temporary repairs of various Hetch Hetchy facilities to restore only partial service ranges from less than a week for pump stations and treatment plants to as long as 30 days for storage tanks, 40 days for pipelines and 60 days for tunnels. Permanent repairs and restoration of full service for most major system components are estimated to take at least 3 months and from 6 to 12 months in many cases. SFPUC concedes that much of its service area could be without new water supplies for 20-30 days, and in some instances as long as 60 days (*See Chart*).

Estimated SFPUC System Restoration Times After Major Seismic Event

Pump Stations	2 days
Water Treatment Plants	3-6 days
Storage Tanks	25-30 days
Tunnels	30-60 days
Pipelines	40 days maximum

SOURCE: SFPUC. Conceptual estimates based on single facilities failure, mechanical repairs required only, one crew available for each facility repair. Multiple facilities failure and structural damage would require more time.

System Demand Assumptions Following a Catastrophic Event

Time Frame	**Demand Assumption**
Prior to event	Average day demand (ADD)
0-24 hours after event (directly impacted areas)	200% of ADD for regional system; slightly higher within San Francisco
0-24 hours after event (outside direct quake damage area)	Approximately ADD
24 hours to 20 days after event (directly impacted areas)	30% of ADD for regional system; 50% of ADD within San Francisco
24 hours to 20 days after event (outside direct quake damage area)	50% of ADD
20-30 days after event (directly impacted areas)	Increasing gradually to ADD
20-30 days after event (outside direct quake damage area)	Approximately ADD
After 30 days (all areas)	Average to maximum day demand

SOURCE: SFPUC

Because Hetch Hetchy is essentially a one-way, gravity-driven system, it is important to distinguish between types of water supply in an emergency. Technically, the Crystal Springs, San Andreas and various San Francisco reservoirs contain enough stored untreated water to meet demand in the event of a disaster and subsequent system failure, over the 30-60 days it would take for temporary repairs. Several factors can cut off Hetch Hetchy customers from major reservoir supplies:

– Water located "downstream" from a break will have lost pressure.

– While Crystal Springs has the technical capability to flow water in the reverse direction, pumping and valve capacity limits the ability to reach all customers.

– Reservoir water must be disinfected and treated; the Harry Tracy Water Treatment Plant can treat 144 mgd but may not be operational, and the City of San Francisco and most suburban water agencies and local suppliers do not have separate treatment capability.

– Even if some treated water were available, a major earthquake would likely rupture smaller tributary pipes in the service area, de-pressurizing local systems.

– Even with a relatively high 4-5 days of storage for the treated water, San Francisco remains vulnerable and has some of the oldest and potentially fragile Hetch Hetchy system components.

– Interties between adjacent water districts have relatively limited capacity, and alternative supplies would require blending and treatment.

Thus, while a limited amount of water can, in theory, be pumped from major reservoirs and other sources outside local communities, it must be assumed for purposes of emergency planning that most or all available water in suburban communities reliant on Hetch Hetchy – and in parts of San Francisco – can only come from local storage and groundwater.

4. Running on Empty

Following a major seismic event, alternative sources of water will be severely limited; throughout the region, businesses face the greatest risk of reduced supply.

Surveys of BAWUA water agencies, as well as retail, commercial, industrial and institutional users and fire departments were conducted for this report and provide a picture of likely 'real-world' impacts in the event of a disaster and prolonged interruption of Hetch Hetchy water service.

Impacts vary depending on each city's dependence on Hetch Hetchy water, its delivery infrastructure and its topography. But in all cases, they begin with the assumption that immediately after an event SFPUC would identify and close valves around damaged sections, to isolate them and permit repairs, to stop leakage and to maintain as much pressure as possible in the remainder of the system. Depending on the location, it may take hours or up to a full day to complete the shutoff.

At this point, local agencies would shut off their own valves to go to an emergency rationing system. This can take up to a full day, during which leaks continue and users are drawing from local systems. Water delivery cannot be precisely regulated at the user level. Homes and businesses located near emergency services will inevitably have access to emergency water supplies. Depending on the ability to reach the public with news and instructions, ordinary use and hoarding of water will compete with fire and emergency uses. All of this contributes to estimates that demand will double within the first 24 hours following a disaster.

It should be noted that a major earthquake may also damage water systems served by the SFPUC, reducing their capacity to distribute water at the local level. In that event, even if water is accessible in SFPUC pipes its accessibility for fire control and other purposes will be limited.

Once SFPUC has isolated failed sections by shutting off valves, everything downstream from the failure is effectively shut off from new Hetch Hetchy supplies and is reliant on water in the pipes, local storage and alternative sources (increased well production, purchases from other districts, etc.) where feasible.

At the end of the SFPUC regional water system line, San Francisco is as vulnerable to disruption as other communities in its service area. For purposes of fire control, fire and emergency services within San Francisco would receive top priority for water. Drinking water for residences would receive priority allocation and, given the mixed-use character in much of the city, small neighborhood retail businesses would also receive water and remain open. Hotels would get priority consideration to the extent that they provide temporary shelter for displaced residents and emergency workers. San Francisco's reservoirs and tanks contain only 4-5 days' supply of treated water at average demand.

As with most regional water district suppliers, contracts with wholesale customers are interruptible and contain force majeure clauses releasing the agency from assured supply commitments in the event of an emergency. However, in recent months SFPUC and BAWUA have launched a crisis management planning process aimed at restoring water servcie in an emergency, establishing an allocation formula, and a bill recently passed by the Legislature and signed by the Governor, AB 1823, requires SFPUC allocate its supplies equitably among San Francisco and suburban users in the event of a service interruption and emergency rationing, to the extent feasible given the physical damage to facilities.

Emergency Response Options

While it is relatively easy to store large volumes of untreated water, capacity to store treated water is more limited.

San Francisco historically has extensive backup storage dating back to its experience after the 1906 earthquake. Today, 12 city reservoirs hold 414 million gallons, a five-day supply at average demand levels. Most of SFPUC's suburban customers have storage in the range from several hours to over five days. Supplies would theoretically be stretched under rationing, but the critical question is how much of the available storage is used in the first 24 hours under emergency conditions. Several factors determine the answer to that question:

- Time required to shut off valves and go onto a rationing plan
- Relative elevation and pressure of supplies
- Time required to notify the public of rationing and provide instructions
- Enforcement of rationing program, especially in zones where water must remain on
- Water required for firefighting and hospital emergency rooms
- Ability to extend potable supplies with additional groundwater, recycled water
- Ability to access supplies through interties with adjacent, less affected agencies
- Competition with adjacent affected cities for finite Hetch Hetchy supplies

Several Peninsula and South Bay cities have plans to expand storage capacity, but these would add at most 1-2 days to existing storage, and in fact more than 3 days of backup potable storage is considered impractical by water utility managers. Cities that own and operate municipal wells would have access to the groundwater basin to augment supplies, and SCVWD may also be able to deliver additional water from state and federal project sources.

South Bay water agencies are limited in the amount of groundwater they can access, first by their pumping capacity and second because most are drawing water from the same large underground aquifers at different locations. A few agencies, such as Daly City, Alameda County Water District, Santa Clara, San Bruno and Palo Alto, can increase groundwater production; some others on the Peninsula (like San Francisco) have no wells. It is a matter of debate among water officials as to whether South Bay communities, facing a 60-day shutoff of Hetch Hetchy supplies, could operate on groundwater alone without dangerously depleting the aquifers.

In the early to mid-1900s, excessive pumping of groundwater in Santa Clara County led to subsidence of up to 15 feet in San Jose. This subsidence was finally halted in the 1960s by importing and injecting State Water Project water into the aquifer. Since that time, the Santa Clara Valley Water District has been given responsibility for managing the levels of water within the groundwater basin on behalf of local communities whose wells access this water. Daly City is working on a similar program with SFPUC and other adjacent water suppliers who draw from nearby wells.

A general assumption is that most or all locally stored water supplies from tanks and small reservoirs would be used up within 48-72 hours for fire, medical and other critical services, plus rationed potable water for drinking and washing. Rationing and increased pumping of groundwater would extend supplies to meet at least partial demand in some locations for 1-2 weeks, assuming delivery systems are functioning. It is not clear how much water, if any, would be available for sewage treatment and discharge functions.

Finally, a severe drop in system pressure could cause many elevated storage tanks to drain, reducing pressurized supplies further.

Interites with other water systems offer another potential source of alternative supply. The Alameda County Water District (ACWD) for example, has access to Delta water from the State Water Project. A $9.1 million, 42-inch pipeline/pump station intertie between the SFPUC and SCVWD systems at Milpitas was completed in May 2002 and allows either to transfer 40 mgd to the other in the event of an emergency, adding to regional system flexibility. The City of Hayward, an SFPUC customer, has two smaller interties with the East Bay Municipal Utility District (EBMUD) and SFPUC is considering a third intertie for emergency and maintenance purposes.

Suburban wholesale customers are working with SFPUC on a crisis management plan for water allocation in an emergency situation. An Interim Water Shortage Allocation Plan is already in place to address a drought situation, by allocating diminished SFPUC supplies first between the San Francisco retail customer base and BAWUA, and then among agencies within BAWUA based on agreed formulas. The plan does not, however, anticipate a sudden, sharp drop in supply, as would be experienced during a system outage, and is not designed to address shortages of more than 20%.

In short, while other long term options to address the challenge of allocating and delivering water in an emergency are being developed, there is consensus among those likely to be most affected by a prolonged Hetch Hetchy service interruption: The most cost-effective solution today is strengthening and modernization of existing Hetch Hetchy assets.

Business Impacts

A major reduction of water supplies will have serious effects on many of those most vulnerable – the homebound elderly, children, hospital and nursing home patients, families displaced from their homes by earthquakes and fire. In attempting to minimize those impacts, local water agencies must make difficult choices within their service territories in assigning priority for water delivery. It is only after emergency, public health and drinking water needs are met that water might be made available for commercial and industrial uses. At the end of the rationing queue, and with few cost-effective alternatives, many businesses will be at serious risk.

Interviews with Bay Area commercial and industrial water users suggest the serious operational and economic impacts that would result from a Hetch Hetchy system failure. The most immediate and damaging impacts from a service interruption are in two areas:

Health and safety. Businesses across the board say they would feel compelled to close buildings that could not provide running water in sinks, toilets and drains, and adequate water or pressure for fire sprinkling systems. Bottled water and portable toilets would be a limited and temporary solution at best.

Plant operations. Most large commercial and industrial complexes have rooftop cooling towers that run water through fan-powered chillers. The water is then routed to building subsystems for drinking and sanitation, for filtration and use in industrial processes, and into closed fire protection and cooling system loops. Even a closed loop system loses water through evaporation and needs replenishing, or chillers will overheat and automatically close down. That in turn shuts off air conditioning, temperature-controlled laboratory environments, computer server clusters and water cooled equipment such as electrical generators and vacuum pumps.

Based on these considerations alone, most businesses experiencing a loss or severe reduction in water supply beyond 2-3 days would probably suspend operations or close down altogether. For example:

Manufacturing impacts would vary considerably by location and the amount of water needed for specific processes. Intel Corp. uses more than 1 million gallons of water daily in its Santa Clara wafer fabrication plant, 75-80% for industrial processes such as cooling or rinsing and 95% of it Hetch Hetchy water. The company could switch to groundwater and water from the Santa Clara Water Department in the event of a Hetch Hetchy failure, with an adjustment of its filtration controls, though production could decline sharply because more water would be needed to produce the same output, at a time when supplies would be rationed. In the longer-term, water consumption would increase, along with filtration and discharge costs. The company uses as much as 2.2 million gallons per day with combined water/sewer costs of $6,500 per day according to local water officials. Intel's losses in chip production from a complete service interruption could be as high as $75 million per day.

New United Motors Manufacturing, Inc. (NUMMI) operates a former General Motors plant in Fremont built in 1963 and designed to use Hetch Hetchy water only. Water is used for sanding and rinsing cars, and for cooling during welding. NUMMI's primary connection to the Alameda County Water District allows it to receive Hetch Hetch water directly, although it can switch to the ACWD's other supplies for a limited time. However, the higher mineral content of those supplies requires significant additional pretreatment and incurs higher costs. Converting the plant to use ACWD's alternative supplies would cost $1 million in new equipment and an added $1 million a year in operating costs. It would also require a 33% increase in water consumption. More importantly, interruption beyond a day or two would close the plant and send most of its 5,000 employees home.

Small and medium-size businesses face similar difficulties. Another ACWD customer, Bay Mirror, uses up to 70 gallons of water a minute for silver plating, washing, beveling, grinding and polishing glass. It would incur significant equipment and downtime costs to regenerate resin filters more often if it switches to alternative ACWD supplies, and lose $50-65,000 per day in production if service were totally interrupted..

Roche Pharmaceuticals uses nearly 2 million gallons of water per month in its 105-acre Palo Alto research facility, for developing drugs for the treatment of viruses, osteoporosis and emphysema. Most of this is used to clean glassware and equipment, in media for growing cultures, in cooling lasers and in maintaining temperature-controlled environments. Palo Alto is dependent on Hetch Hetchy water and has no backup contracts with outside suppliers, although it does have five local wells. A shutoff of water beyond 2-3 days would close the Roche facility and jeopardize ongoing research projects.

Hotels in the area may stay open and receive limited water supplies in order to house local residents and emergency workers. Otherwise, the loss of water for drinking, sanitation, food preparation, fire protection and laundry service would force immediate closure, refunding of room charges, and relocation of current guests and cancellation of scheduled guests and meetings. The 700-room San Francisco Airport Marriott Hotel estimates potential business losses at $500,000-$750,000 a week and all of the hotel's 400 jobs. The 400-room Double Tree Hotel in Burlingame would lose over $300,000 a week and a potential 170 jobs.

Retail stores in commercial districts and in shopping centers would probably close in any event if they were in an area severely damaged by an earthquake. Even in relatively unaffected areas, however, a water service interruption would force many stores to close for lack of fire protection, sanitation and food preparation. Stores selling perishable food, plants or other items could lose refrigeration and water for cleaning and growing, and might have to move or liquidate inventory. A typical regional mall of 1 million square feet might normally have customer traffic of 250,000 people a week (more during holidays) and could lose $1 million per day in sales if closed, with 1,200 to 1,800 jobs at stake.

Offices, particularly suburban office and industrial park complexes, typically use cooling towers and chillers. Depending on location, they could lose water for drinking, washing and toilets, as well as air conditioning and humidifying. After a few days using bottled water and portable toilets, Network Appliance in Sunnyvale, which designs and operates data storage networks, would have to send home most of its 1,300 employees in five buildings. Eventually, the closed loop chilling system would lose water to evaporation and need replenishing. Without new water, servers would have to be relocated or shut down to prevent overheating, and customer service functions would be relocated to regional centers in North Carolina, Singapore and the Netherlands, and design and manufacturing of hardware components would be relocated to Scotland.

Network Appliance, Inc.'s situation is representative of many firms throughout the Bay Area. Another large Silicon Valley firm plans to move its servers out of California altogether by the end of 2002, due to concerns about earthquakes and electricity or water outages. Several companies interviewed voiced additional concerns about the hidden cost impacts of a supply disruption, such as lost customer and supplier goodwill and added legal and insurance costs.

The Silicon Valley Manufacturing Group (SVMG) recently completed a survey of 28 corporate members located inside the SFPUC service area, and four other companies in adjacent areas, on the importance of a reliable water supply to their operations. More than half of the companies surveyed are involved in manufacturing, and a similar proportion are in high-technology industry sectors.

Twenty of the SVMG companies said water is "very critical" in their daily operations. Two-thirds, or 21, said a 30-day water service interruption would shut them down entirely, with 16 reporting that they would incur “major losses” of many millions of dollars. If water service was not interrupted directly but was reduced in nearby communities, 23 firms said they would be affected because suppliers could be shut down; employees might not be able to report for work; food and other vendors would halt service; and recruiting of future employees to the Bay Area would become more difficult.

Twenty-two companies said their employment would be affected by a water system failure, as employees would have to be sent home to work or relocated; shutdown of some operations and loss of business could force layoffs; and sanitation issues would make continued operation difficult.

Significantly, 27 of the surveyed companies – 84 % – have no backup plan in the event of a water shortage. As one executive interviewed for this report said: “We see this as a responsibility of the water utility.”

5. Impacts on the Regional Economy

Economic modeling indicates far-reaching impacts on the regional economy.

This report analyzes business activity in key industry sectors by locality within the Hetch Hetchy service territory, as well as statistical industry data, anecdotal detail from water agency and industry interviews, and existing studies. Its findings reveal the extent to which water is an essential commodity for nearly all Bay Area businesses, and the extent to which the Bay Area economy is directly dependent on water supplied by the SFPUC system (*see Appendix B*).

For the Bay Area, the potential property damage from fire, lost business activity and jobs, legal and insurance costs, damage to the region’s business reputation and ability to attract future economic development that would result from a failure of the Hetch Hetchy system is on an exceptionally large scale.

Costs associated with water service interruption in the 60 days following a major Bay Area earthquake could exceed the costs of repairing and upgrading the Hetch Hetchy system over 12 years by a factor of 10.

Given Hetch Hetchy’s structure and configuration, along with local storage and delivery limitations and likely assignment of priorities following a catastrophic event, commercial and industrial users face a low priority to receive a very limited water allocations from constrained supplies. It is less a question for many businesses of where to secure alternative supplies and what they will cost, than one of whether and when to suspend operations in the absence of water for manufacturing processes, fire protection and sanitation.

Two earthquake scenarios form the basis of this report's analysis of a possible interruption in Hetch Hetchy water service over a 60-day period – a 7.9 magnitude earthquake on the San Andreas Fault and a 7.1 earthquake along the Hayward Fault, both of which intersect major Hetch Hetchy water storage and delivery facilities. Earthquake-induced damage to the SFPUC water supply system is likely to produce two distinct effects. First, following a major earthquake, some proportion of SFPUC customers will experience a complete loss of water supply. Second, those customers that still receive water via the piped system will experience water rationing during the system's repair and recovery period.

Based on earlier engineering studies, this report identifies six geographic damage zones within the SFPUC service territory for the San Andreas M 7.9 earthquake, and four geographic damage zones for the Hayward M 7.1 earthquake. Within each of these regions, SFPUC customers will experience similar water supply disruptions. Cities in italics denote areas with partial shortages within different outage regions.

<u>San Andreas</u>

Group 1: Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Estero, Guadalupe Valley, Hillsborough, Millbrae, North Coast, Westborough

Group 2: Daly City, San Bruno

Group 3: Belmont, CWS – Bear Gulch, Cordilleras, East Palo Alto, Los Trancos, Menlo Park, Palo Alto, Purissima Hills, Redwood City, San Jose, Skyline

Group 4: Milpitas, Mountain View, Santa Clara, Stanford, Sunnyvale

Group 5: Alameda, Hayward

Group 6: San Francisco

<u>Hayward</u>

Group 1: CWS – Bear Gulch, *Cordilleras*, East Palo Alto, Hayward, *Palo Alto, Redwood City*, *San Jose*, Skyline

Group 2: ACWD, Milpitas, Santa Clara, *Stanford*, Sunnyvale

Group 3: San Francisco

Group 4: Belmont, Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Coastside, *Cordilleras*, Daly City, Estero, Guadalupe Valley, Hillsborough, Los Trancos, Menlo Park, Millbrae, Mountain View, North Coast, *Palo Alto*, Purissima Hills, *Redwood City*, San Bruno, *Stanford*, Westborough

Italics denote agencies with partial shortages within each group.

The pattern of water supply interruption and rationing following a major earthquake is shown for each group in Figures 1 and 2.

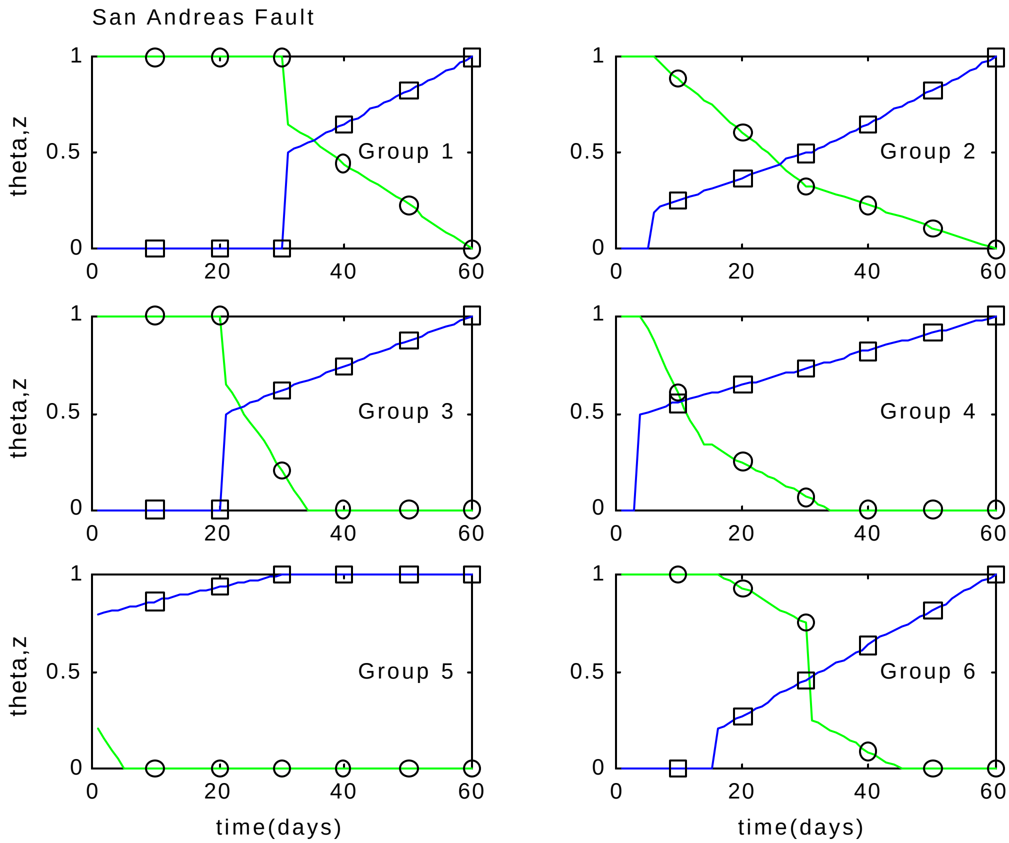


Figure 1. Water supply interruptions and rationing to SFPUC customers resulting from a San Andreas Fault M 7.9 earthquake. The variable *theta* represents the proportion of customers in each group that are without piped water. In the panels of Figure 1, *theta* is plotted using a green line with open circles. For those customers receiving water via the piped system, the variable *z* represents the rationing level (where $z = 1$ corresponds to no rationing). In the panels of Figure 1, *z* is plotted using a blue line with open boxes. Information in this figure is adapted from G & E Engineering Systems Report 54.01.01, Revision 0X.

Residential Sector Damages

For residential customers, damages from a water supply interruption can be measured by the economic concept of consumers willingness to pay to avoid a cutoff. In this context, willingness to pay simply refers to the amount of money that residential customers would pay in order to avoid a break in water service of some duration.

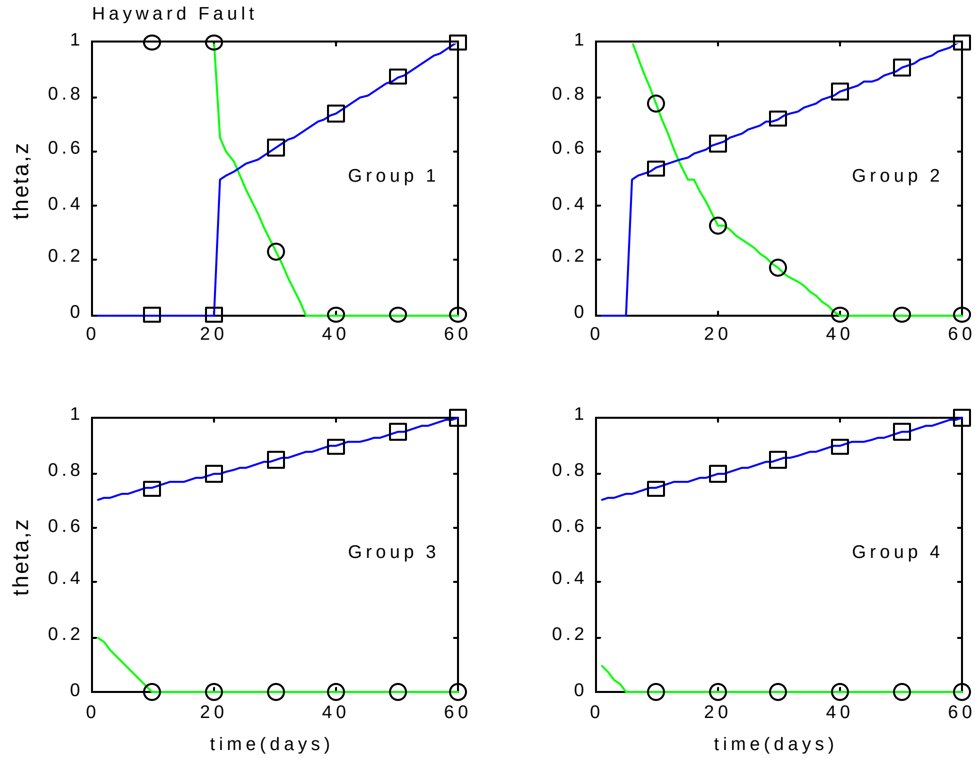


Figure 2. Water supply interruptions and rationing to SFPUC customers resulting from a Hayward Fault M 7.1 earthquake. The variable *theta* represents the proportion of customers in each group that are without piped water. In the panels of Figure 2, *theta* is plotted using a green line with open circles. For those customers receiving water via the piped system, the variable *z* represents the rationing level (where *z* = 1 corresponds to no rationing). In the panels of Figure 2, *z* is plotted using a blue line with open boxes. Information in this figure is adapted from G & E Engineering Systems Report 54.01.01, Revision 0X.

The SFPUC water supply system provides service to a residential customer base of 2.4 million people. Data available from the FY 1999-00 BAWUA Annual Survey provides data on residential per-capita water use in the service area of each BAWUA member, as well as information on the water rate structures. In the BAWUA service area, residential water consumption varies from a low of 50.9 gallons per capita per day in East Palo Alto Water District to a high of 321.2 gallons per capita per day in the Purissima Hills Water District. The differences in average residential water use across SFPUC customers in large part reflect differences in the amount of outdoor irrigation.

Residential water use falls into several broad categories: drinking and basic sanitation, bathing and cooking, laundry use and outdoor irrigation. The willingness to pay for water by residential customers will also depend on its intended use. People will be willing to pay a large amount of money for water for drinking and basic sanitation, less for water to wash clothes, and a much smaller amount for water for washing cars, filling swimming pools, and outdoor irrigation. In order to analyze earthquake-induced economic losses to residential customers, it is necessary to estimate the willingness to pay for each water use category, per day per person.

Because water is essential to life, residential customers willingness to pay for a single gallon of drinking water if no other water is available is enormous. However, this study assumes that an alternative water source – bottled water – remains available throughout the period of emergency shortage. The price of bottled water thus forms an upper limit on the willingness to pay for the first few gallons of water for each residential consumer.

The United Nations defines a "Basic Water Requirement" of 6.6 gallons per capita per day as the minimum required for drinking and basic sanitation, and a minimum requirement of 13.2 gallons per capita per day (gpcpd) when bathing and cooking are included. These amounts can be thought of as the minimum needed to survive for an extended period of time, such as would be encountered following a major earthquake. This study assumes a daily basic water requirement of 10 gallons per capita.

Although residential customers will be quite willing to buy bottled water to meet their basic health needs, they will also be inconvenienced by having to transport many gallons of water daily for an extended period. Thus the willingness to pay for the tenth gallon of the basic water requirement will be less than the willingness to pay for the first gallon. Using this information, consumers' willingness to pay for water is estimated to take the following form (Figure 3). It is assumed that residential customers are willing to pay $2.50 for their first gallon of water, reflecting the price paid for bottled water in a supermarket or from an alternative source. The tenth gallon of water has a willingness to pay of $1.00, reflecting the inconvenience of transportation. Between the first gallon and the tenth gallon, willingness to pay decreases linearly.

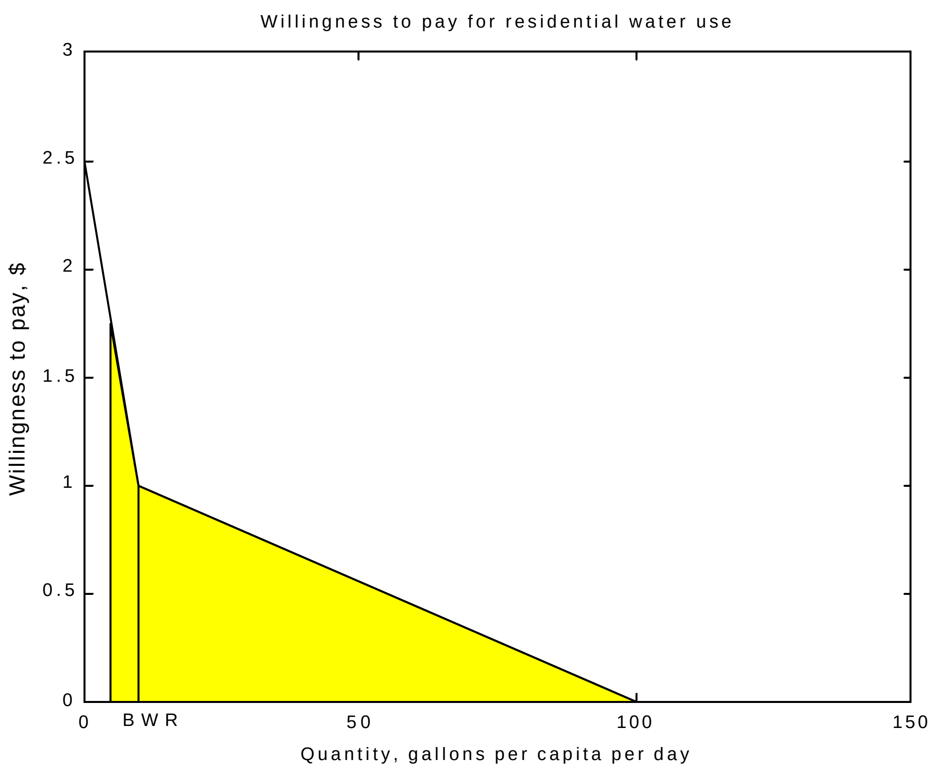


Figure 3. Willingness to pay for water by SFPUC service area residential customers. The Basic Water Requirement (taken in this study to be 10 gallons per capita per day) is given by *BWR*, and corresponds to the change in the slope of the function.

From a willingness to pay of $1 per gallon per capita per day at 10 gallons, we assume that the willingness to pay continues to decline linearly to zero. This decline reflects progressively less valued water use categories for residential customers. The daily quantity of water at which willingness to pay becomes zero is taken to be the average daily demand. Hence, local differences in current water use are captured in this analysis. For example, in East Palo Alto Water District, the willingness to pay for water drops to zero at a quantity of 50.9 gallons per capita per day. Conversely, in the Purissima Hills Water District the comparable value is 321.2 gallons per capita per day.

Additionally, this analysis assumes that willingness to pay to avoid water shortages does not change over time. This means that residential customers are willing to pay the same price for water after a day of shortages as after a week or a month. This is a conservative assumption, as in general, willingness to pay should increase with the duration of water supply interruption.

For all SFPUC residential customers, the marginal water rate per gallon of delivered water is a fraction of a cent. Because the marginal water rate is negligible in comparison to the willingness to pay to avoid water shortages, in this analysis the marginal water rate is taken to be zero. The equations used to measure the economic loss from water supply disruption to residential customers in each BAWUA service area are described in Appendix A.

The economic losses to residential customers resulting from water supply disruption following a magnitude 7.9 earthquake on the San Andreas Fault are shown in Appendix B, Table 1. The aggregate loss to residential consumers supplied by the SFPUC water system is estimated to be $3.77 billion dollars over the sixty-day period before the resumption of normal service. Economic losses to residential customers resulting from water supply disruption following a magnitude 7.1 earthquake on the Hayward Fault are shown in Appendix B, Table 2. The aggregate loss to residential consumers supplied by the SFPUC water supply system is estimated as $1.47 billion dollars over the sixty day period before the resumption of normal service.

Manufacturing Losses

In analyzing the damages resulting from earthquake-induced water shortages on production activities, the appropriate measure is lost revenue. In the short run, small amounts of water rationing can be absorbed with little cost by reducing water uses such as landscaping. However, unlike residential water use, most industrial and other economic activity has a daily water requirement below which all operation ceases. This is true whether water is used as a primary input in production (such as in the beverage industry) or only for fire, sanitation and climate-control purposes (for example, for professional and technical services). It is assumed that facilities that are not operating have a daily value of output of zero, and thus produce zero revenue.

As comprehensive survey data for water use by individual industries is currently unavailable, this analysis uses county-level value of shipments data from the 1997 U.S. Census, and focuses on five sectors of activity – manufacturing; wholesale trade; retail trade; professional, technical and scientific services; and accommodation and food services. Together, these five sectors account for the greater part of economic activity within the Bay Area. The relevant four counties for the analysis are San Mateo County, the City and County of San Francisco, Alameda County and Santa Clara County. The total annual value of shipments for the five sectors used in the production analysis for these four counties is $327 billion (*see Appendix B, Table 3*).

It is assumed that the SFPUC regional water system provides water for all production activities in San Mateo County and San Francisco County, and accounts for 50% and 80% of production activity (by value of shipments) for Alameda County and Santa Clara County, respectively. Note that although the City of Hayward is normally entirely dependent on SFPUC water, Alameda County Water District receives only 30% of its water from SFPUC, and these two agencies combined serve less than 35% of the total population of Alameda County. However, because manufacturing activity is concentrated in the southern portion of Alameda County, this analysis assumes that 50% of the value of production activity in Alameda County is dependent on SFPUC water. The county-level value of shipments data can then be broken down into the same geographic groups as the water supply impacts (*see Figures 1 and 2 above and the residential welfare section for definitions of these*).

Economic losses for each sector and geographic region are based on the assumption that there is a minimum level of water availability below which it is not possible to operate. Between this cutoff level and the mean daily water use, a reasonable assumption is that water supply cutbacks lead to a proportional reduction in output (*Figure 4*). Thus, high-value industries such as high-tech and biotech will suffer much larger losses than low-value industries for the same proportional cutback of water. The formulas to calculate economic losses for production activities are contained in Appendix A, as are the time paths of revenue losses for production activities shown in Figure 5 (for the M 7.9 San Andreas Fault event) and Figure 6 (for the M 7.1 Hayward Fault event). These figures show the upper and lower bounds of the modeled revenue loss profiles as defined by production cutoff levels of 0.5 (high sensitivity) and 0.2 (low sensitivity), respectively.

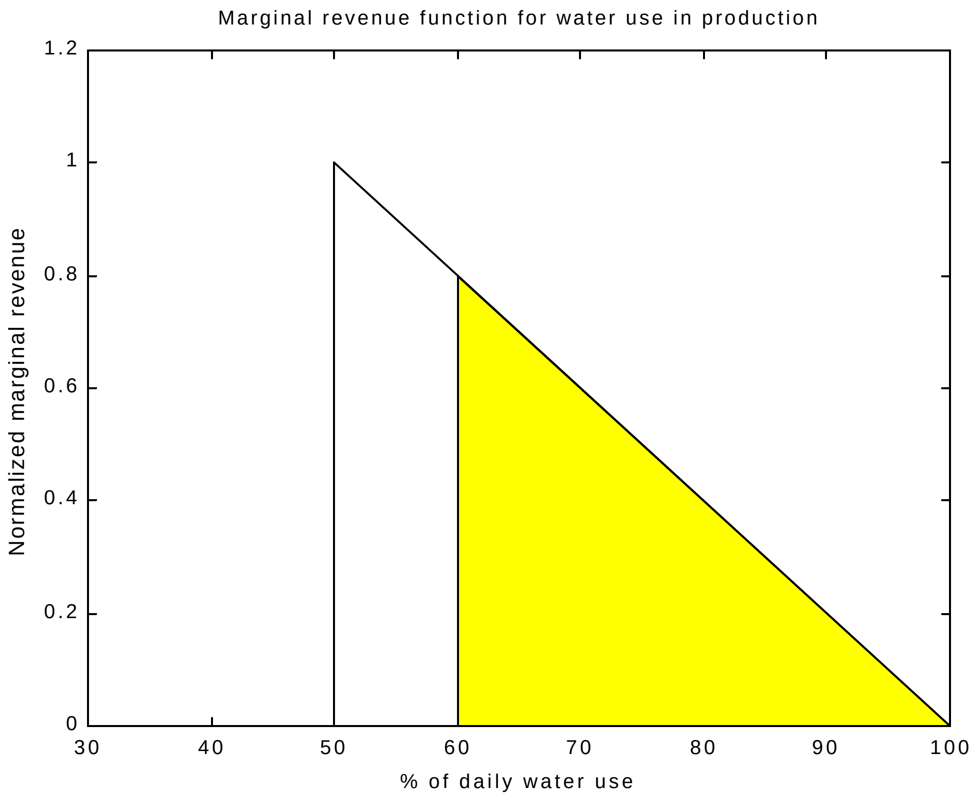


Figure 4. Marginal revenue function for water use in production. This figure depicts a cutoff level of 0.5: for water rationing levels below 50%, production activities cease (on average). The shaded area corresponds to the daily lost revenue resulting from rationing to 60% of normal daily levels.

San Andreas M 7.9 Earthquake

The economic losses to production activities resulting from water supply disruption following a magnitude 7.9 earthquake on the San Andreas Fault are shown in Appendix B, Table 4. The total losses to the five sectors of production supplied by the SFPUC water supply system are estimated at $14.2 billion over the sixty day period before the resumption of normal service. By sector, the total loss estimates are as follows: Manufacturing ($4.4 billion), Wholesale trade ($5.6 billion), Retail trade ($2.1 billion), Professional, scientific and technical services ($1.6 billion) and Accommodation and food services ($0.5 billion).

Hayward M 7.1 Earthquake

The economic losses to production activities resulting from water supply disruption following a magnitude 7.1 earthquake on the Hayward Fault are shown in Appendix B, Table 5. The total losses to the five sectors of production supplied by the SFPUC water supply system are estimated at $9.9 billion over the sixty day period before the resumption of normal service. By sector, the total loss estimates are as follows: Manufacturing ($3.4 billion), Wholesale trade ($4.4 billion), Retail trade ($1.2 billion), Professional, scientific and technical services ($0.6 billion) and Accommodation and food services ($0.2 billion).

Sensitivity Analysis For Manufacturing Losses

Total estimated damages for all production activities are $14.2 billion for the M 7.9 San Andreas Fault event and $9.9 billion for the M 7.1 Hayward Fault event. The loss estimates for production activities depend on the choice of production cutoff level.

Assuming a low sensitivity to water supply interruption (production cutoff equal to 0.2), the total estimated damages for all production activities are $13.8 billion for the M 7.9 San Andreas Fault event and $9.6 billion for the M 7.1 Hayward Fault event. For a high sensitivity to water supply interruption (production cutoff equal to 0.5), the total estimated damages for all production activities are $14.9 billion for the M 7.9 San Andreas Fault event and $10.2 billion for the M 7.1 Hayward Fault event. The range of damage estimates for these two earthquake scenarios and intermediate production cutoff levels are shown graphically in Figures 7 and 8 below. These figures show that the damage estimates are robust with respect to the choice of production cutoff level.

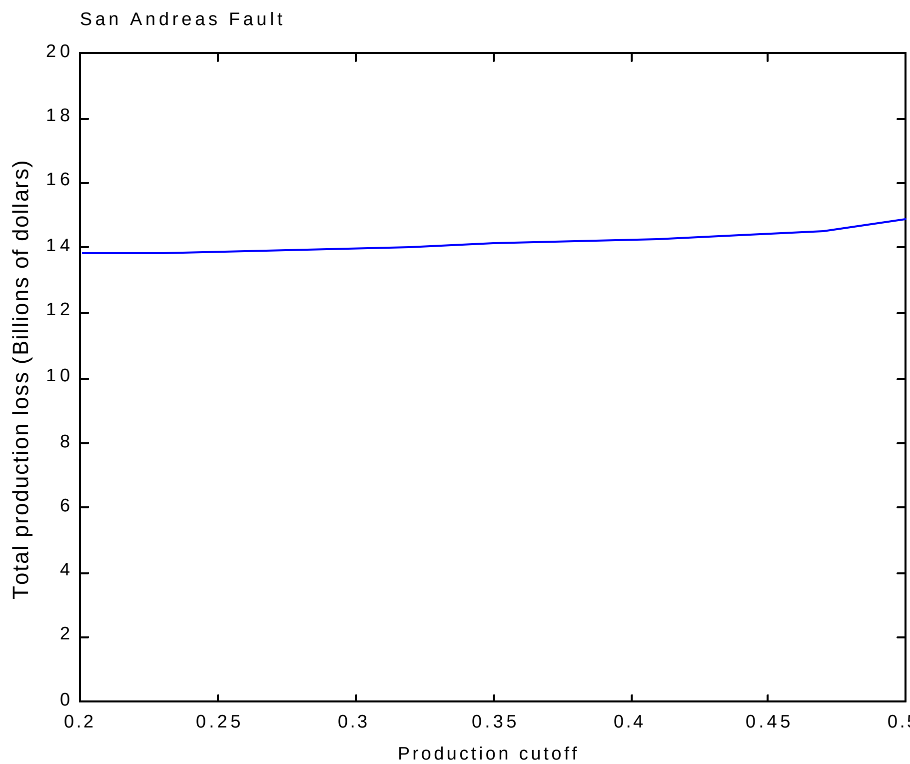


Figure 7. Sensitivity of production loss estimates to specification of production cutoff for the M 7.9 San Andreas Fault earthquake scenario.

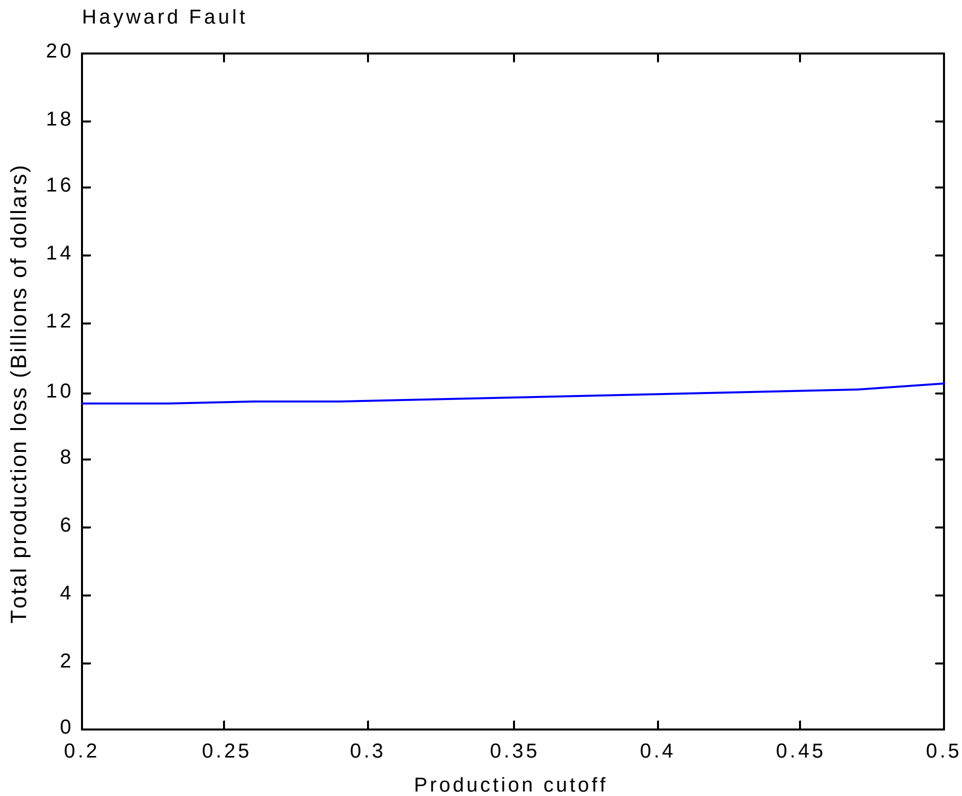


Figure 8. Sensitivity of production loss estimates to specification of production cutoff for the M 7.1 Hayward Fault earthquake scenario.

Water Supply Interruption and Fire-Related Losses

One of the major potential impacts of earthquake-induced water supply shortages is that the operation of emergency services may be compromised. In particular, if water is not available for firefighting purposes, fires can spread further or burn uncontrolled. Fire-related losses to property will thus almost certainly increase. Given the very high value of property in the Bay Area, if water shortages compromise firefighting by even a small amount, the resulting additional damages will be enormous.

In 1992, it was estimated that there were $655 billion in property values at risk from fire following earthquakes in the Bay Area (Scawthorn *et al.*, 1993). This figure represents the total value of residential, commercial, industrial, government and nonprofit property and vehicles. In the Bay Area, as elsewhere, the value of real estate is mostly a function of location. Also, damage estimates should not be based upon the total market value, as in general the value of the building site will not be seriously affected by earthquakes (further details are provided in the National Academy of Sciences publication *The Economic Consequences of a Catastrophic Earthquake*). As a conservative estimate, this analysis assumes that there is now a minimum of $1 trillion in property value at risk in the relevant portion of the Bay Area (the original studies considered the entire Bay Area, not just the portion served by the SFPUC).

Existing studies of the damages caused by fire following earthquakes (Scawthorn, 1987; Scawthorn *et al.*, 1993) do not model water supply disruption at an extremely detailed level, but use estimated levels of water supply functionality by damage regions. A 1987 study by Scawthorn assumes that in the event of a major earthquake on the San Andreas Fault, most regions within the SFPUC water supply area would be able to operate at close to normal functionality, which as this report indicates is not likely to be the case. The water supply disruptions predicted for both San Andreas and Hayward Fault events (as described in the report *Impact of Earthquakes on BAWUA Customers*) are significantly larger than that used in existing studies of fires following earthquakes.

Earlier studies of fire following earthquakes suggest that the post-earthquake fire risk is four to six times higher in the City of San Francisco than in the rest of the Bay Area. However, San Francisco has recently invested in a stand-alone fire suppression system that relies on seawater and covers roughly 75% of the City. In this study, it is assumed that this system has reduced San Francisco's fire risk by 75 – 85%, to the regional average.

Data from Scawthorn (1987) and Scawthorn *et al*. (1993) helps to determine wind speed scenarios, wind speed probabilities and total fire-related damage estimates. It is assumed that the additional water supply disruptions implied in current geotechnical studies will increase total damage by anywhere from 25-150%, depending on wind speed at the time of the earthquake. Hence, the additional fire damages caused by water supply interruption can be estimated as a function of wind speed and probability *(see Appendix B, Tables 6 and 7)*.

Using this methodology, the expected incremental fire damages caused by water supply disruptions are $10.7 billion for the M 7.9 San Andreas Fault event and $5.8 billion for the M 7.1 Hayward Fault event. By comparison, the 1991 Oakland Hills firestorm caused $1.7 billion in insured losses and an estimated total of $3.3 billion in total direct and indirect damages.

Other Sectors of the Economy

This analysis has only considered the major sectors of productive activity. There are several other important sectors whose losses due to earthquake-induced water supply disruption the Economic Forum has not attempted to quantify. In particular, these include the health care and social assistance sector. Water supply disruptions would adversely affect hospitals, nursing homes and other care facilities. Neither these costs, nor the potential costs associated with the public health effects of an extended water supply disruption, are addressed in this report.

Irreversible Damage

This analysis assumes that the only costs of water rationing are from lost revenue, and that the scale of economic output can be changed with no additional costs. This is clearly not the case, however. Manufacturing plants incur large losses when forced to suspend activity for an extended period of time. Because of losses sustained from an extended closure due to impaired water supply, some businesses may choose to relocate outside the Bay Area. Some production activities will not recover from a protracted shutdown following an earthquake-induced water shortage will close permanently. Surveys of individual industries may make it possible to quantify some of these economic losses.

The long-term damage from a reduced economic base could be considerable, even after the region as a whole has recovered from the immediate earthquake effects. These potential impacts are not included in the damage estimates in this report.

Water Supply Disruption vs. Other Earthquake Damage

This analysis focuses on the estimation of damages specifically related to earthquake-induced water supply disruption. Hence, it does not consider other damages related to earthquake shaking and associated effects. The implicit assumption used in generating damage estimates is that the only earthquake-related damages are to the water supply infrastructure, or caused as incremental fire damage.

Arguably, businesses and homes that are destroyed by ground shaking in an earthquake are unable to experience losses due to water supply shortages in the post-earthquake period. However, the total damage estimates are relatively insensitive to the effects of such double-counting. For example, if 10% of all businesses were destroyed in an earthquake, and thus 10% of the value of shipments at risk were excluded from the damage calculation, the damage estimates would decrease by ten percent, namely by $1.4 billion for the San Andreas event and $1 billion for the Hayward event. Similarly, if 3000 people were killed by the earthquake itself and were thus unable to experience any further economic loss from post-earthquake water shortages, the residential damage estimates would be reduced by 0.1%, namely $3.8 million for the San Andreas event and $1.5 million for the Hayward event. Economic losses from water-supply interruption to businesses and homes that are relatively undamaged in an earthquake thus far outweigh the double-counting of damages to destroyed property.

Clearly, economic damages due to loss of life or property in a major earthquake would be enormous. However, analyzing those costs is not the focus of this report.

Scenario-Based Estimates vs. Expected Damage Estimates

This report provides economic loss estimates from water supply disruptions under two specific earthquake scenarios, a M 7.9 event on the San Andreas Fault and a M 7.1 event on the Hayward Fault. It does not attach probabilities to these events and calculate expected damages, even though such a measure would be important if it could be reliably obtained. In order to calculate the correct expected damage measure, it is necessary to know all of the possible earthquakes that might occur. This includes not only all possible events of varying magnitude on the San Andreas and Hayward Faults, but also all possible events on all other faults. Given the current state of seismological science this is not possible. A graphic example is provided by the 1994 Northridge earthquake. This was the most damaging earthquake in recent U.S. history, with estimated total losses of $42 billion. However, the Northridge earthquake occurred on a fault that was unknown at the time of the earthquake, and would thus have had an expected damage of zero.

Total Damages from Water Supply Disruption due to Earthquake

The total damages related to earthquake-induced water supply interruptions for the SFPUC system can be estimated by adding the damages for residential, commercial, industrial and fire-related damages. Thus, for an M 7.9 event on the San Andreas Fault, it is estimated that the total damages from water supply disruption would be at least $28.7 billion. For an M 7.1 event on the Hayward Fault, estimated losses would total at least $17.2 billion (*see Appendix B for breakdown by community*).

Projected Losses from Water Service Interruption
(By Type of Seismic Event)

	San Andreas Fault (7.9)	Hayward Fault (7.1)
Residential Losses	**$ 3.8 billion**	**$ 1.5 billion**
Business Losses		
Manufacturing	$4.35 billion	$3.45 billion
Wholesale/Retail	7.70 billion	5.60 billion
Professional/Scientific/Technical	1.60 billion	0.63 billion
Lodging/Food Services	0.54 billion	0.20 billion
Total Business Losses	**$14.2 billion**	**$9.9 billion**
Fire Damage (from inadequate water supplies)	**$10.7 billion**	**$5.8 billion**
Total Estimated Losses:	**$28.7 billion**	**$17.2 billion**

As a further point of reference, after the last major drought, and during a period of economic and population growth in Silicon Valley, SFPUC considered the probable impacts of a prolonged water shortage. A June 1993 SFPUC response to a Federal Energy Regulatory Commission request for data describes Hetch Hetchy's importance to the semiconductor and computer industry users, which at the time accounted for 52% of water supplies for manufacturing. At that time, even before commercialization of the Internet and the dramatic growth of the tech industry in the late 1990s, those firms accounted for 32% of the region's manufacturing base, generating $12.5 billion annually in sales and supporting 96,000 jobs. SFPUC projected losses of $294 million a year and 2,000 jobs with a 15% reduction in Hetch Hetchy supply; $1 billion annually and 7,000 jobs with a 30% supply shortage; and $3 billion and 20,000 jobs with a sustained 50% shortage. Those numbers were intended to reflect an extended drought situation, where the reduction in water supplies is gradual, with no accompanying physical damage to property or infrastructure and ample time to plan contingencies.

A January 1995 earthquake measuring 7.0 in the Japanese port city of Kobe offers another insight into the kind of damages the Bay Area might face, although building standards and some other factors differ. According to a report commissioned by BAWUA, 580,000 customers lost all water supplies within 12 hours and half of those remained without water two weeks later. Normal supply of 38 mgd dropped to 6.3 mgd. More than 100 of 119 storage tanks throughout the city did not have proper isolation valves and drained empty from lack of pressure. More than 800 tanker trucks were needed to deliver water, and 1,800 distribution pipe repairs were made. Most of the 234 fires on the day of the quake burned themselves out as cisterns and hydrants could not produce enough water. Three of seven wastewater treatment plants were badly damaged and untreated sewage flowed into temporary settling basins and shipping channels.

6. The Price of Inaction

SFPUC and its suburban customers are proposing a $3.6 billion bond issue for 77 capital improvement projects to upgrade Hetch Hetchy. The alternative is far more costly.

Repairing, expanding and seismically retrofitting the Hetch Hetchy system after years of deferred maintenance and neglect will require substantial work. SFPUC has proposed a Capital Improvement Program (CIP)of 77 regional and local San Francisco water projects, costing a total $3.6 billion, to be financed with revenue bonds and completed between 2003 and 2015. Of those, 37 projects involve regional water system improvements valued at $2.9 billion, some portion of which may be financed independently by a new suburban financing authority to carry the regional share of the bonding burden.

Among the major regional projects planned are:

- Expansion and structural reinforcement of the Bay Division Pipelines that transport water across the southern tip of San Francisco Bay, including cross-connections. Cost: $248.9 million

- A seismic upgrade of the Calaveras Dam, built in 1925. Cost: $150 million

- Seismic reinforcement of the Irvington Tunnel located near the Hayward Fault, including backup bypass capability. Cost: $143.9 million

- Expanded capacity for the Sunol Water Treatment Plant. Cost: $81.9 million

- Seismic reinforcement of the Sunset Reservoir, serving western San Francisco and the Peninsula. Cost: $44.8 million

Among the major San Francisco projects are:

- Adding 7 million gallons to San Francisco's recycled water supply, to free up potable water reserves. Cost: $102.7 million

- A new Cross Town Transmission Main linking primary reservoirs in the eastern and western portions of San Francisco. Cost: $17.4 million

- A new Northwest Reservoir serving the Presidio, Marina and portions of downtown San Francisco. Cost: $29.5 million

Revenue bonds covering the CIP are to be repaid with higher water rates for San Francisco and suburban customers. It is estimated that wholesale water rates will increase an average 8.8% annually over the life of the program, from 88 cents per unit today to $2.55 per unit in 2015. SFPUC retail rates to San Francisco customers are expected to increase an average 9.6% annually. Monthly residential water bills (excluding sewer charges) will likely rise from $35 today to $71 in 2015 (including added local distribution charges) in the BAWUA service area, and from $13 to $44 in San Francisco. Business rates are expected to double incrementally over 13 years.

CIP Program Costs (x1000)

	Project Costs	**Financing Costs**	**Total Costs**
San Francisco	$ 584,279	$130,759	$ 715,038
Regional (SF & BAWUA)	$2,380,444	$532,590	$2,913,034
Total Revenue Bonds:			**$3,628,072**

Source: BAWUA/January 2002

Three obstacles to the CIP and revenue bond proposals have been cost, governance, and confidence that the SFPUC can execute the plan on time and on budget. Suburban water agencies have been sharply critical of SFPUC delays in making needed capital improvements to the Hetch Hetchy system and have complained that even when BAWUA is involved in decision making processes, the final word for operational and financial decisions for the entire regional network rests with SFPUC, the city's Mayor and Board of Supervisors and San Francisco voters.

These and other concerns have led to a package of three bills – AB 1823 (Papan), AB 2058 (Papan) and SB 1870 (Speier) – that, among other provisions establish a new water district in the SFPUC service territory to facilitate regional decision making with local representation; permit separate financing of the San Francisco and suburban respective share of costs for improving the regional water system; require needed capital improvements to be made in a timely fashion; and ensure proportionate allocation of available SFPUC supplies in an emergency situation among San Francisco and suburban customers. The California State Legislature has passed and the Governor has signed all three bills, which are awaiting signature by the Governor as this report goes to press.

SFPUC's capital improvement program and financing assumptions have been independently certified by outside audit firm R.W. Beck, Inc. in May 2002 ,and subsequently evaluated by a blue ribbon panel convened at SFPUC's request to review the R.W. Beck findings. Despite the certification, both Beck and the blue-ribbon panel raised concerns that SFPUC may lack the in-house technical and project management expertise to execute the multiple, large projects included in the CIP over a 12-year time frame. Efforts to retain outside consulting support have to date met with opposition from San Francisco community interests and the San Francisco Board of Supervisors, and public discussion has surfaced about possible reorganization of SFPUC as an independent, self-financing agency like San Francisco International Airport.

Given the age, condition and vulnerability of the current Hetch Hetchy system the time required to complete work on the CIP; and the possibility of a major earthquake or other catastrophic event during that period, financing and implementation of the CIP must be assigned top priority for policy makers. It should be viewed as an essential first step in advance of management, governance and other structural changes needed to ensure a reliable, secure regional water system for the future.

7. A Vision for the Future

Hetch Hetchy's problems are the most immediate, but not the only challenge affecting the Bay Area's water security. The CIP is an essential first step toward a more integrated, flexible regional water system.

Unlike much of the region's building and transportation infrastructure, the Hetch Hetchy system has not been upgraded to current seismic standards. SFPUC's Capital Improvement Plan addresses a number of immediate and serious problems. It expands storage and treatment capacity for added system flexibility; performs long needed maintenance and repairs; seismically reinforces key facilities located close to major earthquake faults, using materials and engineering methods not available when those facilities were built or last upgraded; increases reverse flow pump and valve capability; and creates bypasses at key points so that critical facilities can be isolated in a disaster and closed for short-term inspections and maintenance in future. The current CIP does not include projects to resolve the projected shortfall in water supply.

The shift in December 2003 to a common chloramination standard for disinfecting water will increase regional flexibility. Hetch Hetchy water, local groundwater and other supplies can be more easily blended and made available through water agency and district interties. Distinct zones keeping different types of water separate can be consolidated to improve pressure and delivery during peak and low periods. To the extent that commercial and industrial users with pure water needs can adapt to blended supplies, their options will increase in the event of an interruption.

The recently completed SFPUC intertie with the Santa Clara Valley Water District and a third, larger intertie with the East Bay Municipal Utility District will also expand flexibility, as those districts have their own sources of supply. SCVWD accesses a mix of groundwater, local surface water and imported water from the State Water Project and federal Central Valley Project. EBMUD's principal source of supply is the Mokelumne River.

Seven Bay Area water agencies – the Alameda County Water District (ACWD), Bay Area Water Users Association (BAWUA), Contra Costa Water District (CCWD), East Bay Municipal Utility District (EBMUD), San Francisco Public Utilities Commission (SFPUC), Santa Clara Valley Water District (SCVWD) and the Zone 7 Water Agency - have recently formed the Bay Area Water Agencies Coalition (BAWAC) to facilitate planning and implementation for regional water supply and water resource management.

In an effort to ensure a local government and San Francisco regional voice in CALFED implementation in the Bay Area, the Association of Bay Area Governments (ABAG) has convened the ABAG-CALFED Task Force. The Task Force, composed of officials of both water supply/wastewater agencies and local government, meets quarterly to discuss CALFED implementation and linkages between land use decision making and regional water supply reliability. The same agencies are involved in regional water resource planning as part of the ABAG-CALFED Task Force's Water Management Committee. Some agencies have also received U.S. Environmental Protection Agency grants made available after the September 11 terrorist attacks to conduct vulnerability assessments of their facilities, and that work, done in conjunction with the Bay Area Security Information Collaborative effort, should also prove helpful in supply planning.

Bay Area policy makers face long-term choices about how water is collected, stored, delivered used and priced. The central question is how to integrate and expand the regional water network for more efficient delivery, optimize use and allocation to reduce waste and build flexibility for emergencies, and serve a growing customer base. A general consensus is emerging among government leaders and water experts about what a vision for a flexible, reliable regional water system might include:

– Storage of additional surface runoff in wet years;

– Full interconnection among districts, local agencies and large customers;

– Full emergency two-way flow capability;

– Adequate valving and bypassing in the event of failures;

– Increased blending and consolidation of pressure zones; and

– Optimized conservation, recycling and re-use, in particular increasing the supply and availability of recycled water for non-potable uses such as landscaping.

These and other strategies can increase water availability and reliability without the need to build new dams in the Sierra. They can also help direct regional water quickly where it is most needed, whether in an emergency situation or to accommodate regional growth, and reduce the use of high-quality drinking water for non-potable uses such as outdoor landscape irrigation. Implementation of most of these strategies will involve added costs to consumers, and public debate.

Today the Bay Area is a long way from such a system. ABAG estimates that several hundred large and small, public and private water entities supply customers throughout the greater Bay Area. Most only have interconnections to adjacent communities in the event of a drought or shutdown of their systems for a short time for repairs and maintenance. The ABAG-CALFED Water Management Committee is identifying and mapping those providers for the first time in a single, comprehensive GIS database. Additionally, the State Department of Water Resources is collecting and compiling the water management plans of local water agencies and county districts. These efforts will provide important insight into current and projected land use considerations relating to water.

Water agencies and local governments are also cooperating on two programs aimed at improved integration – the Bay Area Regional Water Recycling Program, exploring comprehensive recycling solutions to lower costs, and the Bay Area Water Quality and Supply Reliability Program, which is studying alternative projects to improve water quality and water supply reliability for the Bay Area.

These processes are important to the development of a coherent, long-term Bay Area water strategy. However, decisions affecting the improvement to the SFPUC's Hetch system are before voters and regional decision makers today. The Hetch Hetchy water system is critical regional asset, providing an essential commodity to much of the Bay Area. Its deteriorating condition places the regional economy and the welfare of millons of Bay Area residents at risk Effecting the necessary repairs and improvements to assure Hetch Hetchy's continued reliability, and developing it as part of a larger, integrated water security strategy, is critical to the Bay Area's economic security, competitiveness and quality of life.

Appendixes

Appendix A: Methodology for Economic Analysis

Estimation of Residential Sector Losses

In order to analyze earthquake-induced welfare losses, it is necessary to construct a willingness to pay (or marginal welfare) function for residential consumers. During an emergency water shortage, we assume that residential water users will have a bipartite marginal value function for water use (Figure 3). The total welfare loss from a water shortage is then given by the summation

$$\sum_{i}\sum_{t=1}^{60} N_i \cdot \left\{ \boldsymbol{q}_i(t)\cdot W_i(0) + \left(1-\boldsymbol{q}_i(t)\right)\cdot W_i\left(z_i(t)\right)\right\}$$

The subscript *i* corresponds to each water service provider and t is the number of days after the earthquake. Following existing geotechnical reports, it is assumed that resumption of full service for the SFPUC water supply system will take up to 60 days following a major earthquake. The variable $q_i(t)$ is the proportion of residential consumers within water service provider *i*'s service area that are experiencing water outages at time *t*. The variable N_i is the total number of residents in the service area of water service provider *i*, and $z_i(t)$ is the severity of rationing at time *t* in service area *i* (for those residents receiving piped water but experiencing rationing). Finally, $W_i(z_i(t))$ is the daily individual welfare loss from rationing of severity $z_i(t)$ for water service provider *i*. The variables $q_i(t)$ and $z_i(t)$ are defined for each group of water service providers, for each earthquake scenario, as shown in Figures 1 and 2. The daily individual welfare loss $W_i(z_i(t))$ is given by the formula

$$W_i\left(z_i(t)\right) = \begin{cases} if\ z_i(t)\cdot X_i > BWR \\ \dfrac{\left(1-z_i(t)\right)^2 \cdot X_i{}^2 \cdot P_b}{2\cdot\left(X_i - BWR\right)} \\ \\ if\ z_i(t)\cdot X_i \le BWR \\ \dfrac{\left(X_i - BWR\right)\cdot P_b}{2} + \left(\dfrac{\left(BWR - z_i(t)\cdot X_i\right)\cdot\left(P_b' - P_b\right)}{2\cdot BWR} + P_b\right)\cdot\left(BWR - z_i(t)\cdot X_i\right) \end{cases}$$

The constant *BWR* is the Basic Water Requirement, and the constants P_b' and P_b are the upper and lower bounds of the backstop price, respectively. Finally, the variable X_i is the average daily demand for water (in gallons per capita per day) for water service provider *i*.

Estimation of Manufacturing/Production Losses

For geographic group *j* at time *t* days after a major earthquake, the lost revenue, $L(j,t)$, in any given sector is given by

$$L(j,t)=\begin{cases} V_j\cdot\left[q_j(t)+\left(1-q_j(t)\right)\cdot\dfrac{\left(1-z_j(t)\right)^2}{2\cdot(1-g)}\right] & if\ g<z_j(t) \\ V_j & if\ g\ge z_j(t)\end{cases}$$

where $q_j(t)$ and $z_j(t)$ are the proportion of SFPUC customers in group *j* with no piped supply and the rationing level for those customers who are receiving water, respectively. The constant V_j is the daily value of shipments for each economic sector for group j, obtained from the 1997 U.S. Census. Finally, the constant g is the cutoff proportion of normal daily water demand at which manufacturing activity ceases. We analyze a range of values from 0.2 to 0.5 for the cutoff proportion. These model the effects of both high and low industry sensitivities to water supply interruption. The time paths of revenue losses for production activities are shown in Figure 5 (for the M 7.9 San Andreas Fault event) and Figure 6 (for the M 7.1 Hayward Fault event). These figures show the upper and lower bounds of the modeled revenue loss profiles as defined by production cutoffs of 0.5 (high sensitivity) and 0.2 (low sensitivity), respectively. Results of the loss modeling are presented in Tables 4 and 5. These tables present both the mean loss estimates and the range observed with high and low production cutoff sensitivity. The loss is calculated as the mean of ten model runs with production cutoffs uniformly distributed in the range [0.2, 0.5].

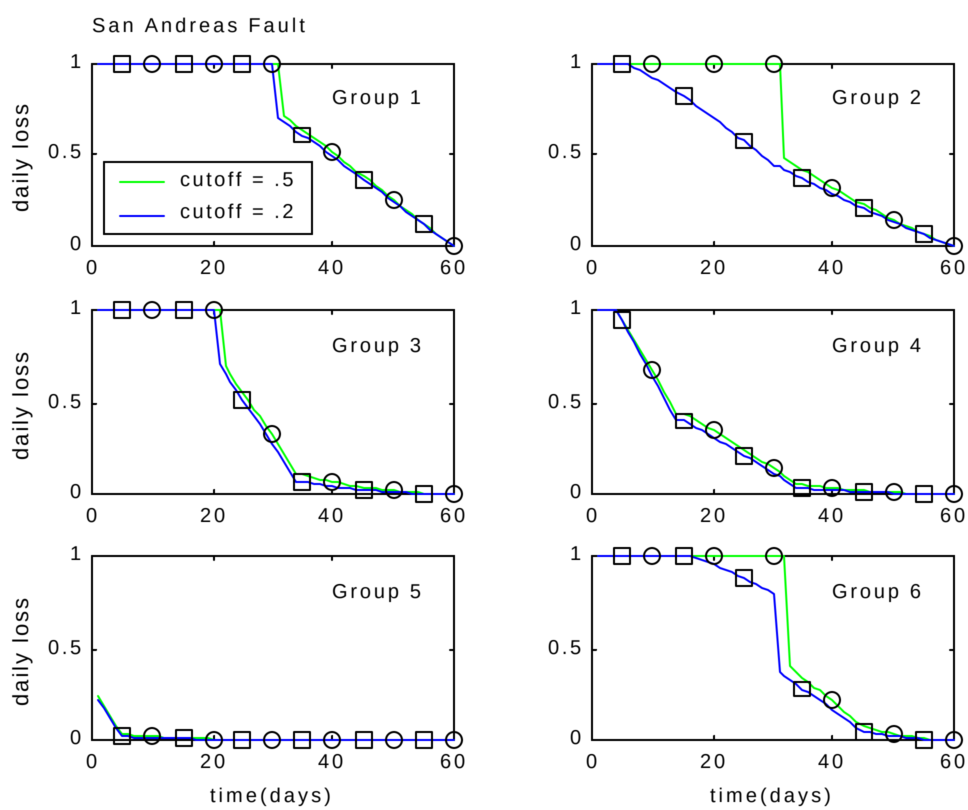


Figure 5. Time paths of revenue losses for production sectors following a M 7.9 earthquake on the San Andreas Fault. The vertical axis shows the daily revenue lost as a proportion of normal daily

revenue generation for each sector. Revenue loss profiles are shown for high (green lines and open circles) and low sensitivities (blue lines and open boxes) to unscheduled water supply interruption, defined by production cutoffs of 0.5 and 0.2, respectively. Group membership by BAWUA and other agencies is defined as follows: Group 1 (Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Estero, Guadalupe Valley, Hillsborough, Millbrae, North Coast, Westborough),

Group 2 (Daly City, San Bruno), Group 3 (Belmont, CWS – Bear Gulch, Cordilleras, East Palo Alto, Los Trancos, Menlo Park, Palo Alto (City), Purissima Hills, Redwood City, San Jose, Skyline), Group 4 (Milpitas, Mountain View, Santa Clara, Stanford, Sunnyvale), Group 5 (ACWD, Hayward), Group 6 (San Francisco).

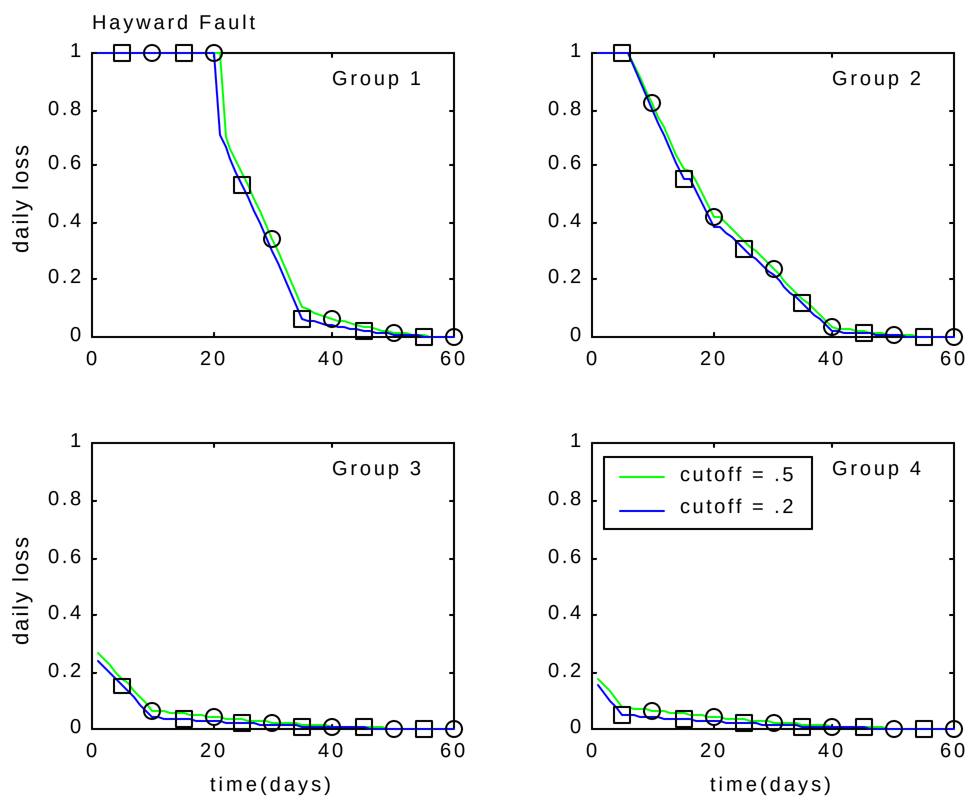


Figure 6. Time paths of revenue losses for production sectors following a M 7.1 earthquake on the Hayward Fault. The vertical axis shows the daily revenue lost as a proportion of normal daily revenue generation for each sector. Revenue loss profiles are shown for high (green lines and open circles) and low sensitivities (blue lines and open boxes) to unscheduled water supply interruption, defined by production cutoffs of 0.5 and 0.2, respectively. Group membership by BAWUA and other agencies is defined as follows: Group 1 (CWS – Bear Gulch, *Cordilleras*, East Palo Alto, Hayward, *Palo Alto (City)*, *Redwood City*, *San Jose*, Skyline), Group 2 (ACWD, Milpitas, Santa Clara, *Stanford*, Sunnyvale), Group 3 (San Francisco), Group 4 (Belmont, Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Coastside, *Cordilleras*, Daly City, Estero, Guadalupe Valley, Hillsborough, Los Trancos, Menlo Park, Millbrae, Mountain View, North Coast, *Palo Alto (City)*, Purissima Hills, *Redwood City*, San Bruno, *Stanford*, Westborough). Italics denote cities with partial shortages within the group.

Group	*Manuf.*	*Wholesale Trade*	*Retail Trade*	*Prof. and Tech.*	*Accomm. and Food*	*Group Total*
1	$247 *[$245-$250]*	$541 *[$538-$547]*	$270 *[$269-$274]*	$119 *[$119-$121]*	$51 *[$51-$52]*	$1,228 *[$1,222-$1,244]*
2	$195 *[$179-$226]*	$428 *[$393-$495]*	$214 *[$197-$248]*	$94 *[$87-$109]*	$40 *[$37-$47]*	$971 *[$893-$1,125]*
3	$2,267 *[$2,231-$2,332]*	$2,329 *[$2,292-$2,396]*	$660 *[$650-$679]*	$381 *[$375-$392]*	$108 *[$107-$111]*	$5,745 *[$5,655-$5,910]*
4	$1,257 *[$1,221-$1,305]*	$1,181 *[$1,147-$1,225]*	$289 *[$281-$300]*	$181 *[$176-$188]*	$45 *[$44-$47]*	$2,953 *[$2,869 - $3,065]*
5	$25 *[$23-$27]*	$53 *[$49-$58]*	$14 *[$13-$15]*	$4 *[$4-$5]*	$2 *[$2-$2]*	$98 *[$91-$107]*
6	$361 *[$349-$386]*	$1,108 *[$1,071-$1,186]*	$616 *[$596-$660]*	$818 *[$790-$875]*	$298 *[$288-$319]*	$3,201 *[$3,094-$3,426]*
Sector Total	$4,352 *[$4,248-$4,526]*	$5,640 *[$5,490 - $5,907]*	$2,063 *[$2,006-$2,176]*	$1,597 *[$1,551-$1,690]*	$544 *[$529-$578]*	**$14,196** ***[$13,824-$14,877]***

Table 4. Economic damage resulting from a San Andreas Fault M 7.9 earthquake. Damage figures are in millions of dollars. Values in square brackets are low and high sensitivity estimates (production cutoffs of 0.2 and 0.5, respectively). Groups are defined as follows:

- Group 1 (Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Estero, Guadalupe Valley, Hillsborough, Millbrae, North Coast, Westborough)
- Group 2 (Daly City, San Bruno)
- Group 3 (Belmont, CWS – Bear Gulch, Cordilleras, East Palo Alto, Los Trancos, Menlo Park, Palo Alto (City), Purissima Hills, Redwood City, San Jose, Skyline)
- Group 4 (Milpitas, Mountain View, Santa Clara, Stanford, Sunnyvale)
- Group 5 (ACWD, Hayward)
- Group 6 (San Francisco)

Group	*Manuf.*	*Wholesale Trade*	*Retail Trade*	*Prof. and Tech.*	*Accomm. and Food*	*Group Total*
1	$1,977 *[$1,947 - $2,033]*	$2,551 *[$2,512- $2,623]*	$728 *[$717-$749]*	$352 *[$346-$362]*	$113 *[$111-$116]*	$5,721 *[$5,633- $5,883]*
2	$1,338 *[$1,312- $1,372]*	$1,619 *[$1,587- $1,660]*	$406 *[$398-$416]*	$201 *[$198-$207]*	$58 *[$57-$60]*	$3,622 *[$3,552- $3,715]*
3	$26 *[$23-$30]*	$79 *[$70-$91]*	$44 *[$39-$51]*	$58 *[$51-$68]*	$21 *[$19-$25]*	$228 *[$202-$265]*
4	$107 *[$89-$132]*	$126 *[$104-$156]*	$42 *[$35-$52]*	$22 *[$18-$28]*	$7 *[$6-$9]*	$304 *[$252-$377]*
Sector Total	$3,448 *[$3,371- $3,567]*	$4,375 *[$4,273- $4,530]*	$1,220 *[$1,189- $1,268]*	$633 *[$613-$665]*	$199 *[$193-$210]*	**$9,875** ***[$9,639- $10,240]***

Table 5. Economic damage resulting from a Hayward Fault M 7.1 earthquake.
Damage figures are in millions of dollars. Values in square brackets are low and high sensitivity estimates (production cutoffs of 0.2 and 0.5, respectively). Groups are defined as follows:

- Group 1 (CWS – Bear Gulch, *Cordilleras*, East Palo Alto, Hayward, *Palo Alto (City)*, *Redwood City*, *San Jose*, Skyline)
- Group 2 (ACWD, Milpitas, Santa Clara, *Stanford*, Sunnyvale)
- Group 3 (San Francisco)
- Group 4 (Belmont, Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Coastside, *Cordilleras*, Daly City, Estero, Guadalupe Valley, Hillsborough, Los Trancos, Menlo Park, Millbrae, Mountain View, North Coast, *Palo Alto (City)*, Purissima Hills, *Redwood City*, San Bruno, *Stanford*, Westborough)

Italics denote cities with partial shortages within the group.

Appendix B:

<u>Estimated Welfare and Economic Losses by Locality and Type</u>

Group Number	*Agencies*	*Residential welfare loss*
1	Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Estero, Guadalupe Valley, Hillsborough, Millbrae, North Coast, Westborough	$1,038
2	Daly City, San Bruno	$204
3	Belmont, CWS – Bear Gulch, Cordilleras, East Palo Alto, Los Trancos, Menlo Park, Palo Alto (City), Purissima Hills, Redwood City, San Jose, Skyline	$552
4	Milpitas, Mountain View, Santa Clara, Stanford, Sunnyvale	$375
5	ACWD, Hayward	$22
6	San Francisco	$1,582
	Total	*$3,774*

Table 1. Residential welfare losses for BAWUA customers resulting from a San Andreas Fault M 7.9 Earthquake. Values are in millions of dollars.

Group Number	*Agencies*	*Residential welfare loss*
1	CWS – Bear Gulch, *Cordilleras*, East Palo Alto, Hayward, *Palo Alto (City)*, *Redwood City*, *San Jose*, Skyline	$514
2	ACWD, Milpitas, Santa Clara, *Stanford*, Sunnyvale	$766
3	San Francisco	$122
4	Belmont, Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Coastside, *Cordilleras*, Daly City, Estero, Guadalupe Valley, Hillsborough, Los Trancos, Menlo Park, Millbrae, Mountain View, North Coast, *Palo Alto (City)*, Purissima Hills, *Redwood City*, San Bruno, *Stanford*, Westborough	$73
	Total	*$1,475*

Table 2. Residential welfare losses for BAWUA customers resulting from a Hayward Fault M 7.1 Earthquake. Values are in millions of dollars. Italics denote cities with partial shortages within the group.

Sector	*Manuf.*	*Wholesale trade*	*Retail trade*	*Prof. and Tech.*	*Accomm. and Food*	*Total*
San Francisco County	$3,979	$12,219	$6,795	$9,017	$3,283	*$35,293*
San Mateo County	$6,690	$14,663	$7,335	$3,235	$1,380	*$33,303*
Santa Clara County	$72,528	$68,095	$16,674	$10,441	$2,592	*$170,330*
Alameda County	$22,338	$47,791	$12,405	$3,875	$1,574	*$87,983*
Total	*$105,535*	*$142,768*	*$43,209*	*$26,568*	*$8,829*	*$326,909*

Table 3. Total value of shipments for the five sectors used in the production loss analysis for San Francisco, San Mateo, Santa Clara and Alameda Counties. All figures are in millions of dollars. Data from the 1997 Economic Census, U.S. Census Bureau.

Group	*Manuf.*	*Wholesale Trade*	*Retail Trade*	*Prof. and Tech.*	*Accomm. and Food*	*Group Total*
1	$260 *[$253-$271]*	$570 *[$554-$595]*	$285 *[$277-$298]*	$126 *[$122-$131]*	$54 *[$52-$56]*	$1,295 *[$1,258-$1,351]*
2	$231 *[$207-$257]*	$505 *[$454-$564]*	$253 *[$227-$282]*	$111 *[$100-$124]*	$48 *[$43-$53]*	$1,148 *[$1,031-$1,280]*
3	$2,631 *[$2,428-$2,939]*	$2,703 *[$2,494-$3,020]*	$766 *[$707-$856]*	$442 *[$408-$494]*	$126 *[$116-$140]*	$6,668 *[$6,153-$7,449]*
4	$1,646 *[$1,430-$1,974]*	$1,546 *[$1,343-$1,853]*	$378 *[$329-$454]*	$237 *[$206-$284]*	$59 *[$51-$71]*	$3,866 *[$3,359-$4,636]*
5	$45 *[$34-$63]*	$97 *[$72-$134]*	$25 *[$19-$35]*	$8 *[$6-$11]*	$3 *[$2-$4]*	$178 *[$133-$247]*
6	$412 *[$381-$453]*	$1,264 *[$1,171-$1,391]*	$703 *[$651-$773]*	$933 *[$864-$1,026]*	$340 *[$315-$374]*	$3,652 *[$3,382-$4,017]*
Sector Total	$5,225 *[$4,733-$5,957]*	$6,685 *[$6,088-$7,557]*	$2,410 *[$2,210-$2,698]*	$1,857 *[$1,706-$2,070]*	$630 *[$579-$698]*	**$16,807** ***[$15,316-$18,980]***

Table 4. Economic damage resulting from a San Andreas Fault M 7.9 earthquake. Damage figures are in millions of dollars. Values in square brackets are low and high sensitivity estimates (production cutoffs of 0.2 and 0.5, respectively). Groups are defined as follows:

- Group 1 (Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Estero, Guadalupe Valley, Hillsborough, Millbrae, North Coast, Westborough)
- Group 2 (Daly City, San Bruno)
- Group 3 (Belmont, CWS – Bear Gulch, Cordilleras, East Palo Alto, Los Trancos, Menlo Park, Palo Alto (City), Purissima Hills, Redwood City, San Jose, Skyline)
- Group 4 (Milpitas, Mountain View, Santa Clara, Stanford, Sunnyvale)
- Group 5 (ACWD, Hayward)
- Group 6 (San Francisco)

Group	*Manuf.*	*Wholesale Trade*	*Retail Trade*	*Prof. and Tech.*	*Accomm. and Food*	*Group Total*
1	$2,285 *[$2,113-$2,546]*	$2,949 *[$2,727-$3,285]*	$842 *[$778-$938]*	$407 *[$376-$453]*	$130 *[$120-$145]*	$6,613 *[$6,114-7,367]*
2	$1,619 *[$1,463-$1,855]*	$1,958 *[$1,770-$2,244]*	$491 *[$444-$563]*	$244 *[$220-$279]*	$71 *[$64-$81]*	$4,383 *[$3,961-$5,022]*
3	$59 *[$40-$86]*	$180 *[$124-$266]*	$100 *[$69-$148]*	$133 *[$92-$196]*	$48 *[$33-$71]*	$520 *[$358-$767]*
4	$310 *[$198-$481]*	$365 *[$232-$565]*	$122 *[$78-$189]*	$65 *[$41-$100]*	$21 *[$13-$33]*	$883 *[$562-$1,368]*
Sector Total	$4,273 *[$3,814-$4,968]*	$5,452 *[$4,853-$6,360]*	$1,555 *[$1,369-$1,838]*	$849 *[$729-$1,028]*	$270 *[$230-$330]*	**$12,399** ***[$10,995-$14,524]***

Table 5. Economic damage resulting from a Hayward Fault M 7.1 earthquake.
Damage figures are in millions of dollars. Values in square brackets are low and high sensitivity estimates (production cutoffs of 0.2 and 0.5, respectively). Groups are defined as follows:

- Group 1 (CWS – Bear Gulch, *Cordilleras*, East Palo Alto, Hayward, *Palo Alto (City)*, *Redwood City*, *San Jose*, Skyline)
- Group 2 (ACWD, Milpitas, Santa Clara, *Stanford*, Sunnyvale)
- Group 3 (San Francisco)
- Group 4 (Belmont, Brisbane, Burlingame, CWS – Mid Peninsula, CWS – South San Francisco, Coastside, *Cordilleras*, Daly City, Estero, Guadalupe Valley, Hillsborough, Los Trancos, Menlo Park, Millbrae, Mountain View, North Coast, *Palo Alto (City)*, Purissima Hills, *Redwood City*, San Bruno, *Stanford*, Westborough)

Italics denote cities with partial shortages within the group.

Wind Speed Scenario	Probability	Fire damage to property	Water supply interruption excess damage	Excess damage to property at risk	Expected damage (billions)
0 – 15 mph	0.70	1.5%	25 – 50%	0.56%	$3.9
15 – 30 mph	0.28	3.3%	25 – 100%	2.06%	$5.8
>30 mph	0.02	5.5%	25 – 150%	4.81%	$1.0
				Total expected damage	*$10.7*

Table 6. Estimate of property damage related to fire following earthquake with water supply interruption, M 7.9 San Andreas Fault earthquake scenario. Wind speed scenarios, probabilities and baseline damages are based on Scawthorn (1987). Damage estimates assume a total of $1 trillion of property at risk.

Wind Speed Scenario	Probability	Fire damage to property	Water supply interruption excess damage	Excess damage to property at risk	Expected damage (billions)
0 – 15 mph	0.70	0.8%	25 – 50%	0.30%	$2.1
15 – 30 mph	0.28	1.8%	25 – 100%	1.13%	$3.2
>30 mph	0.02	3.0%	25 – 150%	2.63%	$0.5
				Total expected damage	*$5.8*

Table 7. Estimate of property damage related to fire following earthquake with water supply interruption, M 7.1 Hayward Fault earthquake scenario. Wind speed scenarios, probabilities and baseline damages are based on Scawthorn (1987) and Scawthorn *et al.* (1993). Damage estimates assume a total of $1 trillion of property at risk.

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Appendix D: Acknowledgements

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