

FIRE FOLLOWING EARTHQUAKE



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The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report



Edited by
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EQE International, Inc.

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Technical Report MCEER-00-0001
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Earthquake Insurance in Turkey



History of the Turkish Catastrophe Insurance Pool

EUGENE GURENKO
RODNEY LESTER
OLIVIER MAHUL
SERAP OGUZ GONULAL

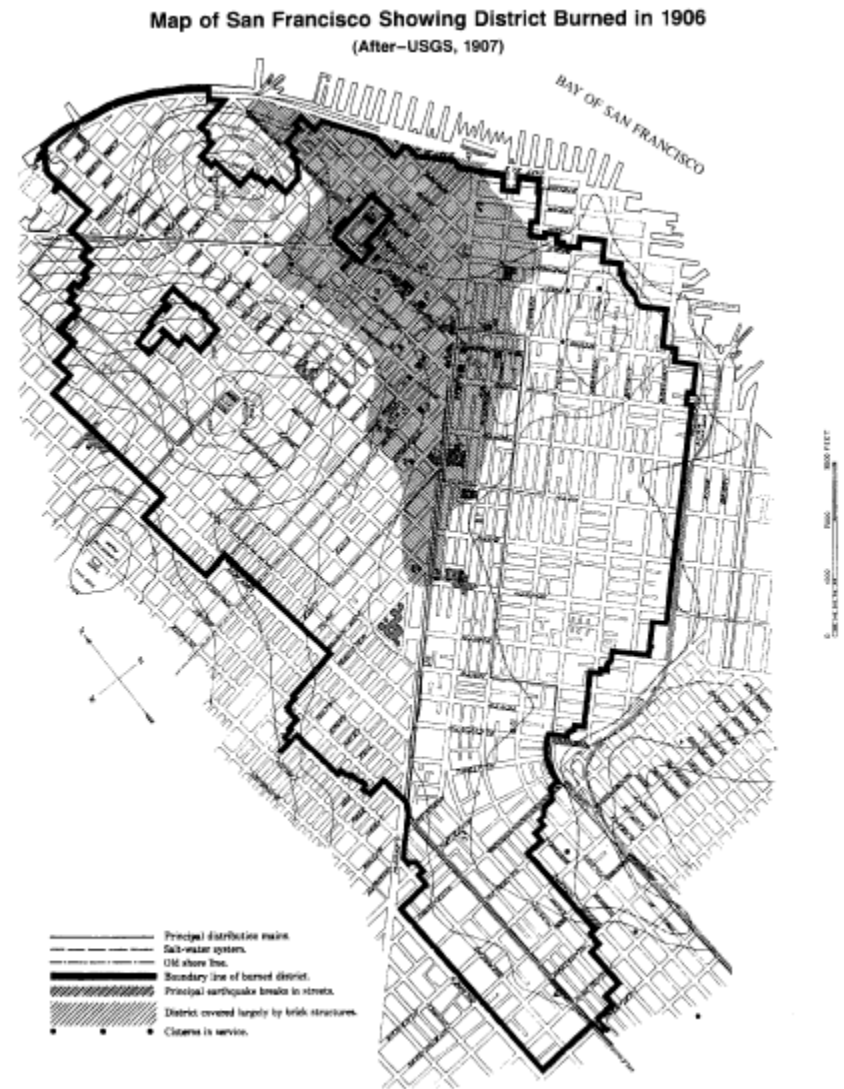
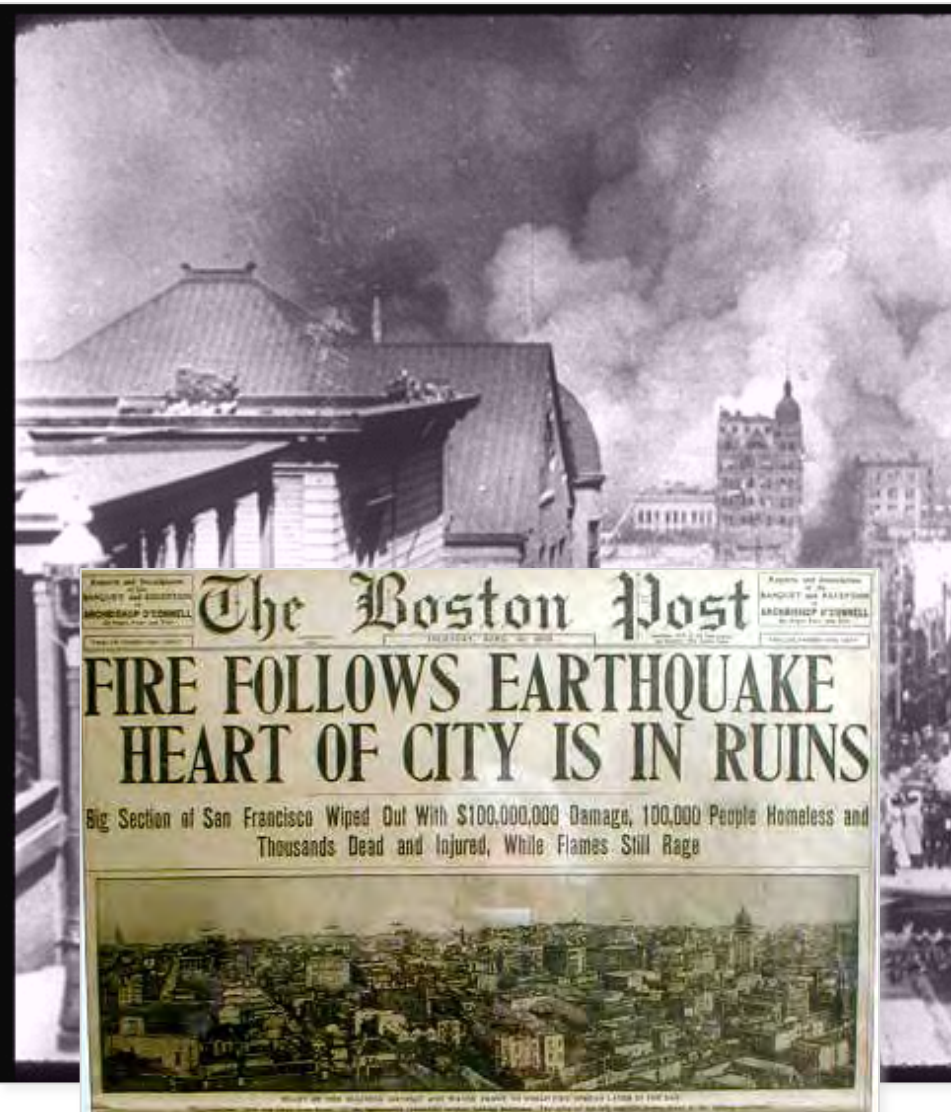


THE WORLD BANK

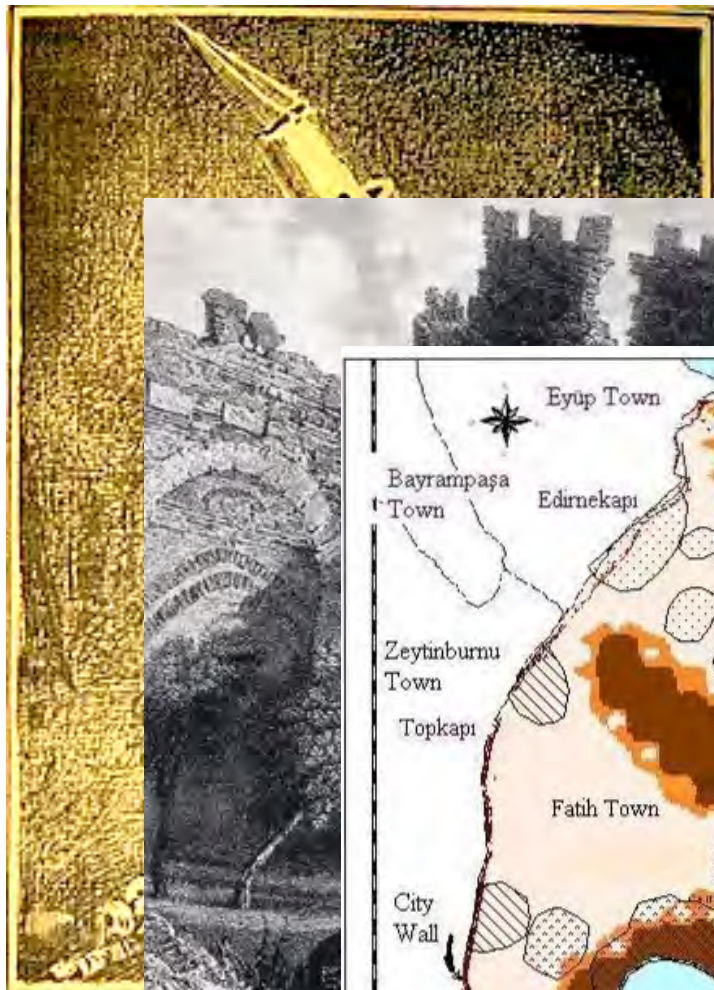
Outline

- Fire following earthquake (FFE) – *why do you care?*
- Overview of FFE
- Analysis of FFE
 - Assets at Risk and Ignitions
 - Communications / Water Supply
 - Fire Response and Spread
- FFE risk for several cities
- FFE Mitigation
- Recent Advances
- Concluding Remarks

Fire following earthquake (FFE) – *why do you care?*







1894 Earthquake (Istanbul)





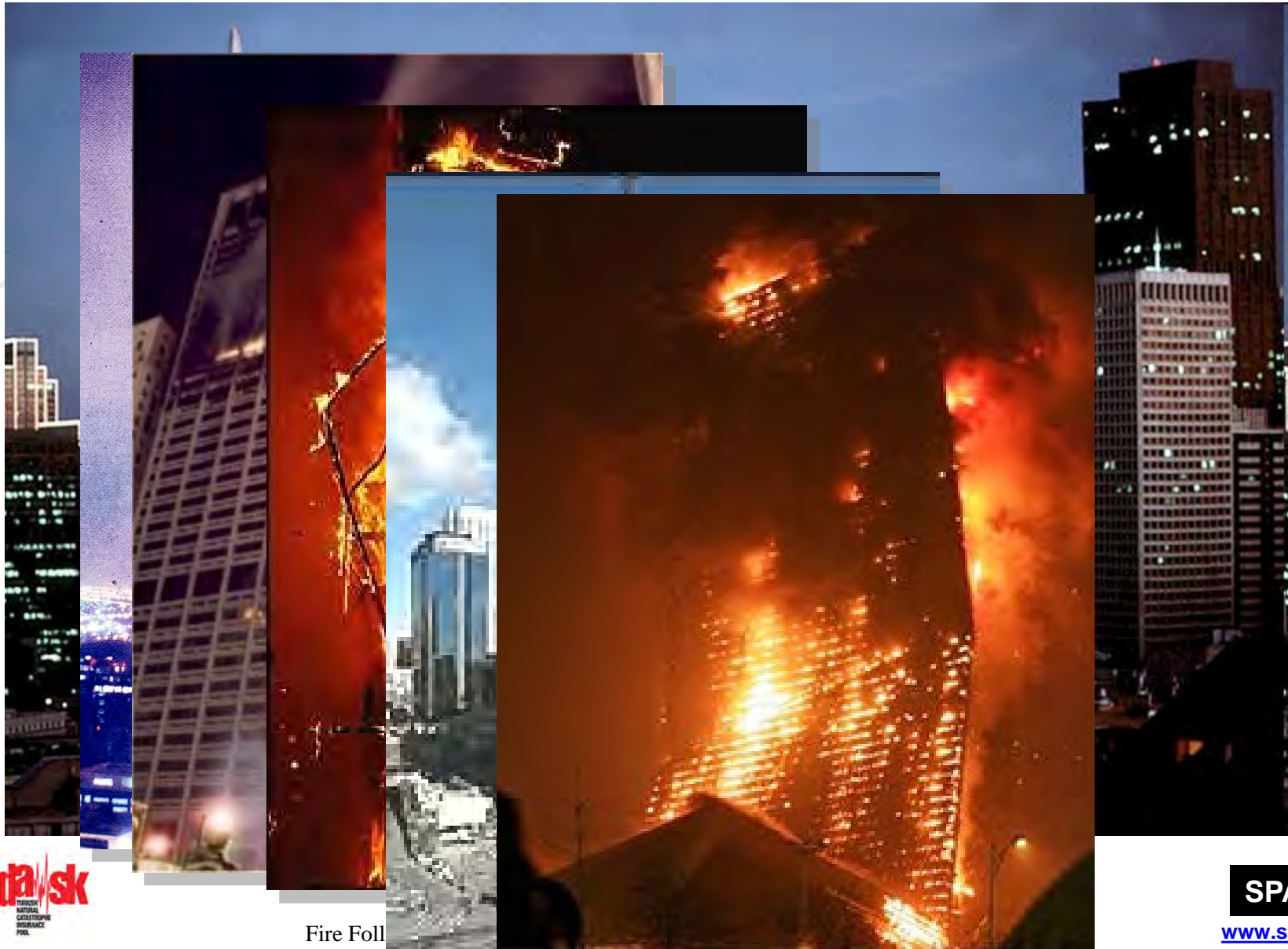
Taksim hospital 2018





Photograph by G. Johnson

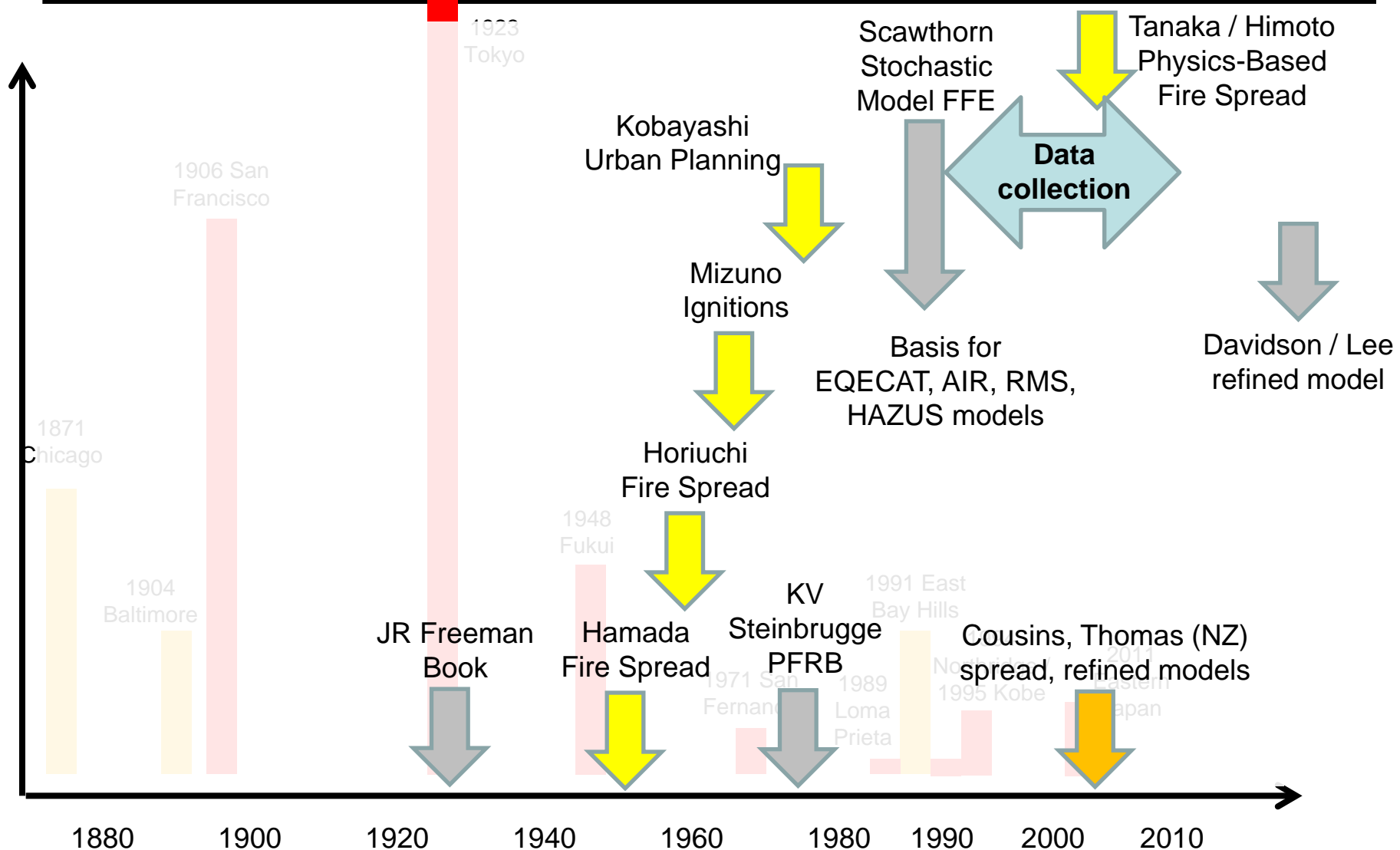
The Problem is Exacerbated Today



Fukushima 2011 – fire following earthquake and tsunami



FFE – Historical Overview



Analysis

Fire-Related Aspects
of the Northridge Earthquake

October 1996

Prepared for:

BUILDING AND FIRE RESEARCH
NATIONAL INSTITUTE OF STANDARDS

FIRE FOLLOWING EARTHQUAKE

Edited by
Charles Scawthorn, John M. Eidinger, and Anshel J. Schiff



Technical Council on Lifeline Earthquake Engineering
Monograph No. 26



Earthquake

San Francisco Bay
in Francisco Area

Bay Bridge

$E[FL|SA]$

International

SPA Risk

www.sparisk.com

Field Investigations

Earthquakes

- 1978 Miyagiken-oki
- 1983 Coalinga
- 1984 Morgan Hill
- 1985 Mexico City
- 1987 Whittier
- 1989 Loma Prieta
- 1993 Hokkaido SW
- 1994 Northridge
- 1995 Kobe
- 1999 Marmara
- 1999 Taiwan
- 2000 Nisqually
- 2004 Indian Ocean Tsunami
- 2005 Pakistan
- 2008 Wenchuan (China)
- 2011 Japan Tsunami

Fires

- 1982 Anaheim
- 1984 Baldwin Hills (LA)
- 1990 First Interstate Bldg
- 1991 East Bay Hills
- 1992 S. Calif. Wildfires
- 1993 S. Calif. Wildfires
- 1999 Oakland Bldg. Fire/collapse
- 2003 S. Calif. Wildfires
- 2010 San Bruno Gas Explosion
- 2011 Japan Tsunami FFE

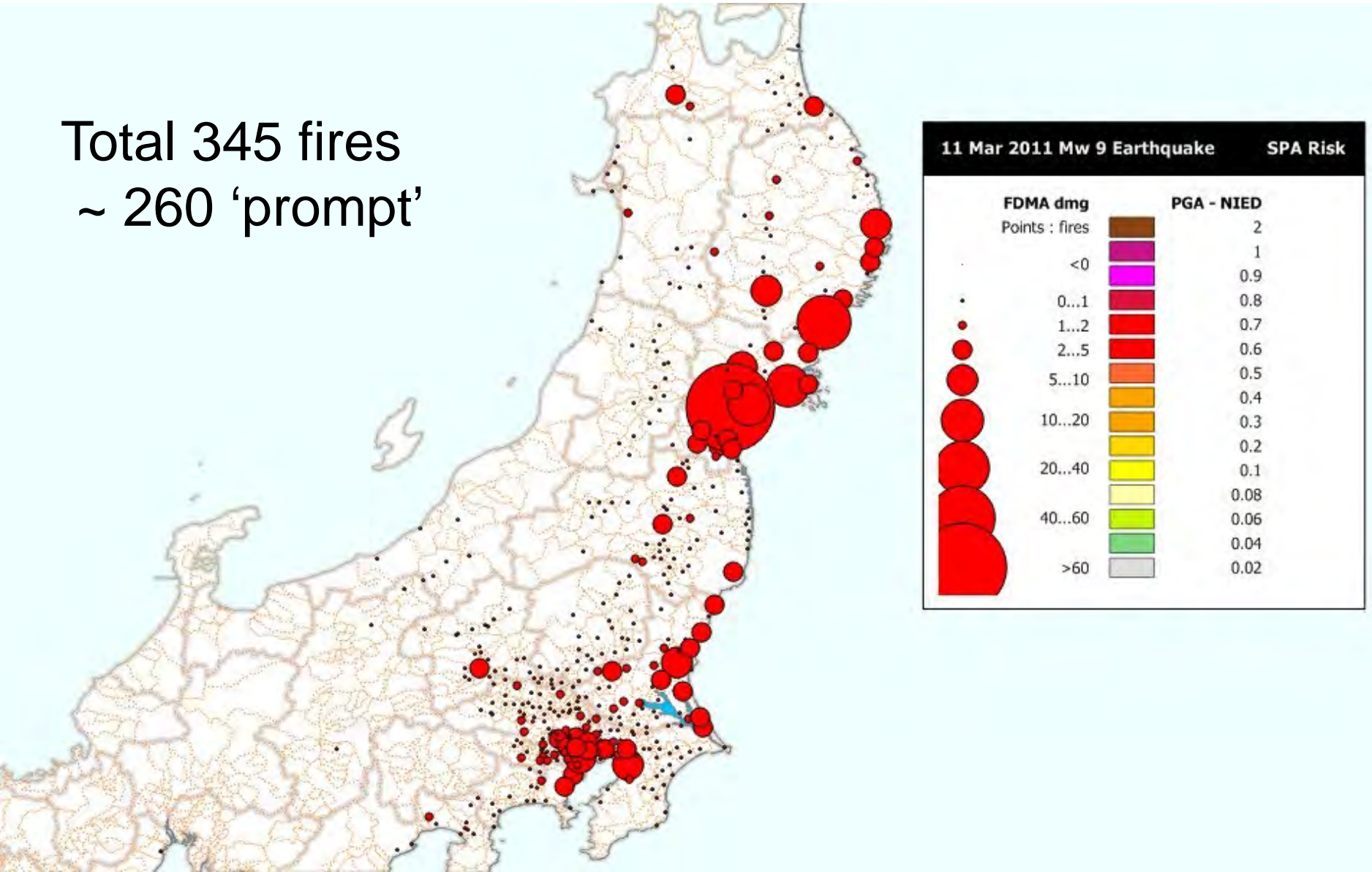
NSF funded research



11 March 2011 Eastern Japan Earthquake

– fire following earthquake

Total 345 fires
~ 260 'prompt'



Earthquake occurs

Phase

Ignition

Discovery

Report

FD Arrival

Fireground operations

1

3

D

R

2

D

R

3

D

R

D

R

6

D

R

7

D

R

8

D

R

Time

Legend

7

Ignition

Fire growth

D
Fire discovery

Suppression

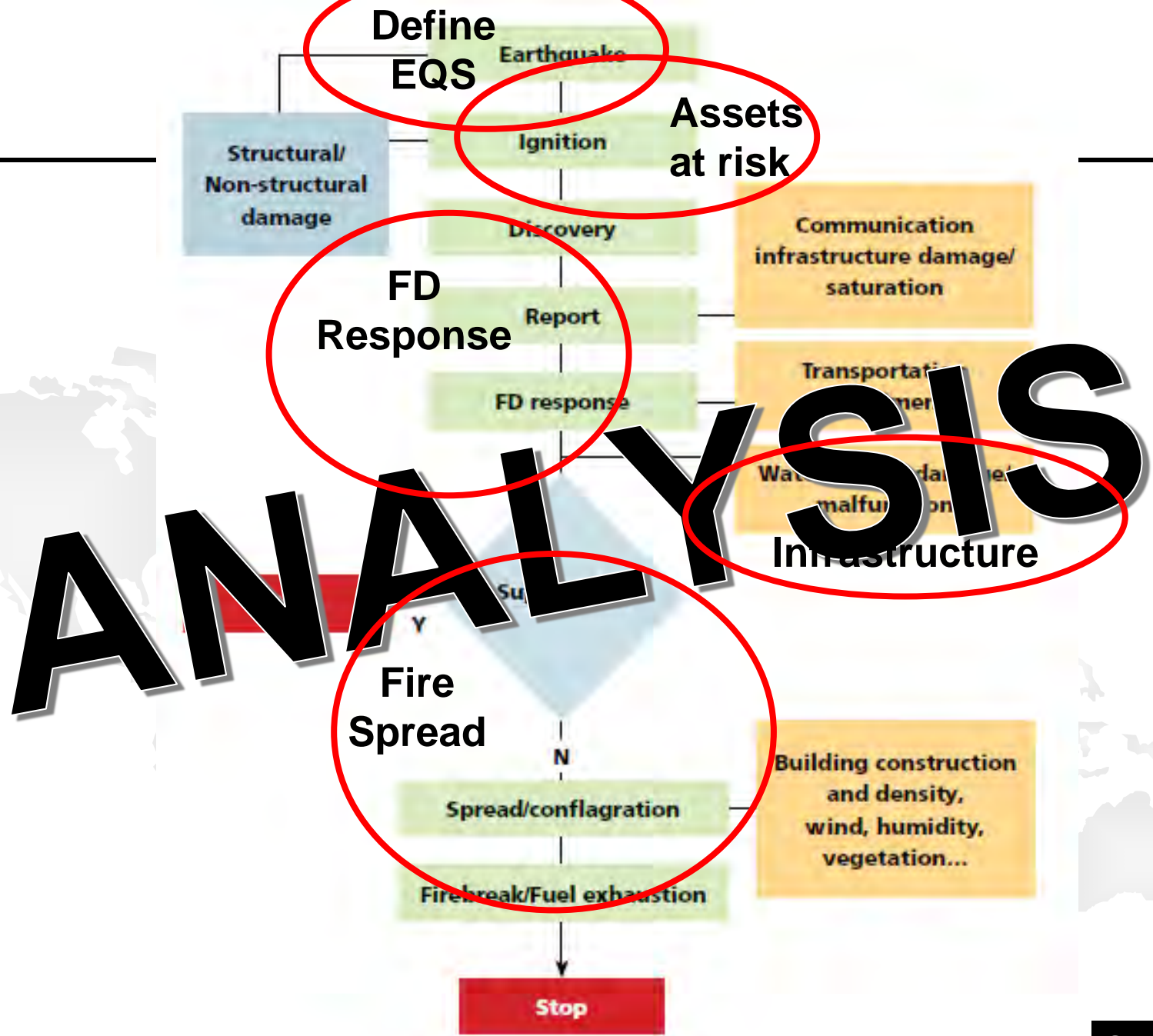
R
Fire report



Fire response

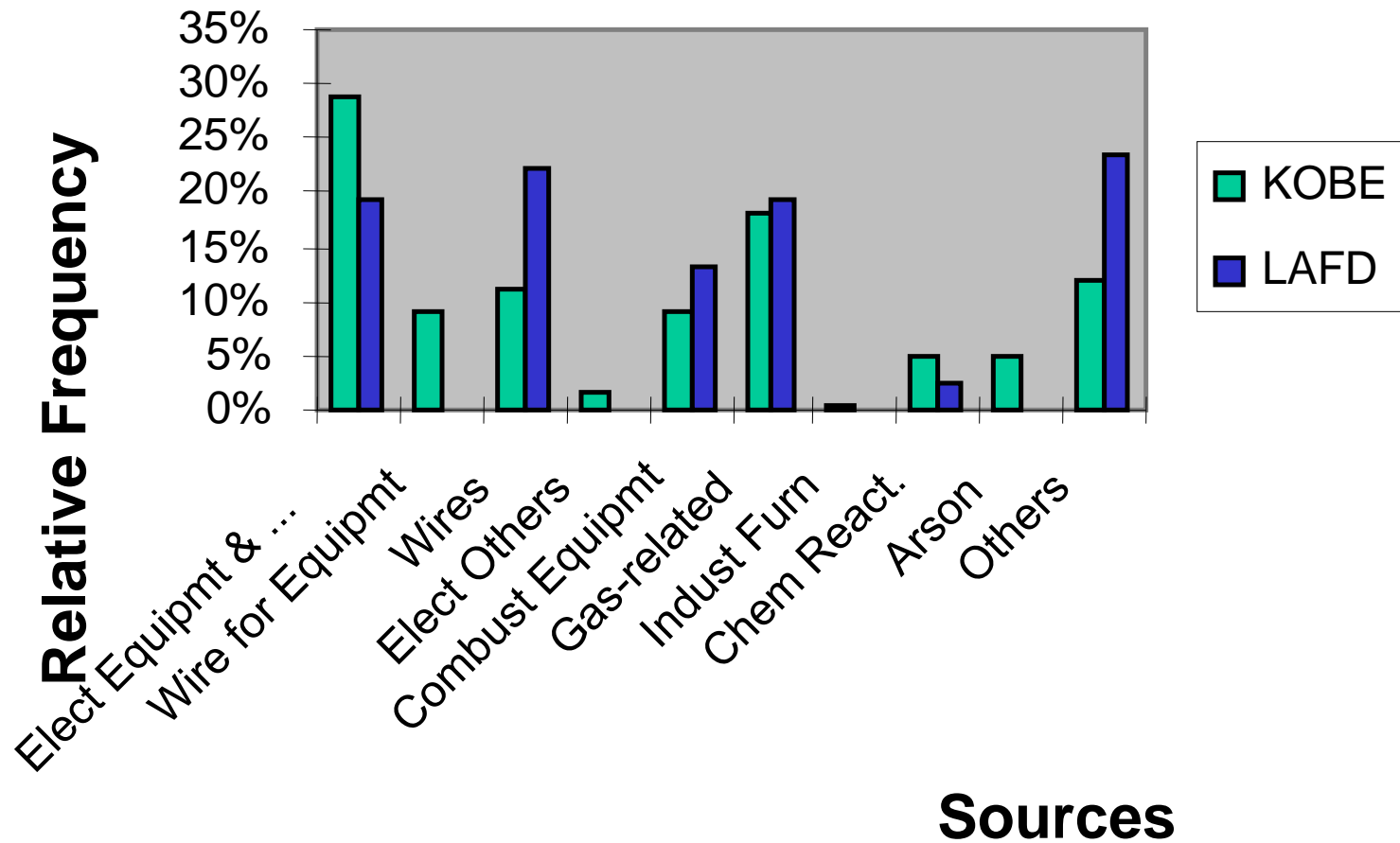
Fire growth (1-3 engine fire)

PROCESS



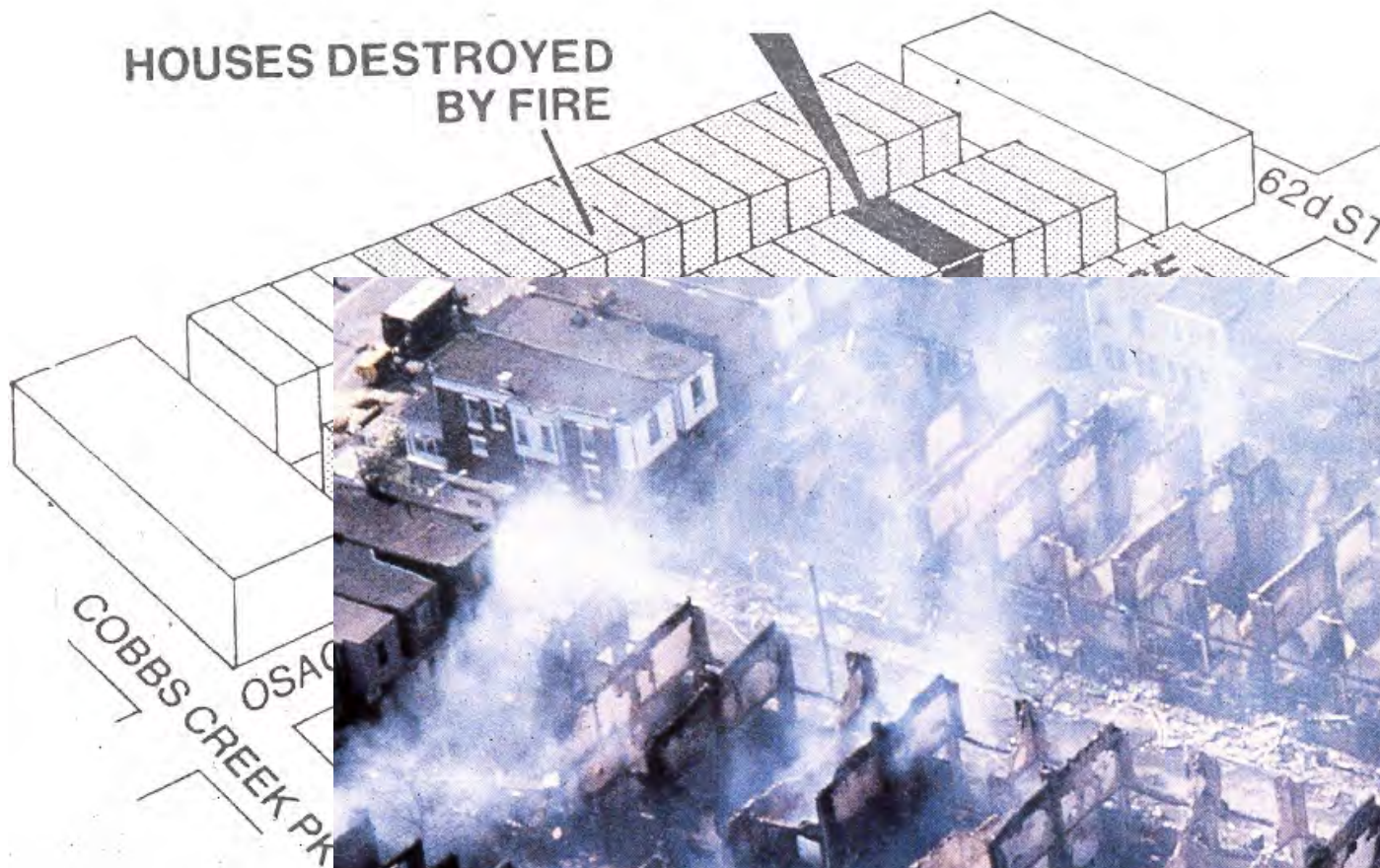
Sources of Post-Earthquake Ignition

Kobe and Northridge Events



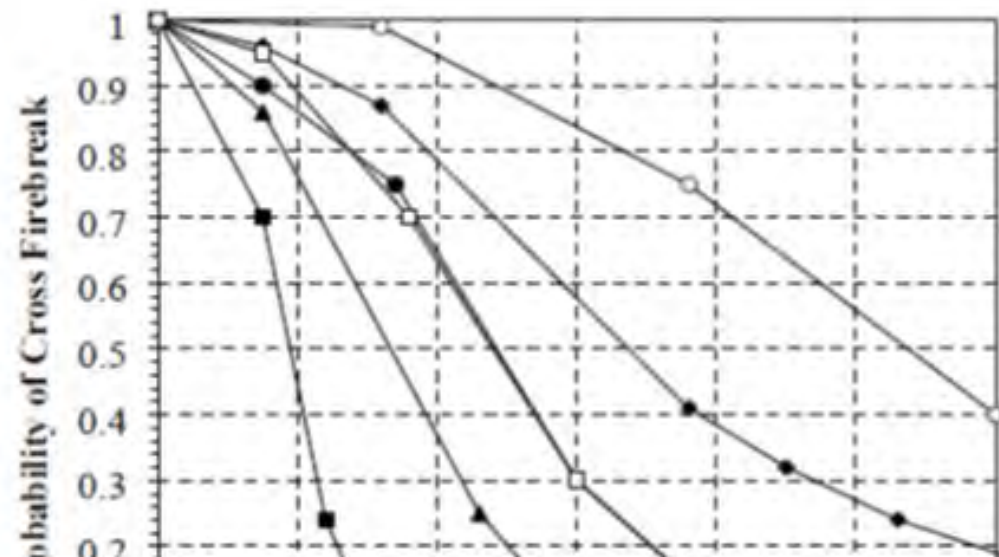
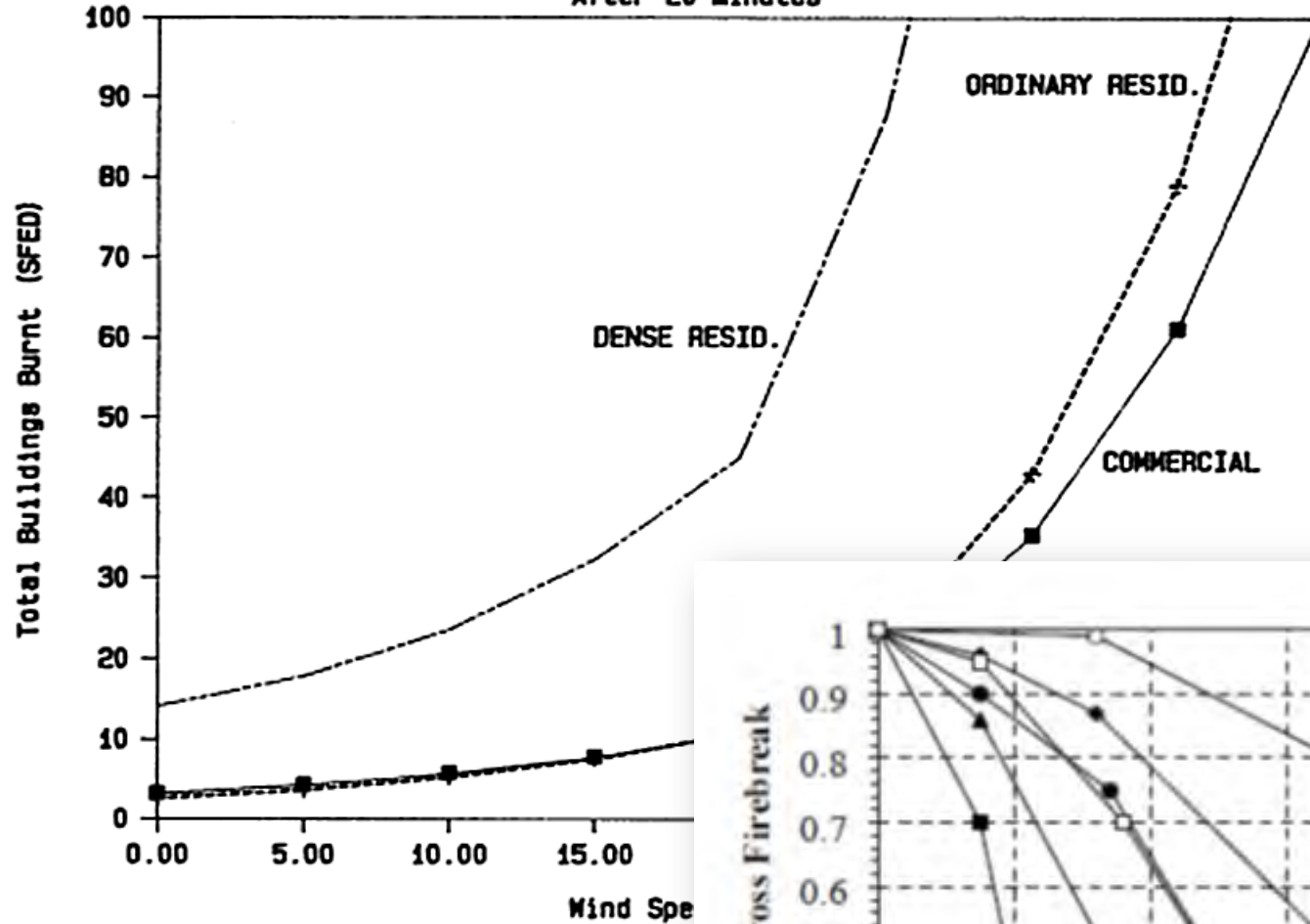


Fire Spread



DOWNWIND FIRE SPREAD

After 20 minutes



Recent Analytical Work – *Physics Based Modeling*

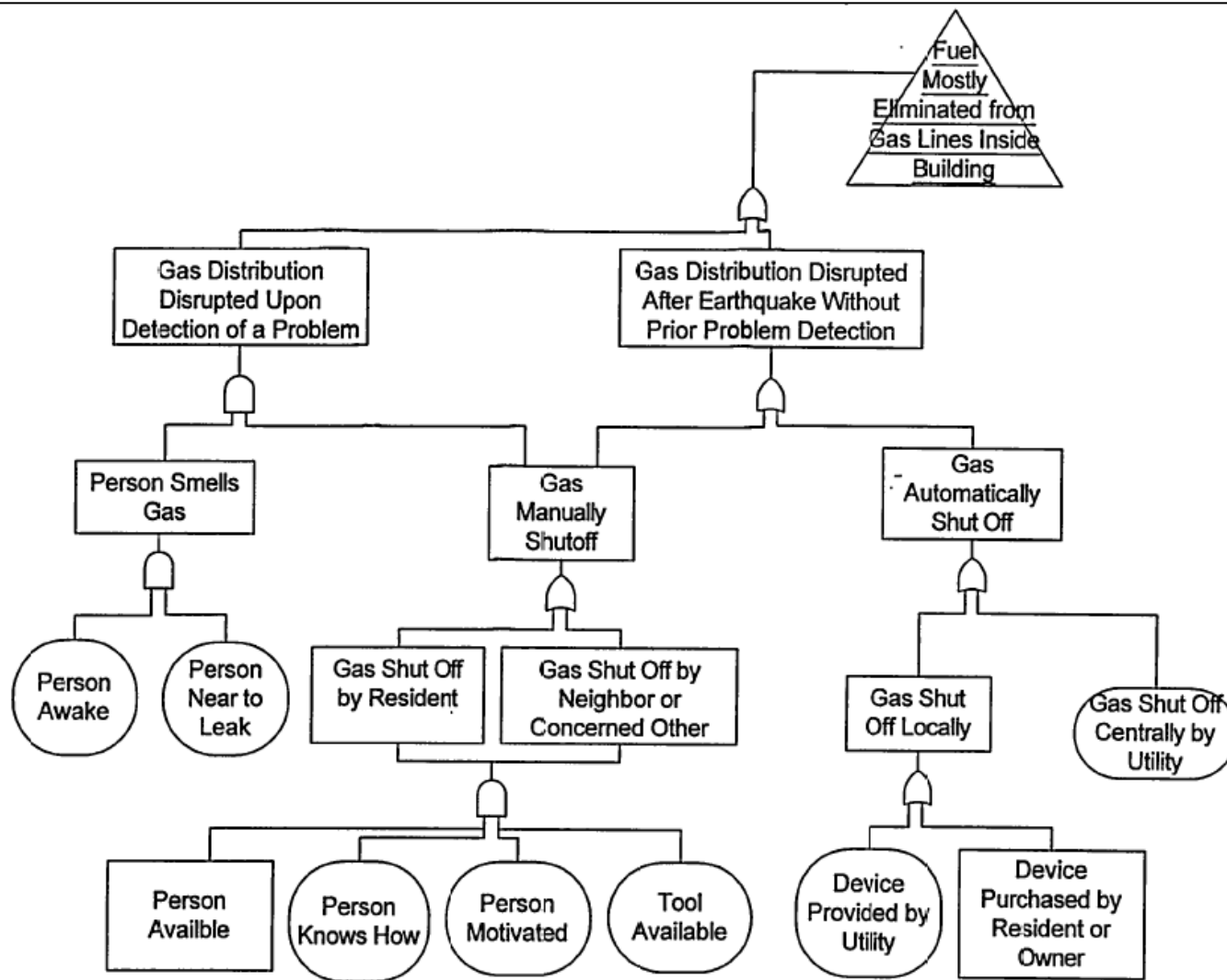


Fig. 4(c)

Radiation

Physics-based simulation model of post-earthquake fire spread

- **Estimates the extent of fire damage to an urban area**
- **Application in Los Angeles County**
- **Modes of spread considered:**
 - Evolution of room fire
 - Room-to-room spread within building by
 - Open doors
 - Burn through walls and ceilings
 - Leapfrogging
 - Building-to-building spread by
 - Radiation from room gas, window flame, roof flame
 - Flame impingement from window flame
 - Branding



Lee, S. (2009) “*Modeling Post-Earthquake Fire Spread*”,
PhD dissertation, R. Davidson, advisor Cornell University, 2009, in prep.

Survey of Water & Fire Agencies

[SURVEY PREVIEW MODE] Fire Dept Survey re Fire Following Earthquake - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.surveymonkey.com/s.aspx?PREVIEW_MODE=DO_NOT_USE_THIS_LINK_FOR_COLLECTION&sm=0GRmCqT8YU7VBXXbJ5%2boXEPCTROp8fwoqbiCknL6sQ%3d#q1

 Fire Dept. Survey re Fire Following Earthquake [Exit this survey](#)

 PEER
PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Fire Dept Survey re Fire Following Earthquake

1. Introduction

This survey seeks to understand post-earthquake firefighting water supply reliability within California, and identify how it might be improved.

While California is *earthquake country*, be followed by multiple simultaneous EMS, may grow into one or more m **perhaps the most crucial issue.**

In order to address this issue, this s sponsorship of the California Seism identify how it might be improved. F

This survey is brief – it shouldn't tak as your being able to make a gener

While we ask for your and your depa will be used to formulate a general u upon for fire suppression purposes

We thank you for your answers and

Contact person for this survey is [Charles Scawthorn](#)

Responses by agencies
representing over 1/3
urbanized California

1. Introduction

This survey is part of a project that seeks to understand water supply reliability within California, especially in regard to post-earthquake firefighting, and identify how it might be made more reliable.

While California is *earthquake country*, major earthquakes don't happen every year. However, when a major earthquake does occur in a large California city, it may be followed by multiple simultaneous ignitions that, combined with loss of water supply and communications and the other demands on the fire service such as search and rescue and EMS, may grow into one or more major urban conflagrations. While there are many critical aspects that contribute to the potential for urban conflagration, **loss of water supply is perhaps the most crucial issue.**

In order to address this issue, this survey is part of a project being conducted by the University of California's Pacific Earthquake Engineering Research Center (PEER) under the sponsorship of the California Seismic Safety Commission. The purpose of the survey is to understand emergency and alternative water supply preparedness within California, and identify how it might be improved. For further information on the overall project, go to [Project Summary](#)

This survey is brief – it shouldn't take you more than about 15 minutes to complete. Most of the questions are multiple-choice, but some provide opportunity for you to comment, as well as your being able to make a general comment at the end.

While we ask for your and your agency's identity, the results of the survey will be collated such that **your individual specific responses will not be disclosed.** The survey results will be used to formulate a general understanding of how reliable California's firefighting water supplies are following a major earthquake – how much they can immediately be counted upon for fire suppression purposes – and what measures might be instituted to improve this post-earthquake reliability.

We thank you for your answers and participation in the survey, which we hope will contribute to improving California's earthquake preparedness.

Contact person for this survey is [Charles Scawthorn](#)

Next

Key Findings from the Water Agencies Survey

- ❑ Most larger urban water agencies not aware of the specifics of the earthquake risk they are exposed to (i.e., two thirds had had no analysis in the last ten years).
- ❑ Earthquake is seen as a key issue by most water departments, but that provision of potable water has a higher priority in some cases than firefighting.
- ❑ Even where water departments have knowledge of the vulnerabilities of their systems, this is not often (only 22%) communicated to fire departments.
- ❑ Both water and fire departments expect major loss of water supply in a major earthquake, with the water department informing the fire department of the details of this about half the time.
- ❑ Many water departments are currently addressing their seismic vulnerabilities with significant engineering programs.
- ❑ Information on when water would be restored is sparse.
- ❑ Some water departments have alternatives given loss of normal water supply, but only a fraction (~1/3) are reasonably equipped to actually move water.
- ❑ Fire and water department liaison is not very good, and are often somewhat indirect, through larger enterprise-wide coordination meetings. Emergency water supply is not a focus.

Case Study: San Francisco / FFE



Dollar Exposure by Specific Occupancy (\$ millions)

Neighborhood	SFR	MFR	Other Res	Retail	Other Comm	IND	Other	Total
Bayview	\$1,354	\$282	\$4	\$63	\$127	\$1,267	\$41	\$3,138
Downtown	\$29	\$3,817	\$5,482	\$2,010	\$15,769	\$941	\$273	\$28,320
Excelsior	\$4,707	\$791	\$27	\$159	\$79	\$116	\$116	\$5,995
Ingleside	\$1,687	\$131	\$0	\$29	\$27	\$2	\$43	\$1,919
Marina	\$286	\$1,375	\$75	\$36	\$44	\$0	\$0	\$1,816
Merced	\$720	\$84	\$0	\$94	\$55	\$0	\$15	\$968
Mission	\$3,264	\$6,595	\$181	\$476	\$388	\$835	\$130	\$11,868
Mission Bay	\$328	\$902	\$13	\$447	\$2,688	\$976	\$35	\$5,390
North Beach	\$222	\$4,483	\$895	\$495	\$1,007	\$54	\$109	\$7,266
Pacific Heights	\$1,448	\$3,341	\$125	\$150	\$250	\$0	\$156	\$5,470
Richmond	\$2,827	\$4,428	\$101	\$209	\$122	\$0	\$148	\$7,836
Sunset	\$7,184	\$2,441	\$40	\$214	\$109	\$0	\$80	\$10,067
Twin Peaks	\$3,250	\$686	\$0	\$52	\$8	\$0	\$22	\$4,018
Western Addition	\$1,313	\$7,179	\$219	\$319	\$823	\$13	\$259	\$10,126
City Wide Totals	\$28,618 27%	\$36,533 35%	\$7,162 7%	\$4,755 5%	\$21,496 21%	\$4,204 4%	\$1,427 1%	\$104,195

Note: Structural values only. Assessed values (avg ~ \$200/sq ft), *not replacement value*. This and loss estimates don't consider other values, such as tenant improvements, furnishings, contents, inventory, cultural objects, etc, or other costs, such as code upgrades, ADA, etc.

Building Inventory

from DPW

Field Name

PARCEL

BLOCKNUM

OCCUPANCY

Description

Parcel Identification Number

City Block Identification Number

Occupancy Type:

- Residential
- Commercial
- Industrial.
- Government/Education

Decade of Construction

Construction Type:

- Wood frame
- Structural Steel, fireproofed
- Masonry or Concrete
- Reinforced Concrete, fire resistant
- Special
- Unknown

DECADE

CONSTRUCTION

BSTOREY

BSQFT

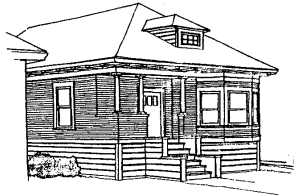
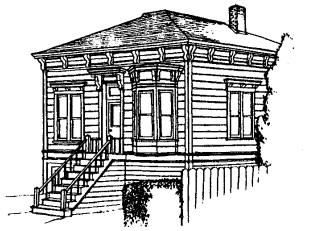
Number of Storeys

Building Area in Square Feet.

~180,000
buildings

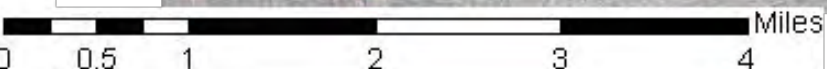
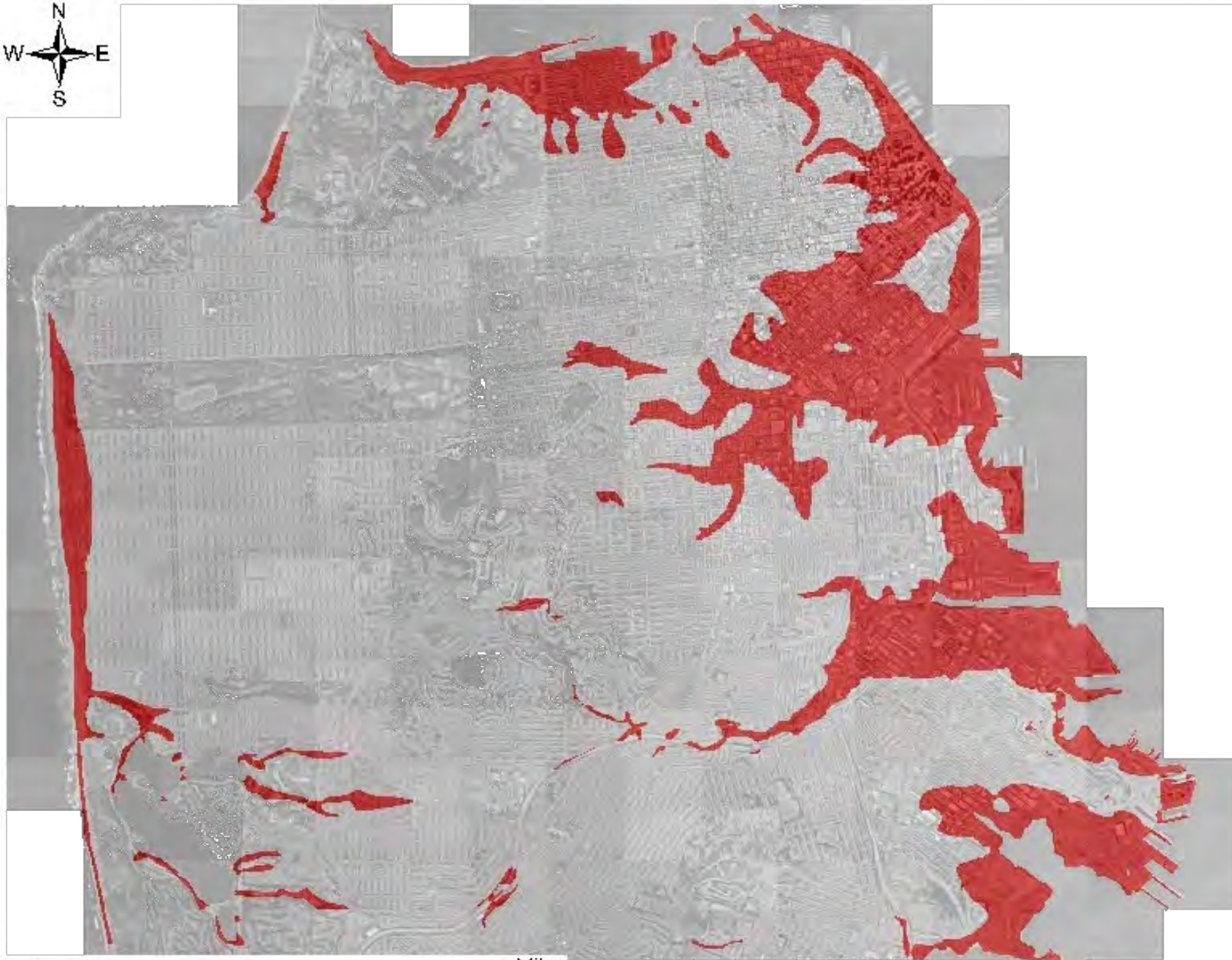
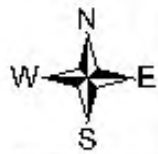
>90% wood

Wood Frame??

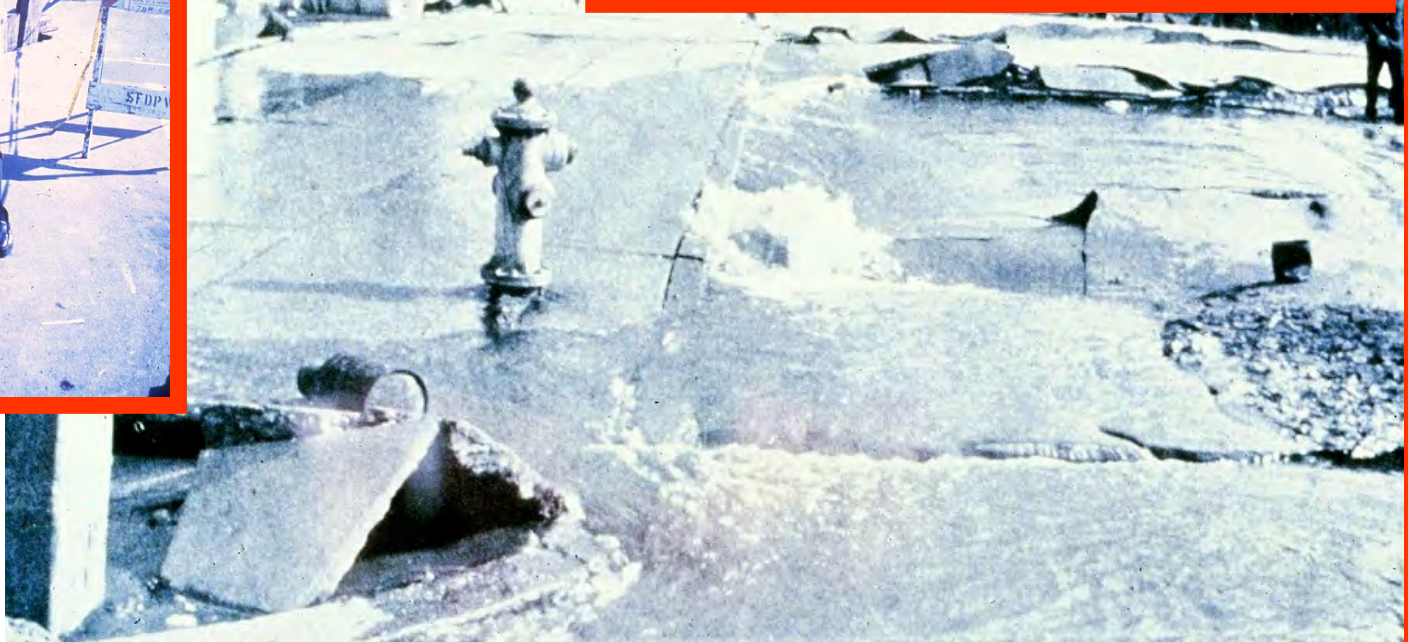


\$1 billion

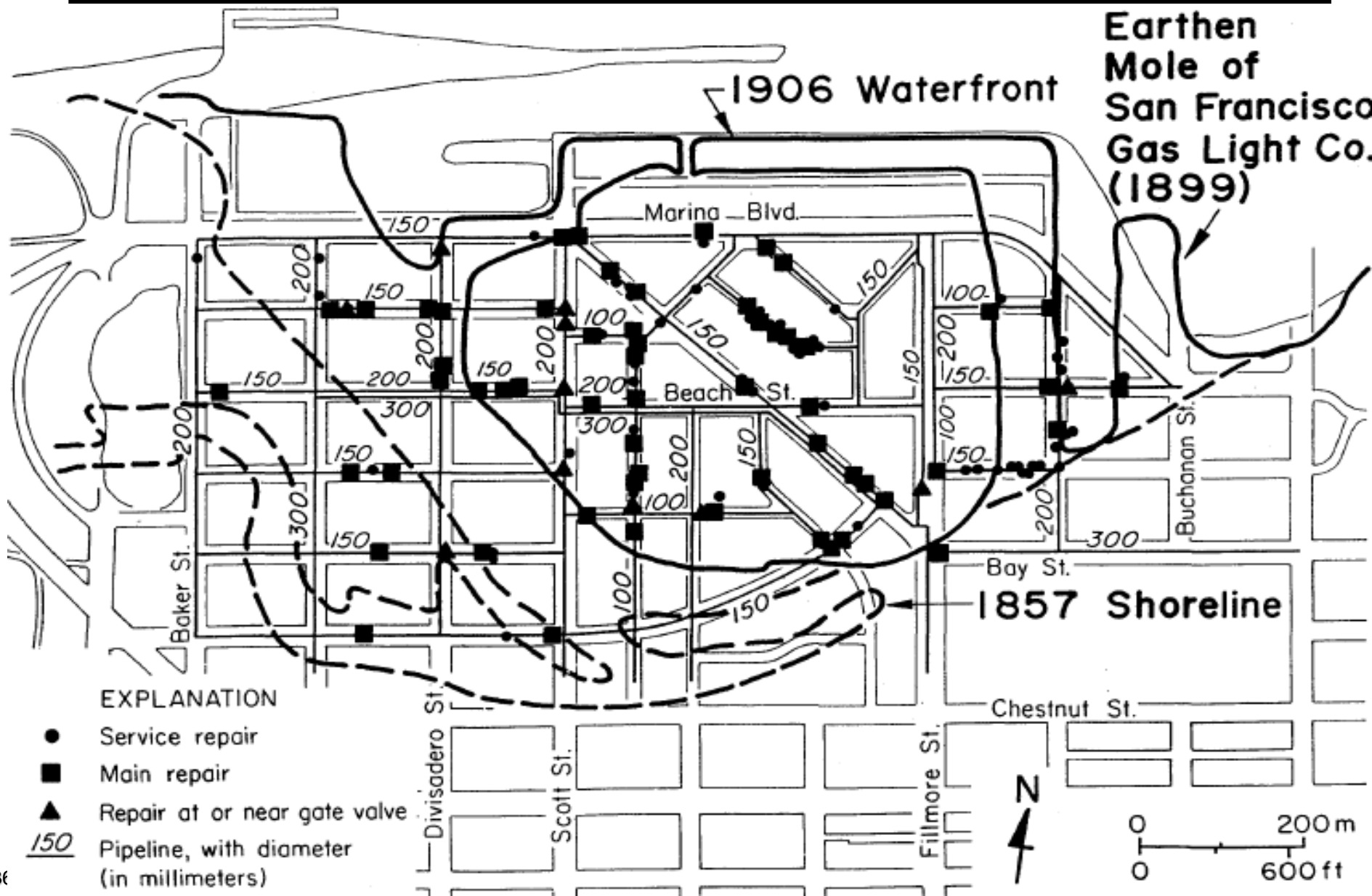




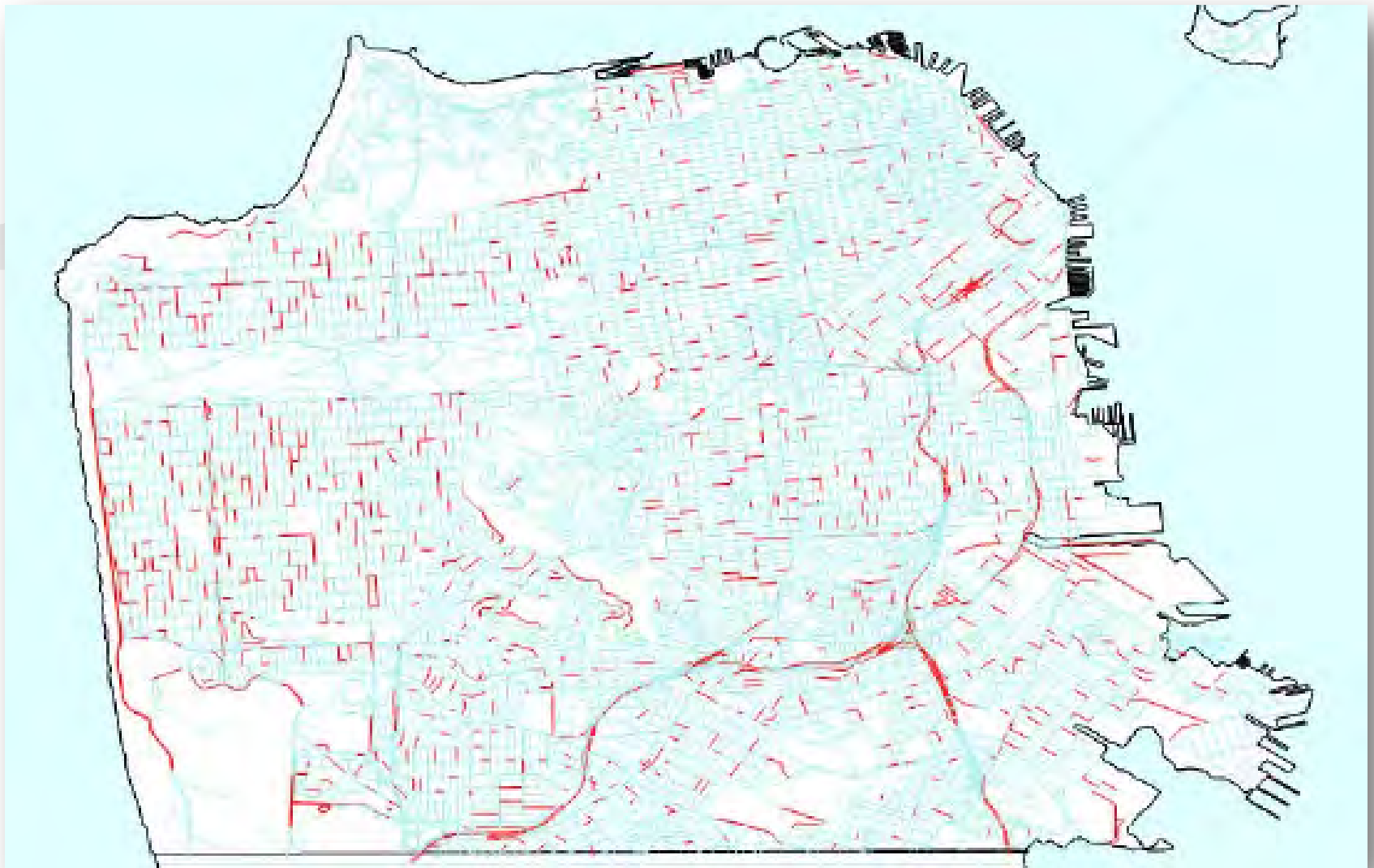
Water System Damage



Marina Fire



Estimated Water Main Breaks Mw 7.9 earthquake



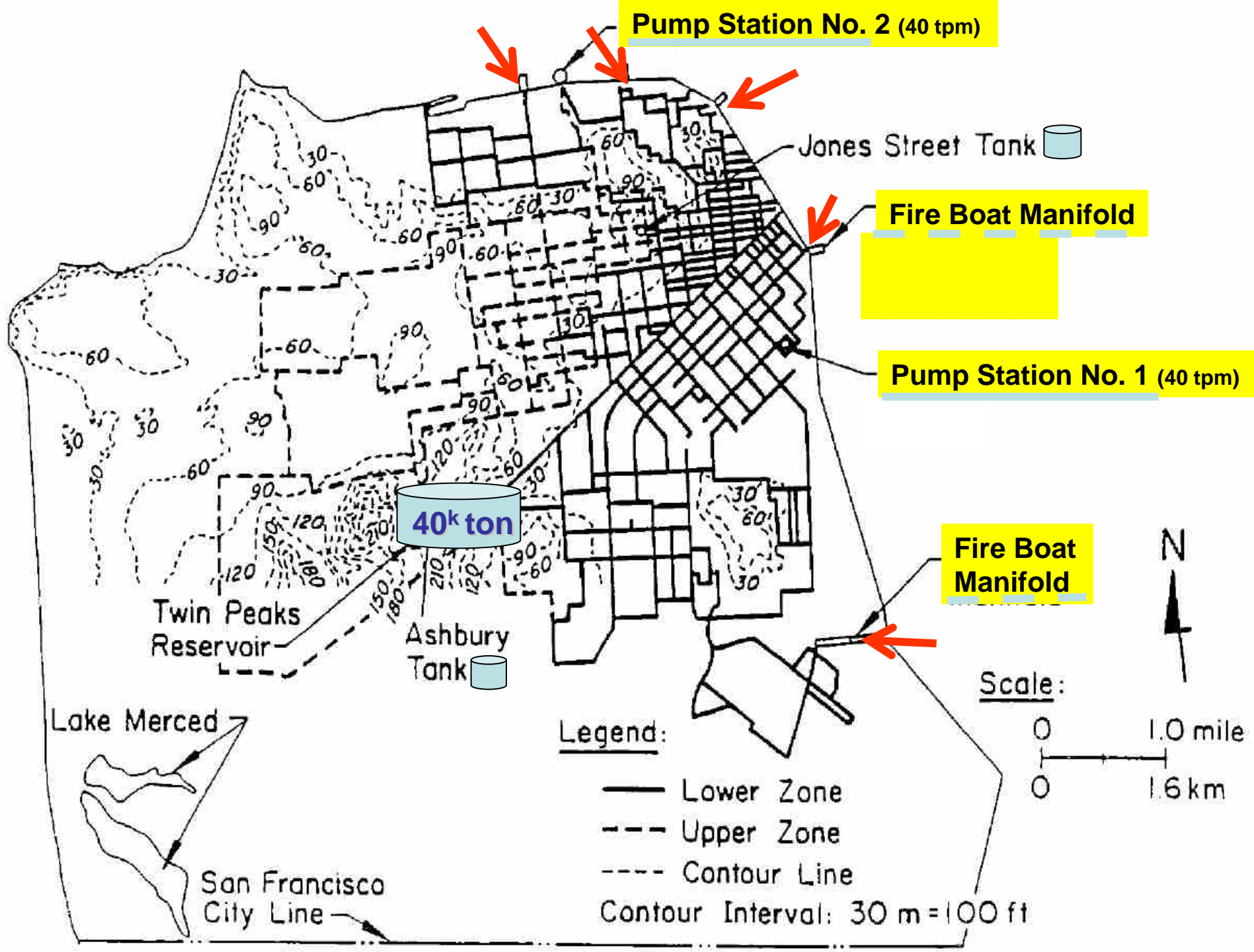
San Francisco AWSS

(Auxiliary Water Supply System)

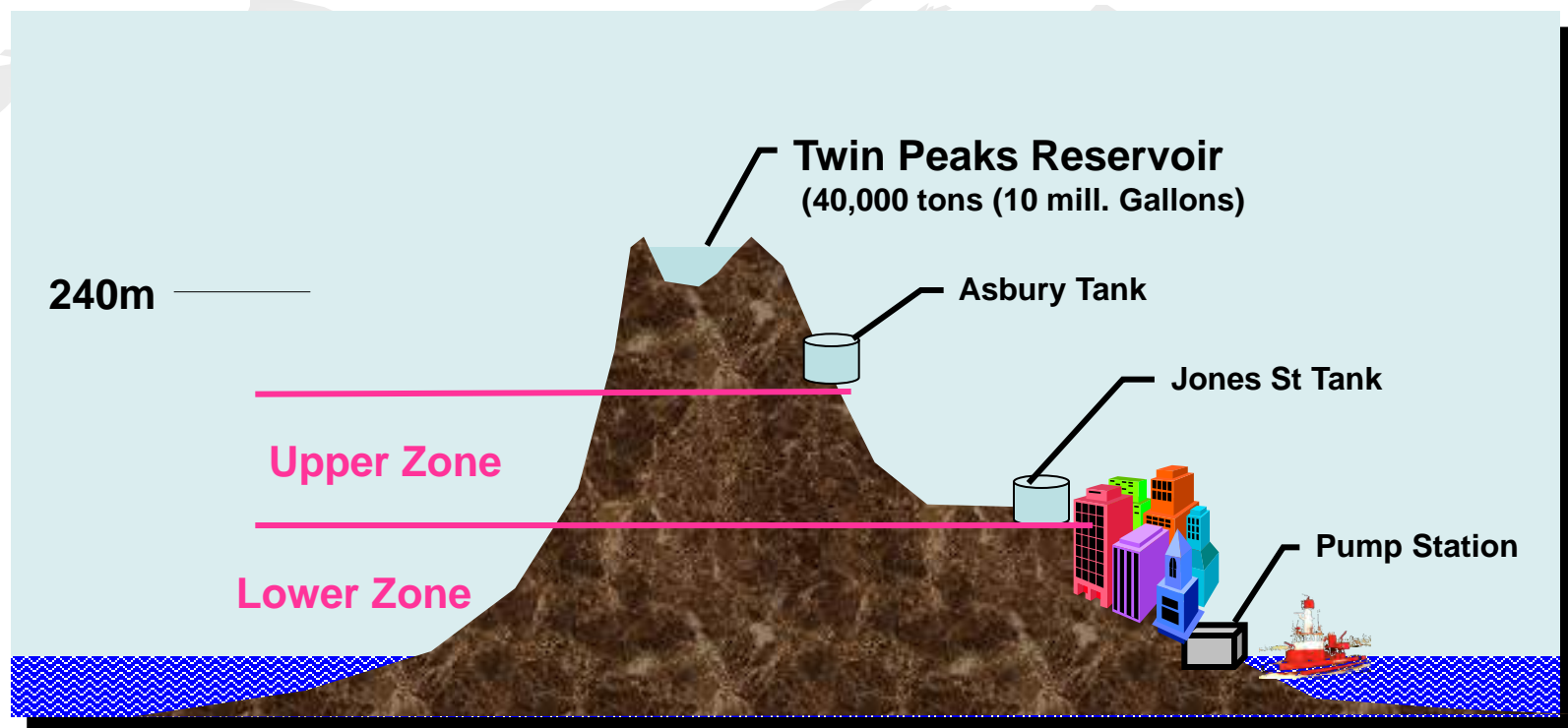
- Proposed in 1905 (pre-earthquake)
- Built 1909-1912 (post-earthquake)
- Continuously maintained / expanded
- Three basic parts
 - Supply (ie, input)
 - Conveyance (ie, transport)
 - Discharge (ie, output)
- Highly Redundant
- Aseismic construction



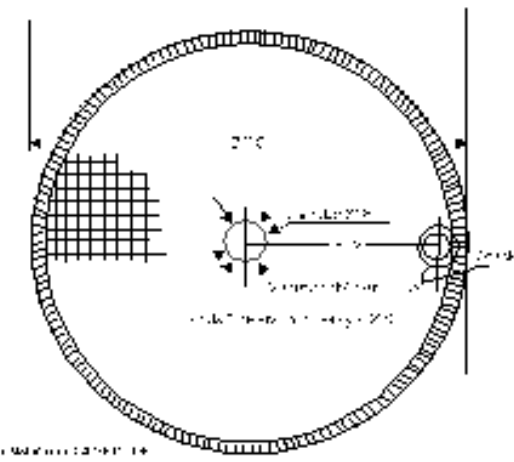
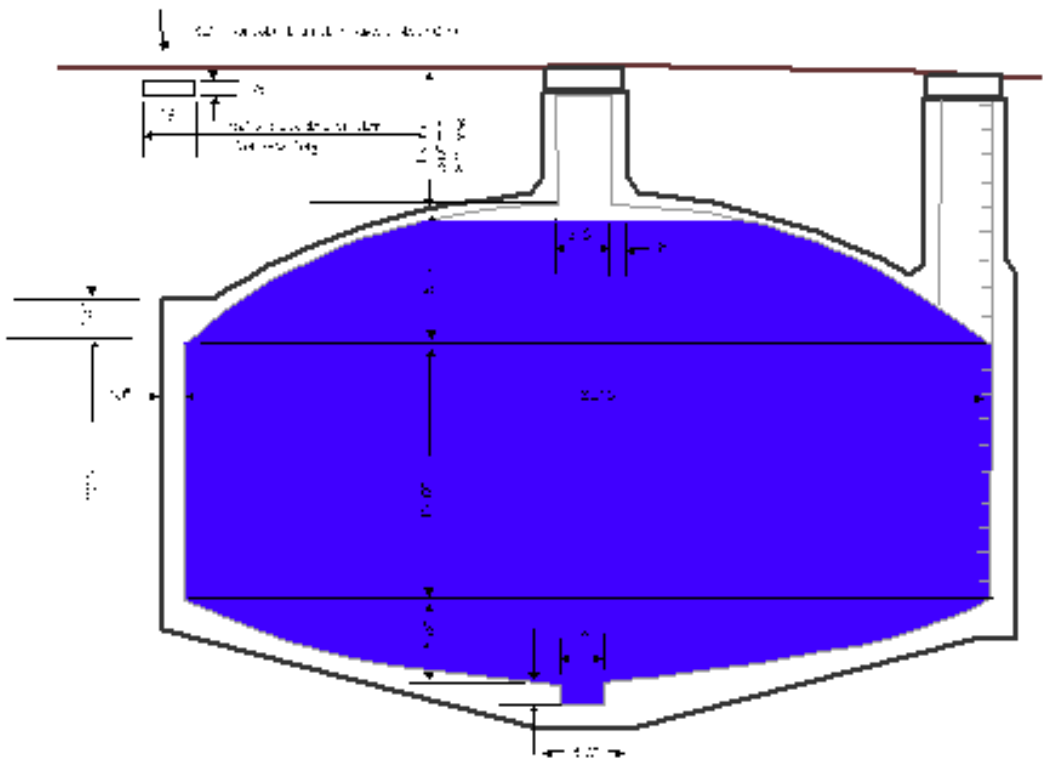
D. T. SULLIVAN
CHIEF ENGINEER OF SAN FRANCISCO FIRE DEPARTMENT.



San Francisco AWSS

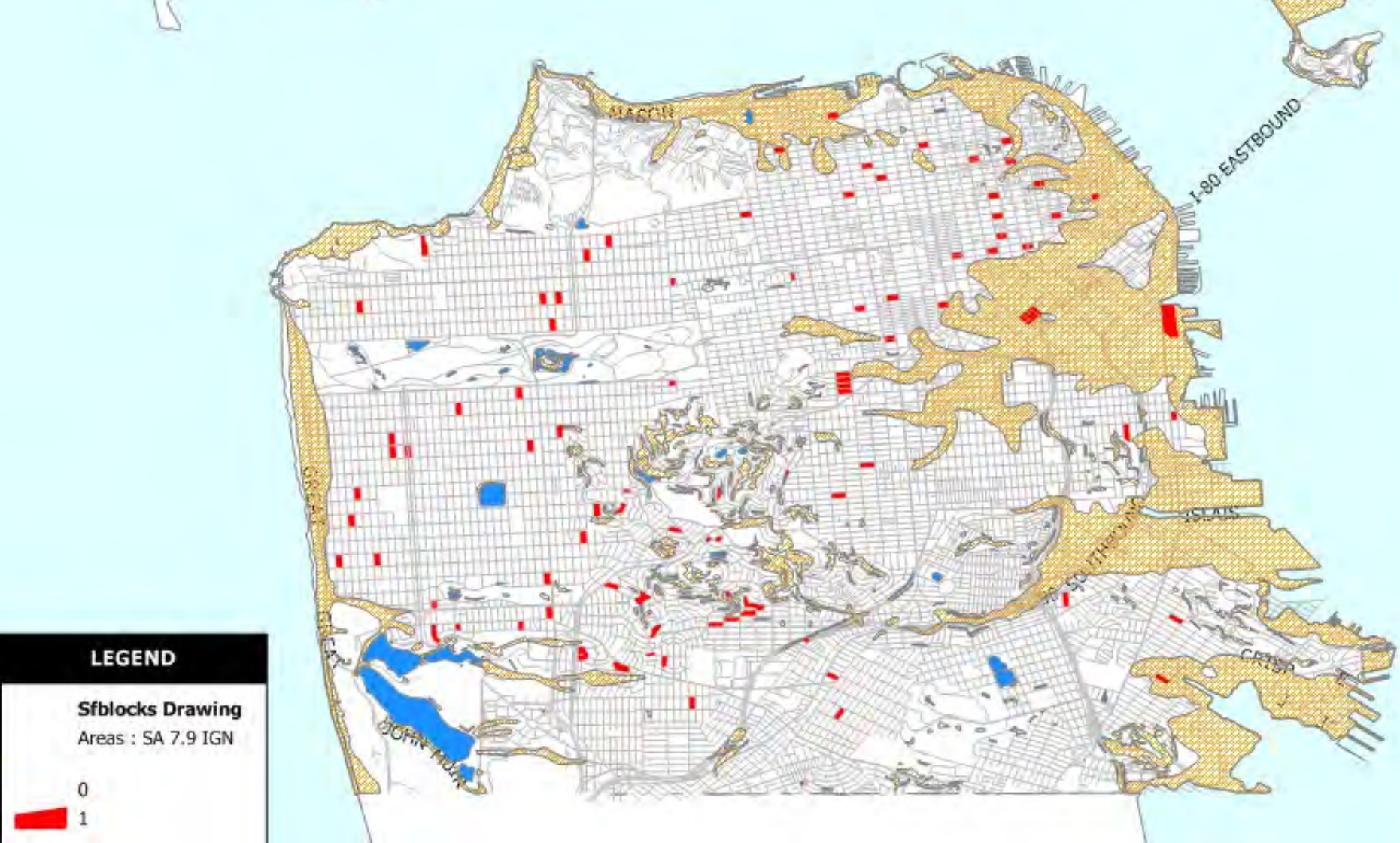


San Francisco Fire Department cistern (170 x 1 hr)





Stochastic Ignitions following M7.9 San Andreas Event



Summary Results by Earthquake Earthquake

– City-wide – Shaking Only

	Single Family Residences	Multiple Family Residences	Other Residences	Commercial Buildings (retail)	Other Commercial Buildings	Industrial Buildings	Other	Total
Total Value	\$ 28,618,150	\$ 36,533,454	\$ 7,161,889	\$ 4,755,180	\$ 21,496,365	\$ 4,203,552	\$ 1,426,589	\$ 104,195,179
Building Damage (\$ thousands)								
San Andreas M 7.9	\$ 10,850,525	\$ 7,342,340	\$ 1,956,354	\$ 1,732,450	\$ 5,541,153	\$ 1,220,926	\$ 446,440	\$ 29,090,188
San Andreas M 7.2	\$ 8,504,318	\$ 4,269,057	\$ 878,315	\$ 741,843	\$ 3,365,300	\$ 671,865	\$ 161,572	\$ 18,592,270
San Andreas M 6.5	\$ 6,077,367	\$ 2,141,633	\$ 405,268	\$ 378,288	\$ 2,257,771	\$ 485,979	\$ 62,677	\$ 11,808,983
Hayward M 6.9	\$ 3,170,245	\$ 1,885,772	\$ 429,577	\$ 417,252	\$ 2,030,615	\$ 511,350	\$ 70,126	\$ 8,514,937
San Andreas M 7.9	38%	20%	27%	36%	26%	29%	31%	28%
San Andreas M 7.2	30%	12%	12%	16%	16%	16%	11%	18%
San Andreas M 6.5	21%	6%	6%	8%	11%	12%	4%	11%
Hayward M 6.9	11%	5%	6%	9%	9%	12%	5%	8%
Total Economic Losses (\$ thousands)								
San Andreas M 7.9	\$ 14,004,648	\$ 9,143,582	\$ 2,941,603	\$ 2,290,701	\$ 8,869,655	\$ 1,783,480	\$ 652,682	\$ 39,686,351
San Andreas M 7.2	\$ 10,911,388	\$ 5,377,772	\$ 1,410,786	\$ 1,073,083	\$ 5,635,814	\$ 1,072,010	\$ 259,168	\$ 25,740,021
San Andreas M 6.5	\$ 7,764,890	\$ 2,728,164	\$ 646,851	\$ 577,210	\$ 3,812,551	\$ 782,667	\$ 109,697	\$ 16,422,030
Hayward M 6.9	\$ 4,035,514	\$ 2,381,974	\$ 673,623	\$ 634,625	\$ 3,459,264	\$ 832,316	\$ 116,903	\$ 12,134,219

Shaking Loss = \$12 - \$39 Billion (8% - 28%)

Summary Results by Earthquake Earthquake – City-wide – Shaking **PLUS Fire Following Earthquake** (Direct Damage only)

		San Andreas 6.5			San Andreas 7.2		San Andreas 7.9		Hayward 6.9	
	TOTAL VALUE	Damage		Damage		Damage		Damage		
Neighborhood	(\$ Millions)	(\$Millions)	% of Total	(\$Millions)	% of Total	(\$Millions)	% of Total	(\$Millions)	% of Total	
Bayview	\$ 3,138	\$ 496	16%	\$ 712	23%	\$ 1,094	35%	\$ 424	14%	
Downtown	\$ 28,320	\$ 6,562	23%	\$ 8,358	30%	\$ 11,696	41%	\$ 6,802	24%	
Excelsior	\$ 5,995	\$ 1,322	22%	\$ 1,914	32%	\$ 2,506	42%	\$ 774	13%	
Ingleside	\$ 1,919	\$ 470	24%	\$ 650	34%	\$ 820	43%	\$ 178	9%	
Marina	\$ 1,816	\$ 480	26%	\$ 546	30%	\$ 680	37%	\$ 460	25%	
Merced	\$ 968	\$ 230	24%	\$ 328	34%	\$ 408	42%	\$ 72	7%	
Mission	\$ 11,868	\$ 1,628	14%	\$ 2,476	21%	\$ 3,732	31%	\$ 1,380	12%	
Mission Bay	\$ 5,390	\$ 928	17%	\$ 1,148	21%	\$ 1,714	32%	\$ 902	17%	
North Beach	\$ 7,266	\$ 1,112	15%	\$ 1,392	19%	\$ 2,190	30%	\$ 1,202	17%	
Pacific Heights	\$ 5,470	\$ 732	13%	\$ 1,128	21%	\$ 1,664	30%	\$ 714	13%	
Richmond	\$ 7,836	\$ 1,416	18%	\$ 2,100	27%	\$ 2,704	35%	\$ 768	10%	
Sunset	\$ 10,067	\$ 2,626	26%	\$ 3,404	34%	\$ 4,102	41%	\$ 1,176	12%	
Twin Peaks	\$ 4,018	\$ 770	19%	\$ 1,144	28%	\$ 1,556	39%	\$ 394	10%	
Western Addition	\$ 10,126	\$ 1,314	13%	\$ 2,046	20%	\$ 3,018	30%	\$ 1,100	11%	
Total	\$ 104,195	\$ 20,086	19%	\$ 27,346	26%	\$ 37,884	36%	\$ 16,346	16%	

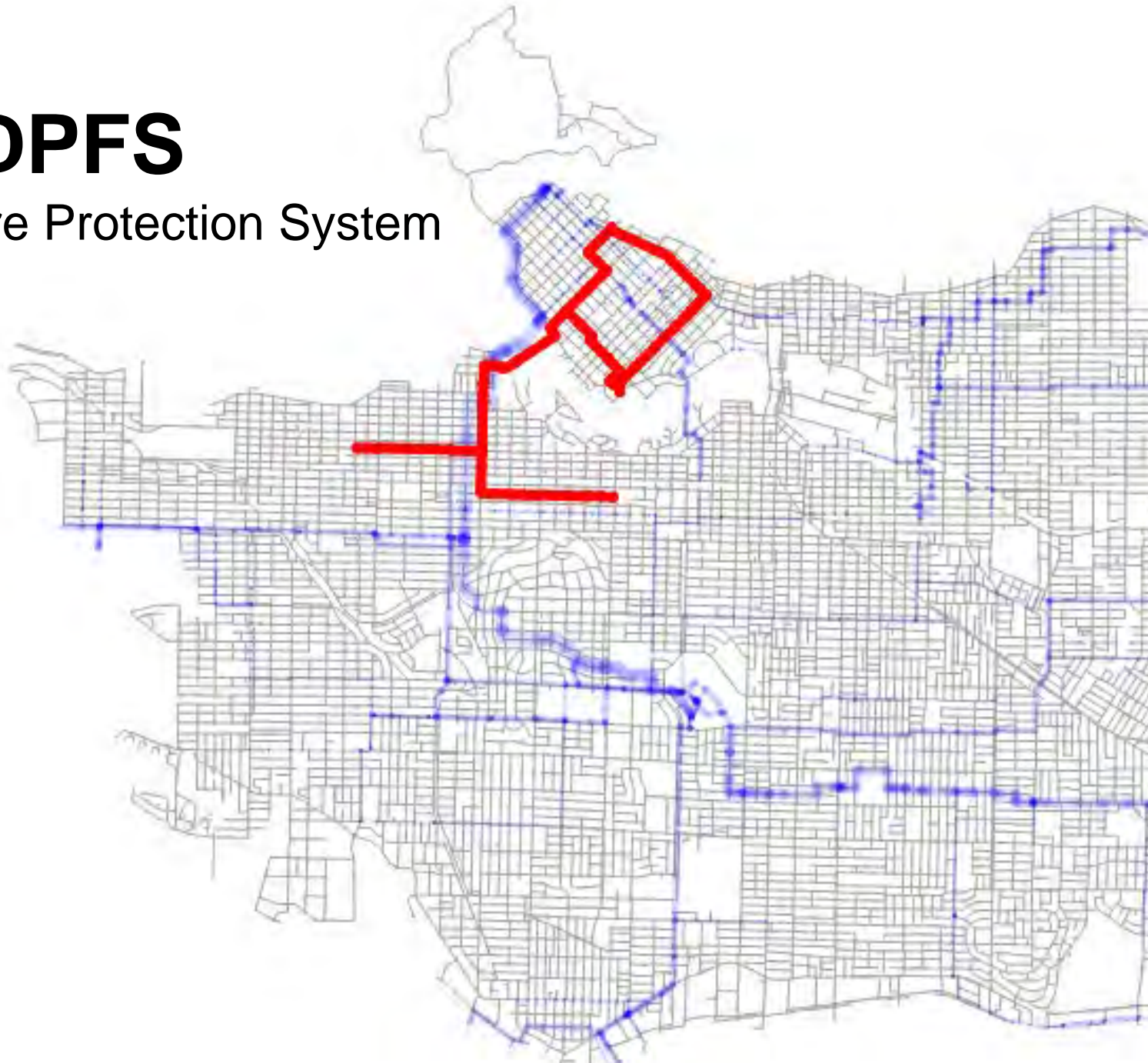
FFE : additional ~\$10 billion

Vancouver, B.C.



DPFS

Dedicated Fire Protection System





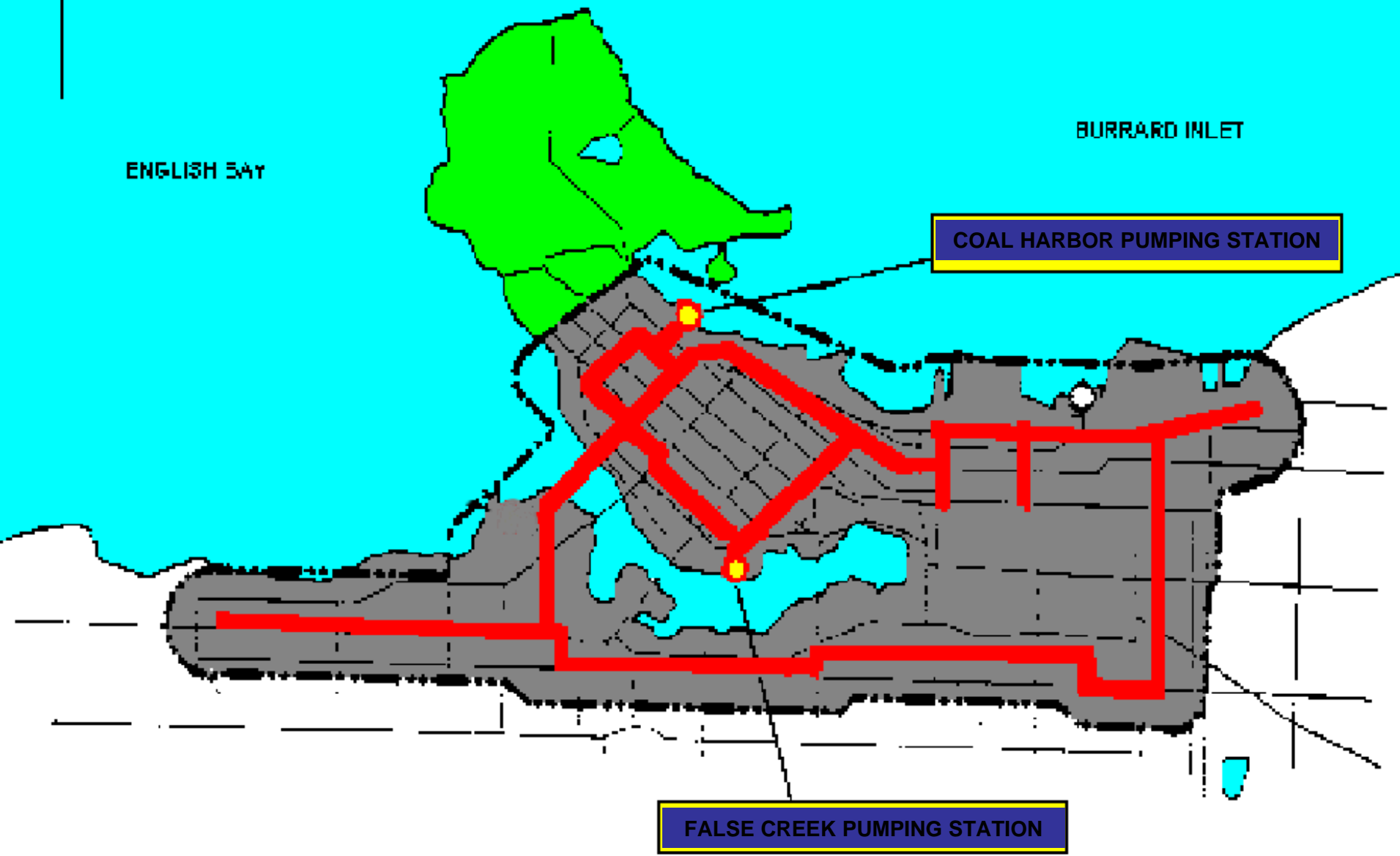
Vancouver Dedicated Fire Protection System (DFPS)

ENGLISH BAY

BURRARD INLET

COAL HARBOR PUMPING STATION

FALSE CREEK PUMPING STATION

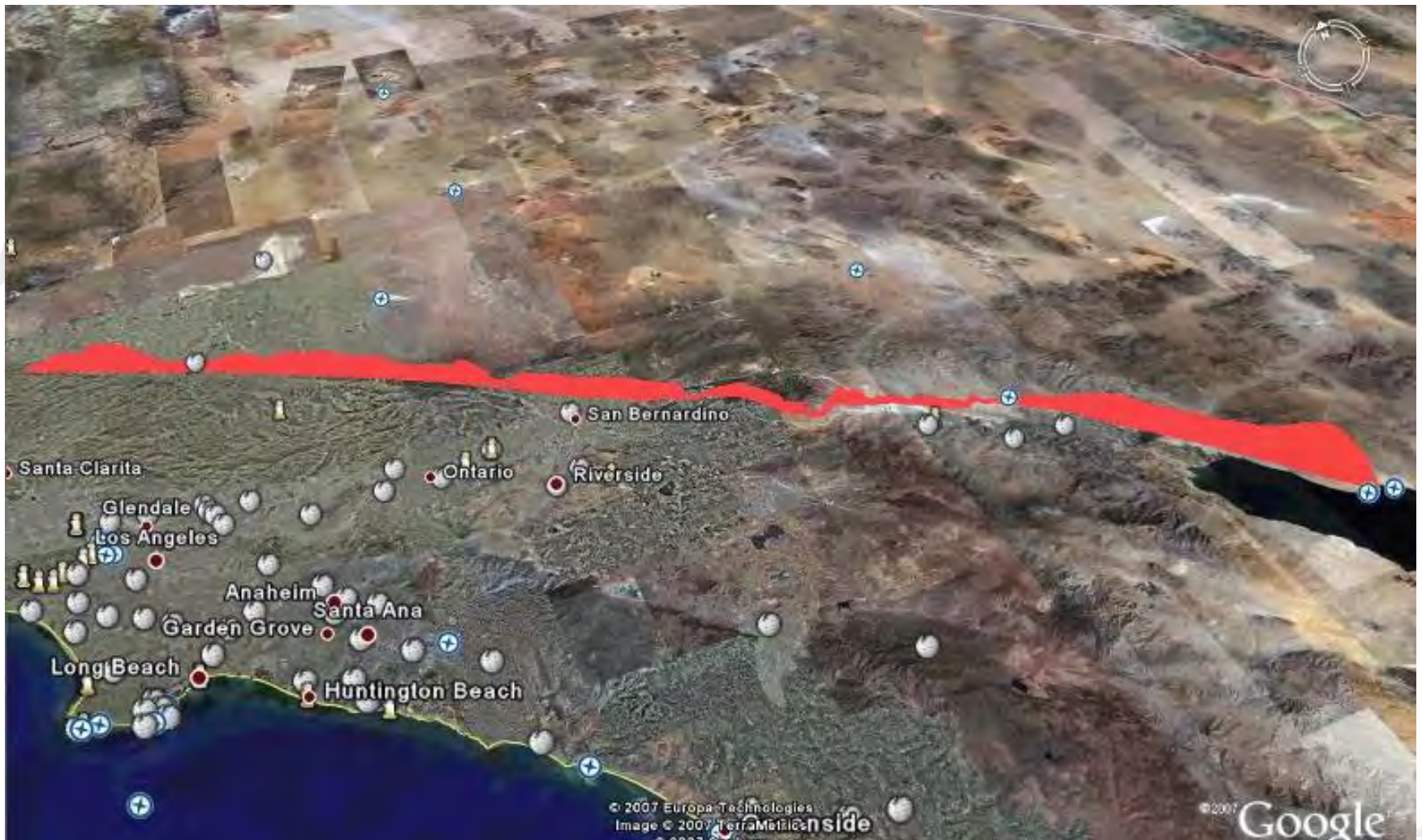








San Andreas M7.8 event: 150 yr return period; 300 yr since last rupture



The Great
Southern California
**Shake
Out**

HOME

THE DRILL

THE SCENARIO

REGISTER / LOGIN

WHAT YOU CAN DO

CALENDAR

RESOURCES

NEWS MEDIA

SPONSORS

SUPPORTERS

ORGANIZERS

CONTACT US

The Great Southern California

At 10 a.m. on November 13, join
Californians in the *ShakeOut Drill*
preparedness activity in U.S. his

*The Great Southern California
ShakeOut* includes the ShakeO
Drill and other events to help us
ready for big earthquakes, and
prevent disasters from becomin
catastrophes.

Main Activities

[ShakeOut Drill](#) (November 13)

[International Earthquake Conference](#)

[Los Angeles Earthquake: Get Ready](#)

[Take One More Step](#) (November 14-16)

In collaboration with [Golden Guardian 2008](#) (November 13-18)



The ShakeOut Scenario

By Lucile M. Jones, Richard Bernkopf, Dale Cox, James Goltz, Kenneth Hudnut, Dennis
Mileti, Suzanne Perry, Daniel Ponti, Keith Porter, Michael Reichle, Hope Seligson,
Kimberley Shoaf, Jerry Treiman, and Anne Wein

USGS Open File Report 2008-1150
CGS Preliminary Report 25
Version 1.0

2008

U.S. Department of the Interior
U.S. Geological Survey

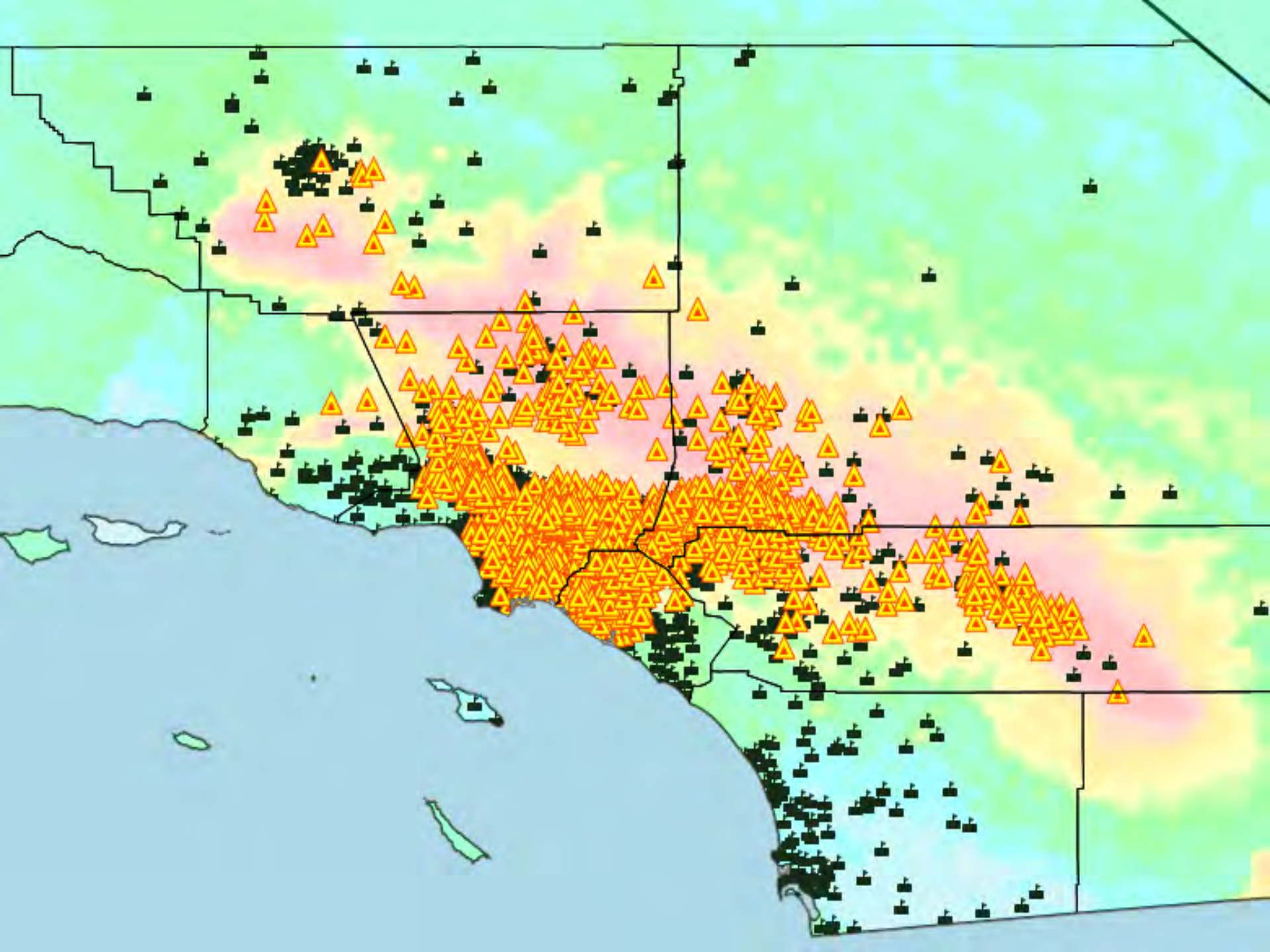
California Department of Conservation
California Geological Survey

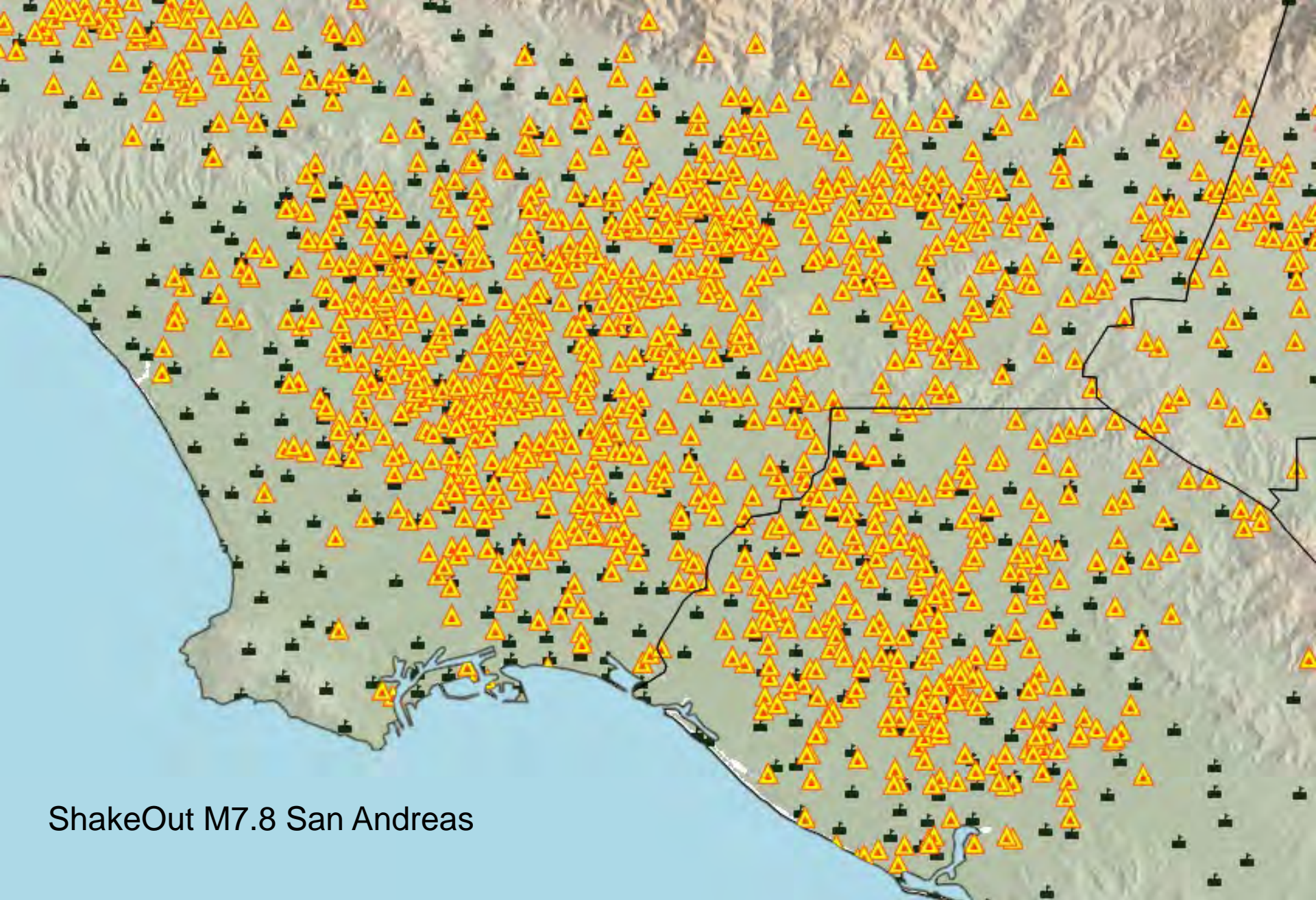
Major Sponsors



3.7 Million and Counting!

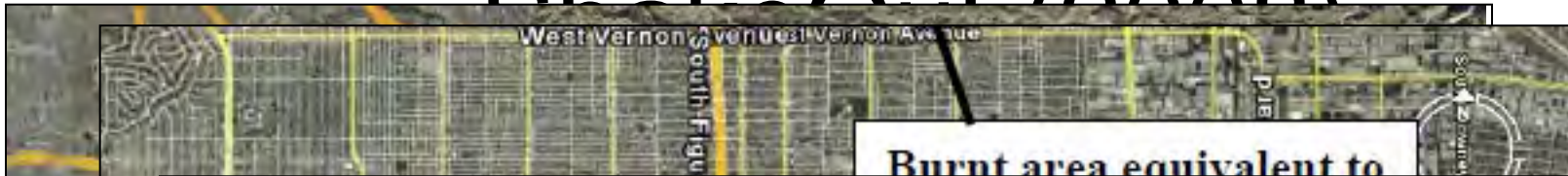
[Participant Login](#)





ShakeOut M7.8 San Andreas

Blackout (0000)

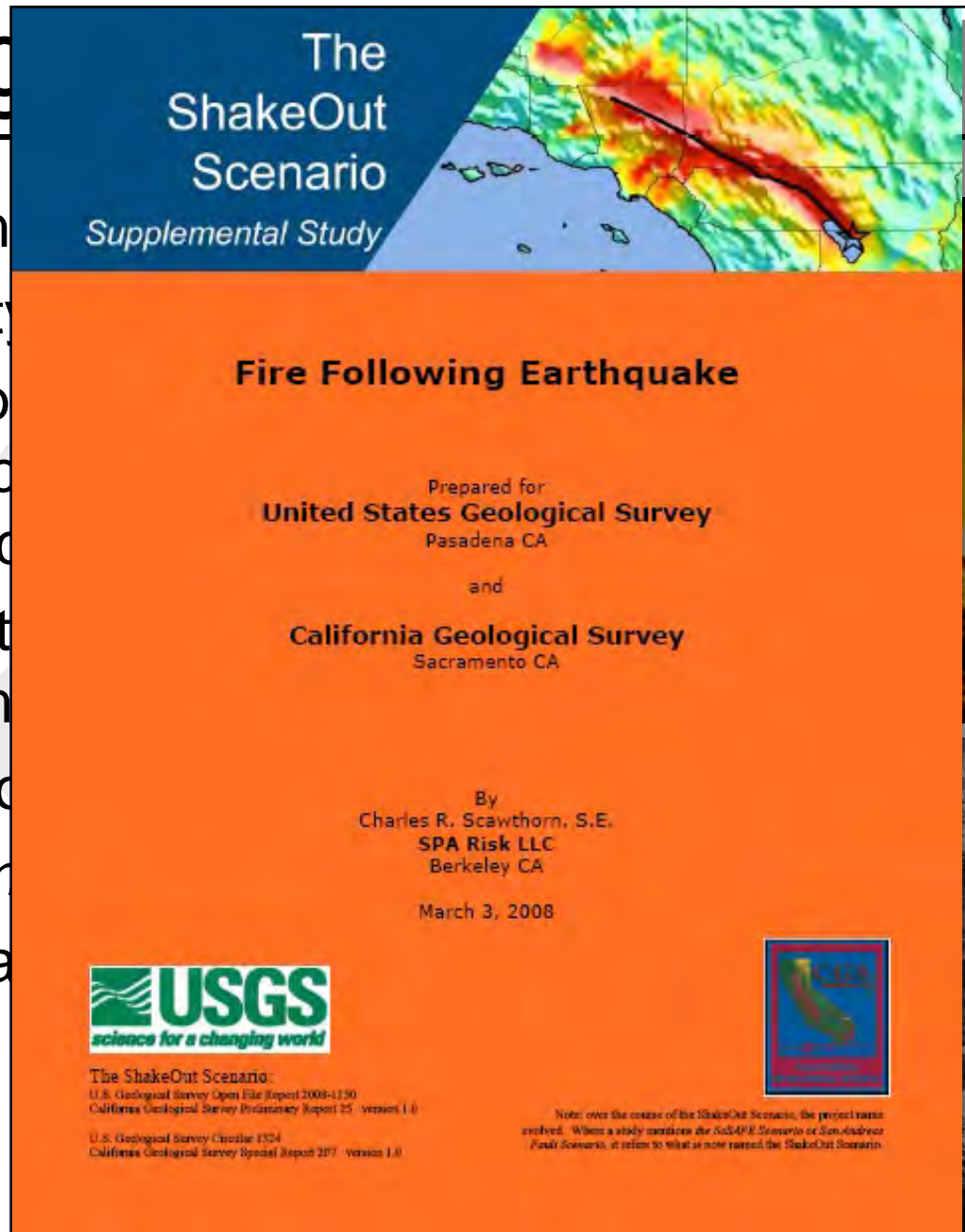




\$ 10 million

Fire following

- 1,600 ignitions requiring
- 1,200 exceed capability
- Orange County & LA b
large fires merge into d
destroying 100s of bloc
- 200 million square feet
≈ 133,000 single fam
- Property loss: \$65 billio
- No Santa Ana winds, r
- Study vetted by top sta
fire officials



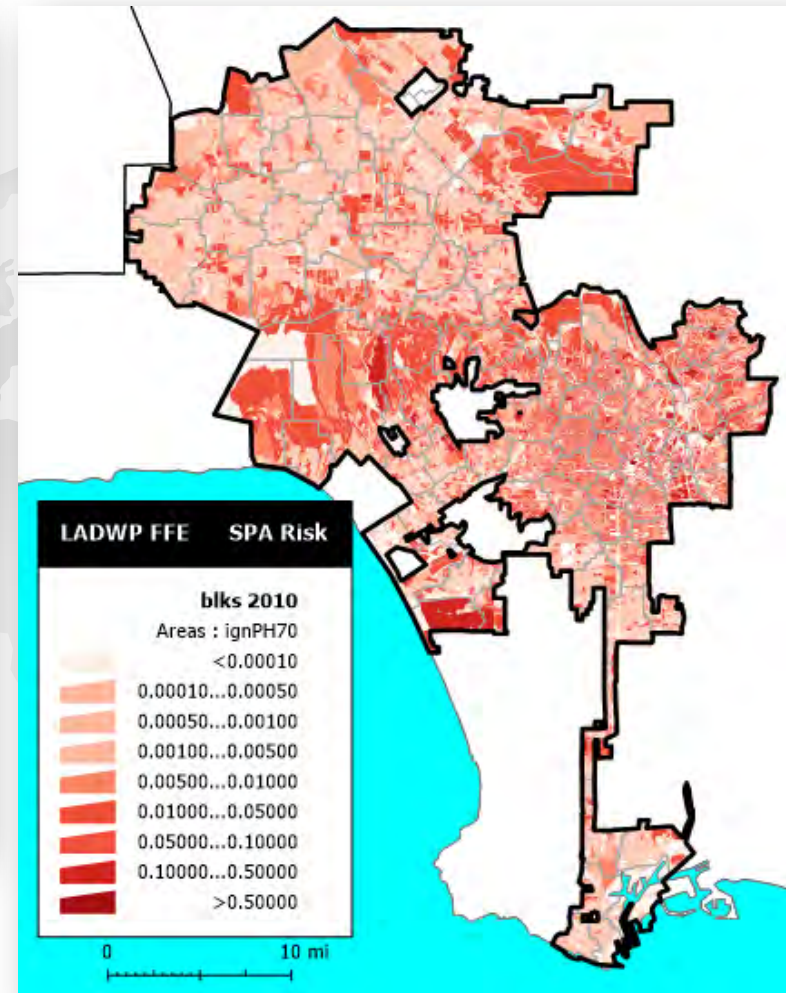
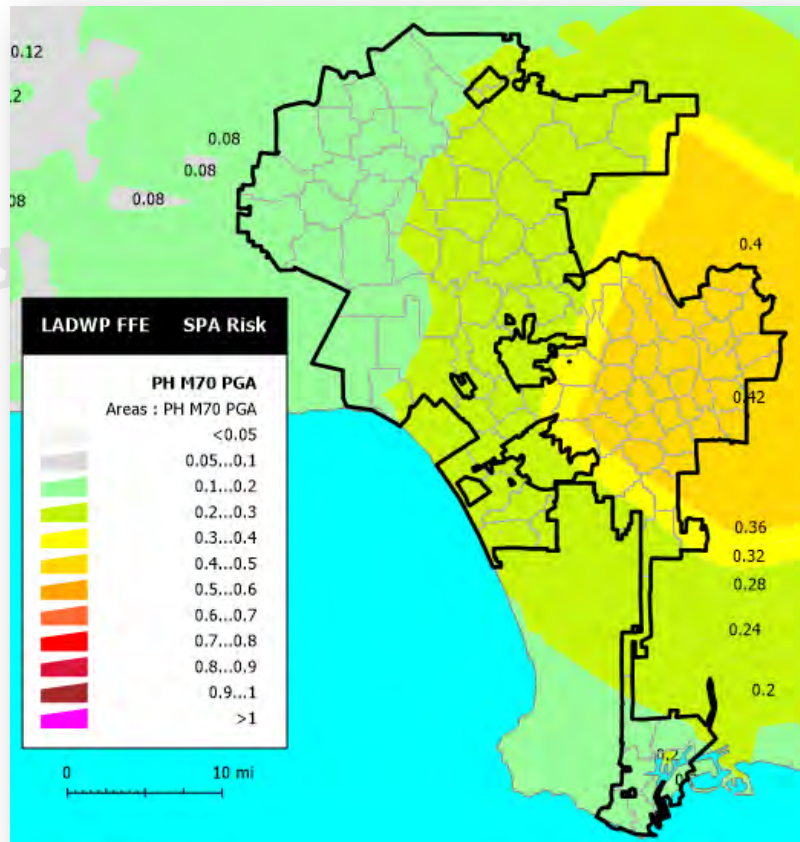
The City of Los Angeles is concerned about fires following large earthquake

The issue: *will firefighting water will be available for LAFD after an earthquake?*

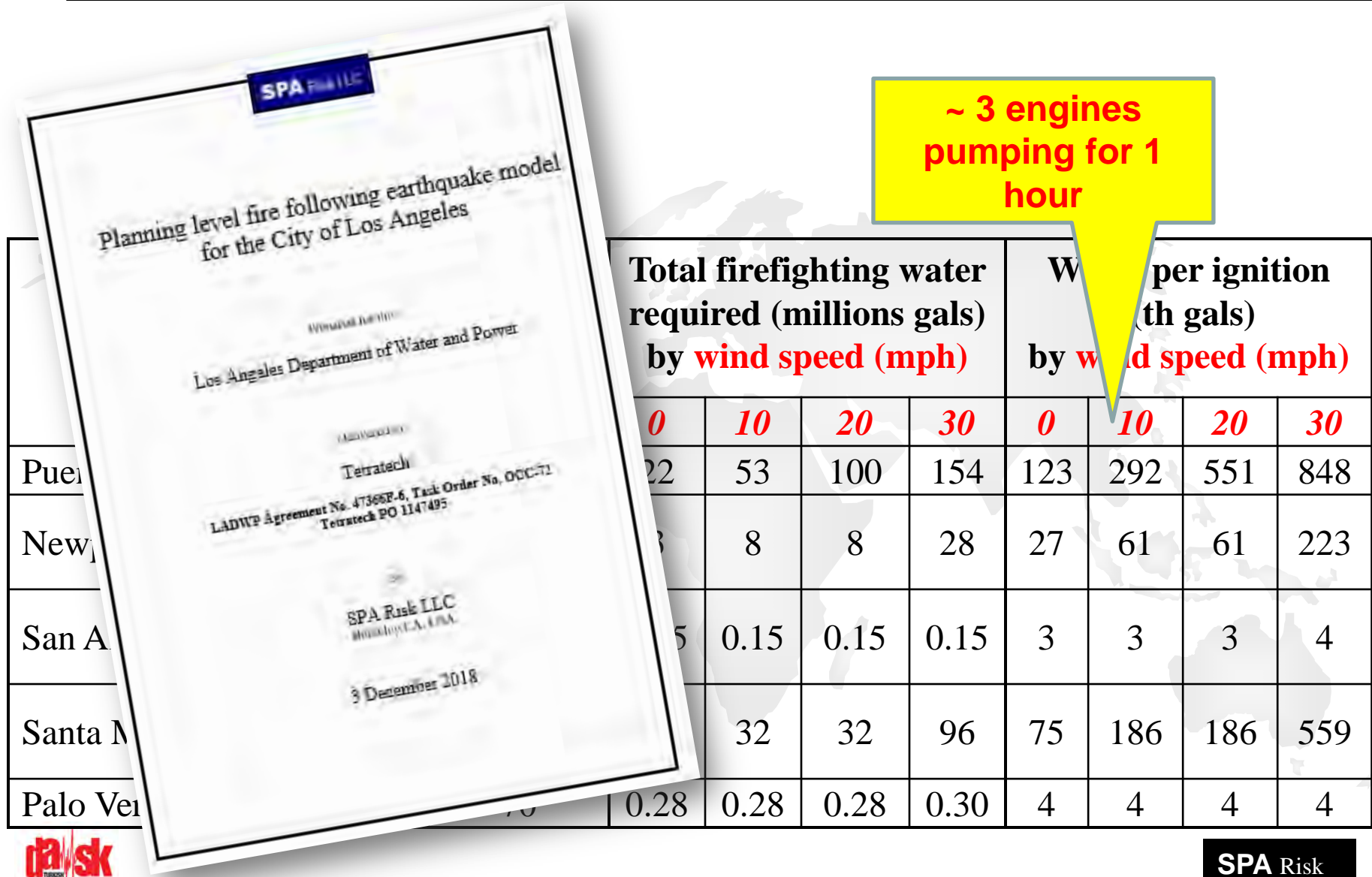


TASK 4 to 6 – MODEL APPLICATION

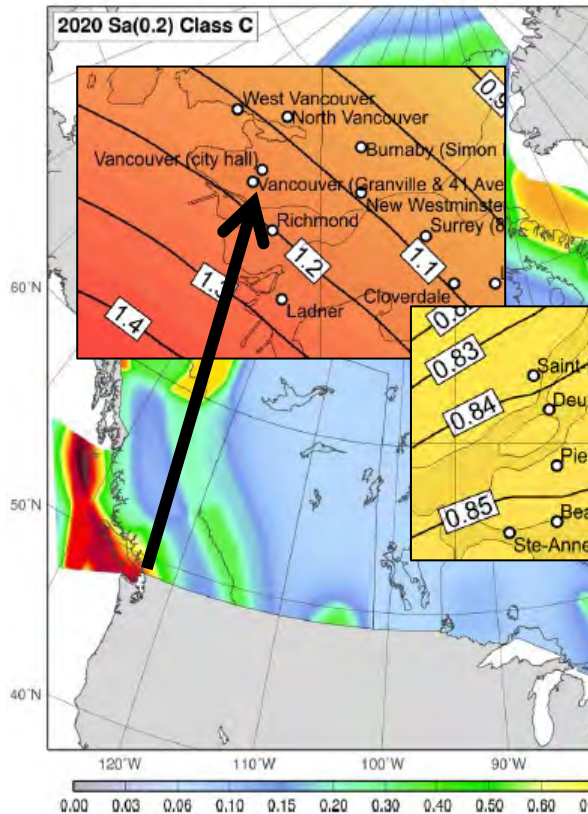
Puente Hills Mw 7.0



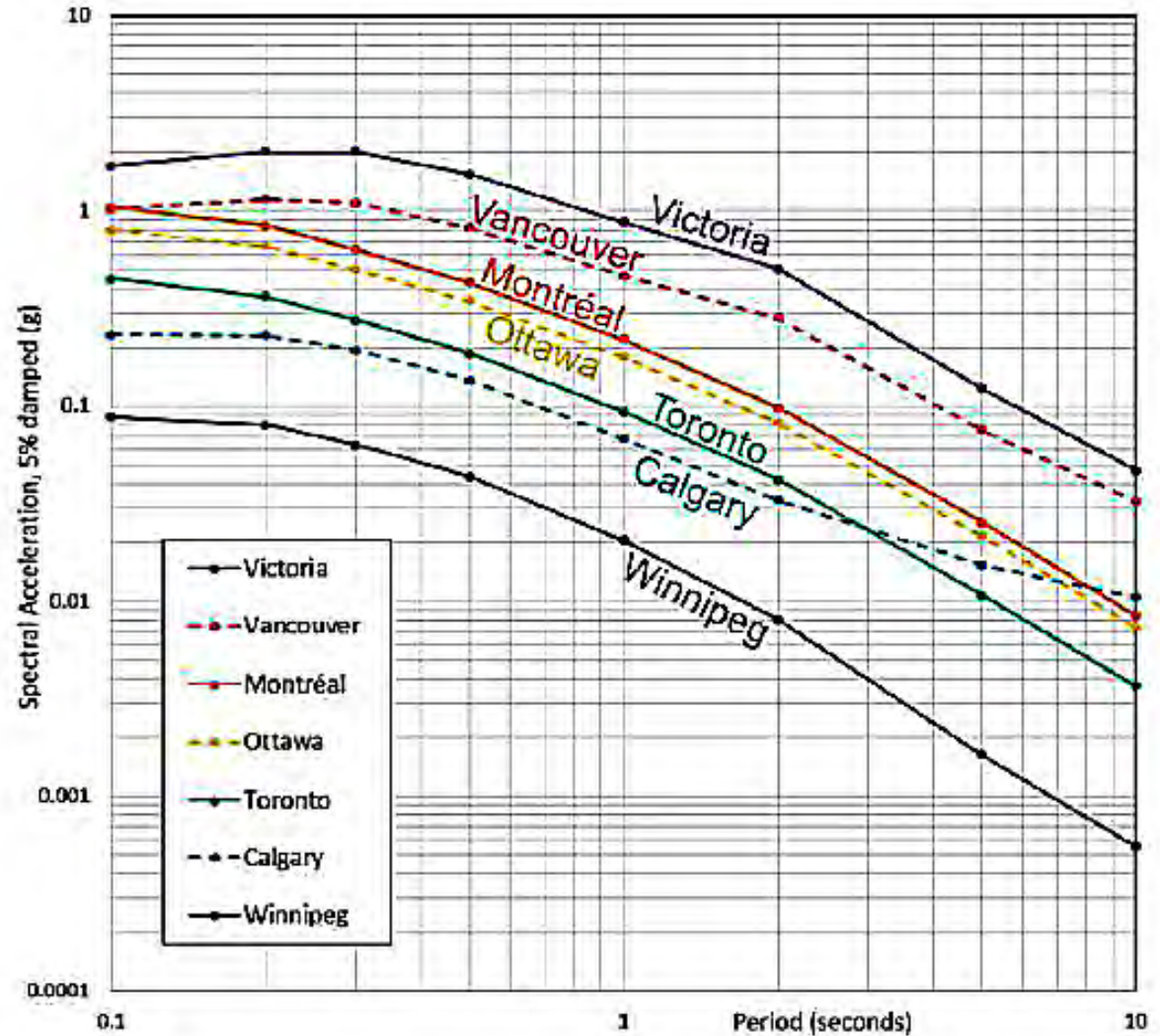
Summary – five scenarios



Montreal, Quebec Canada



$S_a(0.2)$ for Canada (mean values of acceleration for Site Class C and a units = g).



Uniform Hazard Spectra for mean 2%/50 year ground motions on Site Class C for key cities.

Fire Station Vulnerability:



two-thirds MFD stations

Figure 78: Fire station collapse, 1933 Long Beach (CA) earthquake. Note MFD's headquarters building dates from 1932.



masonry Building which also
Buildings were outlawed in

California in 1933

Modified Mercalli Intensity

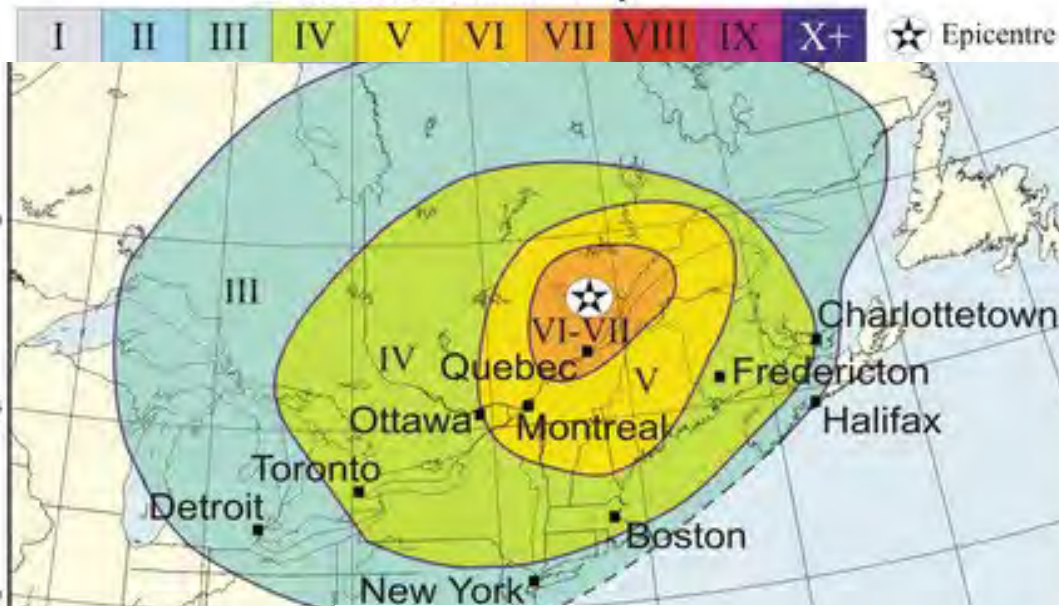
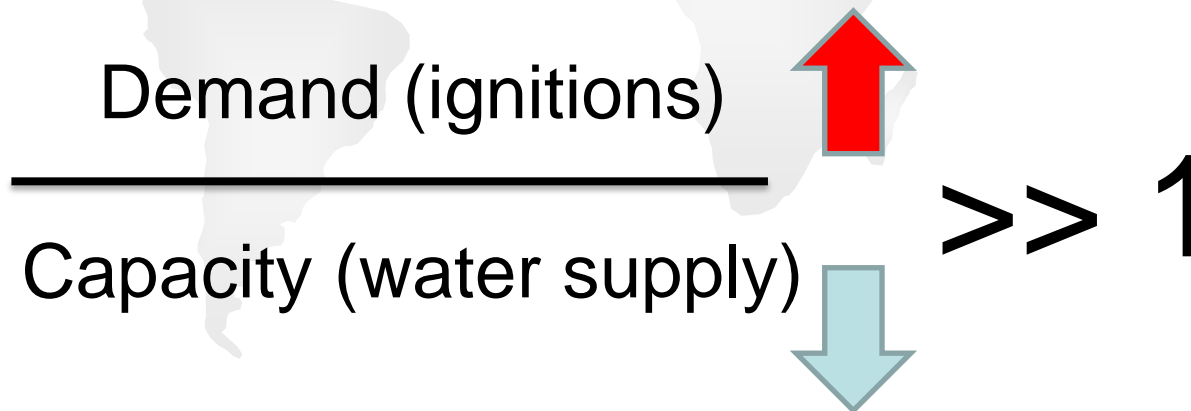
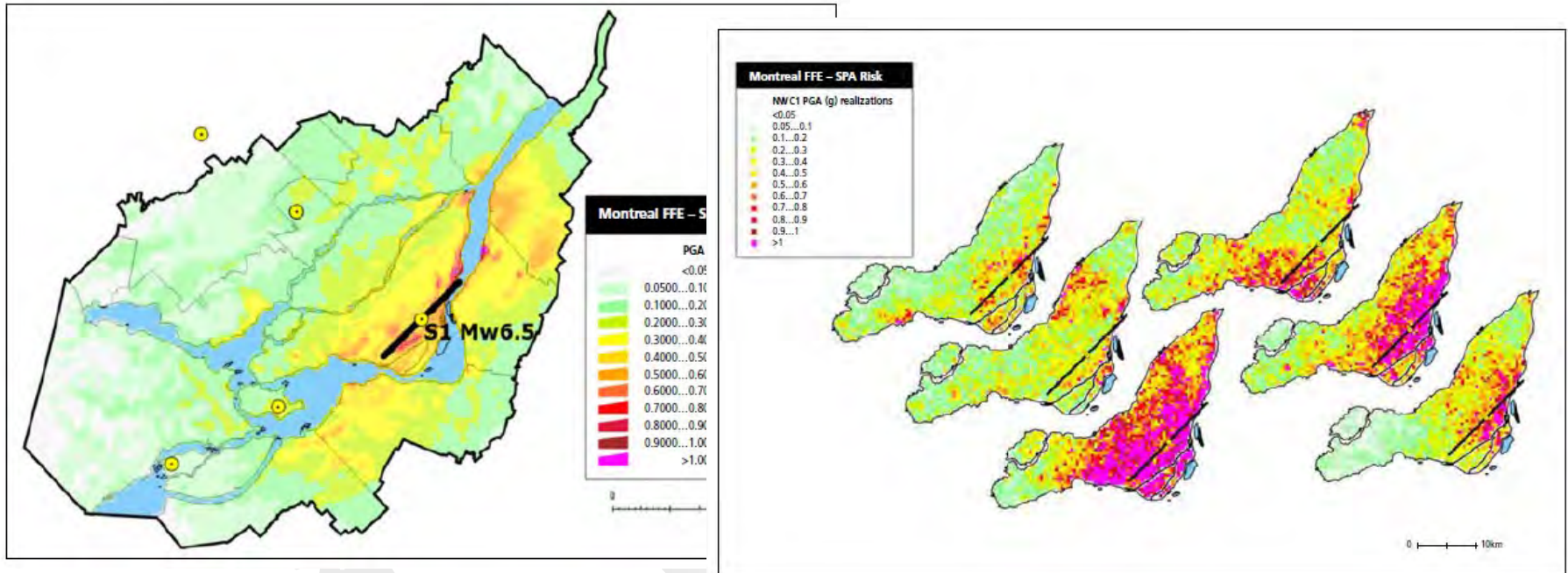


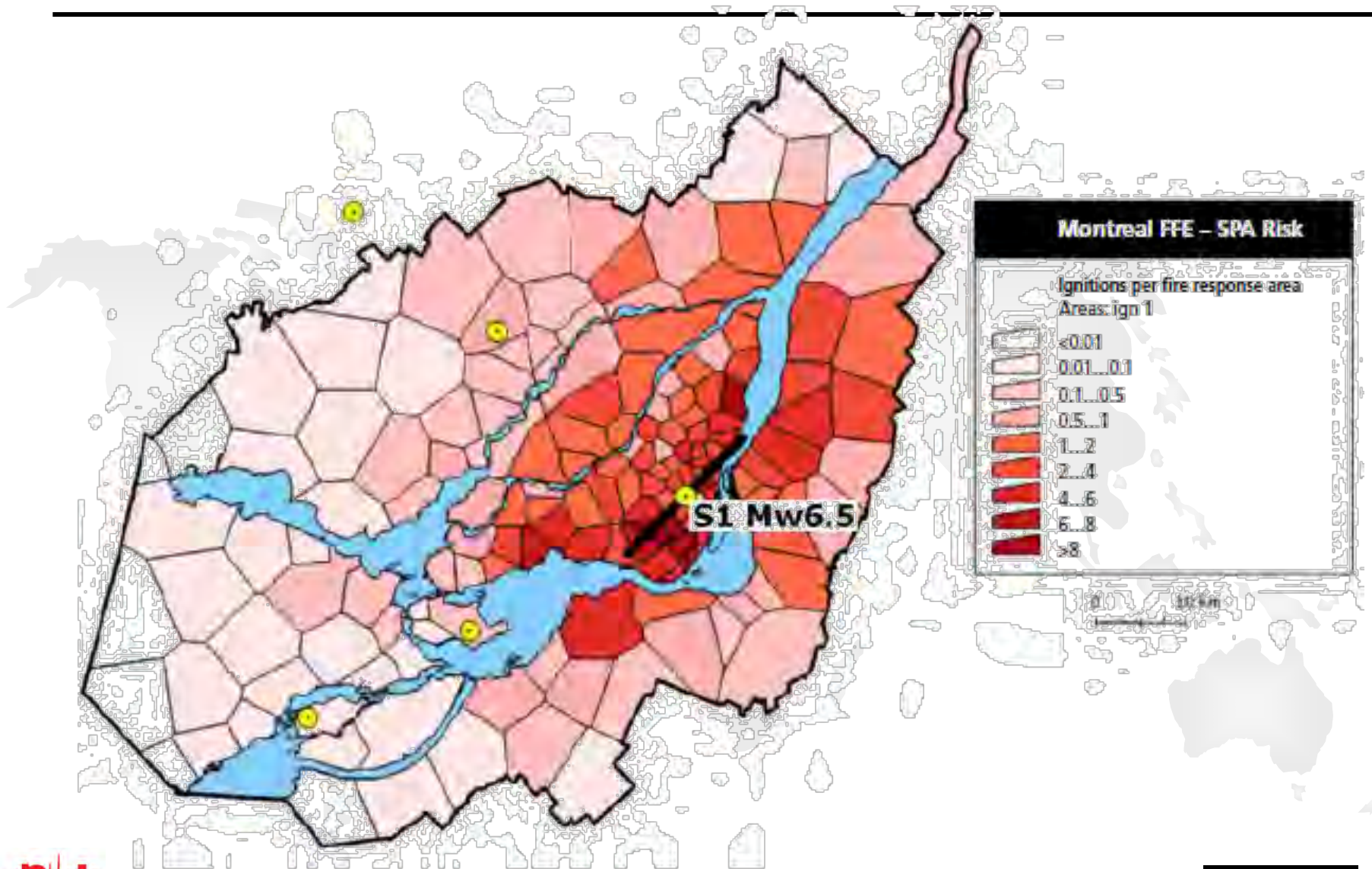
Figure 14: Loss of Montreal East City Hall masonry cladding in 1988 Saguenay earthquake.

Sources: Mitchell, Tinawi and Law (1990)

Ground motion spatial correlation



Montreal M6.5 Ignitions



Final
Loss
Rates

Risk

Boundary
TERIAL
ile Font
Font
ethylene
ethylene
islands
Steel
known
by Area
Districts

Figure 13 Istanbul Water Supply System

FFE Mitigation

Water Supply

- EBMUD, Hetch Hetchy...upgrades

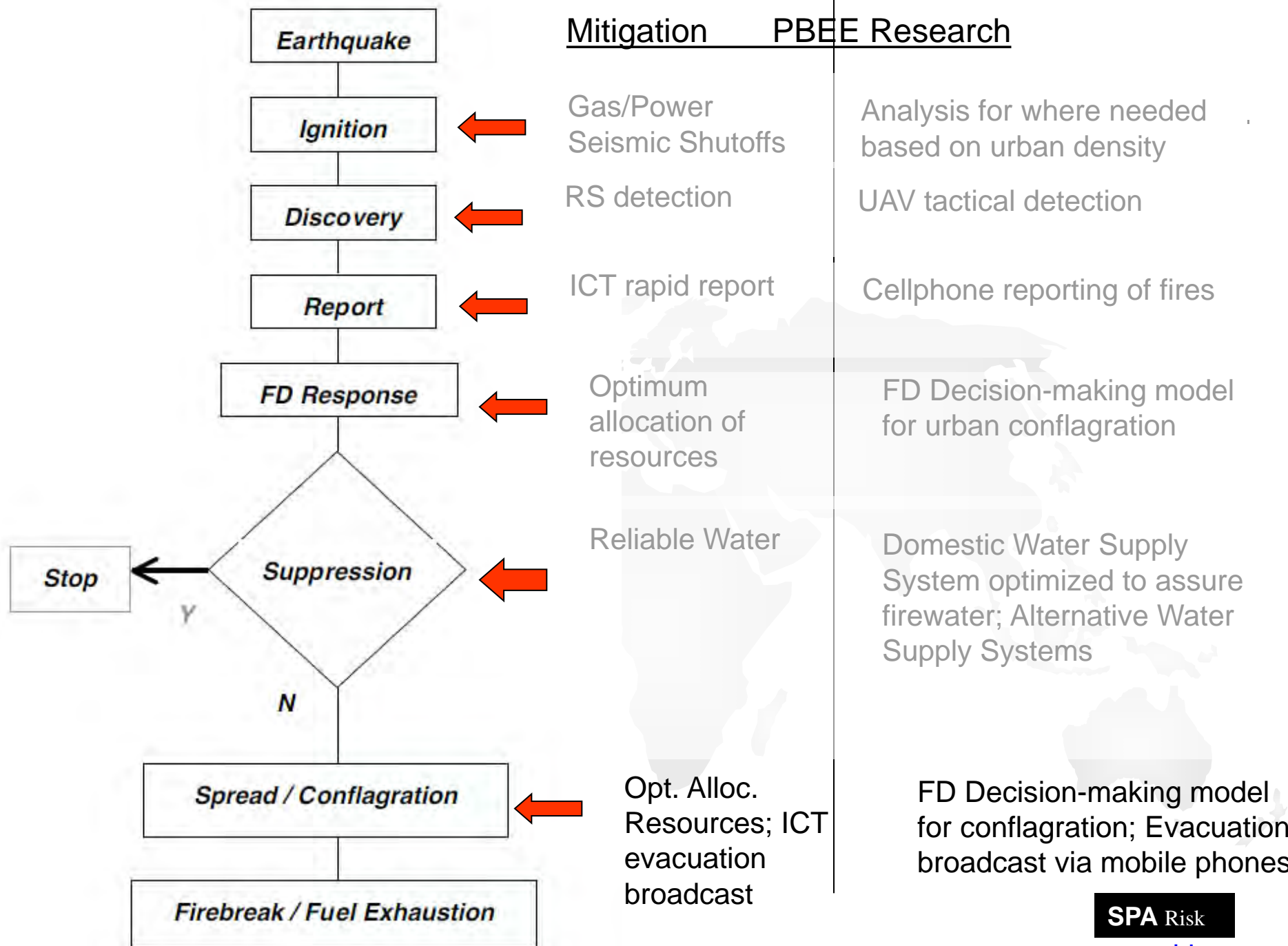
Special Systems

- San Francisco AWSS (1906)
- San Francisco PWSS (1986 → Loma Prieta EQ)
- Vancouver DFPS (1990s)
- Vallejo, Oakland, Berkeley (mini-PWSSs, 1990s)
- Los Angeles (ShakeOut → review of LA

NERT / CERT citizen training programs

Gas / Electric Seismic Shutoff Valves

EEW



SFNERT

Mission Statement

Beginning with ourselves, we will be prepared and work as an individual or together as emergency response teams to assist our families and neighbors in time of disaster and to be prepared to make decisions that do

The Most Good For The Most People

NERT:

Neighborhood
Emergency
Response Team



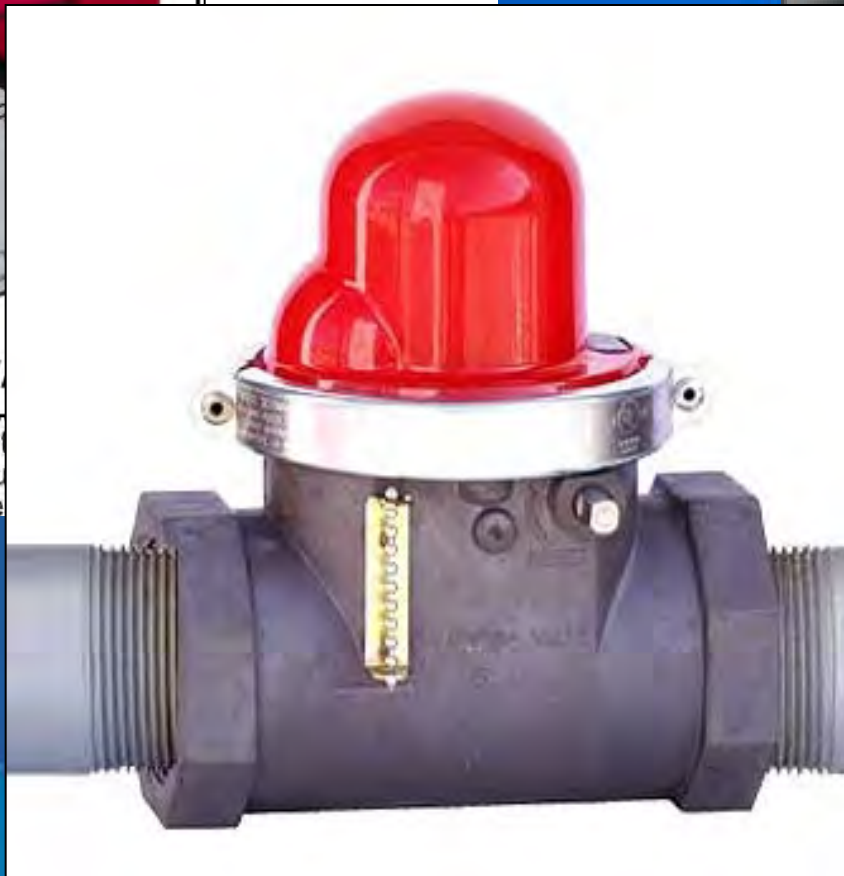
The San Francisco Fire Department makes NERT training available for people that live or work in San Francisco. The training is done by first responders of the San Francisco Fire Department.

Shut-



NORTHRIDGE V

(Edition) require
Seismic gas shut
during a major e



**1" NPT GAS VALVE
(2" VALVE ALSO AVAILABLE)**

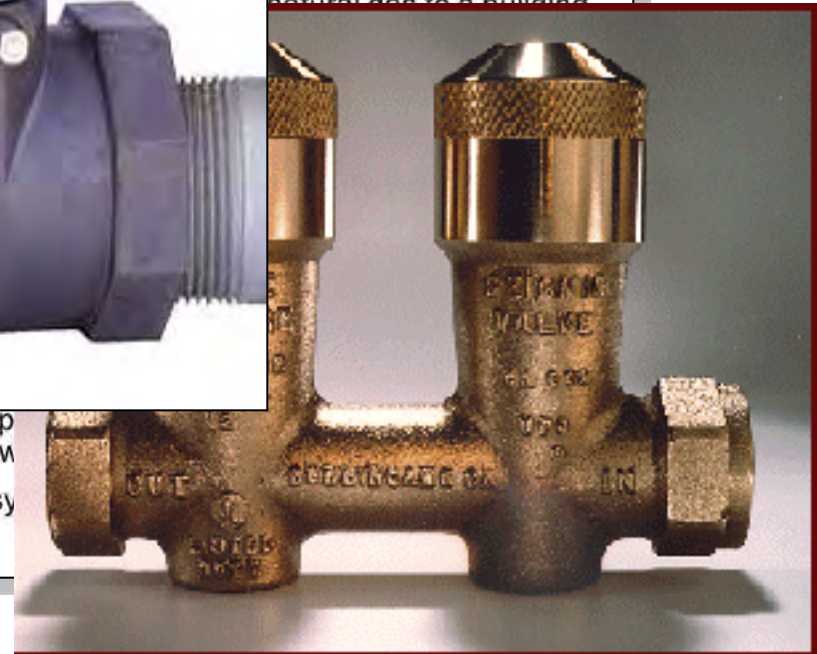


natural gas to a building



GAS VALVE CONTROLLER

Certified to ASCE 25-97



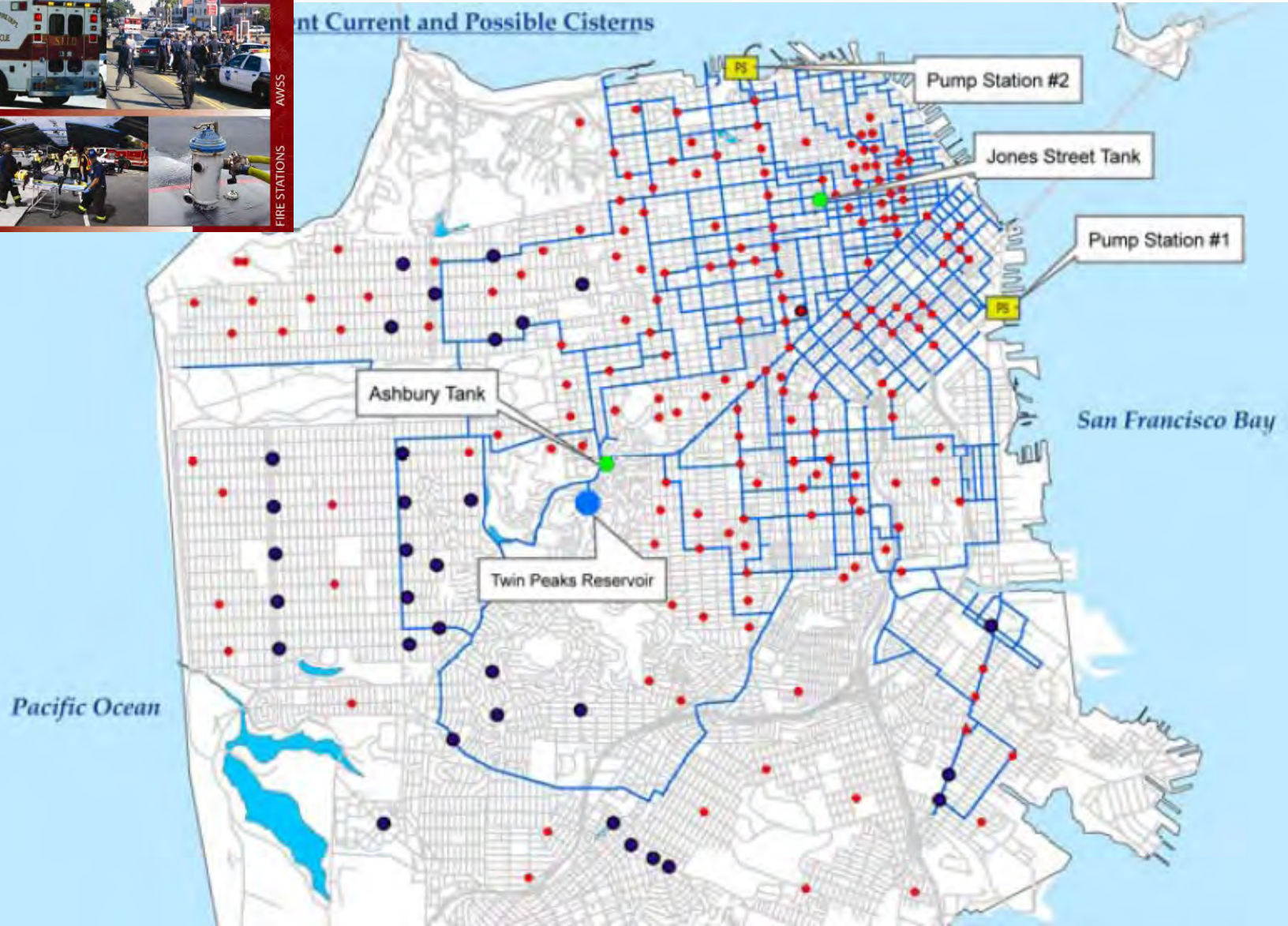
ent for sale or p
in connection w
el gas piping sy

Proposition B (June 2010 ballot) \$412 million

2010 EARTHQUAKE SAFETY AND EMERGENCY RESPONSE BOND



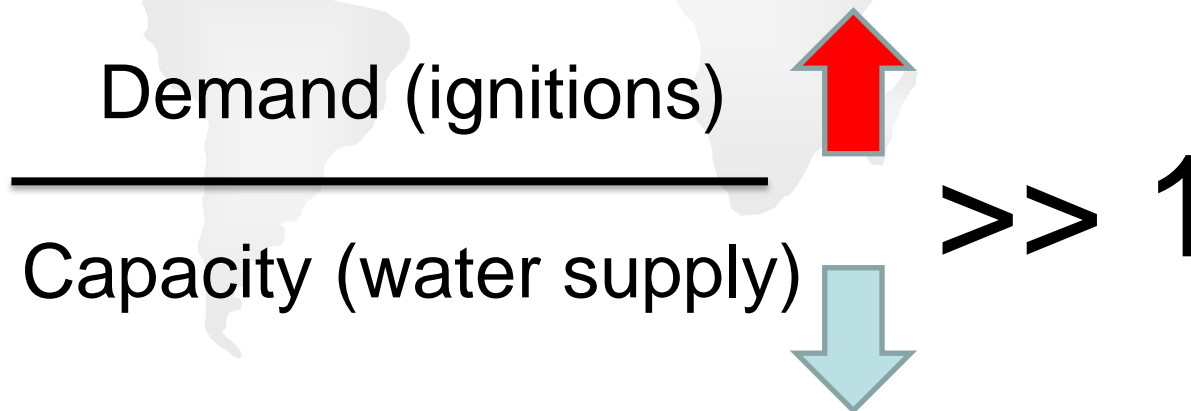
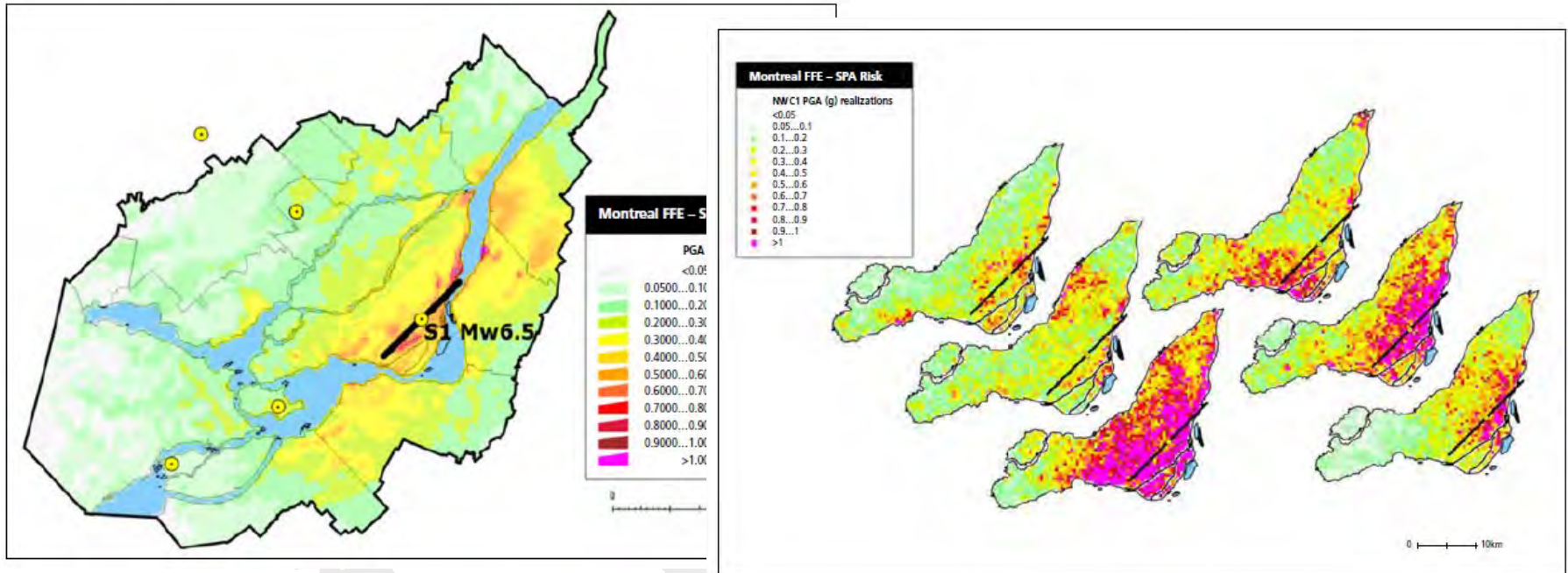
Current and Possible Cisterns



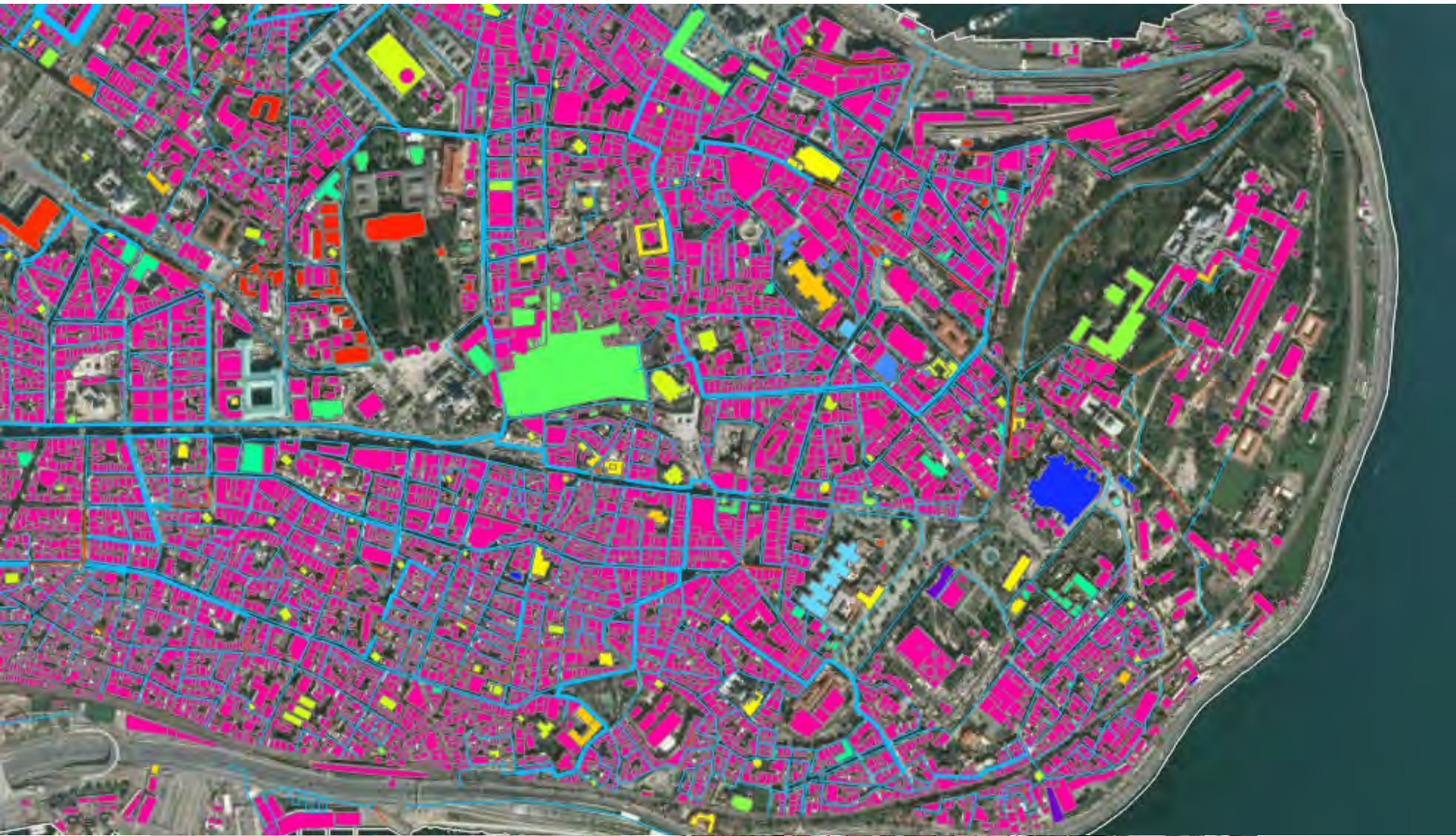
Advances in analysis of fire following earthquake

- **Spatial correlation** in ground motions. Previous underestimates of the number of ignitions and damage to water system.
- **Better data**
 - 345 fires in 2011 Tohoku EQ (Anderson 2016)
 - Actual building footprints
 - Inventories of urban trees
 - better estimation of fire spread
- **Physics based modeling** of fire spread (Himoto 2008)
- **Improved modeling of water** and other lifelines and their interdependencies (Scawthorn et al. 2018)

Ground motion spatial correlation

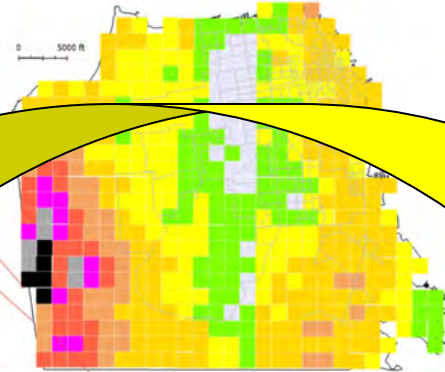
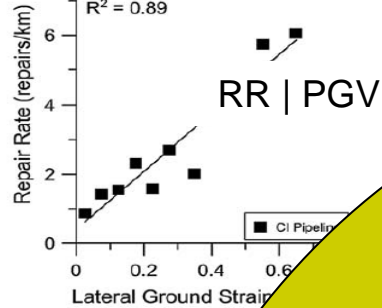


Exposure Data

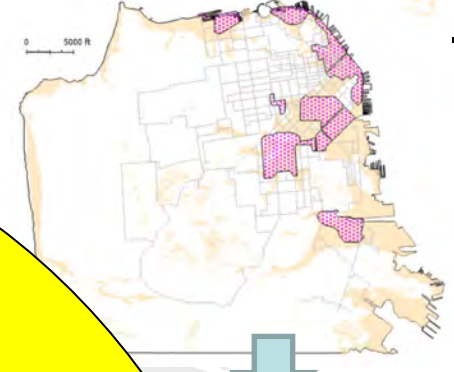


Interdependent infrastructure modeling

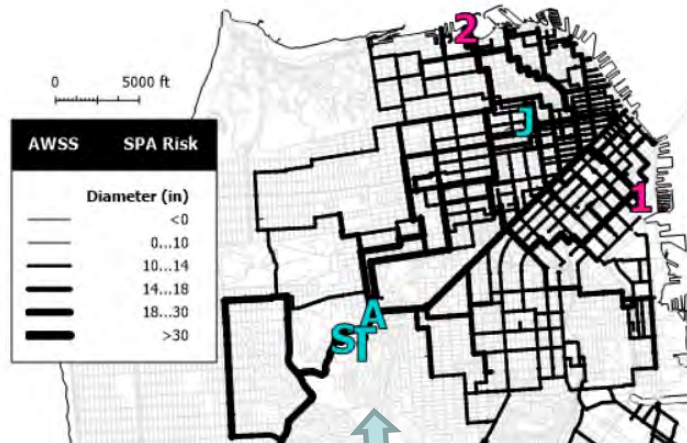
CI Fit Equation:
 $Y = 8.39 * X + 0.41$
 $R^2 = 0.89$



Ground shaking



Areas



Perma
Der

Monte Carlo – thousands of trials

Building density and material
(fuel)

Power / Traffic Interaction

RR | PGD

SPA Risk

www.sparisk.com

Thank you

Questions?

cscawthorn@sparisk.com

