# Chapter 13
# Fire Following Earthquake—The Potential in Istanbul

**C. Scawthorn**

**Abstract** Fire following earthquake is a little recognized risk in seismic regions with significant wood building inventories. Methods exist for quantifying this risk, and examples are provided in this chapter for San Francisco, Istanbul and Montreal. There are many opportunities for reducing this risk, and examples are provided regarding reducing fire station vulnerability and improving emergency firefighting water supply. Once accomplished however, vigilance is required to maintain these mitigation measures.

## 13.1  Introduction

*Fire following earthquake* refers to a series of events or a *stochastic process* initiated by a large earthquake. Fires occur following all earthquakes that significantly shake a human settlement but are generally only a very significant problem in a large metropolitan area predominantly comprised of densely spaced buildings. In such circumstances, the multiple simultaneous ignitions can lead to catastrophic conflagrations that by far are the dominant agent of damage for that event. Regions of high seismicity with large metropolitan areas predominantly comprised of densely spaced wood buildings are particularly at risk, and include Japan, New Zealand, parts of Europe and western North America. Istanbul is a major metropolitan area subject to large earthquakes that has historically sustained large conflagrations, so that the potential for fire following earthquake losses is a significant concern and the focus of this chapter.

C. Scawthorn (✉)
Pacific Earthquake Engineering Research Center, University of California at Berkeley, Berkeley, CA 94720-1792, USA
e-mail: cscawthorn@sparisk.com

Large fires, for example measured in terms of square kilometers of burnt area, have not been unique to fires following earthquakes—indeed, the great fires of London (1666) and Chicago (1871) are only the most noteworthy of a long succession of non-earthquake related urban peace-time conflagrations. Istanbul in its long history has had a number of large conflagrations:

> … the terrible earthquake which took place in 1509, known as "the Little Day of Judgment", dealt a terrible blow to the city's brick and stone houses. Fearing the effects of further earthquakes people began to build their houses of wood instead and in a short space of time Istanbul became a city of wooden houses. … This inevitably led to a rapid increase in the number of fires in the city. As well as the earthquakes of 1765 and 1894, which also caused terrible destruction, Istanbul's greatest enemy has always been fire. …Sometimes these fires would start from the banks of the Golden Horn and burn until they reached Aksaray or even the Sea of Marmara. The last great fires of Istanbul were the Hocapaşa fire of 1865, the Beyoglu fire of 1870, the Laleli fire of 1911, the Gedikpaşa fire of 1912 and the Cibali-Fatih-Altınmermer fire of 1918. …The last big fire of this kind destroyed a large part of the Fener district in 1941 (Ansal 2003).

Still, the two largest peace-time urban conflagrations in history have been fires following earthquakes—1906 San Francisco and 1923 Tokyo, the latter resulting in the great majority of the 140,000 fatalities.

Although a combination of a professionalized fire service, improved water supply and better building practices has largely eliminated non-earthquake related large urban conflagrations in Istanbul, there is still a gap—an Achilles Heel—which is fire following earthquake. This is due to the correlated effects of a large earthquake simultaneously causing numerous ignitions, degrading building fire resistive features, dropping pressure in water supply mains, saturating communications and transportation routes, and thus allowing some fires to quickly grow into conflagrations that outstrip local resources. It is not sufficiently appreciated that the key to modern fire protection is a well-drilled rapid response by professional firefighters in the early stages of structural fires, arriving in time to suppress the fires while that is still relatively feasible. A typical response goal for urban fire departments for example is 4 min from time of report to arrival. If suppression is delayed, due either to delayed response, or lack of water, a single structural fire can quickly spread to neighboring buildings and grow to the point where an entire municipalities' fire resources are required, and perhaps even assistance from neighboring communities. This is for a single ignition. Simply put, most fire departments are not sized or equipped to cope with the fires following a major earthquake. A major earthquake and its associated fires is a low probability event for which, although having very high potential consequences, it may not be feasible to adequately prepare.

## 13.2 Analysis of Fire Following Earthquake

The first step towards solving any problem is analyzing the problem and quantifying its effects. A full probabilistic methodology for analysis of fire following earthquake was developed in the late 1970s (Scawthorn et al. 1981) and applied to major cities in western North America (Scawthorn and Khater 1992), Japan and Istanbul, the methods for which are detailed in (Scawthorn et al. 2005), so that only a brief review is presented here. In summary, the steps in the process are:

- *Occurrence of the earthquake*—causing damage to buildings and contents, even if the damage is as simple as knockings things (such as candles or lamps) over.
- *Ignition*—whether a structure has been damaged or not, ignitions will occur due to earthquakes. The sources of ignitions are numerous, ranging from overturned heat sources, to abraded and shorted electrical wiring, to spilled chemicals having exothermic reactions, to friction of things rubbing together.
- *Discovery*—at some point, the fire resulting from the ignition will be discovered, if it has not self-extinguished (this aspect is discussed further, below). In the confusion following an earthquake, the discovery may take longer than it might otherwise.
- *Report*—if it is not possible for the person or persons discovering the fire to immediately extinguish it, fire department response will be required. For the fire department to respond, a Report to the fire department has to be made. Communications system dysfunction and saturation will delay many reports.
- *Response*—the fire department then has to respond, but is impeded by non-fire damage emergencies they may have to respond to (e.g., building collapse) as well as transportation disruptions.
- *Suppression*—the fire department then has to suppress the fire. If the fire department is successful, they move on to the next incident. If the fire department is not successful, they continue to attempt to control the fire, but it spreads and becomes a conflagration. Success or failure hinges on numerous factors including water supply functionality, building construction and density, wind and humidity conditions, etc. If unable to contain the fire, the process ends when the fuel is exhausted or when the fire comes to a firebreak.

This process is also shown in Fig. 13.1 which is a Fire Department Operations Timeline. Time is of the essence for the fire following earthquake problem. In this figure, the horizontal axis is Time, beginning at the time of the earthquake, while the vertical axis presents a series of horizontal bars of varying width. Each of these bars depicts the development of one fire, from ignition through growth or increasing size (size is indicated by the width or number of bars). Fire following earthquake is a highly non-linear process, modeling of which does not have great precision and is such that in many cases the only clear result is differentiation between situations of a few small fires, versus major conflagration.
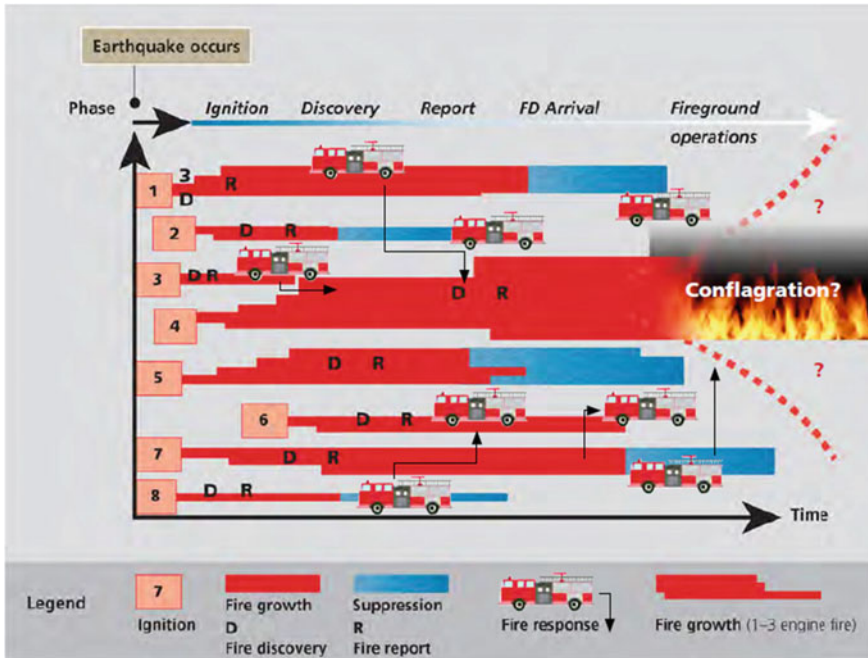
**Fig. 13.1** Fire following earthquake timeline

## 13.2.1 Assets at Risk and Ignitions

Ignitions are a function of shaking intensity and the total amount of building floor area exposed to that shaking—the more buildings, the more sources of ignitions. Figure 13.2 shows total building floor area (in sq. m., per 0.01° grid cell) for Istanbul. While Istanbul was historically composed primarily of wood buildings, in recent decades the region's building stock has become almost entirely masonry and reinforced concrete—good for fire, questionable for earthquake.

Figure 13.3 shows estimated shaking intensity for a M7.5 earthquake expected to occur on the North Anatolian fault in close proximity to Istanbul (Ansal 2003). The actual number of ignitions varies with each ground shaking scenario—for the M7.5 event most of the Study Area would be subjected to PGAs of 0.1—0.4 g, meaning that the total number of ignitions would number perhaps one to two hundred. For comparison, a rule of thumb for ignitions is presented in Table 13.1, where it can be seen that for a population shaken at Modified Mercalli Intensity (MMI) VIII, there will be approximately one fire following earthquake requiring fire department assistance for each 10.5 million sq. ft. of floor area—that is, for approximately 7,000 single family dwellings, or a residential population of about 25,000.
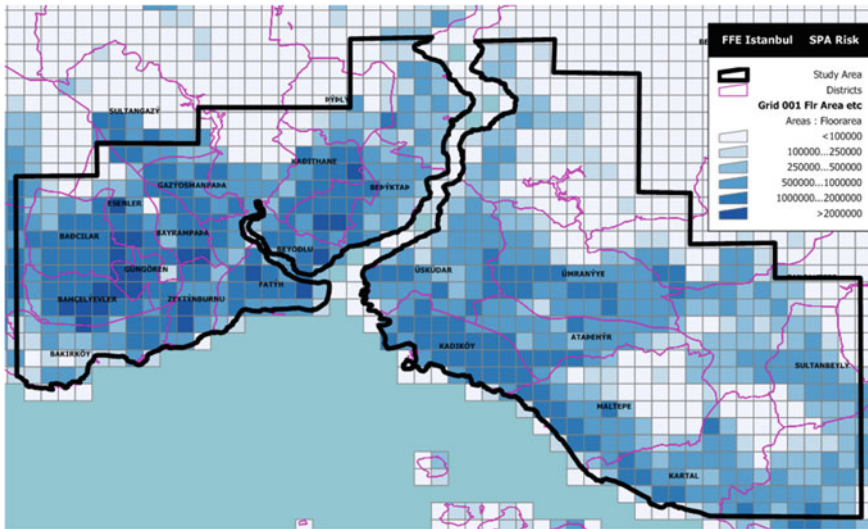
**Fig. 13.2** Total Building Floor Area (sq. m) per 0.01 degree grid cell, Istanbul region

These are ignitions that require fire department response—there will be other, usually minor, ignitions that are suppressed immediately by citizens and typically not even reported.

The cause of these ignitions would likely be similar to causes in the 1994 Northridge earthquake, which is the best US data set for recent fires following an earthquake—about half of all ignitions would be electrical related, a quarter gas-related, and the other due to a variety of causes, including chemical reaction. Also based on the Northridge experience, about half of all ignitions would typically occur in single family residential dwellings, with another 26% in multi-family residential occupancies—that is, about 70% of all ignitions occur in residential occupancies. Educational facilities would be a small percentage of all ignitions (3% in Northridge), and most of these are due to exothermic reactions of spilled chemicals in chemistry laboratories.

A particular concern is oil refineries, tank farms and related energy facilities. When strongly shaken, oil refineries and tank farms have typically had large fires which have burned for days. Examples include the Showa refinery in the 1964 Niigata (Japan) earthquake, the Tüpraş refinery in the 1999 Marmara (Turkey) Earthquake (Fig. 13.4) and the Idemitsukosan Hokkaido refinery fire in the 2003 Tokachi-oki earthquake.
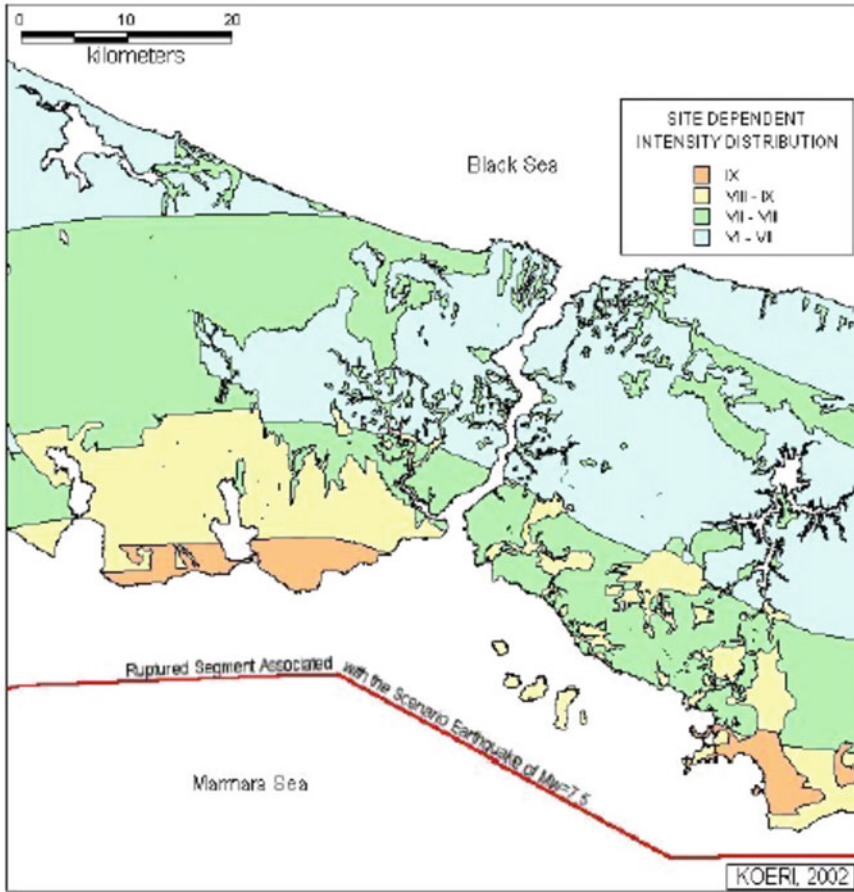
**Fig. 13.3** Site dependent deterministic intensity distribution for M7.5 Scenario Earthquake (Ansal 2003)

**Table 13.1** Approximate Ignition Rate versus MMI (Scawthorn et al. 2005)

| MMI | VII | VIII | IX | X |
|---|---|---|---|---|
| 1 Ign. Per million sq. ft. of Building Floor Area | 18 | 10.5 | 4.5 | 1.5 |

## 13.2.2 Communications/Water Supply

The performance of lifelines, such as water supply, gas, electric power, communications and transportation, is integral to the fire following earthquake process.

Water supply may be severely impacted, depending on the scenario event. Generally, only the water distribution system is relevant to the fire following earthquake process. Water pressure will drop in some portions of the more heavily shaken area

**Fig. 13.4** Tüpraş petroleum refinery, fire following the 1999 Marmara (Turkey) earthquake (Scawthorn 2000). Photo by G. Johnson

due to pipe breaks and tank failures. Water distribution system failure is a function of pipe material, diameter, and soil type, which for Istanbul is shown in Fig. 13.5.

Gas-related ignitions typically account for about 25% of the total number of ignitions. The Istanbul Gas Company (IGDAŞ) system is a relatively new system, Fig. 13.6, and is considered likely to suffer relatively less damage compared with older systems, such as in California (even though these systems are devoting considerable resources to modernization). IGDAŞ also has some capacity for remotely shutting trunk line valves. Nevertheless, the overall impact is that gas related ignitions may be somewhat lower than in California or Japan, due to the relatively light damage the IGDAŞ system is likely to sustain.

Communications systems, particularly telephone, will sustain some damage but not enough to reduce functionality following the scenario event. However, saturation will reduce functionality to a great degree, for several hours or more. This lack of telephone service will result in delayed reporting, with consequences as discussed above.
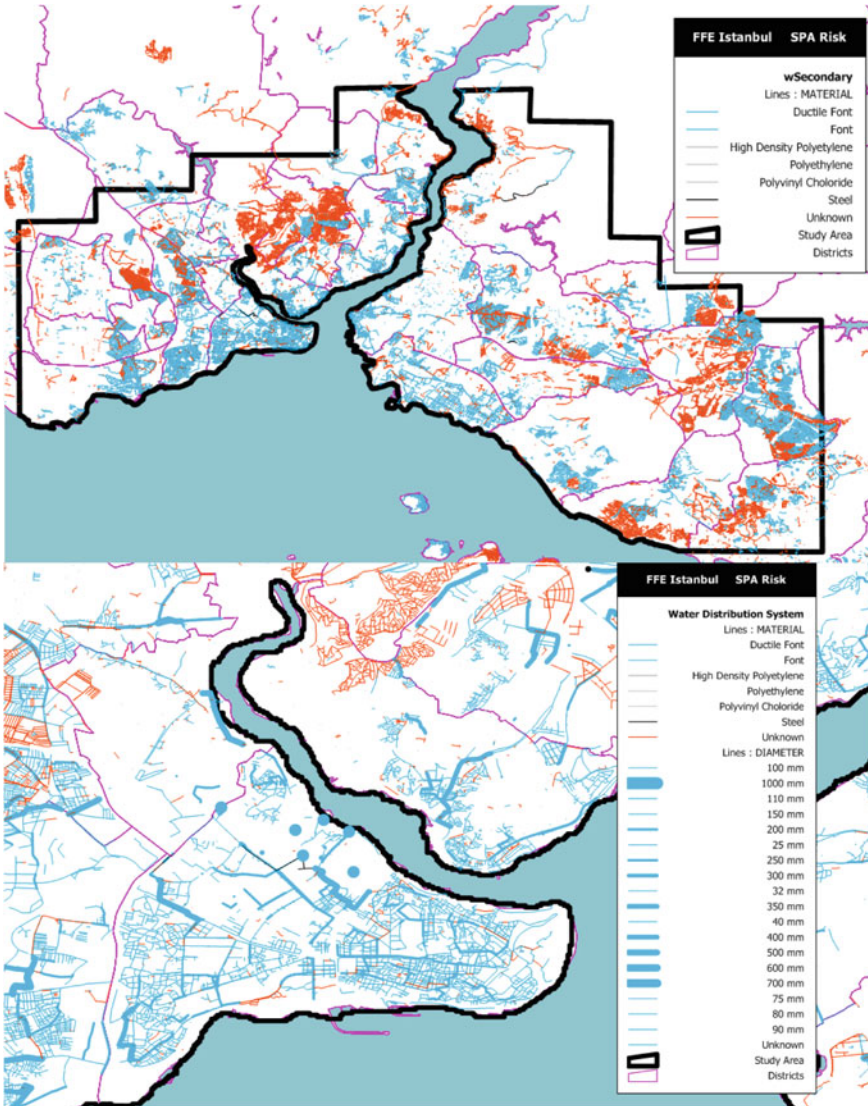
**Fig. 13.5** (top) Istanbul water distribution system, (bott) detail, showing pipe materials and diameters

The transportation system most relevant to fire following earthquake is the road network, which are most vulnerable at bridge crossings. However, for Istanbul the distribution of fire stations is such that road blockage is unlikely to be a major factor, Fig. 13.7.
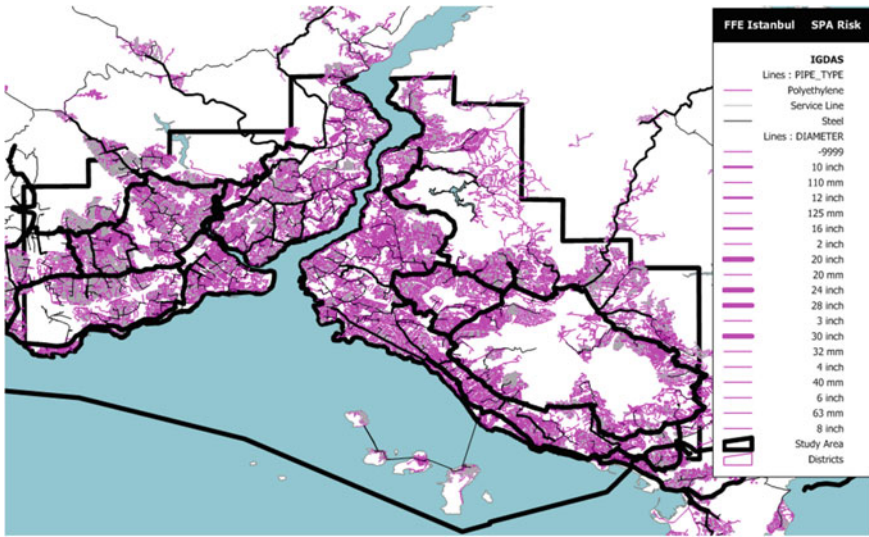
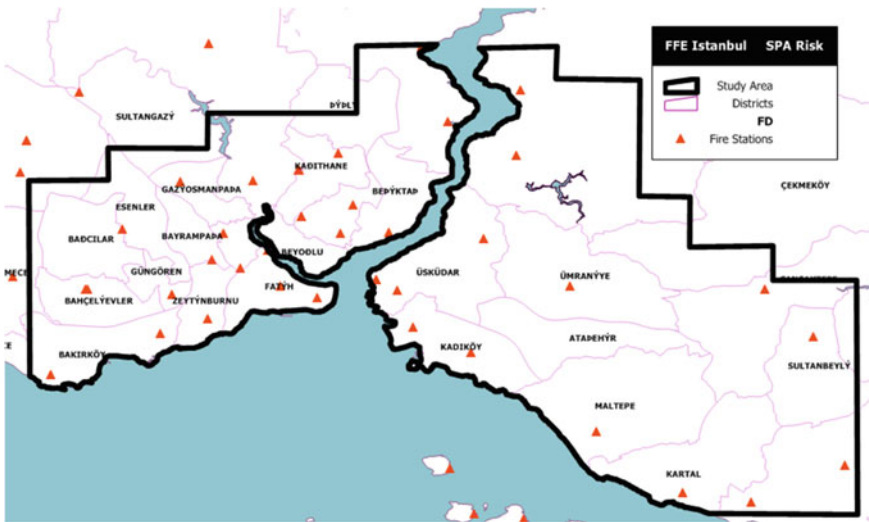**Fig. 13.6** IGDAŞ gas distribution system



**Fig. 13.7** Istanbul fire station locations

### 13.2.3 Fire Spread

Depending on the specific event, only a very few of Istanbul's initial few hundred ignitions will develop into conflagrations. The precise number varies with wind speed and other factors and is difficult to summarize, but an idea can be gained by again assuming a uniform PGA distribution using San Francisco, California, as a study area, Fig. 13.8. The number can be seen to be significantly less than the total number of ignitions.

## 13.3 FFE Risk for Several Cities

The above methods have been applied by the author to a number of cities including San Francisco, Los Angeles, Istanbul, Montreal and Tokyo, for purposes as varied as insurance underwriting, water supply reliability assessment, and emergency planning. In these studies, methods vary from fully deterministic, in which earthquake, wind and other factors are fixed and an average number of fires and associated loss are estimated, to fully probabilistic, in which uncertainty in all relevant factors is considered, and a full probabilistic distribution of losses is analyzed. Other studies are intermediate between these two extremes, varying only several key factors. Monte Carlo and other simulation techniques are commonly employed in these analyses. An example of a relatively deterministic analysis is shown in Fig. 13.9 and Table 13.2, for the city of San Francisco, California (ATC-52-1 2010).

**Table 13.2** Average damage caused by fire following the scenario earthquakes, San Francisco (ATC-52-1 2010)

| Scenario | Shaking damage ($ billions)[a] | Average additional damage due to fire[b] ($ billions) | Shaking plus fire damage[c] ($ billions) |
|---|---|---|---|
| Hayward Fault, Magnitude 6.9 | $14 | $2.7 | $17 |
| San Andreas Fault, Magnitude 6.5 | $20 | $3.0 | $23 |
| San Andreas Fault, Magnitude 7.2 | $30 | $4.3 | $34 |
| San Andreas Fault, Magnitude 7.9 | $48 | $5.8 | $54 |

*Notes*
[a]These figures include direct damage to buildings from shaking and ground failure, in 2009 dollars
[b]These figures are averages for the many analyses with varying circumstances and do not double count shaking damage (i.e., burning rubble). Results are in 2009 dollars
[c]In 2009 dollars. Numbers in table have been rounded, which can make totals differ from sum of columns or rows
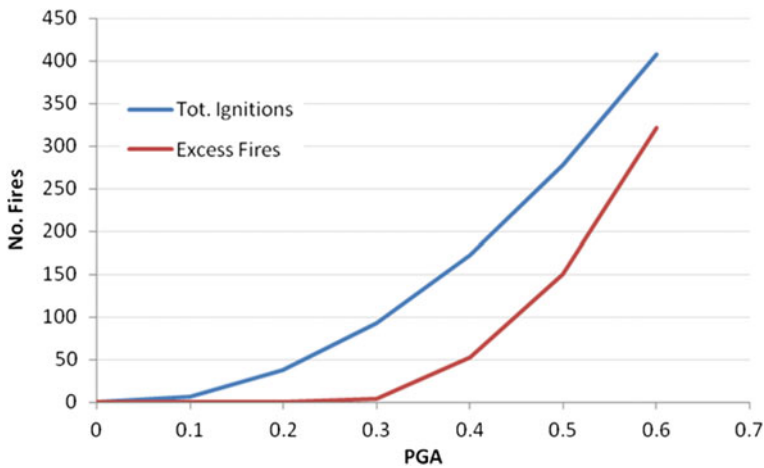
**Fig. 13.8** Average no. ignitions and fires for Istanbul assuming uniform peak ground acceleration (PGA)

Another example is shown Fig. 13.10 for Montreal Canada, for three earthquake scenarios varying from magnitude 6.5–7. Accounting for fire department response, water system damage, weather and other conditions, the growth and ultimate final burnt area of fires were estimated and in summary found to result in losses of between $10 billion and $30 billion, Table 13.3 (Scawthorn 2019). These are median estimates—there are smaller probabilities of greater or less damage and the range is a function of the specific earthquake scenario (i.e., location and magnitude), time of day, weather and other factors, as shown in Fig. 13.11.

## 13.4  FFE Mitigation

Mitigation of fire following earthquake has been extensively discussed elsewhere (Scawthorn et al. 2005), so that only some limited recommendations are provided here, structured according to opportunities for improving fire department response and water service reliability and reducing building post-earthquake fire vulnerability.
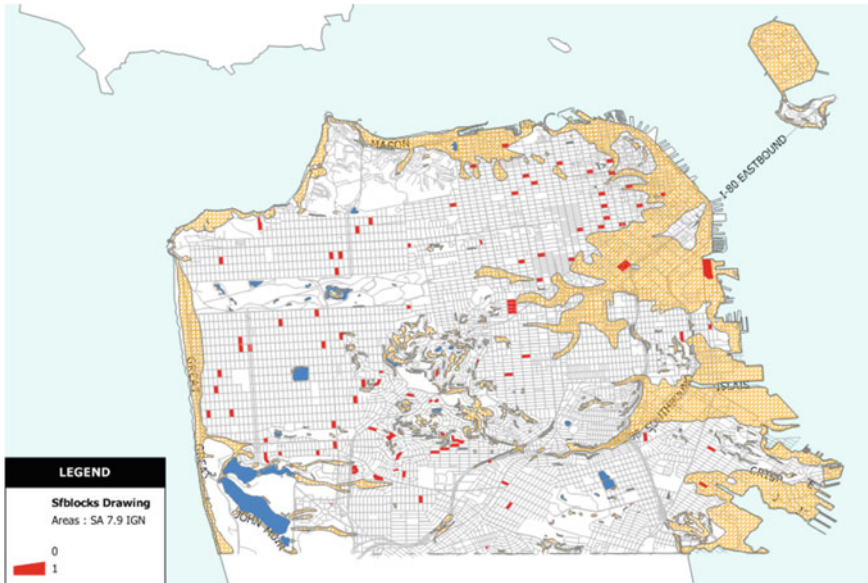
**Fig. 13.9** San Francisco showing one realization of ignitions for a M7.9 earthquake on the San Andreas fault

**Table 13.3** Median results (in billions C$), fire following earthquake, Montreal Canada (Scawthorn 2019)

|  | S1 MC1 Mw6.5 | S2 NW2 Mw7.0 | S3 SW3 Mw7.0 |  |
|---|---|---|---|---|
| Deterministic | $4,215 | $14,706 | $12,558 | Single realization, no uncertainty, daytime mild weather (20 °C, 5 km/h wind, 70% relative humidity) |
| Comprehensive | $11,723 | $29,646 | $30,655 | 100 realizations of spatially correlated ground motions, daytime mild weather (i.e., no uncertainty on weather) |
| Stochastic | $11,766 | $27,653 | $29,453 | 500 realizations of spatially correlated ground motions, uncertainty on weather and time of day |
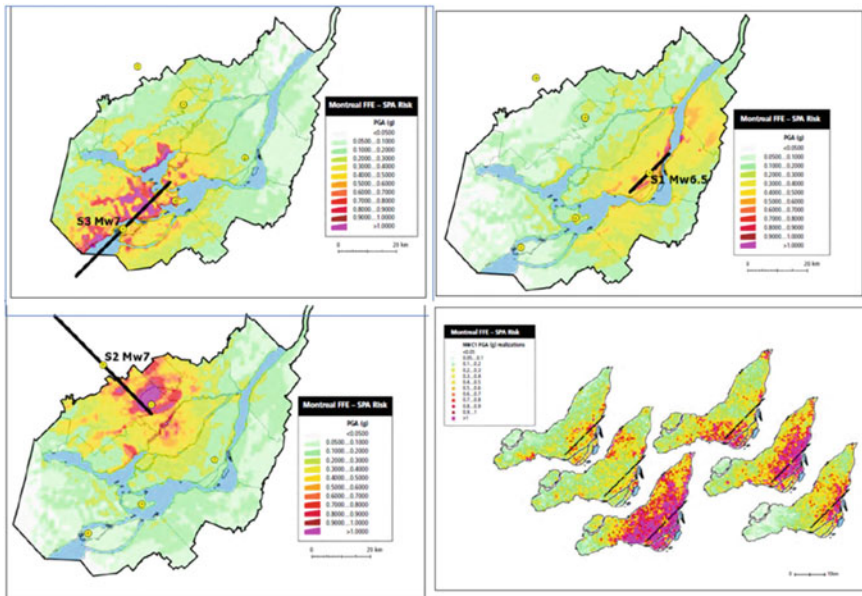
**Fig. 13.10** Montreal Canada, three earthquake scenarios (upper right is Mw 6.5 in CBD, left figures are M7 to NW or SW, fault rupture shown as black line). Lower right is multiple realizations of M6.5 event considering ground motion correlation (Scawthorn 2018)

## 13.4.1 Fire Station Vulnerability

Fire stations and other facilities in seismically hazardous areas require immediate post-earthquake functionality and should be evaluated according to modern methods for essential facilities. In many cities, fire stations can be as much as 100 years old, and in many cases were built before 1980, which is generally considered the beginning of modern seismic design. Fire station seismic vulnerability and its effects, directly on firefighter health and safety and indirectly on the ability of the fire apparatus to respond, has long been recognized and is now well quantified, Fig. 13.12. San Francisco, Los Angeles, Vancouver, B.C., Seattle and other cities have spent millions of dollars reinforcing and replacing aged stations, specifically due to seismic vulnerability concerns (Figs. 13.12 and 13.13).
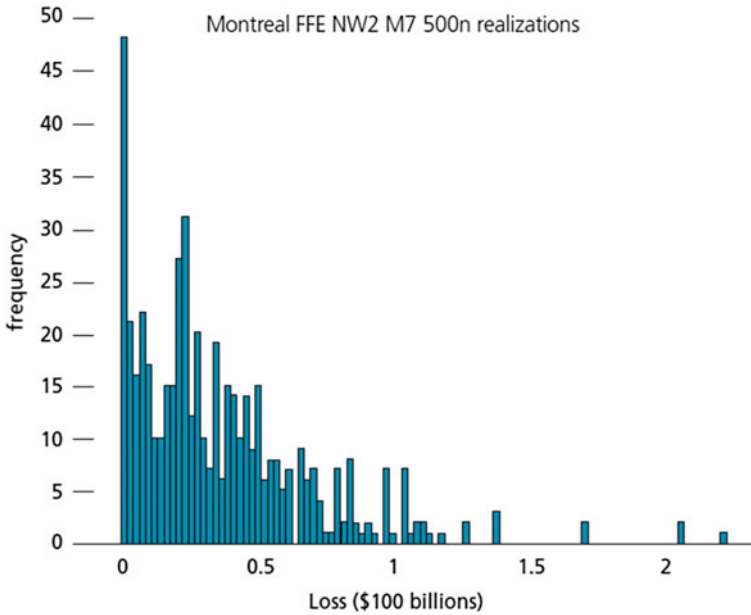
**Fig. 13.11** Scenario 2 (Mw7.5) histogram of 500 realizations: mean $36 billion and median $27.7 billion (Scawthorn 2019)

## 13.4.2 Firefighting Water Capacity

Most cities lie on or near a shore, bay, river or other body of water, as San Francisco did in 1906—indeed, San Francisco had direct access to the largest body of water on earth—yet burned for three days due to lack of firefighting water. Why? Because, similar to the Ancient Mariner, while 'water water [was] everywhere', San Francisco could not move it to where the fires were. A similar situation exists in many cities today, which would have significant difficulty in pumping/relaying water. This situation is not unique but is also not acceptable.

**Fig. 13.12** San Francisco Bay Area fire station vulnerability (Bello and Bott 2006)



Figure 6
Number of Stations per County that are Low, Moderate and High Risk
(Total per county in parentheses)
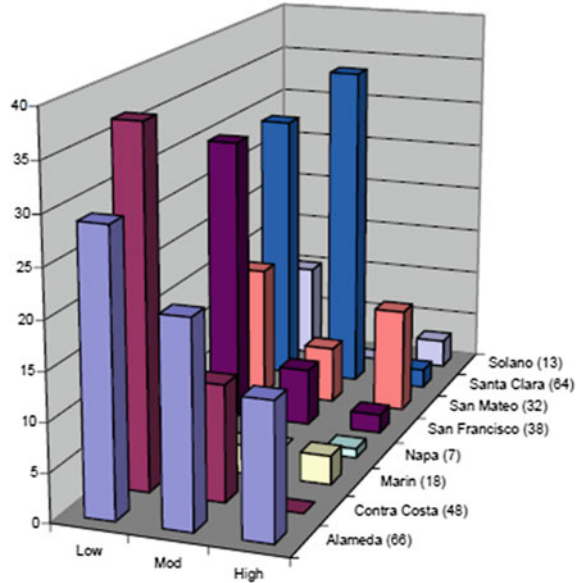
Alternative water supply sources need to be better identified, and access and water transport capabilities enhanced. Large diameter hose (LDH) systems, comparable to San Francisco Fire Department's or Vallejo FD's Portable Water Supply System (PWSS) Fig. 13.14 or Vancouver B.C.'s new LDH hose reel system, Fig. 13.15, should be developed on a regional basis. Note that a PWSS has wider applicability than just earthquake—it can be used in the case of water main breaks to provide potable supply, for wildfires and for dewatering of flooded areas. See Scawthorn (2011) for further details.

**Fig. 13.13** San Francisco 2014 $400 million Earthquake Safety and Emergency Response Bond

**Fig. 13.14** Example of LDH system (Vallejo FD): unit on left is a hose tender with monitor, carrying 5,000 ft. (1,538 m) of 5″ (125 mm) hose; unit on right is Hydrosub, a hydraulically driven detachable pump. The pump head can pump 1,500 gpm (6,000 lpm) up to 20 m vertically from a bridge or other point. Here it shown pumping from San Francisco Bay. See Scawthorn (2018) for more details

## 13.5 Concluding Remarks

In selected urban regions of high seismicity and wood building inventory, fire following earthquake is a significant but little recognized risk. Analyses in many regions has quantified this risk and led to significant mitigation which has reduced the risk. Once accomplished however, vigilance is required to maintain the mitigation measures.

**Fig. 13.15** Vancouver (B.C.) Fire and Rescue new LDH reel system—each trailer-mounted motorized reel carries 6000 ft. of 6″ hose. *Photo* Scawthorn (2019)

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