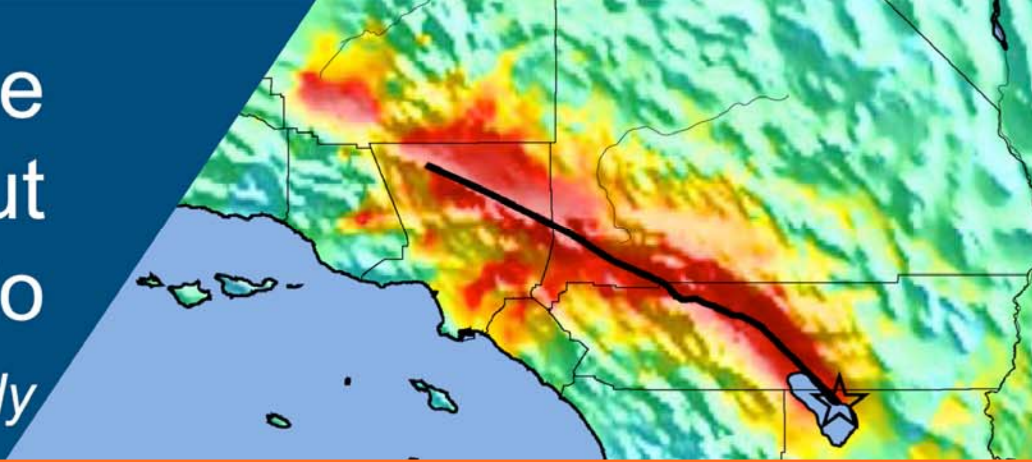
The ShakeOut Scenario

Supplemental Study



Fire Following Earthquake

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Note: over the course of the ShakeOut Scenario, the project name evolved. Where a study mentions *the SoSAFE Scenario* or *San Andreas Fault Scenario*, it refers to what is now named the ShakeOut Scenario.

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Table of Contents

List of Tables

List of Figures

ABSTRACT

Fire following earthquake is a significant problem in California. This Note examines the potential losses arising from fire following earthquake for a hypothetical M7.8 earthquake occurring at 10am on 13 November 2008 on the Southern segment of the San Andreas Fault, resulting in MMI VI-VIII in the Los Angeles basin and accompanied by breezy, low humidity conditions. 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. For the M7.8 scenario, it is estimated that approximately 1,600 ignitions will occur requiring the response of a fire engine. In about 1,200 of these fires the first responding engine will not be able to adequately contain the fire, such that one or several conflagrations destroying several city blocks will occur in Riverside and San Bernardino counties. Of more concern however, are portions of Orange County and especially the central Los Angeles basin, where the dozens to hundreds of large fires are likely to merge into dozens of conflagrations destroying tens of city blocks, and several of these merge into one or several super conflagrations destroying hundreds of city blocks. Under the assumed scenario conditions, a preliminary estimate is that the approximately 1,200 large fires will result in an ultimate burnt area of approximately 200 million sq. ft. of residential and commercial building floor area, equivalent to 133,000 single family dwellings. Directly attributable to these fires following the earthquake will be the loss of hundreds to perhaps a thousand lives, and an economic loss of forty to perhaps as much as one hundred billion dollars, This loss is virtually fully insured and could result in distortions in the US and global insurance industry. Other economic impacts include the loss of perhaps a billion dollars in local tax revenues. A number of opportunities exist for mitigating this problem, including construction of a seismically reliable basin-wide saltwater pumping system, and the mandatory use of automated gas shut-off valves, or seismic shut-off gas meters, in densely built areas.

1 INTRODUCTION

Fire following earthquake refers to series of events or *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 wood buildings. In such circumstances, the multiple simultaneous ignitions can lead to catastrophic conflagrations that are by far the dominant agent of damage for that event. Regions of high seismicity with large metropolitan area predominantly comprised of densely spaced wood buildings include Japan, New Zealand, parts of Southeast Asia and western North America. A large earthquake such as a M7.8 event on the San Andreas fault in southern California (or comparable events in northern California, Puget Sound, or the Lower Mainland of British Columbia) combines all the requisite factors for major conflagrations that, depending on circumstances, can be of uniquely catastrophic proportions.

1.1 Purpose

The purpose of this Note is to qualitatively describe the likely scenario related to fire following a M7.8 earthquake on the Southern San Andreas Fault, with primary emphasis for assisting emergency planning. This Note is technical support of a larger report on all aspects of the SoSAFE[1] project (Jones et al. 2008). The charge for development of the scenario specified that the scenario occurs on November 13, 2008, a day with average November weather conditions, and no Santa Ana winds, that the scenario should be "realistic" and not some 'worst case', and should address the following questions: (i) Provide a realistic scenario of ignitions, fire growth and spread; (ii) How will ignitions be reported after an earthquake, how will fire departments respond, and how long will it take for the fires to be extinguished? What mutual aid agreements are in place and how will they be activated? (iii) How will damage to telecommunications, water supply, and roadway damage affect response? (iv) What if any effective mitigation actions have been undertaken elsewhere that might be practical in Southern California. (v) Briefly state limitations of the FFE scenario and summarize, if appropriate, research that would provide a more realistic, perhaps more challenging or detailed, scenario?

1.2 Background

Large fires, for example measured in terms of square miles 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 conflagrations. Large urban conflagrations were actually the norm in 19th Century America, so that long experience allowed the National Board of Fire Underwriters to state with some confidence (NBFU 1905)

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[1] SoSAFE (Southern San Andreas Fault Evaluation), also referred to as ShakeOut.

> *"...In fact, San Francisco has violated all underwriting traditions and precedent by not burning up. That it has not done so is largely due to tile vigilance of the fire department, which cannot be relied upon indefinitely to stave off the inevitable."*

While the 1906 San Francisco earthquake had major geological effects and damaged many buildings, six months after the above statement was published it was the fire that resulted in 80% of the total damage – a fire foreseen and expected, irrespective of an earthquake. As the fire service was professionalized in the 20th Century however, with improvements in equipment, communications, training and organization, large urban conflagrations tended to become a thing of the past (National Commission on Fire Prevention and Control 1973). Largely, but not entirely however, as witnessed in the 1991 East Bay Hills Fire, where 3,500 buildings were destroyed in a matter of hours.

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.

Much larger wildland fires also occur of course, and continue to be a major source of loss, including almost every year in Southern California. However, historically earthquakes have typically not caused major wildland fires.

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 the US, 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 minutes 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. There are exceptions to this – San Francisco Fire Department, Los Angeles City Fire Department Vallejo Fire Department and Vancouver (B.C.) Fire and Rescue Services have all undertaken special measures, which will be discussed below.

1.3 Modeling of Fire Following Earthquake

The first step towards solving any problem is analyzing the problem and quantifying its impacts. A full probabilistic methodology for analysis of fire following earthquake was developed in the late 1970s (Scawthorn et al. 1981) and has been applied to major cities in western North America (Scawthorn 1992). A recent monograph (Scawthorn et al. 2005) details the current state of the art in modeling fire following earthquake, so that only a brief review is presented here. In summary, the steps in the process are shown in Figure 1:

- *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 may be 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 (e.g., when the fire comes to a firebreak).

This process is also shown in Figure 2 which is a Fire Department Operations Time Line. 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.

1.4 Outline of this Note

In what follows, the presentation of the SoSAFE scenario follows the above succession of events. We begin by briefly presenting the scenario earthquake and associated framework, particularly its intensity distribution. We then use simple rules of thumb to estimate the approximate number and distribution of ignitions, and compare these against resources to identify those areas where large fires may be expected to occur. We then discuss citizen response and reporting, fire service response and other factors to arrive at an estimate of overall impacts. We then review opportunities for mitigating the fire following earthquake problem, and conclude with some remarks on most salient steps that might be taken next.

2 SCENARIO EARTHQUAKE AND PREVAILING CONDITIONS

2.1 Rupture Segment, Magnitude and Intensity

The scenario event is a M7.8 earthquake on the Southern San Andreas Fault, Figure 3. Seismological aspects are discussed by others. MMI distribution was developed by others for this project and furnished for this Note, and is shown in Figure 4. Noteworthy are the high intensities MMI VIII-X along the fault (to be expected), but also the relatively high intensities, MMI VI-VIII throughout the Los Angeles Basin, northern Orange County and in the San Fernando Valley.

2.2 Affected counties, population and fire resources

The counties and populations affected by the scenario are shown in Table 2 – the total affected population is approximately 20 million, and is distributed as shown in Figure 5. Current fire service specific data is not readily available for this Note but based on previous data the total number of fire engines in the affected counties is estimated at just under 2,000, Table 3. Only fire engines are estimated as they apply water in urban structural fires – ladder trucks and other apparatus are also necessary to assist, but without fire engines, suppression of a structural fire is usually not possible.

2.2.1 Time of Day

Time of day is relevant in that more human activity occurs during waking hours, resulting in higher ignition rates at those times. Time of day is specified as 10am for the scenario event.

2.2.2 Wind and humidity

A detailed data analysis and collection of climate data is beyond the scope of this note. In Southern California, November climate tends to have a ‘bimodal’ distribution – some storms occur, with precipitation and lower temperatures, but Santa Ana conditions are relatively prevalent, with very high winds and extremely low humidity. Indeed, the worst fire season in Southern California is October-November. For purposes of the scenario, we assume breezy conditions (10 mph) and relatively low humidity.

3 FIRE FOLLOWING EARTHQUAKE ASPECTS

3.1 Ignitions

Based on methods developed and documented elsewhere (Scawthorn 1987; Scawthorn et al. 2005), and employing data presented above, the total number of fire ignitions likely to occur given the SoSAFE scenario is estimated to be approximately 1,600, as shown in Table 4.

For comparison, a rule of thumb for ignitions is presented in Table 1, where it can be seen that for a population shaken at 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.

Table 1 Approximate Ignition Rate vs. 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

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, Table 5. 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 the large number of oil refineries, tank farms and related facilities in and around Long Beach. These facilities are responsible for one-third of the refined gasoline west of the Rockies. 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 Tüpraçs refinery in the 1999 Marmara (Turkey) earthquake, Figure 6 (Scawthorn 2000), and the Idemitsukosan Hokkaido refinery fire in the 2003 Tokachi-oki earthquake, Figure 7. While the Long Beach area is shown to have lower intensity shaking, the long period effects at the site from the M7.8 scenario event will undoubtedly cause large sloshing in tanks, and fires.

3.2 Initial Response

3.2.1 Citizen response

The approximately 1,600 ignitions requiring fire department response will initially be responded to by citizens – as noted, they will be able to suppress some fires, which are not included in the 1,600. When they realize the fire is beyond their capabilities, they will endeavor to call the fire department, by telephone since fire alarm street pull boxes have largely disappeared from the US urban landscape. Attempts to report via 911 will almost universally be unsuccessful, not so much due to damage to the telephone system as much as simple saturation of the system, and 911 call centers. Citizens will then go by auto to the nearest fire station, but such 'still alarms' will be largely unneeded, since the fire companies will have already responded to the nearest fire ("self-dispatched"), if not dispatched by 911.

Experience shows that citizens on scene will respond rationally (Van Anne 1989) rescuing as many people as possible and protecting exposures. Water supply from mains (discussed below) will often be unavailable but, in Southern California, backyard swimming pools are a valuable and widespread resource (Scawthorn et al. 1998).

Los Angeles City and other fire departments have for several decades developed Community Emergency Response Teams (CERT, see http://www.cert-la.com) – a total count of citizens who have undergone CERT training is not available but is several tens of thousands. Individually and then as organized CERT teams, these teams will save lives and make a difference. However, for large conflagrations, the CERT teams' contribution will be modest.

3.2.2 Fire Service initial response

The initial response of fire companies and personnel in the region of the scenario will be to self-protect during violent shaking, and as soon as possible open the doors and remove apparatus from the fire stations. Different departments have somewhat varying earthquake procedures but in general companies will remove apparatus to a pre-designated location, often simply in front of the fire station, check the station for damage and perform a radio check. By this time, typically within five minutes, they will either have self-dispatched to an observed smoke column, responded to a citizen still alarm, or been instructed to mobilize with other companies into a strike team.

Local fire service resources will be completely committed, and in need of assistance from outside the region. The primary needs will be personnel, additional hose, hard suction hose, foam, light equipment (gloves, hand tools, SCBA) and heavy equipment (cranes, bulldozers, backhoes). Additional fire apparatus (pumpers and ladder trucks) will not be the primary need, initially, but will still prove useful as extra-regional strike teams arrive.

In the initial stage, personnel needs may be significantly supplemented by CERT teams, but will be more significantly strengthened by the recall of off-duty trained firefighters. Off-duty personnel can be expected to have doubled staffing within 3-6 hours, and tripled it within 12-24 hours. While responding, an issue will be how these personnel marry up with their companies, and there will be some inefficiencies as personnel join first available companies. Nevertheless, arrival of off-duty personnel will be very important, to spell on-duty personnel nearing their physical limits.

3.3 Reporting

As noted above, 911 centers will be overwhelmed, and doing as much as possible to triage events and dispatch resources. Reports of fires during the initial period will be haphazard. Most fire departments do not have their own helicopters, and TV helicopter news reporting will be a valuable resource for a few major incidents, but not most. An anecdote demonstrates this – the first knowledge the San Francisco Fire Department EOC had of the Marina fire in the 1989 Loma Prieta earthquake was from television news reports (despite several companies having responded). Quickly gaining an accurate complete situational awareness is still a challenge.

3.4 Local Emergency Services Response

Local, county and state Emergence Operations Centers (EOCs) will activate within a very short period, certainly within an hour, in some cases much quicker. Automatic and Mutual Aid in the affected region will largely be ineffective, due to departments having no resources to spare. The State of California emergency services are organized into six Mutual Aid regions, with the scenario earthquake occurring at the crux of three of these regions (I, V and VI). It will take several hours for these three regions to have a first needs assessment (longer if the earthquake occurs during nightfall, but this scenario assumes a noon event), although state OES will already have dispatched strike teams from other regions.

3.5 Fire Spread

The initial 1,600 ignitions will not all develop into conflagrations. There are approximately 1,900 fire engines in the region, and many will be close by and able to rapidly respond to ignitions. Nevertheless, the normal 4 minute structural fire response goal will hardly be met. This delayed response, due primarily to failure of the 911 system, will result in many of the fires on arrival having grown such that a multi-engine capacity is needed. That is, especially in low humidity conditions, an unfought ignition will grown into a room-sized fire within several minutes, and a fully-involved single family structural fire within several more. To protect neighboring buildings (‘exposures) typically two or more companies are needed. If only one company is available, it’s possible that it might be able to protect two exposures (using monitor and a hand line, with civilian assistance), but often unlikely. In fire following earthquake modeling, such fires, where the fire has grown to exceed one engine company’s capabilities, are termed ‘large fires’. The number of large fires for the scenario event is estimated to be approximately 1,200, Table 4. This does not consider ignitions in wildland or at the wildland urban interface (WUI), Figure 9. About a third of these large fires occur in Imperial, Kern, Riverside and San Bernardino counties, where building density is relatively low, so that even though the fires are initially uncontrollable, their spread within the built environment will be limited due to large firebreaks. Only within the more densely built areas of Los Angeles and Orange counties will there be relatively large fire spread, developing into conflagrations.

3.6 Lifelines

The performance of lifelines, such as water supply, gas, electric power, communications and transportation, is integral to the fire following earthquake process. Others are discussing the performance of specific lifelines, and this Note only briefly discusses these lifelines with regard to fire following earthquake.

Water supply will be severely impacted by the scenario event. Generally, only local water supply is relevant to the fire following earthquake process. Water pressure will drop in some portions of the more heavily shaken area due to pipe breaks and tank failures, despite widespread efforts over the last several decades to upgrade water supply systems in California. Fire departments in many areas will have to resort to alternative water supplies (creeks, ponds, swimming pools, etc). They will be handicapped in this since most engine companies today do not carry hard suction hose, although LAFD in the Northridge earthquake was able to make good use of swimming pools using 1.5" siphon ejectors (Scawthorn et al. 1998). This initial lack of water supply will add to the number of large fires.

Gas-related ignitions account for about 25% of the total number of ignitions. If the number of ignitions could be reduced from 1,600 to 1,200, the number of large fires would be decreased in greater proportion, and the total losses further reduced. Automatic gas shut-off valves are the best way to reduce gas-related ignitions, and should be mandated in densely built areas. Los Angeles City Fire Department (LAFD) has shown excellent leadership in seeking legislation to require gas shut-off valves, but has been opposed by the gas industry and has not been successful. Note that following the 1995 Hanshin (Japan) earthquake, the Japanese gas industry changed all urban gas meters in Japan to a design which has a seismic shut-off (Tokyo Gas, personal communication).

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.

The transportation system most relevant to fire following earthquake is the road network, which is most vulnerable at bridge crossings. Caltrans has virtually completed a major seismic review and retrofit of all bridges under its purview. Additionally, the local and highway networks are typically sufficiently dense that redundant pathways exist within the region such that emergency services will probably not be greatly impeded. . Strike teams arriving from other OES regions however may be delayed due to traffic disruptions at several 'choke-points' on the boundaries of the region (e.g., I-5 at the Tejon Pass).

3.7 Regional and State Response

As noted earlier, OES Regions I, V and VI are at the crux of the scenario earthquake, Figure 8. Within those three regions, the only available significant fire service resources would appear to be those in the San Diego region, and OES brush rigs in the Sierra foothills. It is unlikely that many resources will be made available from the San Diego region, out of concern by local governments there of a sympathetic seismic event closer to their region (as well, there may be some damage in and around San Diego, even at that distance). A more likely source of regional resources will be a number of strike teams assembled by OES from the southern Sierra region, arriving in the affected region within 6-24 hours. While brush rigs are more suited to wildland than urban structural fires, by the time of their arrival the issue will be large fires that have grown into conflagrations, a situation a bit closer to the norm for brush rigs and associated tanker trucks.

Outside the affected region, OES is likely to stage a number of strike teams, drawn generally from the San Francisco Bay Area and the Central Valley. One hundred strike teams, consisting of approximately 500 pumpers and other apparatus, firefighters and officers, is easily within OES capability, and several times this can be managed in extremis. One hundred strike teams can be assumed to arrive at staging areas within about 12 hours, with probably several hundred more in the next days.

3.8 Final Burnt Area

The approximately 1,200 large fires will be spread over a large area, of varying building density, and only a relatively few will grow into major conflagrations. Under the assumed wind and humidity conditions, Riverside and San Bernardino counties are each likely to sustain one or several conflagrations destroying several city blocks.

The real concern is portions of Orange County and especially the central Los Angeles basin, where a large plain of relatively uniform dense low-rise buildings provides a fuel bed such that dozens to hundreds of large fires are likely to merge into dozens of conflagrations destroying tens of city blocks, and several of these merging into one or several super conflagrations destroying hundreds of city blocks. Two special concerns exist in this regard: (a) if Santa Ana winds exist (which is not the assumed scenario), losses can be much larger, and (b) if extremely calm conditions exist (which is also not the assumed scenario), the potential exists for a symmetric wind pattern to develop caused by air drawn inward by uprising air from super conflagrations (an example of *stack effect*). A self-sustaining feedback situation can develop (commonly termed a *firestorm*), which can be very destructive. While relatively unlikely, this potential should not be ignored. Concern (a) is simply a larger mass conflagration, fed by higher winds. Concern (b) is potentially much worse. Both are potentially catastrophic.

Under the assumed scenario conditions, a preliminary estimate is that the approximately 1,200 large fires will result in an ultimate burnt area equivalent to 133,000 single family dwellings (SFED[2]), or approximately 200 million sq. ft. of residential and commercial building floor area.

[2] An average single family equivalent dwelling (SFED) is 1,500 sq. ft. of residential or commercial occupancy floor area, and is used to normalize and communicate overall building losses to a readily comprehensible measure. A loss of 1.5 million sq. ft. of residential and commercial building for example is equivalent to 1,000 single family dwellings. Most people can more readily interpret the loss of 1,000 houses, than 1.5 million sq. ft. of floor area.

4 IMPACTS OF FIRE FOLLOWING EARTHQUAKE

4.1 Human Impacts

Estimating the fatalities associated with the fires following the scenario earthquake is very problematic. A very simple approach is taken here – in the 1991 East Bay Hills fire, which destroyed approximately 3,500 dwellings, 25 persons perished. The building losses projected here are approximately 40 times larger. A pro rata estimate would indicate 1,000 deaths due to fire following earthquake, but such an approach is admittedly very simplistic. However, hundreds of deaths directly attributable to fire following earthquake is a conservatively low estimate. Injuries would probably be an order of magnitude greater. Shelter needs directly attributable to fire following earthquake are estimated to be in the range of half to one million persons.

4.2 Economic and Insurance Impacts

The ultimate burnt area of very approximately estimated to be 133,000 SFED or approximately 200 million sq. ft. of residential and commercial building floor area, which equates to approximately $40 billion of building value[3]. Value of contents and other improvements (e.g., landscaping), will only increase this loss. An additional loss is loss of use – that is, the persons normally living in these destroyed buildings (or conducting business in them) must find other accommodations, which will most likely not be available in the Los Angeles basin given the scenario event. This loss, termed *additional living expenses* (more generally, *business interruption*, or *time element*) by the insurance industry, can be quite consequential, equivalent to many tens of billions of dollars. Accounting for this is problematic - if persons who have lost their dwellings are housed in a hotel at insurance company expense, the accounting is easy – it's the hotel bill – however, if they are forced to live in tents following the event, at public expense, there may be no bill[4]. In such a case, the persons haven't paid for their tent, and can't therefore claim against the insurance company for a financial loss. However, they have lost value in services (of their house) approximately equivalent to the rental value of their house (minus the rental value of the tent), but won't be compensated for those losses. Nevertheless, this is a loss that should be accounted for, overall.

Since virtually all buildings and contents in the US are insured for fire, and US insurance contracts include fire following earthquake losses under the fire policy, the direct fire following earthquake losses for the scenario event are likely to result in a loss approaching one hundred billion dollars of insurance claims. Losses of this magnitude are probably sustainable by the US insurance industry, with some strains (the $60 billion in insured claims arising from 9/11 were handled without great strain). Another data point is the 1991 East Bay Hills fire, where the 3,500 homes lost resulted in about $1 billion in insured losses – the event project here is 17 years of inflation later, and about 40 times as large. In summary, the fire following earthquake losses are

[3] Based on replacement cost of $200 per square foot – note this is a conservatively low estimate of replacement cost.

[4] However, note that public authorities may attempt to recoup their expenses, if the sheltered persons are insured.

likely to be the largest portion of the insured losses in the scenario event, and could result in major distortions within the industry.

Another aspect of the economic impacts is the loss of real estate tax revenues. A loss of $50 billion in value of improvements is likely to result in a decrease in regional real estate tax revenues of a billion dollars, for several years, directly attributable to fire following earthquake.

5 MITIGATION OF FIRE FOLLOWING EARTHQUAKE

Mitigation of fire following earthquake has been extensively discussed elsewhere (Scawthorn et al. 2005), so that only some limited observations specific to the scenario are provided here.

5.1 Fire Service Opportunities

The fire service in Southern California is among the finest in the world, and perhaps the best practiced in the world in dealing with large conflagrations, due to the wildland fires recurring annually in the region. The fire service has also been relatively diligent in preparing for a large earthquake – the CERT program is a model in that regard. However, the following opportunities are cited, to name a few:

- Capability for more quickly assessing the incident, and facilitating incident reporting, should be improved. Reconnaissance using unmanned aerial vehicles (UAVs), and cellular text messaging incident reports directly to a 911 portal, should be developed and operationalized.
- Alternative water supply capability needs to be enhanced. Hard suction hoses should be carried on all engines. Large diameter hose (LDH) systems, comparable to San Francisco Fire Department's Portable Water Supply System (PWSS) (Scawthorn et al. 2006), should be developed on a regional basis.
- Los Angeles currently has little ability to access seawater and move it significant distances inland – relaying via street-laid hose and engines is not an efficient way of doing this. A special saltwater pumping system, similar to that of San Francisco's AWSS (Auxiliary Water Supply System, built following the 1906 earthquake and fire) and Vancouver's DFPS (Dedicated Fire Protection System, built in the 1990s and based on observations in the 1989 Loma Prieta earthquake) is quite feasible for Los Angeles. Several saltwater pumping stations could be built (e.g., Sta Monica, LAX, LA Harbor) and large diameter seismically resistant pipe could be laid in the LA and other river channels and the County's extensive storm drain system (see Figure 10) to form a looped high pressure system, accessible from high pressure hydrants.
- A regional task force should be formed within the fire service, to examine urban conflagration potential in more detail. The task force should be multi-disciplinary.

5.2 Water Service Opportunities

The water service in Southern California has done a lot to prepare for a major earthquake, but more can of course still be done. One overriding issue with regard to fire following earthquake is that water agencies typically aren't institutionally responsible for fire protection. That is, while they provide hydrants, if the hydrants fail to supply water, they aren't responsible. Therefore, water system upgrades are typically more oriented to maintenance of customer service, and minimizing direct damage to the system, than to maximizing firewater supply reliability. A mandate needs to be developed to make water agencies more responsive to this need. Given the realities of water in California, this may be unlikely to occur, but should at least be pointed out. A real way in which water agencies could be more responsive to the fire following earthquake problem is if each agency were to configure and upgrade their system so as to provide a 'backbone' system of water mains of high seismic reliability, that provided water to major sections of the community and from which the fire service could draw water to feed water to a conflagration via LDH systems. (see also discussion above re saltwater looped system).

5.3 Energy Industry Opportunities

The gas industry could contribute significantly to reducing the fire following earthquake problem by developing a program to either install automated gas shut-off valves, or redesigned meters with seismic shutoffs, in densely built up areas. Note that the industry in Japan moved to do this proactively following the 1995 Kobe earthquake.

More problematic is an opportunities in regard to electricity. Electric power often fails in large earthquakes, due to automatic system trips as well as damage to the system – however, the power failure usually takes several seconds, during which power is a source of many ignitions. Certain electric appliances (e.g., those with heating elements) can still cause fires even after power is cut. Large scale intentional curtailment of power is problematic, since some communications and other essential equipment would then be useless.

The petroleum refineries and related facilities in the Long Beach area are likely to sustain major fires in the scenario event. Their earthquake preparedness should be reviewed.

6 CONCLUDING REMARKS

Fires follow all earthquakes affecting human settlements, but are potentially catastrophic phenomena in selected areas, such as Southern California. A large earthquake will occur on the Southern San Andreas Fault, similar to many ways to the scenario considered here. Just as the fires following the 1906 earthquake were quite foreseeable, the fires following a SoSAFE event are generally foreseeable, and will likely constitute a significant portion of the overall impacts of that event.

To put these estimates in perspective, Figure 11 is a series of Google Earth Images that make two key points:

(a) the estimated 200 million sq. ft. of burnt building floor area, while an enormous loss, is only a small fraction of the exposure (1.5%) – the red rectangles indicate the equivalent area (very approximately) relative to the total exposure;

(b) as the latter images show, the high density of wood buildings typical of the central LA basin. Note the small inter-building spacing and almost total building coverage of many blocks. While there are broader avenues, and even freeways, which serve as firebreaks, flying brands can easily drift thousands of feet and/or several miles downwind, crossing such firebreaks (this was seen for example in the 1991 East Bay Hills fire, where the fire jumped Highway 24, a ten lane freeway).

However, while foreseeable, quantification of the fire following earthquake risk is still very imprecise. The only previous quantified estimates of fire following earthquake risk for Southern California were done one to two decades ago (Scawthorn 1987; Scawthorn and Khater 1992), and this Note is only a very approximate estimate. The size and importance of the problem warrants much more detailed analysis using the latest data and methods.

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Table 2 Counties and Populations affected in the Scenario

County	2006 est. population (millions)
Imperial	0.17
Kern	0.81
Los Angeles	10.3
Orange	3.1
Riverside	2.1
San Bernardino	2.0
Ventura	0.83
Total	**19.31**

Source: California State Association of Counties website (http://www.csac.counties.org/default.asp?id=399 accessed 28 Dec 2007)

Table 3 Estimated No. Fire Engines per County

County	2006 est. Fire Engines
Imperial	29
Kern	140
Los Angeles	586
Orange	391
Riverside	328
San Bernardino	320
Ventura	143
Total	**1,937**

Table 4 Estimated Ignitions, Large Fires and Final Burnt SFED
M7.8 SoSAFE Scenario
(12 noon 13 Nov 2008 breezy conditions low humidity)

	Est No. Ignitions	Est. No. Large Fires	Est. Burnt SFED (thous)
Imperial	131	45	negligible
Kern	167	82	negligible
Los Angeles	612	583	94
Orange	206	165	37
Riverside	239	157	1
San Bernardino	234	151	1
Ventura	18	0	negligible
Total	**1,606**	**1,182**	**133**

Table 5 General Sources of Ignition, LAFD Data, Northridge Earthquake
(Scawthorn et al. 1998)

Source	Fraction
Electrical	56%
Gas-related	26%
Other	18%

Table 6 Property Use for 77 LAFD Earthquake-Related Fires
4:31 TO 24:00 hrs, January 17, 1994 (Scawthorn et al. 1998)

General Property Use	Fraction
One or Two Family Residential	45%
Multi-Family Residential	26%
Public Roadway	8%
Office	5%
Primary / Secondary School	3%
Vacant Property	3%
Restaurant	1%
Commercial	1%
Power Production/Distribution	1%
Other	5%
Unknown	1%

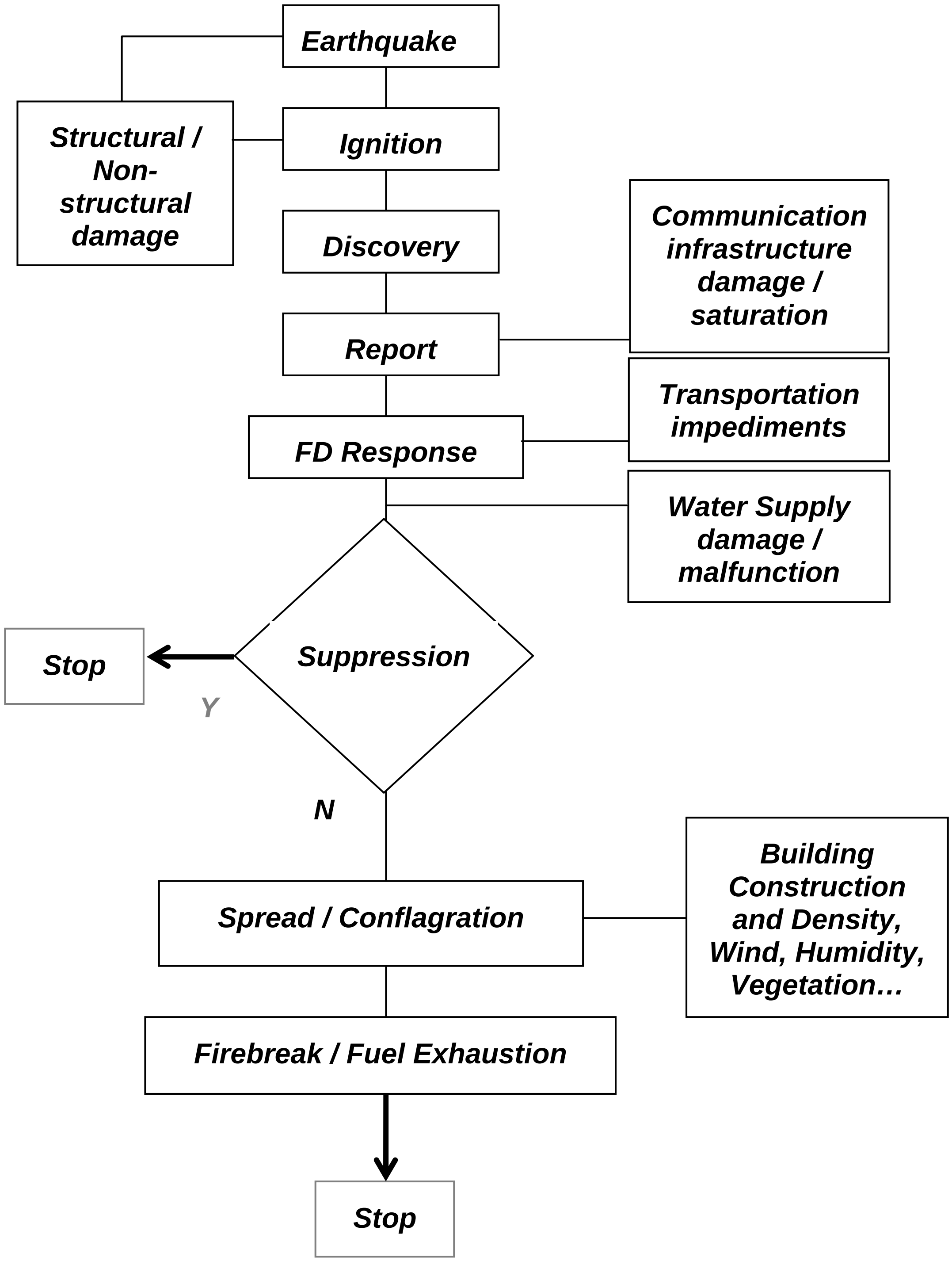


Figure 1 Fire following earthquake process (Scawthorn et al. 2005)

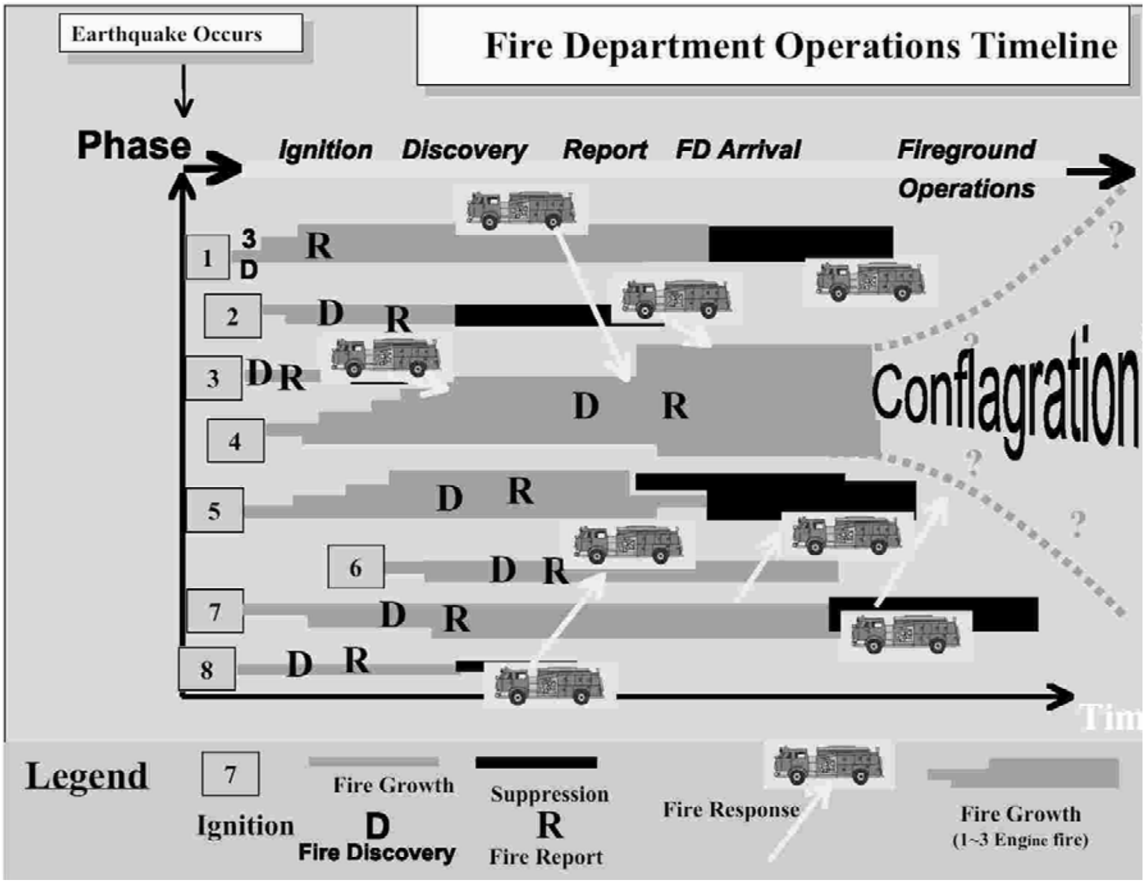


Figure 2 Fire department Operations Time Line (Scawthorn et al. 2005)

Figure 3 Scenario M7.8 Fault trace and offset (Porter, 2007)

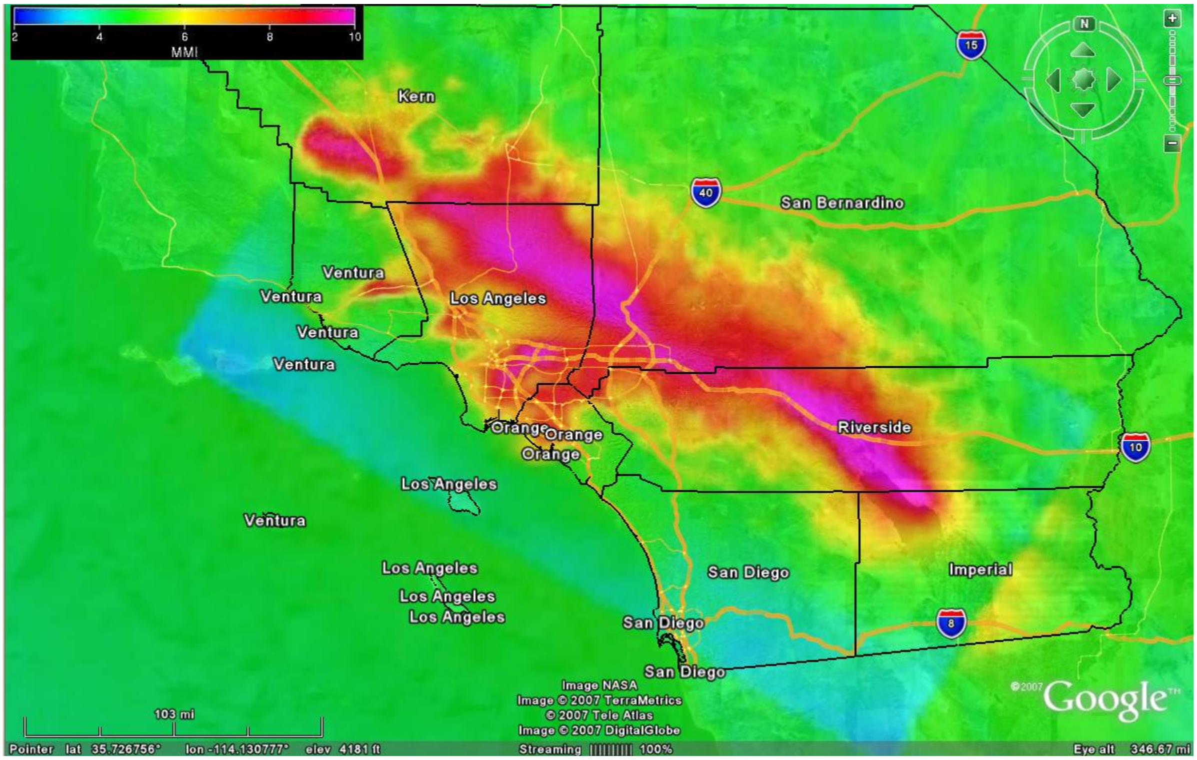


Figure 4 MMI Map for M7.8 SOSAFE Scenario (Porter, 2007)

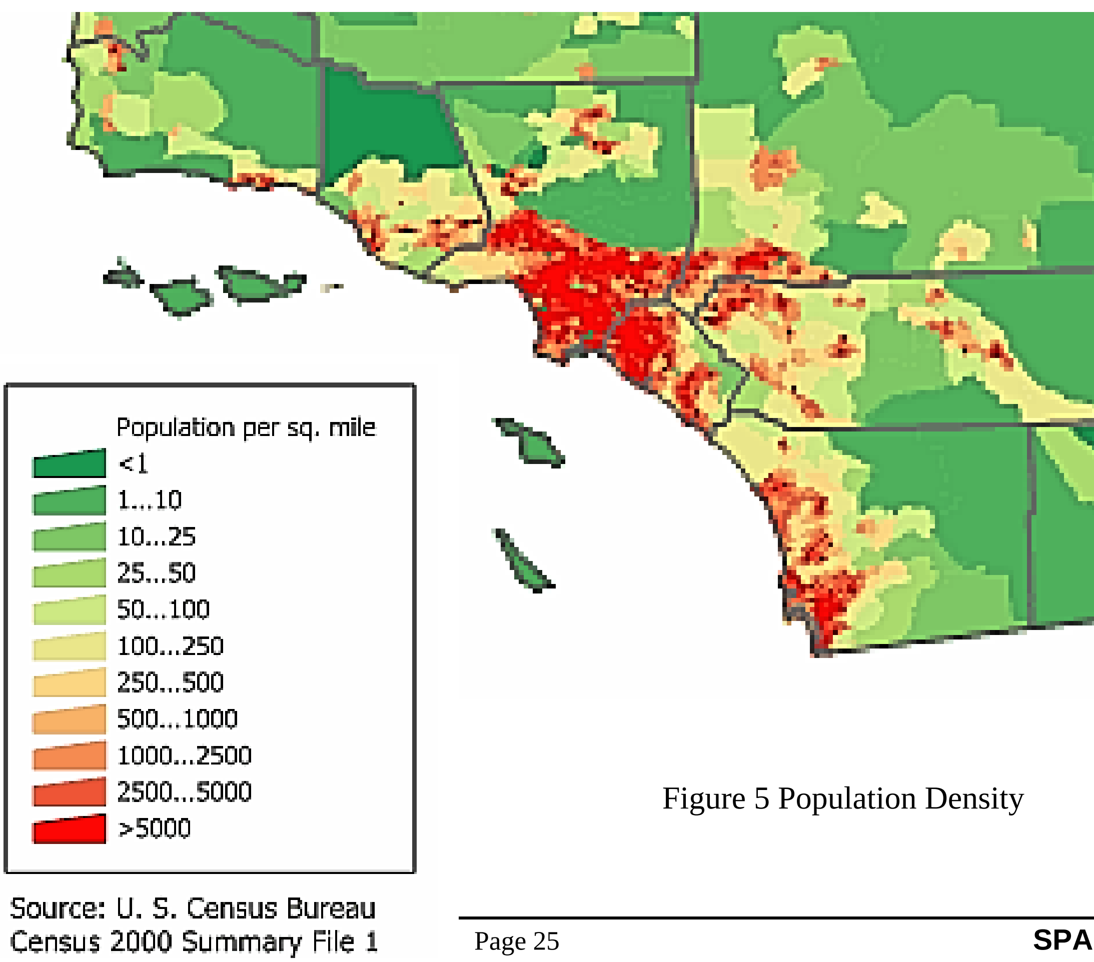


Figure 5 Population Density

Photograph by G. Johnson

Figure 6 Tüpraçs refinery, M_w 7.41999 Marmara (Turkey) earthquake
Photo by G. Johnson in (Scawthorn 2000)

Figure 7 Idemitsokan Fire, 2003 M8 Tokachi-oki earthquake (Japan)
(Source: upper photo Fire and Disaster Management Agency of Japan;
lower photo Hokkaido Shimbun)

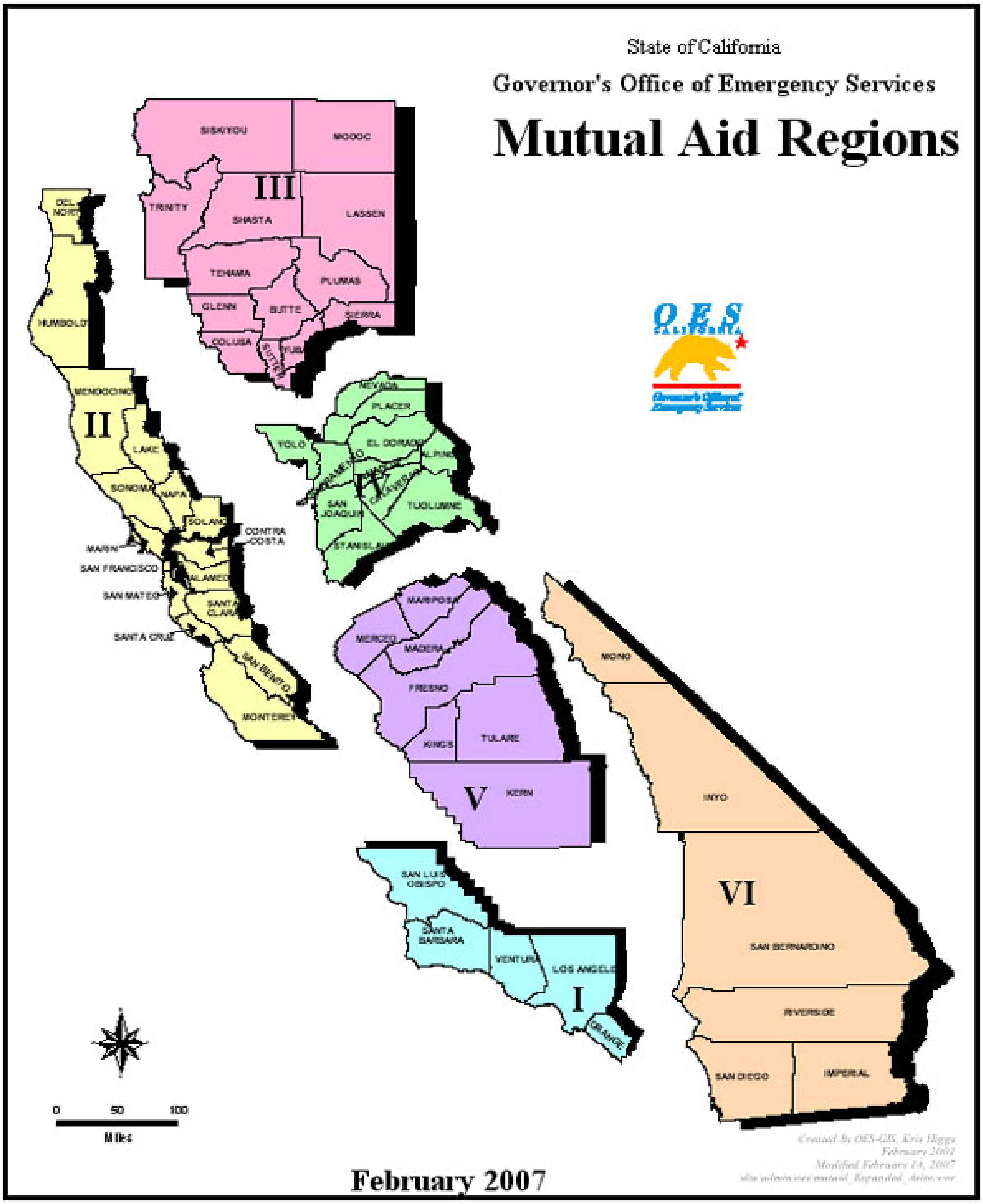


Figure 8 California OES Mutual Aid Regions

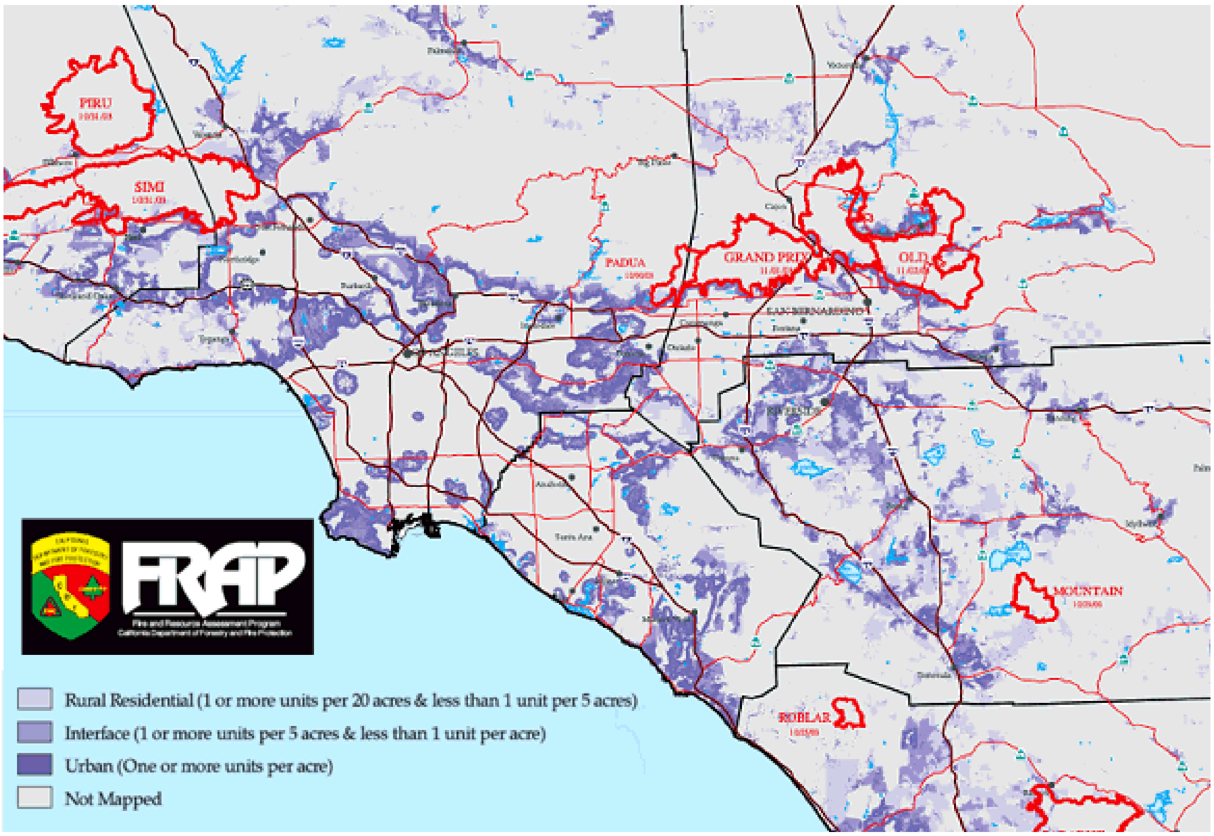
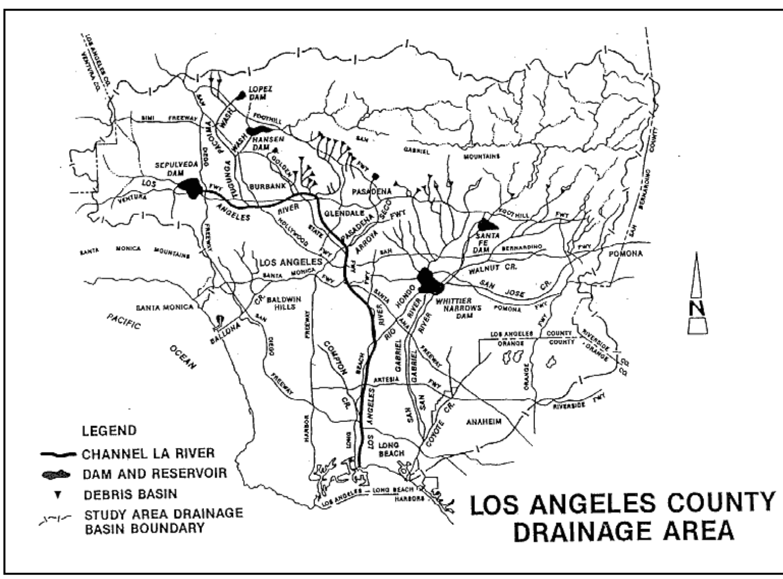


Figure 9 Fires and Wildland Urban Interface
(OES Fire and Resource Assessment Program, http://frap.cdf.ca.gov/socal03/maps/sc_wui.pdf)



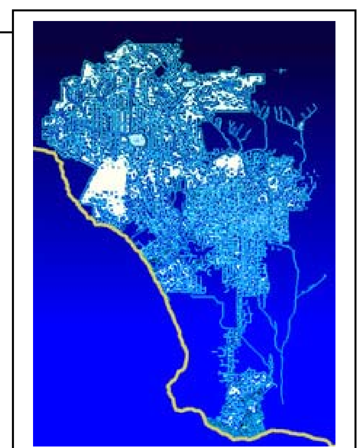


Figure 10 Maps of Los Angeles and San Gabriel Rivers, LA County drainage and Storm Drain system; scene from film "Terminator 2" showing typical LA open storm drain

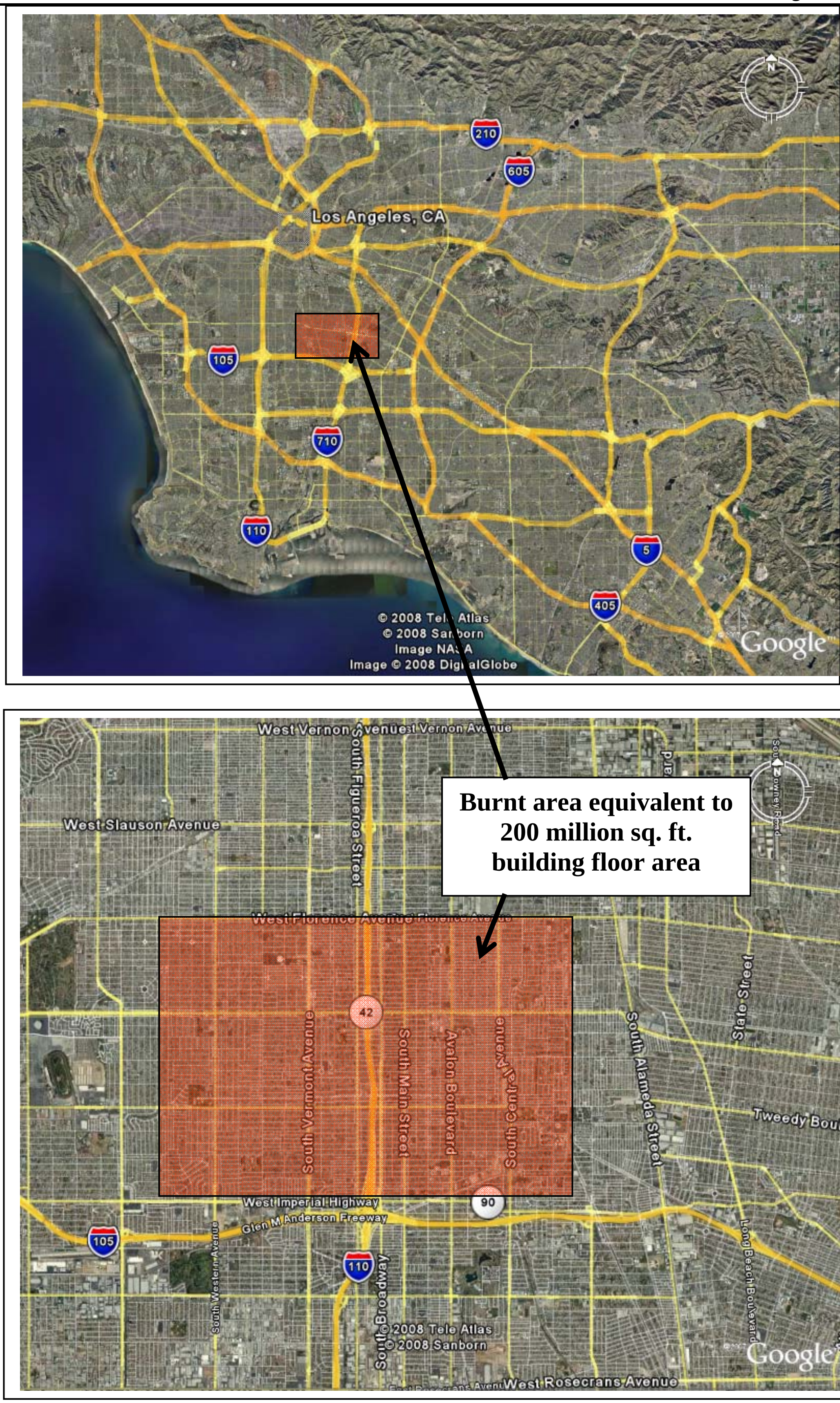


Figure 11 (see next page for caption)

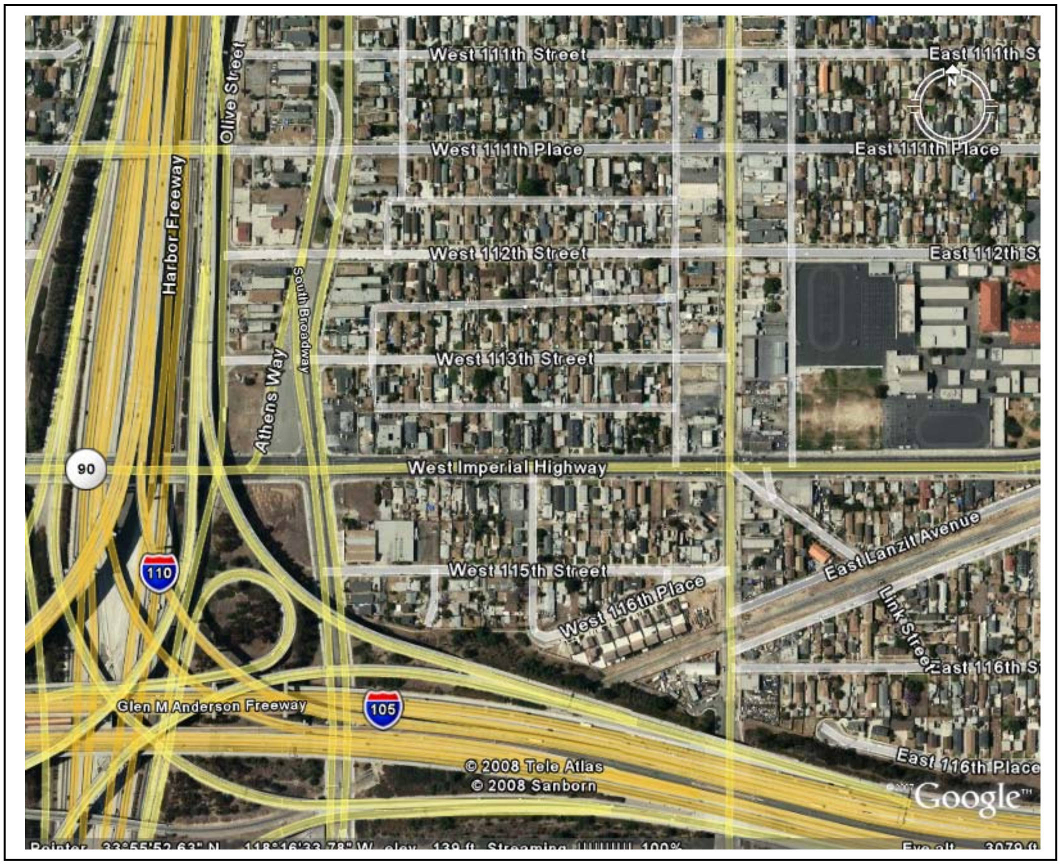


Figure 11 (see next page for caption)

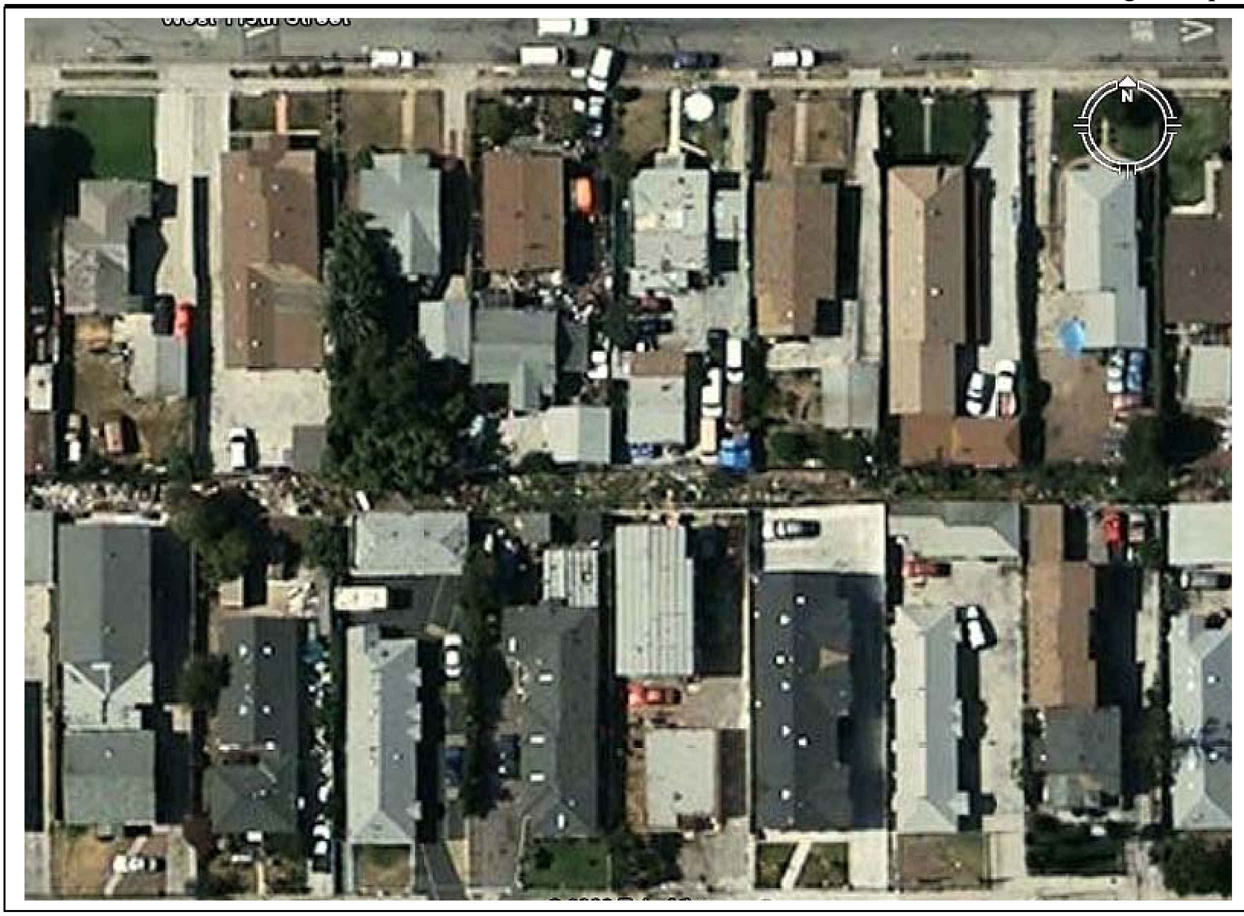


Figure 11 (total of five images from Google Earth): first two images show an area centered above the 110-105 Freeway intersection, approximately equivalent to 200 million sq. ft. of building floor area. Next three figures zoom in on area just north east of the 110-105 Freeway intersection, to show high density of wood buildings, typical of much of LA basin.