Six Tips for Building an Earthquake Scenario:

Lessons Learned from coordinating the economic consequences of the Southern California ShakeOut Scenario

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The ShakeOut earthquake project (Jones et al., 2008, Perry et al., 2008) is an extraordinary accomplishment of "science for decision making" that is rich in experience and lessons learned. The Mw7.8 ShakeOut earthquake scenario along the San Andreas fault in southern California was built from scientific foundations and extensive interdisciplinary collaboration and stakeholder participation. The U.S. Geological Survey and California Geological Survey had more than 300 partners from government, academia, emergency response, and industry contribute to the construction of the scenario by participating in expert panels, workshops, or review. Thousands of exercise planners and players made use of the ShakeOut scenario through the Golden Guardian 2008 emergency response and recovery exercise and 5.5 million people signed up to participate in the ShakeOut drill at www.shakeout.org.

My role of economic consequence coordinator entailed bringing together social scientists with earth scientists and engineers and interacting with stakeholders. Economic consequence activities are uniquely positioned at the end of a chain of scientific and engineering activities, and therefore dependent on their schedules and inputs. A reflection on lessons learned, in this role for the ShakeOut scenario, is summarized as six tips for building an earthquake scenario:

Tip 1: A high profile project leader attracts attention and enhances credibility

Tip 2: Visualize task time management and centralize data organization

Tip 3: Define your vision of science for decision-making

Tip 4: Be prepared with spontaneity, creativity, and expertise at the model interfaces

Tip 5: Develop strategies for data issues

Tip 6: Effectively communicate results to meet needs of users

The Scenario

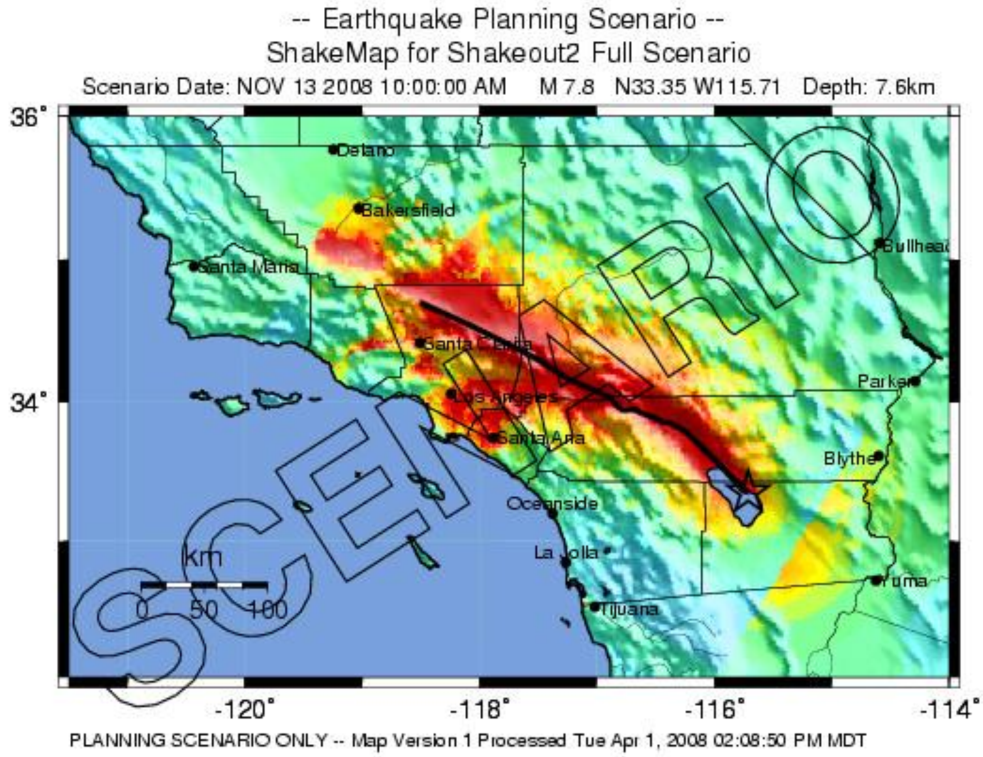
What if a magnitude 7.8 earthquake on the southern San Andreas Fault (Figure 1) occurred? This plausible, but hypothetical, earthquake was developed by a diverse group of scientists. Fault geologists considering the amount of stored strain on that part of the fault with the greatest likelihood of imminent rupture for a large earthquake. Seismologists and computer scientists modeled the ground shaking that would occur from the ShakeOut earthquake scenario throughout the eight county region of southern California. Geologists transformed the shaking into liquefaction and landslides. Engineers and other professionals used the shaking to produce a realistic picture of this earthquake's damage to buildings, roads, pipelines, and other infrastructure. From these damages, social scientists projected casualties, emergency response procedures, and impact on southern California's economy and society. The earthquake, its damages, and the resulting losses represent one realistic outcome, deliberately not a worst-case scenario, but rather one worth preparing for and mitigating against (Perry and others, 2008).

Overall, the scenario can be conceived as a stack of building blocks of multi-discplinary research providing support for policy making (Figure 2).

In the role of an economic consequence coordinator, the author embraced five primary aspects of economic impacts and disaster recovery and resilience including:

- Determination of highway system damage and effects on traffic and goods movement through the San Pedro ports,
- Preparation of spatial and temporal disruption of lifeline services, (e.g., power, water, gas, and transportation service interruptions and restorations) needed for the economic impact analysis,
- Estimation of direct and indirect business interruption losses resulting from lifeline service interruptions, building damages from shaking and fire following earthquake for the regional and two local economies,
- Definition of economic resilience and analysis of resilience strategies submitted by stakeholders throughout scenario development and exercise planning,
- Identification of regional and local recovery issues following the ShakeOut earthquake.

These activities were completed with the assistance of economist Adam Rose and recovery expert Laurie Johnson.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. Shakemap representation of the ShakeOut scenario (from Jones et al. 2008). The warmer colors of the Instrumental Intensity indicate areas of more intense shaking and damage. The star locates the earthquake source. The black line indicates the extent of fault rupture.

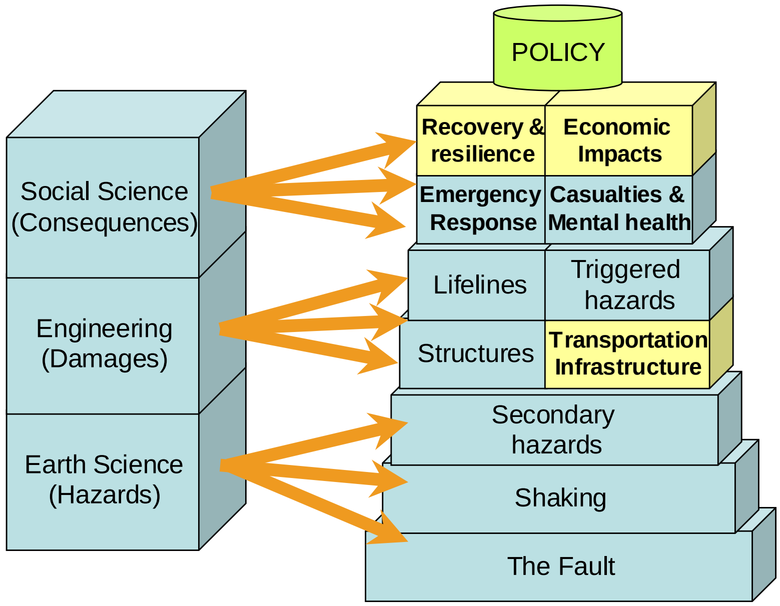


Figure 2. Building blocks of the ShakeOut earthquake scenario with the author's coordination roles highlighted in yellow. Secondary hazards include shaking induced liquefaction and landslides. Triggered hazards result from damages and include fire and hazardous waste spills.

The culmination of the ShakeOut scenario coincided with an Earthquake Engineering Research Institute (EERI) workshop on guidelines for developing an earthquake scenario that prompted reflection on what worked and what could be improved when developing future natural hazard scenarios. This author's reflection evolved into the following six tips as a contribution to the National Earthquake Hazards Reduction Program (NEHRP) forum (http://www.nehrpscenario.org/), a venue for sharing experience among earthquake scenario development teams.

Six Tips to Building a Successful Scenario

Tip 1: A high profile project leader attracts attention and enhances credibility

A “celebrity” scientist for a project leader attracts attention, interest, and broad and active participation for the duration of the project, from the launching of the scenario through to the subsequent workshops; it contributes to the initial credibility and sustained momentum of the project. From the start, project lead Dr. Lucy Jones attracted high caliber partners and media attention. Subsequently, a participant admitted that he attended a workshop with the hope of meeting Dr. Jones. The ShakeOut earthquake scenario was launched at a workshop attended by a broad spectrum of the Southern California community (including emergency responders, representatives from special district and humanitarian organizations, earth and social scientists, engineers, planners, and disaster consultants). This diverse group brainstormed the scope of the scenario and laid the foundation for outlines of work under the scenario building blocks described below.

Tip 2: Visualize task time management and centralize data organization

There were numerous challenges in managing the large-scale complex, and multi-discipline ShakeOut scenario project. To visualize the staging of the activities, we used a proven project management tool, a pert network chart of predecessor and successor tasks for each step of the scenario development process (Figure 3). We came to appreciate that 1) implementation requires open communication and willing cooperation among coordinators, 2) it is important to build in time for review of each task, and 3) delays have ripple effects that impact the time line of the entire project.

We needed convenient access to information from the other topic coordinators. A web-based depository and retrieval system allowed us to share initiatives and plans, PowerPoint presentations, discussions, results, and reports, to receive email notification about new additions. It provided a forum for geographically dispersed coordinators to interact; for successor coordinators to track predecessor outputs and be alerted to emerging - and, perhaps, unanticipated - results of importance; and for successor coordinators to communicate back their needs and expectations for inputs.

Work across disciplinary boundaries required additional start-up time and communication. When a coordinator activity cut across disciplinary boundaries (as was the case with highway damage and traffic modeling for economic analysis) we needed to rely on an earth scientist to package data outside of our area of expertise and the engineer to clarify the scope of work. Though obvious in hindsight, time had not been sufficiently budgeted for cross disciplinary activities. We also underestimated the time (by weeks, in some cases) needed for expert and stakeholder reviews and verifications of information delivered in written reports, powerpoint presentations, and/or panel discussions. It is important to build review time into the schedule.

Early in the project, there were delays that worked in our favor by providing additional time for review, yet they also compromised the social science tasks in two ways: 1) delays reduced what was achievable before the fixed due date for scenario and 2) delays introduced inconsistent assumptions when successors were forced to work in parallel with predecessors

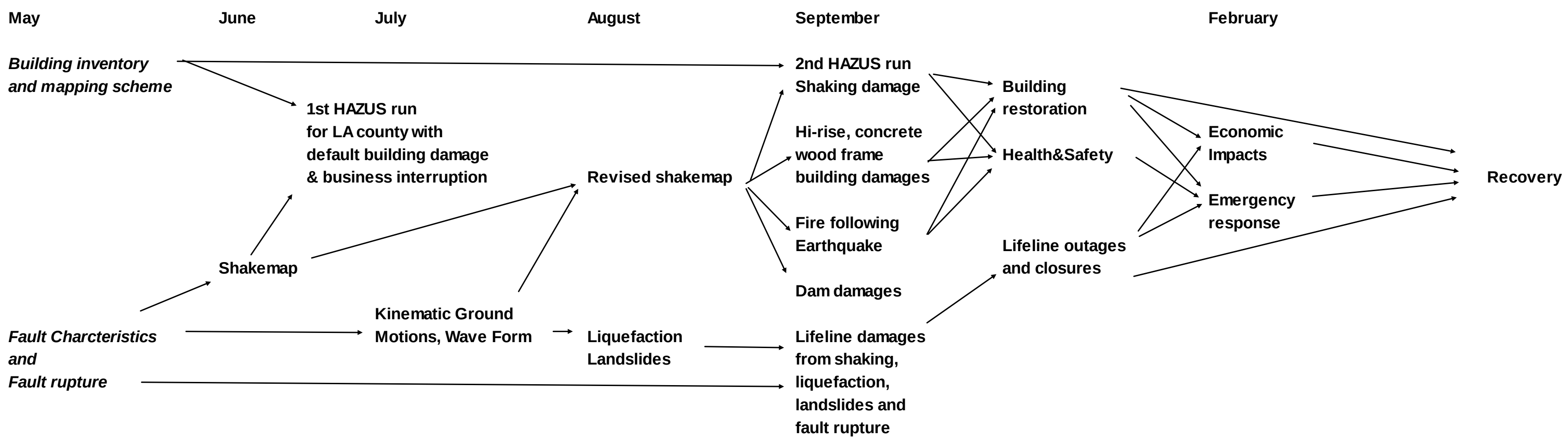


Figure 3. A rendition of a pert chart of ShakeOut scenario development across earth science, engineering, and social science disciplines within a rigid timeframe

Tip 3: Define your vision of science for decision-making

Reaching a consensus on a clear set of priorities and objectives for a "science for decision-making" project requires sensitivity to multiple discipline/scientific perspectives. It may be insightful to consider the methods of outreach relative to decision-making across disaster phases and levels of decision-making.

Time and conversation were needed for coordinators from multiple science disciplines, with a range of experiences and perspectives, to converge towards a common set of scenario objectives and project priorities and trade-offs (for example, scientific rigor versus the project schedule and budget). The dominance of the emergency response exercise, at times, confused the purpose of the economic consequence activity. We discovered that an economic impact analysis demands more information than might be delivered for an emergency response exercise and the information elevated issues for recovery planning as well as enhanced the input for emergency response. For example, the economic impact analysis pushed the frontier beyond damages to information about lifeline service outages and restoration times. Power, water, telecommunications, and gas services were analyzed across the region by county or Instrumental Intensity zone and over months of time.

During further contemplation of the project outreach and the means to influence decision-making, we considered how stakeholder participation informed decision-making across phases of the disaster cycle (i.e., emergency response, recovery, and mitigation) and levels of public and private decision making (e.g., range from individuals and households to federal agencies). Stakeholders participated in the ShakeOut scenario development, the Golden Guardian exercise planning and implementation, and/or the ShakeOut Drill. During the development of the ShakeOut scenario, workshops harnessed businesses, lifeline sectors, communities, counties, regional and state level agencies to posit and/or verifying damages and consequences, and to submit recommendations to improve response, speed recovery, and mitigate losses. The Golden Guardian 08 (GG 08) used the Shakeout scenario to challenge emergency response and recovery exercise planners and players in new ways. The ShakeOut Drill (www.ShakeOut.org) broadened the reach of the emergency response exercise to individuals, households, businesses, and schools. Table 1 summarizes the author's observation on the forms of participation by ShakeOut stakeholders and the types of decisions involved.

Decision Level	Emergency Response Preparedness	Recovery (effective post disaster)	Mitigation (effective pre disaster)
Federal	**GG**		
State	**GG**	**GG**	
Region	**GG**	**SW GG**	**SW**
County	**GG**	**GG**	
Special District	**SW GG SD**	**SW GG**	**SW**
Local	**GG SD**	**SW GG**	**SW**
Business	**SD**	**SW**	
Individual/household	**SD**		

Table 1. Levels and types of decision making exercised by the ShakeOut earthquake scenario (SW: Shakeout development Workshops, GG: Golden Guardian planning and exercising, SD: ShakeOut Drill)

Tip 4: Be prepared with spontaneity, creativity and expertise at the model interfaces

Model interfaces are typically challenging for integrated multi-disciplinary analyses. Although Hazards U.S. multi-hazards (HAZUS-MH, 2010) offers this function, HAZUS-MH was used only for ordinary building damage. Consequently, there were disconnects between the physical damage outputs and inputs needed for the economic impact model. Due to the large study area and compressed project development time, it was not practical to model the effects of damages to lifeline system (e.g., power, water, gas and telecommunication) components on spatial and temporal lifeline services that are sources of business interruptions. Instead, we depended on experts that are intimately knowledgeable of lifeline networks, and willing to speculate lifeline service outages and restorations over time and across space given damage assessments to system components, Such estimates may evolve and diverge as the scenario unfolds because expert opinion is subjective, sensitive to exposing vulnerabilities, and limited by the current unknowns. However, revisions of lifeline service outages and restoration estimates are useful as inputs for sensitivity analysis of recovery time paths..

Tip 5: Develop strategies for data issues

The multi-disciplinary nature of the study required data exchanges between groups that do not normally share or collaborate. Consequently, numerous data issues emerged including mismatched spatial units of data compilations, access to comparable data spanning the size of the problem, suppressed data, and incommensurable data formats from multiple sources. These issues were addressed with varying success and we recommend consideration of partnerships with data providers. For example, before we could integrate damage and economic and insurance data, it was necessary for us to develop an algorithm to convert census tract data to zip code data, which was done via data allocations at the smaller census block level. In addition, we had to prioritize spatial data collections and associated analyses for counties. For example, for the traffic analysis

Southern California Association of Governments (SCAG) automobile and truck origin-destination data covers six of the eight counties in the scenario, but it was time and budget prohibitive to get comparable data for the other two counties. It was practically prohibitive to use such data for the whole eight county study region because the problem size exceeded the capacity of the traffic analysis component (REDARS 2, Werner et al., 2008). While the HAZUS-MH analysis could be run at the county level it is complex to decouple a regional system (e.g., highway) analysis. In the future, agreements with data providers may reduce problems of suppressed data due to sensitivity of the information at smaller spatial units (e.g., zip code versus county) by allowing use of unsuppressed data while prohibiting the reporting of it. Additionally, collaborations with providers of complementary data (e.g., public and private insurance data) will yield more complete and consistent datasets from different sources.

Tip 6: Effectively communicate results to meet needs of users

To effectively communicate science-based information, it helps the users if the project coordinators can meet or communicate with stakeholders after results are released and to participate in exercise workshops. It is also more efficient to deliver materials in a format that meet the needs of a diverse set of users.

To increase the uptake of the scenario information, we participated in Golden Guardian workshops and led community workshops. At emergency response and recovery exercise planning meetings we contributed presentations and responded to questions. Our own community workshops involved representatives across community functions to facilitate networking and sharing among public agencies and private businesses, large and small, and to support local emergency response and recovery planning.

Understanding exercise planner needs up front enables scenario developers to better define and more efficiently and effectively deliver the scenario products in terms of content, format, presentation (e.g., tables, maps), exercise planner domains (e.g., county, utility, recovery), and levels of detail. At the time of scenario release, to reduce time responding to various requests for information, we advise 1) delivering the scenario in an exercise ready format (e.g., exercise forms that currently exist for counties/communities), 2) retaining the standard HAZUS-MH output format for the supplemental study (non-HAZUS-MH) results, 3) providing results at both the county and regional level when regional exercises are organized by county, 4) extracting and providing scenario information by the key sectors (e.g., water), 5) publishing the details of the scenario analysis (e.g., fault slip affecting various types of infrastructure), and 6) posting the GIS layers of particular interest such as Instrumental Intensity, fault rupture and offset, landslide probability and liquefaction probabilities. Following these suggestions should reduce the need to support individual requests for customized information and maps from counties and special districts.

Discussion and Conclusions

This summary of various tips learned through the process of developing and delivering a natural hazard scenario with economic consequences may be useful for future natural hazard scenario developers. Our economic consequence and recovery analyses were empowered by the launching of the scenario construction, the organization of and collaboration among the scenario task coordinators, and the cooperation of many external partners and experts. Our challenges primarily pertained to project priorities within a compressed time frame, data acquisition, and the interfaces to economic impact modeling. The process of communicating the scenario results revealed ways to more efficiently and effectively deliver materials.

Throughout the process, we discovered some of the limitations of our economic consequence analysis. The most frequently asked questions from stakeholders pertained to fuel availability. Also, labor issues due to employees dealing with personal damages and losses, disrupted commute patterns, and school closures, and effects on tax bases were ignored, but are important to end users.

Further examination of model interfaces and assumptions is warranted. For example, the HAZUS-MH and economic model interface requires alignment of building occupancy classes with industrial sectoring and building occupancy damages with sector productivity reductions (e.g., construction sector productivity is determined by damages to construction offices). The highway damage and economic impact interface remains a challenge because it is difficult to disaggregate traffic (people and goods movement) impacts to industrial sectors. For budget reasons, we employed an economic input-output (I-O) analysis that is a static representation of an economy. A more dynamic and sophisticated, but more costly, tool for estimating economic losses is a computable general equilibrium model that can incorporate market and behavioral response. In addition, further studies of economic resilience during the recovery period are needed to improve estimates of business interruption losses.

The ShakeOut scenario was accepted by stakeholders as a plausible devastating earthquake but there was necessarily some divergence and customization in the implementation of the exercises: some exercise planners chose to ramp up damages to overwhelm currently available resources (e.g., Los Angeles county increased the number of casualties to stress mortuary services), or take advantage of the opportunity to exercise particular concerns, while others chose to soften the blow to avoid overwhelming staff and ensuring a successful learning experience.

Many stakeholders have expressed appreciation for the scenario and the opportunity to think ahead to encourage problem solving at all levels within and outside of their organizations, across functions, and across the region. Organizations have recognized their interdependencies, and have taken the initiative to involve others. For example, water districts assembled part suppliers to discuss response and recovery issues. Also, communities recognized that their suppliers are concentrated in highly impacted areas and not geographically diversified. At times, we did meet some resistance to popularizing a devastating earthquake, creating a fear that the information would decrease the desirability of a location. However, the overriding sentiment was the positive spin of "better to be prepared for the worst than ignore the possibility and be caught unawares".

Finally, while a hazard scenario is well suited to providing the foundation for an emergency response exercise; for recovery and contingency planning and testing; for developing methods to transform earth science information into social and economic consequences; for stimulating stakeholders to identify potential solutions; and for exploring the systemic aspects of a disaster or catastrophe, a scenario is limited in its ability to analyze and justify investments into mitigation and resilience strategies. Indeed, some workshop participants hinted at the need to understand the cost-effectiveness and cost-benefit ratios of mitigation and resilience enhancement strategies that would reduce losses from a range of plausible earthquakes. These analyses need to be grounded in an earthquake risk analysis (based on multiple earthquake scenarios), and possibly multiple hazard risk analyses in the cases of resilience strategies that are effective for multiple hazards.

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Appendix: Partners

Sample list of the some of the organizations involved, showing the diversity of contributors.

Alameda Corridor Engineering Team
American Red Cross
Arizona State University
Art Center College of Design
Bureau of Labor Statistics
California Earthquake Authority
California Geological Survey
California Seismic Safety Commission
California State Employment Development Dept.
California Utilities Emergency Association
Caltrans
Caltrans
Carnegie-Mellon University
Center for Continuing Study of the Calif. Economy
City of Riverside
City of Torrance
Coachella Valley Water District
County of San Bernardino
Desert Water Agency
Earth Mechanics, Inc.
FEMA
Governor's Office of Emergency Services
Hess Engineering Inc.
Jet Propulsion Laboratory
KFWB Radio
Lim & Nascimento Engineering
Los Angeles City Emergency Preparedness Dept.
Los Angeles County Fire Dept.
Los Angeles County Metropolitan Transportation Authority
Los Angeles County Public Works
Los Angeles County Public Works
Los Angeles County Sanitation
Los Angeles Dept. of Water and Power
Los Angeles Dept. of Water and Power
Los Angeles Unified School District
Metrolink
Metropolitan Transit Authority
Metropolitan Water District

Metropolitan Water District
Metropolitan Water District
NBC-Universal
Office of Homeland Security
Office of Los Angeles City Councilmember Greig Smith
Office of the State Fire Marshall
Ohio State University
Palm Springs Fire Dept.
Port of Long Beach
Riverside County Fire Dept.
Riverside Fire Dept.
San Bernardino County Sheriff's Dept.
San Bernardino Valley Municipal Water District
Southern California Association of Governments
Southern California Edison
Southern California Gas Company
Stanford University
State Farm Insurance
University of California, Irvine
University of California, San Diego
University of California, Santa Barbara
University of Southern California
URS Corporation
Water Replenishment District Of Southern Calif.
Wells Fargo Bank
Zenith Insurance Company