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December 16, 2005

To: Mayor Michael D. Antonovich
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From: David E. Janssen
Chief Administrative Officer

THE COUNTY OF LOS ANGELES' ABILITY TO RESPOND TO A LARGE-SCALE DISASTER

On September 20, 2005, on a motion from Supervisor Molina, your Board directed the Chief Administrative Office's Office of Emergency Management (OEM) to report on the following:

1. A post-mortem assessment of the County's ability to respond to large-scale disasters, like Hurricane Katrina.
2. A public outreach campaign plan for disaster preparedness.
3. An assessment of the County's Operational Area Emergency Response Plan (OAERP) with recommendations to improve its effectiveness in large-scale disaster response.

This report provides information on the County's current level of preparedness followed by a description of the methodology used to assess our readiness for a catastrophic event. The report culminates in findings and recommendation designed to strengthen our preparedness for catastrophic disasters.

CURRENT STATUS OF PREPAREDNESS

The County uses the California Standardized Emergency Management System (SEMS) to coordinate and respond to disasters. SEMS is based on the Incident Command System which was developed in California by Firescope in the early 1970s. SEMS provides common functional descriptions, common terminology, and a common organizational structure for the coordination of damage information and resource requests. Under SEMS, the County, also known as the Operational Area (OA) Coordinator, serves as the intermediate level of government that coordinates and communicates response needs between the cities within its geographic boundaries and the state. As the OA Coordinator, the County also coordinates pre-event planning, training, exercises, and much more with our cities, community-based organizations, utilities, state agencies, and other OA partners. SEMS is an effective system that has served us well for the past ten years. The Federal government based much of the new National Incident Management System (NIMS) on SEMS.

In 1989, your Board approved the development and construction of a state-of-the-art CEOC. We broke ground on the facility in 1992, and took occupancy in 1995. The CEOC is base-isolated to withstand an 8.3 earthquake. It has multiple redundant communications systems, fuel, water, emergency generators, audio/video capabilities, and a host of other technical capabilities. The CEOC is designed around the Incident Command System with planning rooms for Operations; Plans and Intel; Logistics; and Finance, Administration, and Recovery.

The CEOC is equipped with an Emergency Management Information System (EMIS) that allows us to communicate directly with all 88 cities plus the Governor's Office of Emergency Services (OES); County departments; Red Cross chapters; school districts; and other agencies using internet web-based technology. We are able to get rapid reconnaissance reports from our cities, followed by more detailed damage information and resource requests. This ability to communicate with our cities allows us to quickly identify areas of damage and to receive resource requests so that County and mutual aid resources can be sent to the impacted areas.

The County continues to make great strides in its efforts to protect the public from acts of terrorism. Several recent advancements in this area demonstrate the extent of that progress. Homeland Security grants provided to public safety agencies in the County have enhanced our OA's corporate equipment, training, exercises, and plan development capability. First responder equipment purchased with these funds increases the County's ability to safely and efficiently respond to threats and acts of terrorism. Ongoing training and exercise programs, targeting specific threat types, have furnished a forum for first responder disciplines to enhance their capabilities. Funds designated for law enforcement agencies to prevent and interdict acts of terrorism have significantly enhanced our ability to discern and act preemptively on threats before they materialize.

Information-sharing activities between and among Federal, State, and local public safety agencies has continued to develop as well. With the opening of the new Joint Regional Intelligence Center in Norwalk in January of 2006, member agencies, which include the Federal Bureau of Investigation, the United States Attorney's Office, the State Office of Homeland Security, the Los Angeles Police Department, and the County Sheriff's Department, will reap tremendous benefits from the co-location of our counter- and anti-terrorism assets. The Center will be the first in the nation to leverage law enforcement partnerships at all levels of government and incorporate the knowledge and capabilities of other Terrorism Early Warning group agencies (fire service, emergency medical, and public health disciplines, etc.), to prevent, mitigate, and respond to acts of terrorism.

County-wide public safety agencies, working through the Terrorism Liaison Officer program, Homeland Security and Urban Area Working groups, and a variety of critical asset inventory and assessment initiatives, have broken new ground in creating public and private sector partnerships which provide a united front to counter the continuous threat of terrorism.

One of the most critical aspects of emergency preparedness is the coordination of plans before disasters and the coordination of response and recovery activities after disasters. The County has 38 departments that provide a vast array of services to our county's 10 million residents. Many of our departments provide countywide services such as health and public health, public social services, coroner, and mental health. In addition, the County Fire Department is responsible for providing fire protection to 57 of our cities as well as the one million people in our unincorporated areas. Our Sheriff's Department provides law enforcement protection to 42 cities plus our unincorporated areas. In addition, our Sheriff and Fire departments are the Mutual Aid Regional Coordinators for their respective disciplines. The County operates hospitals, health clinics, libraries, and numerous other public facilities, all of which must be prepared to provide essential services following emergencies and disasters. The County works very closely and on a regular basis with the City of Los Angeles. We exchange staff in our respective EOCs during activations. We also exchange staff with our OES partners.

On a day-to-day basis, OEM coordinates planning and exercises with the County's 88 cities by working with our Disaster Management Area Coordinators (DMACs). Each DMAC works with a consortium of cities within their area to ensure that emergency plans are coordinated among their cities and the County OA. OEM also coordinates major countywide exercises every year. For the past several years we have concentrated on terrorist-driven scenarios. OEM invites all 88 cities to participate in each year's exercise program and, over the years, we have engaged almost all our cities to one extent or another in Emergency Operations Center (EOC) activations, tabletop exercises, and full-scale events. Our 2005 exercise program includes 36 tabletop exercises, three County Emergency Operations Center (CEOC) functional exercises, and a full-scale event.

Because of the many natural and manmade hazards we face, the County has for many years had an aggressive emergency preparedness program. All County departments are required to have department emergency plans that describe how they will continue their non-deferrable services and emergency missions during disasters. All departments must also have building emergency plans to address the life/safety of occupants and visitors to County buildings.

In addition to their department emergency plans, all County departments are in the process of developing departmental Business Continuity Plans (BCPs). Departments use BCPs to ensure the continuity of government following disasters. This effort is still in progress; however, OEM will examine each of the plans upon completion to identify critical planning gaps. (NOTE: BCPs are not discussed further in this report because your Board receives information regarding BCPs via the established BCP quarterly reporting process).

Public education is an essential component of any emergency preparedness program. In 1988, your Board approved a motion by the late Supervisor Kenneth Hahn to develop of an earthquake preparedness public education program. In 1989, the OEM launched a public education campaign called the Emergency Survival Program (ESP) - formerly called the Earthquake Survival Program. The goals of the program are to provide valuable preparedness information for a wide variety of hazards and to reach as many people as possible with preparedness information.

OEM designed the award-winning ESP to help the public prepare for earthquakes and other emergencies in a cost-effective manner by encouraging them to take a different preparedness step each month of the year. Since its inception in 1989, ESP has published a variety of all-hazards documents, including: the award-winning ESP Family Steps to Survival; ESP Neighborhood Preparedness AWARE plan; ESP Activity Book for Kids; annual campaign information; and other publications.

ESP's outreach now includes over a million people who receive the information each month. OEM distributes free ESP information at emergency preparedness expos, safety fairs, Town Hall meetings and other community events. OEM also makes ESP presentations at schools, churches, businesses, etc. ESP materials are available on our Operational Area website at www.lacoa.org, and on other agencies' websites. OEM also established an ESP website (www.espfocus.org) which provides information to the public. Department Emergency Coordinators distribute ESP information to County employees. The media has been instrumental in promoting ESP to its millions of viewers and listening audiences. Recently, CBS 2-TV, KCAL 9-TV, KCET-TV and KABC, KLOS and KDIS Radio conducted major ESP promotions at no cost to the County.

REPORT METHODOLOGY

OEM used the following methodology to assess the County's state of readiness and to address the three actions requested by your Board:

- In conjunction with subject-matter experts, OEM identified the highest probable impact threats facing the County.

- County departments and OEM conducted a self-examination and in-depth review of existing plans with the goal of examining the County's overall ability to respond effectively to a catastrophic disaster.

- Based on the self-examination results, OEM, in conjunction with stakeholder groups, identified planning and response weaknesses requiring improvement and recommendations.

OEM conducted both an internal meeting of its personnel and a joint meeting of the Emergency Management Council (EMC) Steering and Subcommittees to begin this process. OEM tasked each of the three groups, in addition to representatives from all County departments, to identify critical aspects of existing County emergency plans. From these sessions, participants identified 138 questions designed to help define gaps in current plans. OEM then conducted an internal review to: (1) identify valid gap areas; and (2) remove redundancy.

HIGHEST IMPACT THREATS

Following a review of all plausible threats facing the County, OEM, in conjunction with subject-matter experts Dr. Lucy Jones, U.S. Geological Survey, and Lieutenant J. R. Coffman, Terrorism Early Warning (TEW) Group, identified the two most likely scenarios with the potential to produce catastrophic disaster impacts:

1. Major Earthquake. (See attachment: *Loss Estimates for a Puente Hills Blind-Thrust Earthquake in Los Angeles, California*. This attachment provides a complete scenario of an earthquake on the Puente Hills thrust which, according to Dr. Jones, is most likely the County's worst case scenario).
2. Terrorism Incident: Radiological Dispersal Devices, or "Dirty Bomb". According to the TEW, the most likely terrorist act with catastrophic consequences would be a multi-faceted, multi-location attack. Given the difficulty in planning and carrying out such an attack, the most likely scenario resulting in mass casualties and loss of life in the County is a "dirty bomb" (this scenario was used for last year's Operational Area exercise *Operation Talavera)*. As a security precaution, the TEW was unable to provide OEM with specific scenario details for this report.

Both scenarios listed above correlate with two of the fifteen high-impact scenarios facing our nation as identified by the Federal Department of Homeland Security (DHS) in the *National Preparedness Goal*. Federal DHS published these high-impact event scenarios for use by local governments in homeland security preparedness activities.

Identification and analysis of these "highest impact threats facing the County" provided the foundation for identifying the response capabilities and resource requirements necessary for effective prevention, response and recovery to major disasters.

FINDINGS AND RECOMMENDATIONS

The information provided below is in response to the three actions requested by your Board. As a result of the self-examination process and in-depth review of existing plans, using the highest impact threat scenarios identified above, OEM has identified the following planning gaps and recommendations. These findings, organized by category or function, reflect the highest priority planning, preparedness, and public outreach needs that County departments identified based on a catastrophic event.

General

Finding #1

While first responder agencies have good plans for how they handle their specific responsibilities, for the most part, defined unincorporated areas within the County do not have hazard-specific, coordinated Emergency Response Plans specifically developed for their communities. Although the OAERP provides the structure and tasking of the County's response, it does not specifically address detailed community-specific plans for the unincorporated areas.

Recommendation: Assess the preparedness needs and hazards in the various unincorporated areas and the ability to establish County Emergency Services Coordinators to address community-specific coordinated response plans.

Finding #2

Special needs populations must receive increased consideration in planning efforts, as evidenced by Hurricane Katrina. The State is currently addressing and developing evacuation standards and guidelines, to include special needs population issues. Once released, OEM and stakeholder department will integrate these State standards and guidelines into County emergency plans, policies, and procedures.

Recommendation: The County should commit additional time and resources to work with volunteer and non-profit organizations and members of special populations groups when conducting future emergency planning sessions. The County should more actively engage these groups in the development of emergency plans that address their capabilities.

Alert and Warning

Finding #3

Currently, the Emergency Alert System (EAS) provides alerts and warnings over television and radio as the primary means for alerting and warning the public. There has been minimal effort to include public education materials about this emergency alert and warning system in current disaster preparedness programs. Additionally, there is a lack of alternative alert and warning methods (sirens, etc.). Alternative alert and warning methods have not been identified and integrated into current plans, policies, and procedures.

Recommendation: County evacuation planning must address the use of alternative alert and warning systems and a plan to educate the public regarding all alert and warning methods and systems.

Evacuation

Finding #4

Although law enforcement has evacuation plans and does an excellent job of evacuating residents during fires and other small to moderate events, current plans need to be enhanced to address the massive numbers of evacuees that might be generated by a catastrophic event. The State has also identified statewide gaps in this area of planning and is currently developing evacuation standards and guidelines. Sheriff and OEM representatives have met with the State and stakeholders to discuss evacuation issues to be addressed in the State guidelines.

Recommendation: The Sheriff's Department and OEM will continue to participate in State-sponsored meetings to assist in the development of State evacuation standards and guidelines. Once released, OEM and the Sheriff will work with appropriate departments and support agencies to ensure the integration of State evacuation standards and guidelines into County plans.

Management/Situation Analysis

Finding #5

With few exceptions, OEM identified a shortage of well trained, redundant County managers and staff to perform emergency management duties and situation analysis. As with other types of response, extensive management and situation analysis training is necessary in order to ensure appropriate response.

Recommendation: While OEM and County departments conduct training for all CEOC staff, more frequent and more extensive training must be provided to all CEOC and Department Operations Center (DOC) staff to ensure proficiency. This should include training within a given timeframe for all newly hired staff. Trainees should also take post-training tests to measure the effectiveness of the training.

Medical/Mental/Public Health

Finding #6

Lack of resources for catastrophic events is a major concern. Consequently, medical and mental health care facilities are not adequately prepared for mass casualty events, including quarantine events.

Recommendation: Additional mass casualty, evacuation, and quarantine planning and training should be required for all medical, mental and public health care facilities. This includes contingency planning for: (1) all such facilities in the event staff/patients must evacuate them; and (2) ensuring the availability of adequate supplies and other resources.

Finding #7

There is a need for a medication supply and distribution plan for victims impacted by the disaster.

Recommendation: Primary and support departments, along with appropriate agencies, should develop a medication supply and distribution plan, particularly for mental health (psychotropic) and other critical medications (insulin, etc.).

Care and Shelter/Human Services

Finding #8

Current plans need to be enhanced to better enable the County to handle massive numbers of victims in need of shelter. While shelters are typically managed by non-profit organizations, such as the American Red Cross, more coordination between local, State, and Federal government and shelter operators is required to address this issue. The State has also identified statewide gaps in this area of planning and is currently developing care and sheltering standards and guidelines.

Recommendation: The County must expand its work with local, State, and Federal government and shelter operators to address planning gaps and, once they are released, to integrate State standards and guidelines regarding care and sheltering into County plans, policies, and procedures.

Terrorism

Finding #9

Last year's scenario for the Operational Area exercise *Operation Talavera* provided a means for the TEW to conduct a "gap analysis" on their terrorism plan and make needed amendments. The TEW will continue to assess and modify their approach, as needed. The TEW did not identify any specific gaps or needs for this report.

Recommendation: None at this time.

Utilities

Finding #10

In some cases utility companies are not given sufficient consideration during the development of emergency plans. Utilities have tremendous infrastructure and resources that the County may need to rely on during disasters.

Recommendation: The County needs to engage utility companies more actively in the development of plans. Planning groups must routinely include public utility agencies in the development of response plans and OA exercises.

Public Outreach Campaign Plan for Disaster Preparedness

Finding #11

OEM conducted an evaluation of the ESP public outreach campaign to determine methods to enhance its effectiveness. The program's most significant shortcoming is the lack of funds to promote emergency preparedness information to all members of the general public.

Recommendation: To enhance its effectiveness, OEM has identified three primary recommendations: (1) print and provide large quantities of handouts to members of the public without internet capability or without sufficient funds to print copies for their constituents; (2) promote the ESP website on a larger scale; and (3) produce radio and television public service announcements to air during primetime. OEM is currently considering a well-integrated community outreach communications program to expand the ESP's reach to the public. This proposal involves a wide variety of advertising, including paid prime-time media advertising. If OEM can identify funding for these recommendations, ESP will significantly expand to saturate all areas of the County.

NEW FEDERAL PREPAREDNESS REQUIREMENTS

On December 17, 2003, President Bush called for the development of a national goal to enhance National Homeland Security objectives. The Department of Homeland Security (DHS) published the National Preparedness Goal (Goal) on March 31, 2005, calling for the nationwide implementation of the National Incident Management System (NIMS) and National Response Plan (NRP). NIMS is a comprehensive, national framework for incident management, applicable at all jurisdictional levels and across all functional disciplines. NRP is an all-discipline, all-hazards plan for incident management. Together NIMS and NRP provide a nationwide template for incident response regardless of cause, size, location, or complexity of the incident. The Goal identifies capabilities (resources, mutual aid) required of all jurisdictions nationwide to accomplish pre-identified tasks in response to various multi-hazard scenarios.

Beginning in Federal fiscal year (FFY) 2005, Federal DHS is requiring States to implement a phased-in adoption and implementation of NIMS and NRP. Local government compliance is required by the end of FFY 2006. This compliance requires the integration of NIMS and NRP into all plans, policies, and procedures relating to emergency preparedness, incident management and response. Earlier this year, your Board approved a NIMS resolution formally recognizing and adopting NIMS. OEM also pro-actively developed a NIMS Implementation Plan to demonstrate the County's intent to fully comply with this directive. The Federal Emergency Management Agency (FEMA) has indicated that Federal DHS will provide further directives relating to the Goal's integration into Emergency Operations Plans (EOPs) next year.

Hurricane Katrina added to the urgency of plan, policy, and procedure review and integration of the Goal, NIMS, and NRP. State and regional partners are currently conducting workshops that address the adequacy of State and local government mass casualty planning, including large-scale evacuations and care and shelter issues. Federal DHS is currently conducting reviews of nationwide EOPs to ensure the following:

- The scope and concept of operations are sufficient to accomplish required tasks identified in plans.
- Local jurisdictions synchronize and integrate local plans with Federal and State plans.
- Plans integrate Goal concepts (scenarios, tasks, and capabilities), NIMS, and NRP.

All County emergency plans, policies, and procedures must be reviewed and updated to ensure compliance with Federal, State, and local emergency planning standards and guidelines. OEM's County NIMS Implementation Plan sets the County on a course to meet the new Federal requirements by established deadlines.

ACTION PLAN

This report identifies ten emergency planning areas in need of strengthening. In some cases, in order to accomplish a higher degree of readiness, additional resources may be necessary. In other cases, re-prioritization of some of the County's current planning efforts may be necessary. For this reason, additional time is needed to put together a well-considered action plan that tasks departments with lead and support actions to accomplish specific planning and training goals. This action plan must incorporate the goals already established in the National Preparedness Goal, NIMS, and NRP, and must establish timelines for completion along with the identification of the resources needed to accomplish each goal. Working with the involved departments, the OEM will develop a specific action plan and time-table for implementation. OEM will submit this action plan to your Board within 60 days of this report.

SUMMARY

Although we have a strong emergency management program in our County, there is still work to be done. The OEM has already conducted an internal review of all Operational Area and OEM plans, policies, and procedures requiring Goal, NIMS, and NRP integration. OEM is developing a strategy to incorporate the National Goal, NIMS, NRP, and additional Federal requirements into the Operational Area's and County's plans, procedures, and policies. OEM will also develop a strategy for integrating all applicable Federal standards and guidelines into current applicable training programs.

OEM, in developing these strategies, must ensure compliance with all Federal DHS and State planning guidelines and standards, and has created a workgroup to assist in the refinement and finalization of the draft strategy. This workgroup consists of OEM staff and members of the Emergency Management Council Subcommittee.

Additionally, OEM is currently participating in both Federal and State-sponsored workshops to assist in the development of planning guidelines related to mass casualty issues. OEM will ensure County compliance with the resulting Federal and State guidelines and standards as they are developed and released.

County departments and OEM will continue to use annual OA exercises to test the OA Emergency Response Plan to identify additional gap areas and areas for improvement.

It should be noted that the many additional Federal planning requirements are placing an ever-expanding workload on already strained emergency management resources. As part of the County's Action Plan, it will be essential that departments identify resource needs as part of their overall implementation strategy.

In summary, the goal for this effort is to enhance the County's capability to respond to catastrophic events. An Action Plan for the ten recommendations will be submitted to your Board in 60 days.

DEJ:CP
KG:cm

c: Each Department Head
Emergency Management Council
Emergency Preparedness Commission
Each Board Emergency Preparedness Deputy

Loss Estimates for a Puente Hills Blind-Thrust Earthquake in Los Angeles, California

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Based on OpenSHA and HAZUS-MH, we present loss estimates for an earthquake rupture on the recently identified Puente Hills blind-thrust fault beneath Los Angeles. Given a range of possible magnitudes and ground motion models, and presuming a full fault rupture, we estimate the total economic loss to be between $82 and $252 billion. This range is not only considerably higher than a previous estimate of $69 billion, but also implies the event would be the costliest disaster in U.S. history. The analysis has also provided the following predictions: 3,000–18,000 fatalities, 142,000–735,000 displaced households, 42,000–211,000 in need of short-term public shelter, and 30,000–99,000 tons of debris generated. Finally, we show that the choice of ground motion model can be more influential than the earthquake magnitude, and that reducing this epistemic uncertainty (e.g., via model improvement and/or rejection) could reduce the uncertainty of the loss estimates by up to a factor of two. We note that a full Puente Hills fault rupture is a rare event (once every ~3,000 years), and that other seismic sources pose significant risk as well. [DOI: 10.1193/1.1898332]

INTRODUCTION

Recent seismologic and geologic studies have revealed a dangerous fault system, the Puente Hills blind thrust, buried directly beneath Los Angeles, California (Shaw and Shearer 1999, Shaw et al. 2002, Dolan et al. 2003). This source, referred to as "blind" because it is covered by approximately 3 km of sediment, was first inferred from small-earthquake locations, seismic reflection profiles, and petroleum wells (Shaw and Shearer 1999). The fault has a long-term slip rate of 0.62–1.28 mm/yr and is thought to accommodate some of the 4.4–5.0 mm/yr compression occurring across the northern Los Angeles basin (Shaw et al. 2002). Considering the overall extent and geometry of the source, Shaw et al. (2002) estimated the moment magnitude (Mw) for a complete fault rupture to be 7.1. However, a subsequent study of shallow-sediment folding near the surface projection of the fault inferred at least four large (Mw 7.2–7.5) earthquakes over the past 11,000 years (Dolan et al. 2003).

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Earthquake Spectra, Volume 21, No. 2, pages 329–338, May 2005; © 2005, Earthquake Engineering Research Institute

An important question is the societal impact of such a Puente Hills earthquake, were it to occur today. Using the HAZUS-99 loss estimation methodology, developed by the National Institute of Building Sciences under a cooperative agreement with the Federal Emergency Management Agency (Whitman et al. 1997), the California Geological Survey estimated the total direct economic loss for such an event to be $69 billion (Rowshandel et al. 2004). In fact, of the many scenarios they considered, including a repeat of the 1857, Mw 7.8 San Andreas Fault earthquake, their Puente Hills event was found to cause the greatest direct economic loss (although many other sources pose significant risk as well).

There are two potential issues with the loss estimate of Rowshandel et al. (2004). First, it is based on the Mw 7.1 estimate of Shaw et al. (2002), rather than on the more recently inferred range of Mw 7.2–7.5 (Dolan et al. 2003). Second, their calculation was based on a single attenuation relationship, whereas several equally viable alternative ground-motion models exist that would give different loss estimates. Without exploring the range of losses implied by the alternative magnitudes and ground motion models, it is difficult to know how reliable their single estimate is. This is akin to making an inference about an unknown probability distribution from a single observation.

In this study we consider alternative magnitude estimates and attenuation relationships to quantify the probability of experiencing various losses in a Puente Hills event. This analysis has been made possible, in part, by a recently developed, open-source computational infrastructure for seismic hazard analysis, known as OpenSHA (Field et al. 2003). Our loss estimates are also based on HAZUS. However, we use a newer version, HAZUS-MH (http://www.fema.gov/hazus) that includes, among other improvements, updated building inventory and demographic data.

In addition to direct economic losses, we present the estimated number of casualties, displaced households, short-term public shelter needs, and the amount of debris generated by the earthquake. We do not report on indirect economic losses, which would include effects such as lost jobs and reduced tax revenues, because the HAZUS-MH Technical Manual (2003) states that "there have not been adequate tests for [these estimates]...." We also have not included the effects of ground failure, landslides, or liquefaction, all of which could significantly add to the losses.

THE PUENTE HILLS EARTHQUAKE SOURCE

The Puente Hills fault is composed of three north-dipping ramps, known as the Los Angeles, Santa Fe Springs, and Coyote Hills segments (Shaw and Shearer 1999). We used the most recent geometric representations for these segments found in the Community Fault Model of the Southern California Earthquake Center (Plesch and Shaw 2003). Assuming upper and lower seismogenic depths of 5 and 17 km, respectively, and an average dip of 27 degrees (Shaw et al. 2002), the combined area of these segments is 1206 km^2. For simplicity, these three segments were merged into a single fault surface for our calculations (shown in Figure 1). This simplification, however, has a negligible influence on our results because the ground motion estimates are insensitive to this level of detail.

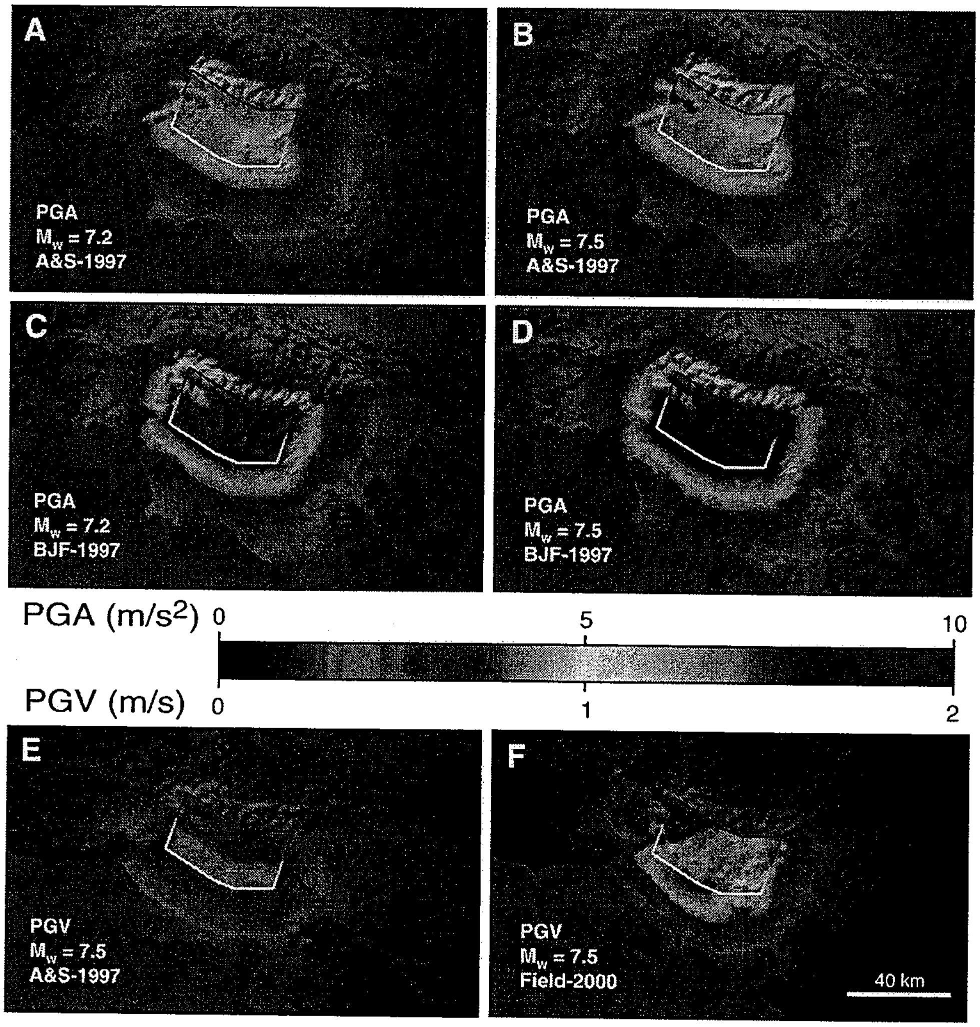

Figure 1. Earthquake shaking maps for some of the scenarios considered in this study. "Mw" is the earthquake magnitude, and the attenuation-relationship labels are as abbreviated in Table 1. The black and white line is the fault-rupture outline (dipping north). The maps for peak ground acceleration (PGA) are qualitatively similar to 0.3-second SA, and the maps for peak ground velocity (PGV) are simply the results for 1-second SA multiplied by the scalar conversion factor given by Newmark and Hall (1982). The latitude and longitude bounds of the map are 33.5 to 34.5 and −117 to −119 degrees, respectively, although the region considered for the loss estimates was larger (33.2 to 35.0 and −119.5 to −116.18, respectively). Downtown Los Angeles is located over the most westerly extent of the rupture surface.

The average co-seismic slip for each of the four paleoseismically inferred earthquakes is 2.2, 2.2, 4.6, and 4.4 m (Dolan et al. 2003). According to the magnitude versus

Table 1. The attenuation-relationship models used in this study

Abbreviation	Reference
A&S-1997	Abrahamson & Silva (1997)
BJF-1997	Boore et al. (1997)
Sadigh-1997	Sadigh et al. (1997)
C&B-2003	Campbell and Bozorgnia (2003)
Field-2000	Field (2000)
ShakeMap-2003	Wald (2003)*

* This relationship combines the rock-site predictions of Boore et al. (1997) with the amplification factors of Borcherdt (1994).

slip regression of Wells and Coppersmith (1994), these slip estimates correspond to Mw 7.2, 7.2, 7.5, and 7.4 events, respectively (Dolan et al. 2003). Remarkably, these magnitudes are the same as those obtained from the standard Mw versus moment relationship (Hanks and Kanamori 1979), where moment is computed as the product of co-seismic slip, the total fault area of 1206 km^2, and a shear rigidity of $3*10^{10}$ N-m. These estimates are also consistent (within one standard deviation) with the various magnitude-versus-area relationships used by the most recent Working Group on California Earthquake Probabilities (2003). We therefore use the three magnitudes (7.2, 7.4, and 7.5) inferred by Dolan et al. (2003), together with their relative frequencies of occurrence (0.5, 0.25, and 0.25, respectively), as an approximate probability distribution for the magnitude of a full-fault Puente Hills rupture.

ANALYSIS AND RESULTS

For each earthquake scenario, HAZUS-MH requires maps of median shaking levels for peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration (SA) at 0.3- and 1.0-second periods. In addition to the three alternative magnitudes discussed above, we used the six different attenuation relationships listed in Table 1. These represent the viable models in terms of being published and currently used in research and practice. Following the National Seismic Hazard Mapping Program (Frankel et al. 2002), we assign an equal weight to each relationship.

The earthquake shaking maps for each of the 18 scenarios (three magnitudes and 6 attenuation relationships) were computed using an OpenSHA application that is freely available at http://www.OpenSHA.org. This application includes site effects by converting the classification given in the map of Wills et al. (2000) into the classification scheme specific to each attenuation relationship. Basin depth is also included for those models (e.g., Field 2000) that utilize this parameter, as are hanging-wall effects (e.g., Abrahamson and Silva 1997, Campbell and Bozorgnia 2003). All implementation details can be found in the OpenSHA documentation, which is also available at http://www.OpenSHA.org

Examples of some of the Puente Hills scenario shaking maps are shown in Figure 1. Interestingly, the choice of ground motion model (e.g., Figure 1a versus 1c) can be more influential than the choice of magnitude (e.g., Figure 1a versus 1b). An important factor is how sediments are assumed to influence ground motion within a model. For example, the red patch in Figures 1a and b at the northwest corner of the earthquake-rupture outline, which represents the Verdugo Mountains, indicates that rock-site PGA is relatively high compared to that at sediment sites for this model (Abrahamson and Silva 1997). However, the opposite behavior is predicted by the Boore et al. (1997) model used in Figures 1c and d. This difference is a manifestation of assumptions regarding nonlinear soil response. Another feature is that most models predict the highest levels of shaking will be directly over the rupture surface (e.g., Figures 1a–e), whereas the model used in Figure 1f (Field 2000) predicts that PGV will be highest just southwest of the rupture (over the deepest part of the LA Basin) due to the impact of basin depth.

For the scenario depicted in Figure 1f, Figure 2 shows an example of the spatial distribution of total direct economic losses predicted by HAZUS-MH. Also shown for comparison is the distribution of economic exposure (e.g., building value) throughout the region. The vast majority of losses are shown to occur in Los Angeles County directly over the rupture surface. However, tangible losses are also predicted for counties located to the southeast of the Puente Hills fault as well. The percent losses predicted for this event are greater than those observed for the 1994 Mw 6.7 Northridge earthquake (e.g., Kircher et al. 1997), both because of the higher magnitude and because the heavily shaken area during Northridge was mostly wood-frame residential structures, whereas Puente Hills sits under older and more vulnerable commercial and industrial structures.

Figure 3 shows the total direct economic loss as a function of magnitude for each of the ground motion models considered in this study. The total range of losses is \$82 to \$252 billion, with differences among the ground motion models being potentially more influential than differences due to magnitude. Identical plots for the number of casualties, displaced households, short-term public shelter needs, and the amount of debris generated exhibit very similar relative trends (and are therefore not shown).

Assuming each ground motion model has equal probability of being correct, together with the relative probabilities assigned to each magnitude above, Figure 4 shows the probability of exceeding various losses given an event. The mean value for total economic loss is \$130 billion (with a range of \$82 to \$252 billion as indicated in Figure 3). This range is well above the previous estimate of \$69 billion (Rowshandel et al. 2004). It also exceeds the \$44 billion cost estimate for the 1994 Mw 6.7 Northridge earthquake (Eguchi et al. 1998), but is roughly consistent with estimates for the 1995 Kobe earthquake (Munich Re Group 2000). Even if the lowest value in our range is correct (\$82 billion), this event would still constitute the costliest disaster in U.S. history.

Using proprietary software, Williams et al. (2004) have also estimated losses for a range of Puente Hills scenarios. However, they focused exclusively on insured economic losses (i.e., what insurance companies would pay in claims) rather than the total direct economic losses considered here. Their mean estimate of \$24 billion is consistent with ours (\$130 billion) if ~18% of the overall exposure is insured.

Figure 4 also shows the estimated number of fatalities to range between 3,000 and 18,100, with a mean estimate of 7,600 (Northridge had 33 [Peek-Asa et al. 1998] and Kobe had 6,348 [Munich Re Group 2000]). The total number of injuries (not shown) is between 56,000 and 268,000, with a mean of 120,000. Both the fatality and injury es-

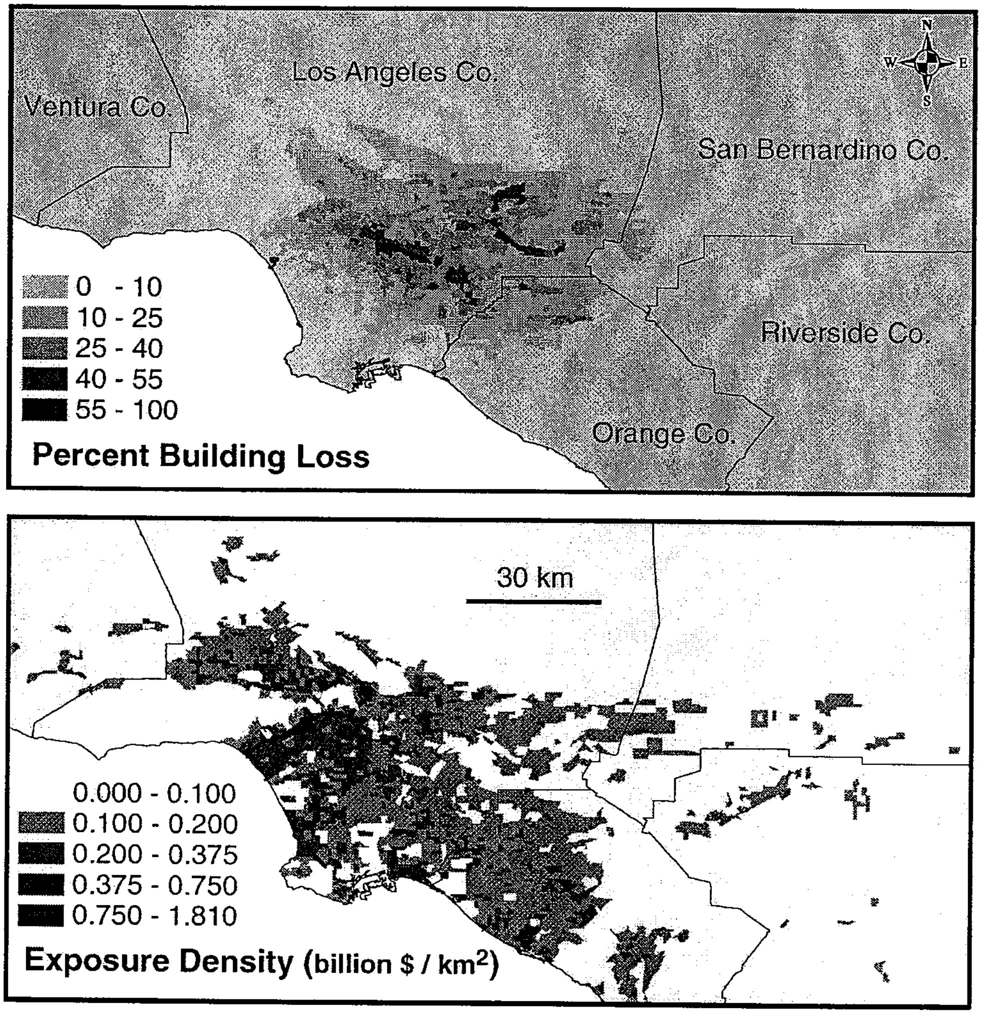

Figure 2. Shown at the top is the spatial distribution of total building damage, expressed as a percent of total building exposure, for each census tract for the Mw 7.5 and Field-2000 scenario shown in Figure 1f. Below is the exposure density throughout the region (the total value of the HAZUS-MH building inventory that could potentially suffer losses divided by the area of each census tract).

timates assume the event occurs at 2:00 p.m. during a weekday, when many people are at work. The number of displaced households is 142,000–735,000 (mean=274,000), and 42,000–211,000 (mean=80,000) individuals will need short-term public shelter provided by relief agencies. Finally, the amount of debris generated by the earthquake (not shown) is between 30,000 and 99,000 tons (mean=51,000 tons).

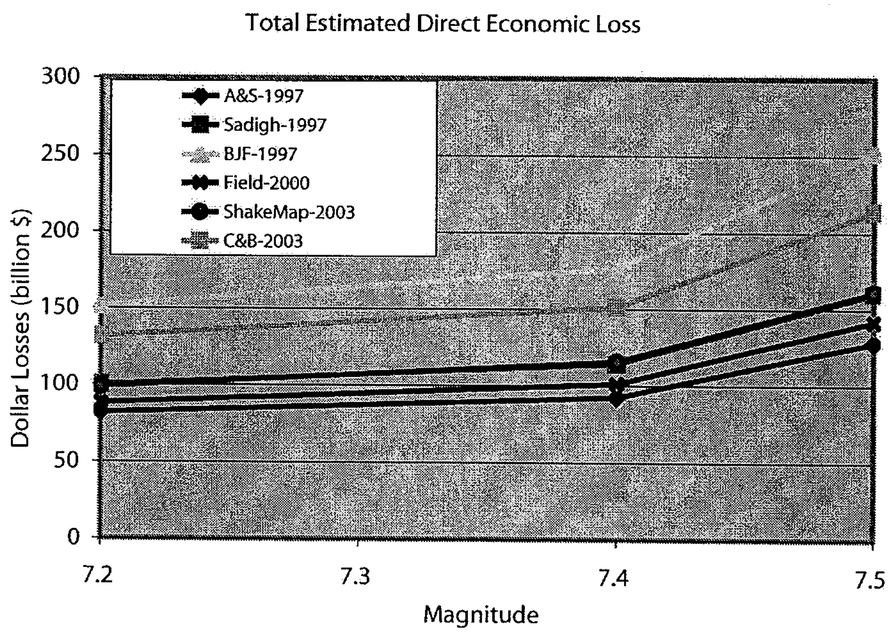

Figure 3. Total direct economic losses as a function of earthquake magnitude and attenuation relationship (label abbreviations are given in Table 1). HAZUS-MH estimates of total direct economic loss include capital losses (building damage costs, lost contents, and inventory), as well as income losses related to building damage (rental income losses, wage losses, and business interruption).

DISCUSSION

It's important to note that the loss exceedance curves presented here are themselves uncertain. For example, we have considered only three magnitudes for a full fault rupture, whereas other values are certainly possible. Furthermore, the occurrence of the 1987 Mw 6.0 Whittier Narrows earthquake on this fault (Shaw and Shearer 1999) exemplifies the fact that the next earthquake may not be a full fault rupture (and would therefore produce losses that are lower). However, possibly the most important unresolved uncertainty is related to the loss estimates themselves. That is, even if the magnitude and consequent ground shaking were known perfectly, there would still be considerable uncertainty associated with the losses. Formal quantification of such uncertainties is a very challenging and currently unresolved issue with respect to HAZUS-MH. The technical manual states that the total uncertainty (including that of the ground shaking) is "... possibly at best a factor of two or more." Our results demonstrate that uncertainty from the ground shaking, alone, accounts for at least a factor of two. Although the full uncertainty remains unquantified, this study nevertheless represents an important step in quantifying the range of losses for a Puente Hills earthquake.

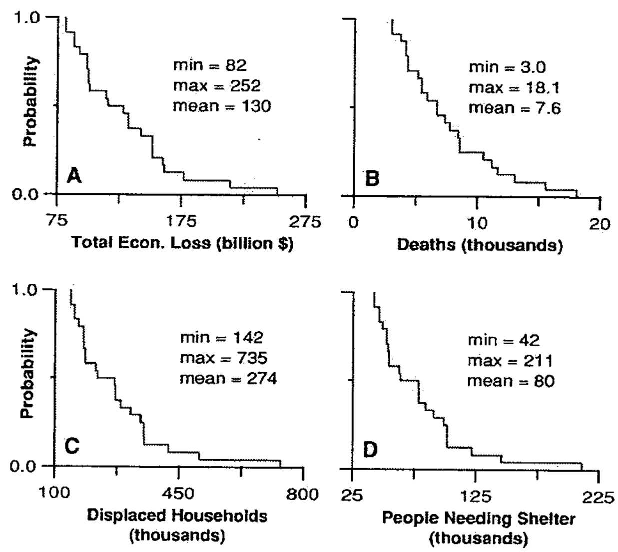

Figure 4. The probability of exceeding various levels of (a) total (direct) economic loss (in billions of $), (b) fatalities, (c) displaced households, and (d) the number of individuals needing short-term public shelter.

Of course, it remains possible that any one of the model components used here is seriously flawed. Unfortunately, it is not only beyond the present scope, but indeed a practical impossibility, to validate each and every aspect of the analysis. Therefore, this paper does not constitute a statement of what the true uncertainty actually is, but rather what is implied by current state-of-the-art methodology. If there are indeed problems with the analysis, then we hope this paper will provide motivation to identify and solve them.

Our calculations presume the occurrence of a full Puente Hills fault rupture, which begs the question of what the probability for such an earthquake actually is. The inference of four such events in the last 11,000 years (Dolan et al. 2003) implies a Poisson 30-year probability of ~1% (a conditional probably based on the date of the last event is not warranted given the large uncertainties cited by Dolan et al. [2003]). This rather low probability of occurrence must, of course, be weighed against the consequent impact to society if it were to occur.

CONCLUSIONS

Our results demonstrate that the choice of ground-motion model can be more influential than the magnitude of the event (Figure 3), at least for full fault-rupture on the Puente Hills fault. The choice of an attenuation relationship represents epistemic uncertainty as only one of these ground motion models can be correct—we just do not know which one this is at the present time. In fact, all the models are probably wrong, just some less so than others. The good news is that this uncertainty is potentially resolvable if we can collect the data necessary to test and reject some models, or to produce improved alternatives. For example, the loss uncertainty in this study would be cut by more than half if we could reject all but one attenuation relationship. The results presented here can serve as a basis for comparison in future studies that explore effects such as rupture directivity, or that apply full waveform modeling and/or nonlinear, dynamic structural response (the "rupture to rafters" solution). Furthermore, it will be interesting to see whether the models under development in the Next Generation Attenuation Relationships (NGA) Project, sponsored by the Pacific Earthquake Engineering Research Center (PEER) Lifelines Program, will reduce the uncertainty in our estimated Puente Hills earthquake losses.

ACKNOWLEDGMENTS

We gratefully acknowledge helpful review comments from Lucile Jones, Paul Reasenberg, William Ellsworth, and two anonymous reviewers. We are also grateful to Bruce Worden for providing code that converts shaking data into HAZUS shape files. This research was supported in part by the Southern California Earthquake Center (SCEC). SCEC is funded by NSF Cooperative Agreement EAR-0106924 and USGS Cooperative Agreement 02HQAG0008. The SCEC contribution number for this paper is 825.

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(Received 23 September 2004; accepted 25 January 2005)