

GLOBAL BLUEPRINTS FOR CHANGE

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The Global Blueprints for Change contain guidance for working together to improve the capability to identify indicators of physical, social, enterprise, and environmental vulnerabilities throughout the world and to select and implement realistic solutions to reduce them towards acceptable levels.

THEME A: LIVING WITH THE POTENTIAL FOR NATURAL AND ENVIRONMENTAL DISASTERS

Topic A.4: Enhancing Public Awareness

"Use of Earthquake Loss Estimates to Enhance Public Awareness of Risk Exposure and Stimulate Mitigating Actions--A Blueprint for Loss Reduction"

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USE OF EARTHQUAKE LOSS ESTIMATES TO ENHANCE PUBLIC AWARENESS OF RISK EXPOSURE AND TO STIMULATE MITIGATING ACTIONS--A BLUEPRINT FOR LOSS REDUCTION

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ABSTRACT: This Blueprint presents new opportunities and ideas for loss estimation to be used as a communication tool to increase public awareness.

Background

New multi-disciplinary technological developments such as FEMA's publicly available, consensus-based loss estimation model, HAZUS, enable us to estimate future earthquake losses at a regional scale in order to assist policy makers and the public to appreciate the extent of their exposure. The HAZUS model employs both earthquake hazard and structural fragility terms to calculate damage ratios and estimate damage costs. As a result, we can more quantitatively estimate risk and present this information to the public. We use the term risk to mean the product of multiplying the consequences of damaging events, such as damage costs and secondary economic effects, by the probability of the events occurring during a specified time period. As earth scientists, engineers, and emergency managers, we need be no longer constrained to only characterizing the hazards in our policy dialogues. We also should collaborate with engineers to make these estimates of future losses as robust as possible. Most importantly, we don't have to wait for the next disaster to stimulate improvements in seismic safety based on characterizations of the extent of future damage. Armed with this powerful capability, we should redouble our communication efforts.

Barriers to Public Loss Reduction Actions

Earthquake hazard and risk communications face some formidable barriers to their being understood and believed by many recipients. Moderate and large damaging earthquakes are relatively rare, high-impact events. Actions in response to receipt of successful hazard and risk messages include both the private decisions based on the recipient's perception of risk, their personal aversion to that risk, and the public community's consensus that loss-reducing regulations and other types of actions are justified to keep the exposure to risk within a specific comfort zone. The upper boundary of the comfort zone is usually referred to as the "level of acceptable risk".

The most important public policy efforts to reduce future earthquake losses in California have come on the heels of disastrous events rather than through the receipt of hazard and risk messages. Our policy makers want to show that they "are doing something" after disasters. Following all extensively damaging earthquakes in California during the last

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70 years, changes have been made to the statewide building code requirements in order to correct problems that have been observed in structural performances. For instance, after the 1933 Long Beach earthquake, the California Legislature passed the Field Act requiring improvements in building designs for public schools (K-12). The observed effects of the 1971 San Fernando earthquake motivated passage of legislation establishing a state active fault zoning program to avoid placement of structures over active faults where future ground rupture is expected. Other post-event policies to reduce future losses include higher seismic design standards for new hospitals (San Fernando earthquake), higher seismic design standards for existing hospitals (Northridge earthquake), acceleration of Cal Trans' retrofitting of bridges and overpasses (San Fernando and Loma Prieta earthquakes), state zoning of potential liquefaction and earthquake-induced landslide areas to protect new construction (Loma Prieta earthquake), and state-sponsored residential earthquake insurance (Loma Prieta and Northridge earthquakes).

The Federal Stafford Act was created to provide post disaster matching funds to reduce losses from future events. Grants under the Stafford Act were used to strengthen many eligible publicly owned structures after the Loma Prieta and Northridge earthquakes.

Application of Loss Estimation to Earthquake Loss Reduction

In a democratic society, the things that are given significant attention are generally "consumer driven" issues. It is clear that both citizens and public policy makers of the state are unaware of the extent of their exposure to earthquake risk, and consequently they do not have the motivation to invest in loss reduction improvements. In other words, our attempts at risk and hazard communication are not strategically successful. The citizenry will only advocate and support policies that advance seismic safety if they appreciate the extent of their own risk exposure and find it to be above their consensus level of acceptability. Properly used, the newly developed HAZUS loss estimation modeling capability can enable us to justify improvements without waiting for the next disastrous earthquake.

The citizens receiving our messages, as voters, are the key to any improvements in seismic safety that may be made. Can we improve our communications to remedy this situation? We can. We do not have to wait for the next disaster! First we must strive to eliminate barriers to the recipient's perception of our messages and then construct our messages so that the recipients are prompted to take action. To assist us, let's take a brief look at some of the insights available from risk communication specialists. Miletti and Sorenson¹ recognize six stages of processing of risk messages by recipients: receiving; understanding; believing; personalizing; responding, (with a decision) and information seeking (additional information needed to implement the decision). But we do little or no systematic follow-up assessment of how the recipients of our messages process the information we provide and whether or not they act on it. We do not know on which of the six processing stages of our messages have foundered. We should endeavor to learn by analyzing feedback and apply the lessons to improve our communications.

¹ *Communicating Risk to the Public; International Perspectives*, 1999, Kluwer, Academic Publishers.

Estimated Losses in California Earthquakes during the last 30 Years

Looking at the past 20 years, earthquake losses have increased dramatically. Table 1 shows tabulation by the Federal Emergency Management Agency of earthquake losses in California between 1964 and 1994.

Table 1

Earthquake	Date	Magnitude	Total Loss²
San Fernando	February 9, 1971	6.7	2,240
Imperial Valley	October 15, 1979	6.5	70
Coalinga	May 2, 1983	6.4	18
Loma Prieta	September 18, 1989	7.0	8,000
Northridge	January 17, 1994	6.7	23,000 ³ 46,000 ⁴

Three of these earthquakes occurred in relatively unpopulated areas (Loma Prieta, although it occurred beneath the Santa Cruz Mountains, caused significant damage in nearby Santa Cruz and in the more distant, heavily populated, San Francisco Bay area). As urban areas continue to expand, the population and infrastructure at risk increases. If these or similar events were to recur, or occur closer to populated areas, damage would be much more significant. For example, the San Fernando earthquake occurred in 1971, had a fault rupture beneath the mountains, and caused slightly over \$2 billion in damage. The Northridge earthquake occurred after 23 years of continued development, had a fault rupture directly beneath the San Fernando Valley, and caused about \$46 billion in damage.

The thirty-year (1970-2000) average annual loss (AAL) is about \$1.1 to 1.9 billion (2000 dollars, range depends on which numbers used for the Northridge earthquake). However, two-thirds to 80% of that loss is from the Northridge earthquake alone! And the estimate does not include smaller earthquakes such as the 1984 Morgan Hill (M6.2) or the 1987 Whittier (M6.1) earthquakes. Thus, past earthquakes may not provide a realistic estimate of future earthquakes' effects.

California decision makers are frequently called upon to make decisions on development, redevelopment, and hazard mitigation priorities. Clearly, these decisions could profit from an understanding of the expected future losses from earthquakes. This understanding should begin on a regional scale, applicable to regional policy decisions. To this end, to provide a credible first order estimation of future earthquake losses in California, the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey have jointly implemented an evaluation of expected earthquake losses in California. Of course, we cannot say when and where earthquakes

² Update of FEMA estimate to 2000 dollars.

³ California Governor's Office of Emergency Services

⁴ California Governor's Office of Emergency Services

will occur, how big they will be and what their effects will be. But we do apply the best available current understanding of earthquakes and their effects to produce this evaluation. The approach used provides a publicly available model that can be applied at regional scales to assist in the development and prioritization of mitigation, response and recovery strategies. To this end, we include a short list of policy questions and issues that arise from the damage analysis.

At the same time that CDMG was doing its analysis; FEMA was using HAZUS to estimate the average annual earthquake loss for the entire country by aggregating census tract estimates. We coordinated our estimate for California with FEMA. The results are different because CDMG had some refinements in the probabilistic hazard analysis model it employed and the state used a CDMG developed soils map rather than the single default soil type of HAZUS that FEMA employed nationwide. CDMG and FEMA released the reports with a joint news announcement and media briefing that explained the differences in results.

Since all hazard and risk estimates have uncertainties, we need to think through the best ways to express them to the public and to policy makers in responsible ways that do not negate the significance of our conclusions.

Estimation of Future Earthquake Losses

The evaluation of expected losses uses an earthquake model developed jointly by the Department and the U.S. Geological Survey,⁵ in collaboration with geologists and seismologists familiar with California's seismic hazards. This model includes all known active faults in and near California. The expected frequency of earthquake occurrence along each fault is estimated from the historical and geologic earthquake activity.

The estimates of ground motion that can be anticipated from those earthquakes incorporate the variability of shaking from different earthquake sources. These ground-shaking estimates have been incorporated into the new International Building Code, with will begin to be incorporated into California's building codes, replacing the Uniform Building Code, beginning in 2001.

The building damage that results from the ground shaking emanating from these earthquakes is estimated using HAZUS,⁶ a program developed by the National Institute of Building Sciences for the Federal Emergency Management Agency to calculate levels of damage that can be expected from a variety of natural disasters. The input to HAZUS can be a specific earthquake or an already developed ground motion map. In either case,

⁵ Frankel, A. D., C. Mueller, T. Barnhard, D. Perkins, E. V. Leyendecker, N. Dickman, S. Hanson, and M. Hopper, 1996, National Seismic Hazard Maps, June 1996, Documentation: U.S. Geological Survey, Open-File Report 96-532, 100 p., and Petersen, Mark D., William A. Bryant, Chris H. Cramer, Tianqung Cao, Michael S. Reichle, Arthur D. Frankel, James Lienkaemper, Patricia A. McCrory and David P. Schwartz (1986) Probabilistic Seismic Hazard Assessment for the State of California. California Division of Mines and Geology Open-File Report 96-08 and U.S. Geological Survey Open-File Report 96-706. 85 p.

⁶ National Institutes of Building Sciences, 1997, Earthquake Loss Estimation Methodology, HAZUS. Prepared for the Federal Emergency Management Agency. Technical and Users' Manuals, 4 Volumes.

the result is a damage scenario, the level of damage expected from a specific earthquake or specific levels of ground motion. HAZUS also can incorporate the probabilities of the ground motions to produce an estimate of the expected loss per year (expected annual loss). This paper uses the scenario results of HAZUS to produce that estimate.

HAZUS as published by FEMA contains a number of default databases, including faults and their hazard levels, soil types, and structure inventories. This paper uses the default structure inventories. For our calculations, HAZUS was run for different levels of ground motion at census tract centroids statewide. The damage effects (at a regional scale) of soil liquefaction are also incorporated into the analyses. The output of each run is the expected dollar damage, structural and nonstructural, to the inventory of buildings located in the census tract. Contents loss and direct (loss of income, rental loss, etc.) and indirect economic losses are also calculated. The buildings are divided into 15 different structure types, each with its own response to ground shaking. The results of each HAZUS run are combined with the probability of that ground motion occurring during one year to produce an estimate of the expected annual loss, structural and nonstructural, to buildings in California.

We have not considered all structures or types of earthquake losses in California in the estimates presented here. For example, we did not include damage to airports or most lifelines. In addition, we did not consider the effects of catastrophic losses caused by damage to facilities such as dams, nuclear power plants, liquefied natural gas facilities, or military installations. We have not evaluated the losses due to fires following earthquakes, social losses, or the indirect losses that may result from the effects of the earthquake. While all of these factors can contribute significantly to the overall loss, direct damage to structures should constitute a large part of the dollar damage.

Results of Loss Estimation

Initial results give an Expected Annual Loss in California of \$3.9 billion. This estimate includes only structural and non-structural damage to buildings. When associated losses, such as losses to contents, inventory and income, are included, the expected annual loss for all of California increases to about \$4.7 billion. The estimated total value of the building inventory in the HAZUS database is \$1.6 trillion. Thus, the annualized total damage estimate represents a small portion, 0.29%, of the total exposure.

Expected annual loss, by county, is illustrated in Figure 1. Table 2 lists the top 16 counties in average annual total loss. Counties most affected include Los Angeles, Alameda, Orange, Santa Clara, San Bernardino and San Francisco. Los Angeles has by far the largest expected annual loss, fully 1/3 of the statewide total. Alameda follows with about 10% of the statewide total. Clearly, the differences result from both a larger inventory (exposure) in Los Angeles and a greater hazard level in Alameda. In fact, the sum of expected annual total losses for Los Angeles, Orange, San Bernardino Counties (about \$2.25 billion) is about 60% greater than that for the 5 San Francisco Bay area counties of Alameda, Santa Clara, San Francisco, Contra Costa and San Mateo (about \$1.43 billion).

Looking at it from another angle, the expected annual total loss for the 5 Bay area counties, with a total population (in 1990) of about 5 million, is only slightly smaller than the total for Los Angeles, with a population of over 12 million. So, when the population of each county is taken into account, the picture changes somewhat. Figure 2 shows the per capita expected annual total loss (loss divided by population). Table 3 shows the results for the top 17 counties. In terms of the earthquake impacts on the individual citizens of the county, San Francisco rises to the top (with its large commercial structure inventory but relatively small population) with a per capita expected annual loss of \$491. Imperial County rises to third, because of its great hazard but very low population density, and Los Angeles falls to ninth.

Uncertainties in Loss Estimation

We have not completed an analysis of the total uncertainty in the estimate of annual expected loss. However, it is important to note that the uncertainty is large, on the order of a factor of 4 or so. This seemingly large uncertainty (the annual expected loss may be as small as \$1 billion or as large as \$16 billion, within the 95% confidence limits) does not negate the estimate itself. Any decision based on the annual expected loss estimate must be able to take into account the uncertainty.

Relative numbers are probably less uncertain. That is, it makes sense, because of the known seismic hazards and because of the population, structures and infrastructure at risk, that Los Angeles and the San Francisco Bay area would have the greatest expected losses. Results can be compared for areas smaller than counties. However, as the area gets smaller, uncertainties will grow, because the default inventory incorporates assumptions that do not apply to individual census tracts, although they may be appropriate for the aggregate.

Comparison with other published estimates

The loss estimates we present seem very large. We have compared the results of our analyses with previously published results. Hayes⁷ estimated in 1990 that earthquake losses in the United States would average about \$1 billion per year. Most of those losses would occur in California. But his estimate was made before the 1994 Northridge earthquake radically changed our view of potential earthquake damage. It is now widely held that, even if the rate of occurrence of natural disasters is not increasing, the damage that results from them is increasing as the number of people, and structures, exposed to the hazards increases.⁸

In 1996, the California Earthquake Authority published an estimate of expected annual damage to single-family residences in California that have earthquake insurance.⁹

⁷ Hays, Walter W. (1990) Perspectives on the International Decade for Natural Disaster Reduction. Earthquake Spectra V. 6, No. 1, pp 125-145.

⁸ Mileti, Dennis S., (1999) Disasters by Design. Henry Joseph Press. 351 p.

⁹ EQECAT, 1995, California Earthquake Authority Residential Property Portfolio Earthquake Loss Modeling: Summary. EQECAT, Inc., San Francisco, California.

Expanding their estimate to all residences gives \$2 billion per year. Singling out single-family residential structures from our analyses produces \$1.6 billion per year. These two numbers, given the uncertainties and reasonable differences in the two analyses, are very close. The CEA has calculated more recent estimate¹⁰ based on the actual book of insurance and may be more susceptible to adverse selection (and, therefore, not applicable statewide) than the earlier estimate.

In 1983, the Applied Technology Council published ATC-13,¹¹ a survey and compilation of expert opinion on the damageability of various types of structures as a result of earthquake ground shaking. We have examined what ATC-13 would estimate for earthquake damage to low-rise, wood-framed structures, the predominate structure type in California. ATC-13 based its damage estimates on Modified Mercalli Intensity (MMI), a scale that reflects the effects of an earthquake, not directly on ground shaking. Depending on how the conversion from MMI to ground shaking is done, damage levels from \$0.8 to \$2.6 billion are estimated. Separating this structure type in our analysis gives \$2 billion, within that range. It is interesting to note that fully half of the anticipated earthquake damage in California will be to low-rise, wood-framed dwellings, which includes nearly all single family residences and many low-rise commercial structures. However, before instituting a program to solve the "wood-frame problem," it must be realized that the total damage number given is the sum of a very small average damage to a very large inventory of structures.

The Federal Emergency Management Agency recently released an estimate for average annual earthquake losses for the whole country¹². They estimate an average annual total loss of \$3.2 billion for California, which directly compares with our estimate of \$4.7 billion. Because of differences in how HAZUS was used in the calculations, these apparently different estimates are actually in better agreement than they appear at first glance.

Although FEMA also used HAZUS to produce their estimate, our approach to using HAZUS differed slightly from theirs. We have augmented the defaults of HAZUS in two areas. First, HAZUS defaults to a uniform soil condition (ground-shaking amplification condition), assuming alluvium everywhere. We have incorporated a statewide soils map into our considerations. Those portions of California not alluvium are mostly built on soils that would shake less than alluvium (the exception being the Bay muds located around the fringes of San Francisco Bay and the soft fills found in the older developments along coastal areas). This difference would cause FEMA's estimate to be higher than ours, leading to slightly more conservative results. A second difference is that HAZUS includes only ground motions that are expected to return every hundred years or more. We have incorporated levels of ground shaking expected to occur more frequently. Although the more frequent ground motions are small, leading to small losses

¹⁰ California Earthquake Authority direct communication (1999)

¹¹ Applied Technology Council (1985), Earthquake Damage Evaluation Data for California. Report ATC-13, 492 p.

¹² Federal Emergency Management Agency (2000), HAZUS99 Average Annual Earthquake Losses for the United States. 35 p.

when they occur, they occur frequently enough that their net effect is large. This is probably the principle reason for the difference between our estimate and FEMA's.

From these comparisons, we conclude that the \$4.7 billion total expected annual loss estimate is not unreasonable, but is similar to other estimates made with different approaches and assumptions.

Additional Topics for Investigations

The estimates presented here lead to a number of questions, both technical and polity-related.

Some of the technical questions relate to the distribution of the loss. Several questions have arisen that we are beginning to answer:

- (1) How much of the loss results from the largest earthquakes (e.g. repeats of the 1906 or 1857 magnitude 7.8 events) and how much results from the more frequent magnitude 6 to 7 or 7.5 events?
- (2) Which faults generate earthquakes that produce the highest losses?
- (3) What is the range of dollar losses that could occur should a large earthquake occur in a metropolitan area?

Other technical questions include: Can the uncertainties be reduced? If so, how? How can we better estimate the uncertainties in the calculation? Although we have presented an expected annual loss, what is the largest loss (probable maximum loss?) that might occur in a given year in California?

Policy Issues Identified by this Loss Estimation

Policy questions abound. The expected annual loss only from structural and non-structural damage to buildings amounts to a cost to each Californian of about \$130 each year. And these costs do not reflect those additional costs associated with injuries to occupants. Damaged buildings (and contents) are more likely to injure the occupants than undamaged buildings (and contents). Efforts to reduce that cost should have high priority.

Given that it will be impossible to mitigate to zero expected damage, how much of the expected damage can be effectively mitigated and at what cost? How should society plan to recover from the residual losses? What kinds of structures contribute most to the cost? Is structural mitigation a cost-effective approach to reducing the damage? What role should earthquake insurance have? If a building owner does nothing to reduce or cover the damage, should the owner be penalized or rewarded by the government during recovery? The damage is principally an existing structure problem, not a new structure problem. What is the role for the financial community? How should the financial community incorporate this level of expected losses into its operations? What role does local, regional, and State government have in identifying specific hazards, and in encouraging or forcing reduction of building damage?

Recommendations to Create Further Earthquake Awareness and Initiation of More Effective Loss Reduction Efforts

Where do we go from here? It is clear that California faces a serious financial threat to its buildings and economy from future earthquake losses. But the problem receives serious attention only after catastrophic events. And solutions seem too expensive for the nebulous gain to be received at some distant time in the future. What can we, as scientists, engineers, economists and sociologists, do to help alleviate these future losses?

Better communication needs to take place between the technical community and the policy makers and general public. To many people, the threat of \$150 per person per year doesn't seem like very much money—slightly more than \$12 per month—especially if the federal government is likely to pay the brunt of the cost. Scenario loss estimates fair just as poorly. A scenario event may be catastrophic and cost tens of billions of dollars, but it's likely not to occur in our lifetime, or at least in the tenure of a City Councilperson or County Supervisor. New approaches must be invented to better communicate the level of risk to the general public, the public policy and decision makers and the financial institutions. A process of assessing the success of important new communication efforts by surveying the intended audiences will facilitate continuing improvement of our efforts.

Communication of the risk is worthless without also providing advice the appropriate response options for the public, public officials and financial institutions. What are current cost-effective loss-reduction solutions? What interdisciplinary efforts could be undertaken to develop better, more cost-effective solutions? How can the investment advantages of these solutions be best communicated to the public? To public officials? To financial institutions, such as lending institutions and insurance companies? The development of answers to these questions needs urgent attention. An interdisciplinary working group empanelled to make recommendations to both earth science and engineering communities is urgently needed.

We recognize that it's difficult to understand how to use estimates of future loss that are uncertain by a factor of four. We need to put both the uncertainties and the significance of the current loss estimates into a perspective that will justify action and not favor procrastination.

In addition, the technical community must continue its efforts to improve the loss estimation methodology and to reduce the uncertainty in the results. Dollar loss estimates should be more comprehensive, including loss estimates for critical facilities and lifelines. The better the results presented to the public, the more credible the message and the more useful the understanding is to design mitigation strategies. Together these increase the likelihood that the public and policy makers will respond meaningfully to the loss estimation insights.

Table 2

Annual Average Total Loss			
County	Loss (K\$)	1990 Pop	Per Capita (\$)
Los Angeles	1,604,009	8,902,000	180.19
Alameda	424,440	1,284,800	330.36
San Francisco	357,579	727,900	491.25
Orange	350,078	2,417,600	144.80
Santa Clara	347,470	1,504,400	230.97
San Bernardino	291,996	1,436,700	203.24
Riverside	178,219	1,194,600	149.19
San Mateo	153,946	651,400	236.33
Contra Costa	145,121	807,600	179.69
San Diego	135,444	2,511,400	53.93
Ventura	132,618	670,200	197.88

Table 3

Per Capita Annual Average Total Loss			
County	Loss (K\$)	1990Popl	PerCapita (\$)
San Francisco	357,579	727,900	491.25
Alameda	424,440	1,284,800	330.36
Imperial	28,581	110,800	257.95
San Mateo	153,946	651,400	236.33
Santa Clara	347,470	1,504,400	230.97
San Bernardino	291,996	1,436,700	203.24
Ventura	132,618	670,200	197.88
Humboldt	22,395	119,600	187.25
Los Angeles	1,604,009	8,902,000	180.19
Contra Costa	145,121	807,600	179.69
San Benito	6,523	37,000	176.31
Marin	39,518	230,200	171.67
Santa Cruz	38,829	230,400	168.53

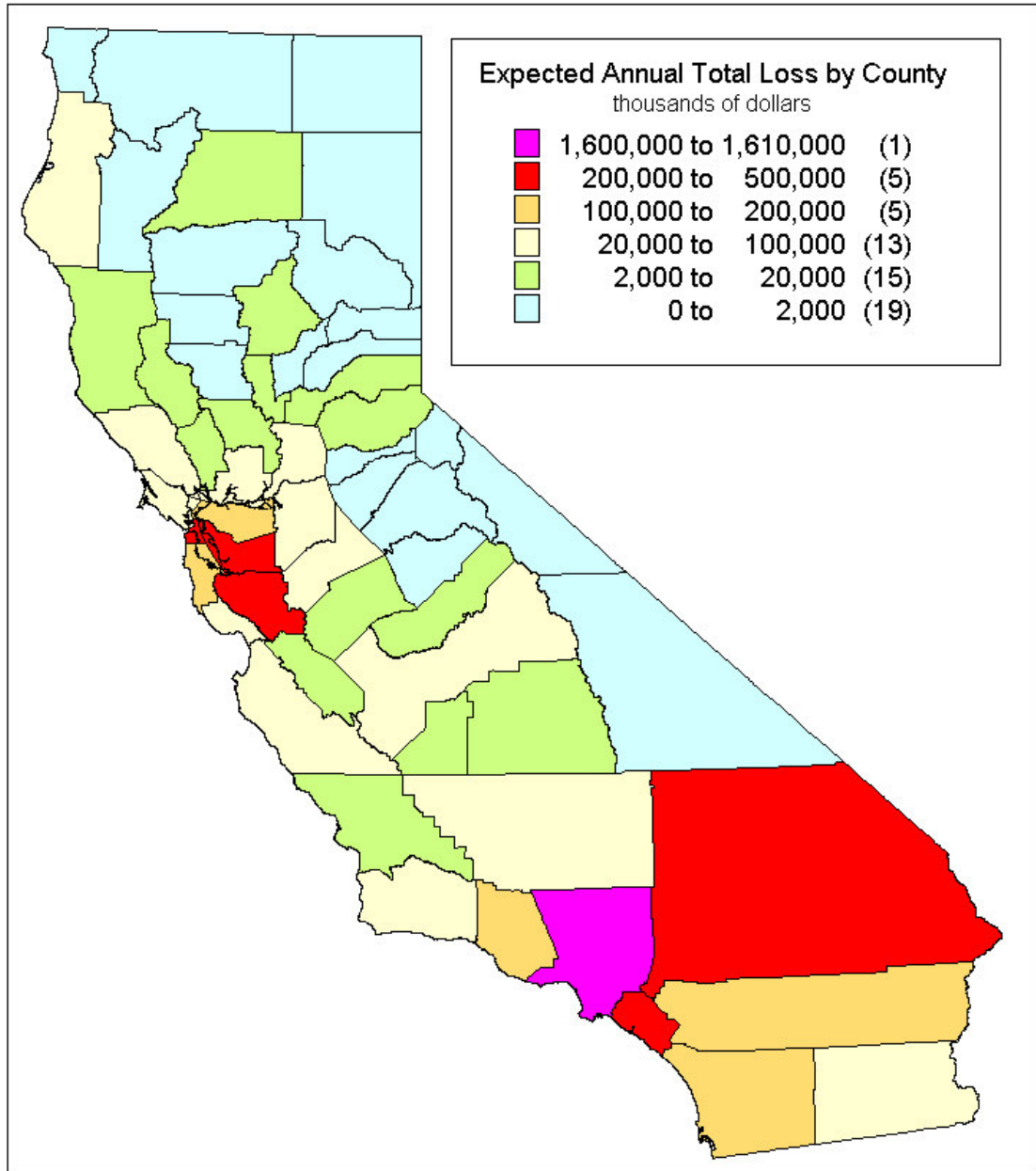


Figure 1: Annual Expected Loss by County

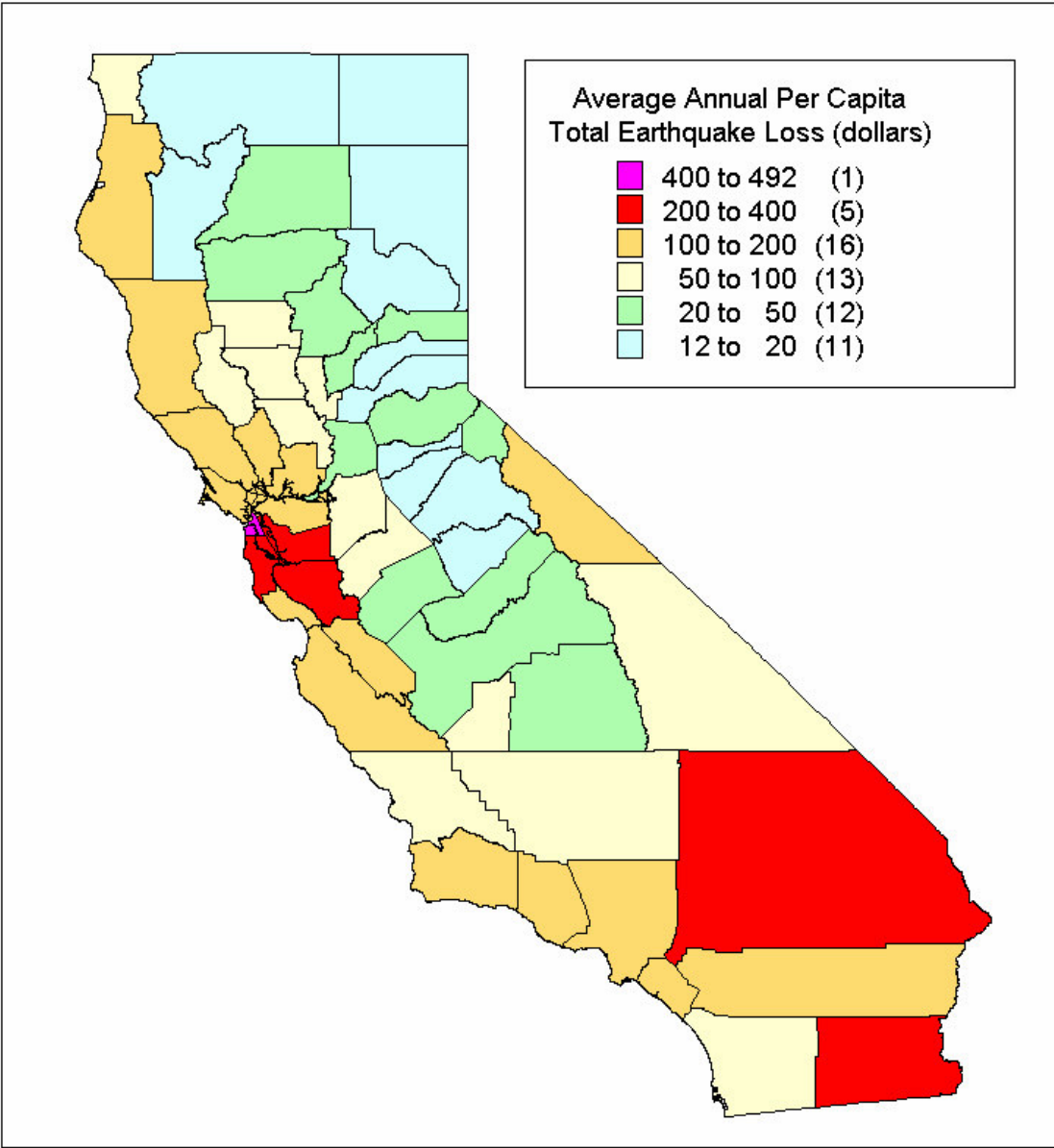


Figure 2: Per Capita Expected Annual Loss by County