Oregon earthquakes: Preliminary estimates of damage and loss

by Yumei Wang, Oregon Department of Geology and Mineral Industries

INTRODUCTION

Oregon is especially vulnerable to earthquake hazards because of its location on the Pacific "Ring of Fire" and its plate-tectonic setting. To better understand public needs that involve earthquake hazards and the health, safety, and welfare of the state's population, the Oregon Department of Geology and Mineral Industries (DOGAMI) has conducted earthquake damage and loss estimation studies for Oregon. Results from this study can be used to help increase earthquake awareness, stimulate mitigation and risk reduction action (e.g., strengthening facilities), support and set policies and legislation, and develop emergency response plans.

This paper reviews the modeling of estimated damage and losses for (1) a magnitude 8.5 (M8.5) subduction zone earthquake off the coast of Oregon and (2) 500-yr return interval probabilistic ground motions for the entire state. The two data sets included detailed geologic information contained in a statewide Uniform Building Code (UBC) soil map.

Results from the statewide estimates show that Oregon is unprepared for earthquake hazards. A large subduction zone earthquake will cause over ten billion dollars of building damage alone. Losses from the 500-yr ground motions are almost three times the amount of the subduction zone earthquake. Most of the damage costs are located in western Oregon, where the expected ground motions and population density are higher than in eastern Oregon.

BACKGROUND

Recent earthquakes have caused damage in Oregon, and future damaging earthquakes are inevitable. Damage and losses from recent worldwide earthquakes have devastated local communities due to the vulnerable developments in those areas. The earthquakes of Kobe, Japan (1995, M6.9); Northridge, California (1994, M6.7); and Loma Prieta, California (1989, M7.1), caused about 100, 42, and 10 billion dollars, respectively, in direct economic losses.

Oregon has numerous potential earthquake sources that can produce strong ground shaking and damage to the communities. The Cascadia subduction zone fault, which lies just offshore, can produce a M8.5 earthquake or perhaps even larger (Yamaguchi and others, 1997). Inland faults, such as the Mount Angel fault that triggered the M5.6 Scott Mills ("Spring Break") quake in 1993 and the West Klamath Lake fault zone that, during the same year, triggered the two Klamath Falls main shocks of magnitudes 5.9 and 6.0, are examples of crustal earthquake sources. About 30 and 10 million dollars in damage were inflicted by the Scotts Mills and Klamath Falls earthquakes, respectively. As a result of growing awareness of earthquake hazards in Oregon, steps are being taken to better understand and prepare for the threat of a large-magnitude Cascadia subduction zone earthquake as well as for inland earthquakes. The present study is one such example. Another example is that more stringent building code requirements have been adopted. In 1993, the Seismic Zone designation for western Oregon was raised from 2B to 3 in the Uniform Building Code (UBC); in October 1998, the central and south coast area was raised from Zone 3 to Zone 4.

Balancing the public safety benefits with limited funds can be more effective with a better understanding of the economics at stake, that is, the possible damage and losses. With these estimated losses, planners and policy makers have useful information to guide public policy issues to reduce future loss of life and property. Various interest groups can reduce the possible impact in specific areas by targeting information in the predicted damage and loss estimates. Although loss estimations have inherent uncertainties and limitations, the results can be viewed as important information. Both regional and local mitigation can be implemented based on these results. For example, this work may help formulate state legislation that focuses on improving the state's building inventory database and furthering the state's risk reduction efforts. Or, this work may help instigate or substantiate the seismic evaluation or strengthening of older school buildings in a local school district.

METHOD

The damage and loss estimates for future earthquake ground shaking were obtained using HAZUS97 software produced by the Federal Emergency Management Agency (FEMA) (National Institute of Building Sciences, 1997; Risk Management Solutions, Inc., 1997). HAZUS97 has recently become available to the public and operates through a geographic information system (GIS) to display earthquake hazard information, inventory data, and estimated losses in the form of both maps and tables. This software was developed through a cooperative agreement between FEMA and the National Institute of Building Sciences (NIBS). Risk Management Solutions, Inc., of Menlo Park, California, developed the software under the oversight of a panel of recognized experts in their respective fields. The software was calibrated with past earthquakes and pilot-tested in two communities in the nation, one of them Portland, Oregon The estimates discussed here are only samples of the possible types of damages and losses that can be modeled with this software.

The method involves modeling an earthquake source and attenuation relationships or ground motions, determining the damage based on fragility curves, which indicate the probable degree of damage, and then quantifying the losses on the basis of the inventory database. The procedure yields quantitative estimates of losses in terms of direct costs for repair and replacement of damaged buildings, direct costs associated with loss of function (e.g., loss of business revenue, relocation costs), casualties, displacement of people from residences, and removal of debris generated. In addition, functionality losses for emergency and essential facilities and components of transportation and utilities are quantified.

In HAZUS97, the ground motions are characterized by spectral response based on a standard spectrum shape, peak ground acceleration (PGA), and peak ground velocity (PGV). Elastic response spectra (5-percent damping) are used to characterize ground shaking. The spectra have the same standard shape defined by a PGA value at zero period, spectral response at a 0.3-second period in the acceleration domain, and spectral response at a 1.0-second period in the velocity domain. The shape is adjusted for site amplification and distance from the source to the site.

Building damage is estimated by applying fragility curves, capacity curves, building type, seismic design level, and ground response. Owing to the limited amount of building inventory data and the regional approach of this method, model groups of buildings (or population groups) are evaluated on a census tract basis. Single buildings at specific locations are not evaluated. The damage functions include (1) building fragility curves that describe the probability of reaching or exceeding different damage states at a given peak building response; and (2) building capacity ("pushover") curves that are used with damping-modified demand spectra to determine peak building response. The damage state probabilities are used as inputs to estimate induced physical damage and direct economic and social loss, such as casualties, monetary losses, and shelter needs. For this study, all buildings were placed at low seismic design level.

Loss estimates are based on (1) structural repair costs depending on extent of damage, model building types and occupancy classes; (2) nonstructural repair costs for all occupancy classes, both acceleration-sensitive damage (from the shock waves themselves) and drift-sensitive damage (from the structure's deformation in response to the shock waves); (3) value of building contents as a percentage of building replacement value for all occupancy classes; (4) contents damage as a function of damage state; (5) annual gross sales or production for agricultural, commercial, and industrial occupancy classes; (6) business inventory as a percentage of gross annual sales for agricultural, commercial and industrial occupancy classes; and (7) business inventory damage as a function of damage state for agricultural, commercial and industrial occupancy classes. A large amount of default economic data is included in the method to develop the direct economic losses.

Study region and source data

The study region is the state of Oregon, with a population of just over 3 million people. The highest population concentration is in the western part of the state, especially in the Willamette Valley.

HAZUS97 evaluates the study region by census tracts. Oregon has a total of 727 census tracts. HAZUS97 includes numerous databases from a variety of sources, including information on geography, demographics, economics, buildings, and lifelines. Demographics and residential buildings are obtained from the 1990 data of the United States Census Bureau. Nonresidential data, such as commercial and industrial structures, are obtained from 1995 reports by Dunn and Bradstreet. HAZUS97 estimates a total building exposure (i.e., replacement value, not market value) of about $160 billion for the state.

The soil map (see second map from top on cover illustration) includes the six soil categories defined in the 1997 Uniform Building Code (UBC) (Wang and others, 1998). UBC soil types were estimated on the basis of published digital regional geologic and agricultural soil maps, previously mapped material properties, and shear-wave velocities measured on the unit or similar units. In order to conduct the HAZUS97 analyses, soil profile type S_F (soil requiring site-specific evaluation) has been reclassified into type S_E (soft soil). Also, the soil map is modified within HAZUS97 to a census tract basis for analyses of most buildings.

Except for the soil data, this study has relied on the HAZUS97 default databases. Therefore, the results provide relative, not absolute, estimates of losses. Statistical uses, for example at the county level, are appropriate.

Earthquakes modeled

Two earthquake types were evaluated: (1) a (deterministic) M8.5 Cascadia subduction zone earthquake and (2) 500-yr return interval probabilistic bedrock ground motions.

M8.5 Cascadia earthquake

The M8.5 earthquake is produced by a rupture along the Cascadia margin that lies generally parallel to Oregon's coastline. The M8.5 model assumes a rupture length of 480 km and a hypocentral (or focal) depth of 10 km. The fault is modeled as a low-angle reverse (or thrust) fault with an equal bi-directional rupture pattern (i.e., a rupture extending equally in both directions from the center of the quake). For this model, we used the Project 97 Pacific Northwest attenuation relationship available in HAZUS97, which is based on earlier work by Frankel and others (1996). This relationship applies to rock sites and uses 50 percent each of (1) the attenuation curves for deep and subduction zone earthquakes by Youngs, Chiou, Silva and Humphrey (1997) and (2) the attenuation curves by Sadigh, Chang, Abrahamson, Chiou, and Power (1993). Attenuation ("lessening") relationships are used to calculate the peak ground acceleration (PGA) which decreases with distance from the earthquake.

After the PGA is calculated, deterministic ground motions (spectral responses) are calculated from algorithms stored in HAZUS97 relational databases. Those values are then amplified by factors based on local soil conditions as determined by the soil map described earlier. The ground motions in the general building damage analyses are computed at the centroid (the mathematical "middle") of a census tract.

Output ground motions for PGA (Figure 1), peak ground velocity (PGV), and spectral acceleration (S_A), spectral velocity (S_V), and spectral displacement (S_D) at periods of 0.3 and 1.0 seconds are provided on a census track basis. The maps include soil influence and thus represent motions at the ground surface.

500-yr return interval ground motions

The ground motions modeled are taken from the U.S. Geological Survey (USGS) earthquake ground motion hazard map with a 10-percent probability of exceedance in 50 years (Frankel and others, 1996; see cover illustration, second layer from bottom). This map represents single median ground motions for the region over the next 475-year period, commonly referred to as the "500-year" return interval. These probabilistic ground motions include peak ground acceleration (PGA), peak ground velocity (PGV), and spectral velocity (S_V) at 0.3 seconds and 1.0 seconds.

The USGS probabilistic maps, which were used as the basis for design value maps of the 1997 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (Building Seismic Safety Council, 1997), show the ground motion levels with specified probabilities of being exceeded in a 500-yr return interval. Ground shaking motions with a 500-yr return interval are equivalent to a 10-percent probability of being exceeded in 50 years or, in other terms, an annual frequency of exceedance of 0.002. The probabilistic approach incorporates all fault sources capable of generating earthquake ground shaking and includes earthquake wave propagation from the sources to include all areas

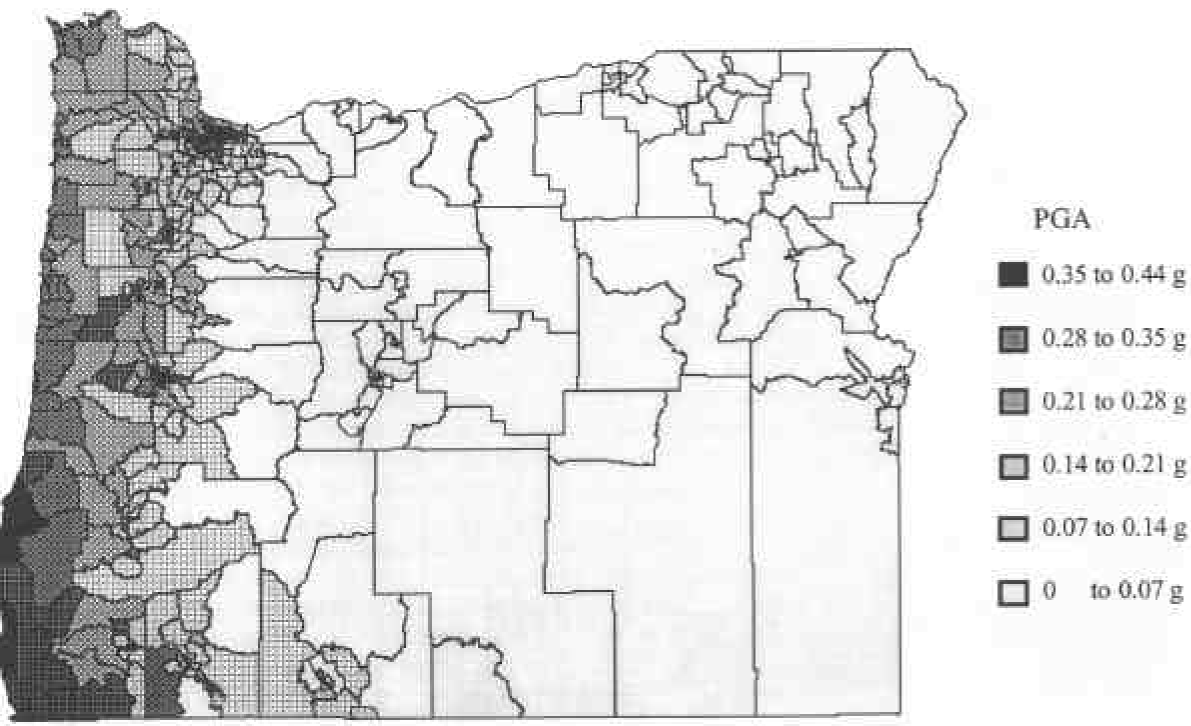


Figure 1. Peak ground acceleration (PGA) for M8.5 Cascadia subduction zone earthquake on census tract basis. Convention of yellow-to-red coloring for progression from least to most dangerous rendered here as light-to-dark shading.

of Oregon. Thus, for each given site, the ground motion levels (peak ground accelerations) for all the earthquake locations and magnitudes in the vicinity are represented. Probabilistic maps provide an equal representation of likelihood of various levels of ground motions across the state.

Output ground motions for PGA (Figure 2); PGV; and S_A, S_V and S_D at periods of 0.3 and 1.0 seconds are provided on a census track basis. These maps include soil influence and thus represent motions at the ground surface.

The damage and loss estimate from the 500-yr model does not represent a single earthquake occurrence nor does it provide an uppermost estimate of losses. This is because the 500-yr map does not represent a single earthquake event. Also, smaller earthquakes that produce lower levels of ground shaking and are not represented on the probabilistic map are expected to occur and produce additional damage and loss not estimated in this study. Thus, if all expected earthquakes were included, the cumulative losses over the next 500 years would be higher than the estimated losses reported in this study.

Discussion of method

From a user's standpoint, HAZUS97 is a powerful tool to assess earthquake losses. A user can obtain a sense of the order of magnitude of damage and loss for the items reported in Figures 3 and 4, such as casualties and building losses.

HAZUS97 has a number of limitations. A notable example of a limitation is that HAZUS97 evaluates most building losses on a census tract basis. However, many geologic hazards are not easily portrayed and represented by a single census tract value. Other geology-related limitation examples are, e.g., that user-supplied ground motion models are not able to incorporate user-specified soil maps and that certain specifics of fault ruptures, such as fault dip and oblique senses of motion, cannot be modeled.

One significant limitation is that the default inventory database is incomplete. Thus, the estimated losses are necessarily in error. For example, although there are numerous unreinforced masonry structures (URMs) in Oregon, the currently available default building database does not include any URMs. Thus, the reported damage and loss estimates may seriously under-represent the actual threat. In studies that incorporate URMs in the inventory, the death and injuries toll is likely to increase significantly due to the nature of catastrophic failure of URMs.

Other examples of incomplete building inventory involve schools and emergency facilities. A simple case study for Klamath County shows the default inventory

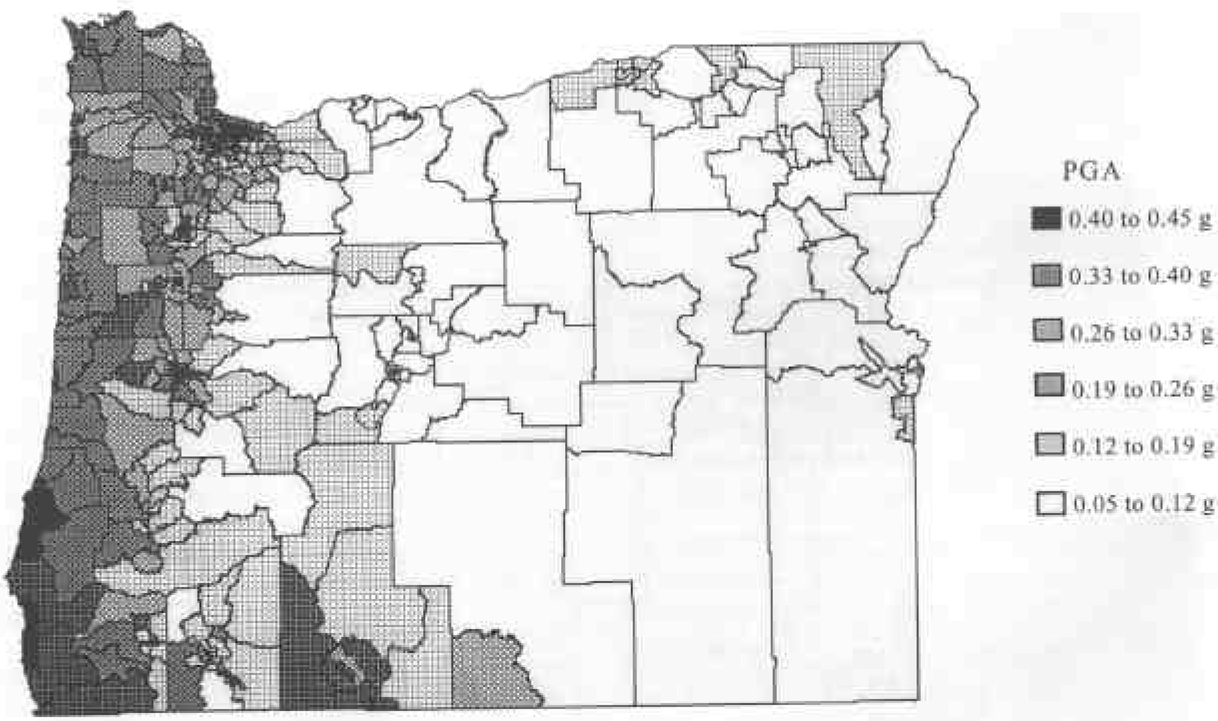


Figure 2. Peak ground acceleration (PGA) for 500-yr return interval ground motions on census tract basis. Convention of yellow-to-red coloring for progression from least to most dangerous rendered here as light-to-dark shading.

to have eight schools and five emergency facilities. The actual count is 34 schools and 35 emergency facilities (William Thompson, Klamath County Emergency Services, personal communication, 1998). For emergency facilities, a simple statewide assessment was made. The default database includes 438 emergency facilities, whereas the assessment shows 792. Thus, assuming the counts were approximated in a similar manner, the default database underestimated the emergency facility count by almost a factor of two. An underrepresentation of schools and emergency facilities could produce erroneously results, especially involving damage and functionality. The default lifeline inventory also appears to be seriously incomplete and requires user input to achieve a sense of damage and loss values.

HAZUS97 has several programming errors, which are being corrected in later versions. One example is obtaining a probability of 1 when summing the computed damage states for buildings by building type in the summary reports. Also, the summary reports, at times, failed to print the results from several counties. In addition, conducting successive runs without creating a new scenario is problematic in that previously calculated numbers are reported as the new calculations. A related problem seems to arise with the export function for individual study regions.

RESULTS

The statewide results from the two modeled earthquakes, the M8.5 Cascadia earthquake (referred to below briefly as "the M8.5") and the probabilistic 500-yr return interval ground motions (referred to below briefly as "the 500-yr") are summarized in Figures 3 and 4, respectively. Estimates include social losses (deaths and injuries, displaced households, short-term shelter needs) (Figures 3a and 4a), monetary building losses (Figures 3b and 4b) and number of buildings damaged (Figures 3c and 4c). Also discussed below are the functionality of emergency facilities, schools, transportation systems (highway and airport economic loss and bridges damage state and functionality), and communication facilities; and the debris generated.

The method used generates estimated loss results for both the direct physical damage and the direct economic loss resulting from damage to the inventory in the study region. Damage and loss results are reported for each census tract and may be viewed as maps or tables produced by HAZUS97. Additional information from this study, such as summary tables on a county basis, ground motion maps, and other information that is not discussed in this text can be found in Wang (1998). Certain results from the 500-yr ground motion model are not provided here, because they are not appropriately applied to real-world conditions: they cannot be experienced in a single event. Thus, for example, the functionality of schools, emergency facilities, transportation systems, and the like is not reported for the probabilistic model.

Social losses

Social losses including casualties, displaced households, and short-term shelter needs are reported below. The census data are used to help estimate these losses.

Deaths and injuries

Deaths and injuries are estimated at 7,700 and 24,600 for the M8.5 and 500-yr, respectively (Figures 3a and 4a). These values are divided into four severity levels: Severity 1 is described as "Injuries requiring only basic medical aid but no hospitalization"; severity 2 is described as "Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life-threatening status"; severity 3 is described as "Injuries that pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are a result of structural collapse and subsequent collapse [trapping -*ed.*] or impairment of the occupants." Severity 4 is described as "Instantaneously killed or mortally injured."

For the M8.5, about 6,300 are estimated at severity 1; 1,200 at severity 2; 200 at severity 3, and 100 at severity 4. For the 500-yr, about 19,700 are estimated at severity 1; 3,800 at severity 2; 600 at severity 3; and 500 at severity 4.

For both models, estimated casualties are highest for a 2 p.m. earthquake. These casualties can be attributed mostly to damages of commercial and industrial buildings. The number of casualties varies depending upon time of day of the earthquake, building type, occupancy class, and traffic pattern. Casualties in residential buildings are higher at 2 a.m. and 5 p.m. earthquake events.

Displaced households

The displaced households are estimated at 17,300 and 47,400 for the M8.5 and 500-yr, respectively (Figures 3a and 4a).

Short-term shelter needs

The short-term shelter needs are estimated at 12,400 and 32,700 for the M8.5 and 500-yr, respectively (Figures 3a and 4a).

Buildings

Building damage

States of structural and acceleration-sensitive and drift-sensitive nonstructural damage to the general building stock are generated for each occupancy class and for each building type according to five damage states: None, Slight, Moderate, Extensive, and Complete. Reported values include: (1) building damage by count by general occupancy, (2) building damage by general occupancy, and (3) building damage by building types for low seismic design level.

(1) *Building damage by count by occupancy class.* For the M8.5, the building damage by count of buildings is estimated at 717,000, 130,000, 75,000, 35,000, and 19,000 for damage states None, Slight, Moderate, Extensive, and Complete, respectively. From these damage state results, about 885,000 buildings are estimated to be green-tagged (i.e., the building has been inspected, and there are no restriction on use or occupancy), 55,000 are estimated to be yellow-tagged (i.e., off limits to unauthorized personnel), and 37,000 are estimated to be red-agged (i.e., unsafe, not to be entered or occupied) (Figure 3b).

For the 500-yr, the building damage by count of buildings is estimated at 425,000, 253,000, 182,000, 75,000, and 41,000 for damage states None, Slight, Moderate, Extensive, and Complete, respectively. From these results, about 769,000 buildings are estimated to be green-tagged, 129,000 are estimated to be yellow-tagged, and 79,000 are estimated to be red-tagged (Figure 4b).

(2) *Building damage by percent by occupancy class.* For the M8.5, building damage by general occupancy is estimated at 51, 11, 13, 9, and 5 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively. For the 500-yr, building damage by general occupancy is estimated at 24, 13, 19, 18, and 16 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively.

(3) *Building damage by percent by building type.* For the M8.5, the building damage by building types assuming low seismic design levels for all buildings were estimated at 41, 10, 15, 12, and 7 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively. For the 500-yr, the building damage by building types assuming low design levels for all buildings were estimated at 18, 10, 19, 20, and 19 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively.

Direct economic losses to buildings

The total direct economic losses to buildings are estimated at $11.8 and $31.6 billion for the M8.5 and 500-yr, respectively. These losses include both capital stock losses and income losses.

For the M8.5, capital stock losses are $2.03 billion for structural damage, $4.31 billion for nonstructural damage, $0.95 billion for contents, and $0.03 billion for inventory damage. Income losses are $1.21 billion for relocation, $1.35 billion for capital-related loss, $1.20 billion for wages, and $0.73 billion for rental income (Figure 3c).

For the 500-yr, capital stock losses are $5.05 billion for structural damage, $12.22 billion for nonstructural damage, $2.76 billion for contents, and $0.06 billion for inventory damage. Income losses are $3.04 billion for relocation, $3.76 billion for capital-related loss, $2.94 billion for wages, and $1.80 billion for rental income (Figure 4c).

Essential facilities

In HAZUS97, police stations, fire stations, and emergency operation centers are considered to be essential facilities. These are facilities that provide services to the community and should be functional after an earthquake.

The functionality of emergency facilities and schools is estimated for the day following the earthquake. For the M8.5, functionality of 65 percent for emergency facilities and 66 percent for schools is estimated. As mentioned above, because the 500-yr ground motions cannot be experienced in a single event, the functionality of essential facilities for the entire state is not reported.

Transportation

Transportation include highway, railway, light rail, bus, port, ferry, and airport systems. Selected results are provided for highways, including major and urban roadways and bridges; airports, which consists of control towers, runaways, terminal buildings, parking structures, fuel facilities, and maintenance and hangar facilities; and bridges.

Direct economic loss for transportation

For the M8.5, the direct economic loss is estimated at $0.37 billion for highways and $0.12 billion for airports. For the 500-yr, the direct economic loss is estimated at $1.26 billion for highways and $0.32 billion for airports.

Damage states and functionality for bridges

For the M8.5, the highway bridge damage is estimated at 67, 21, 9, 1, and 7 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively. The estimated functionality on the day of the earthquake is 72 percent. For the 500-yr, the highway bridge damage is estimated at 31, 32, 26, 4, and 6 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively.

Utilities

Utility systems include potable water, wastewater, oil, natural gas, electric power, and communication systems. Results are provided for the communication systems, which consist of broadcasting stations from the default inventory. For the M8.5, the estimated functionality for communication systems is 71 percent.

Debris

The total amount of debris generated is estimated for the M8.5 at 9.3 million tons and for the 500-yr at 23.3

(Continued on page 131)

Figure 3. Cascadia M 8.5 damage and loss estimates: (a) Social losses for individuals and households. (b) Number of buildings by damage tags: green tag = building has been inspected, no restrictions on use or occupancy; yellow tag = off limits to unauthorized personnel; red tag = unsafe, not to be entered or occupied. (c) Direct economic losses to buildings.

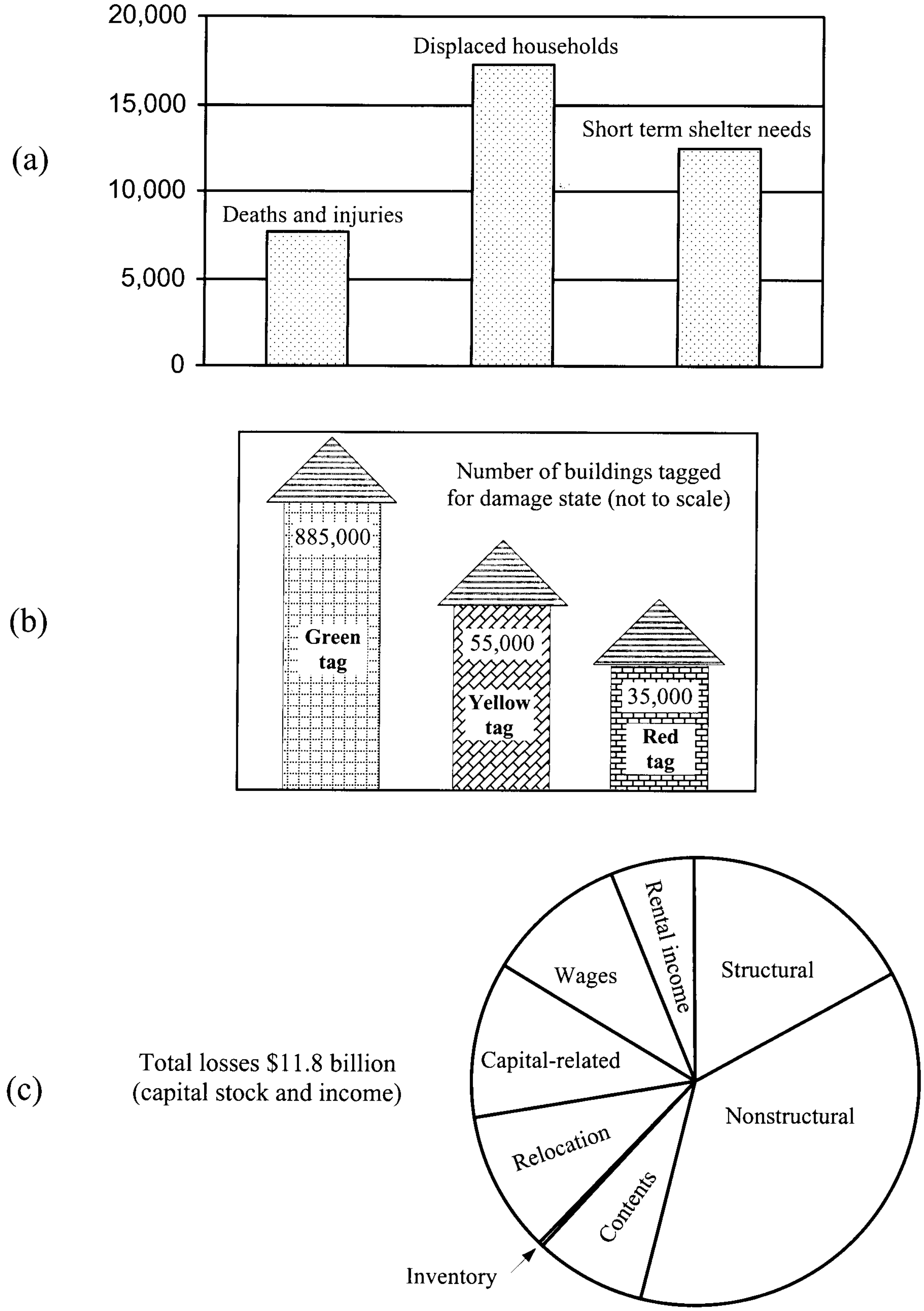
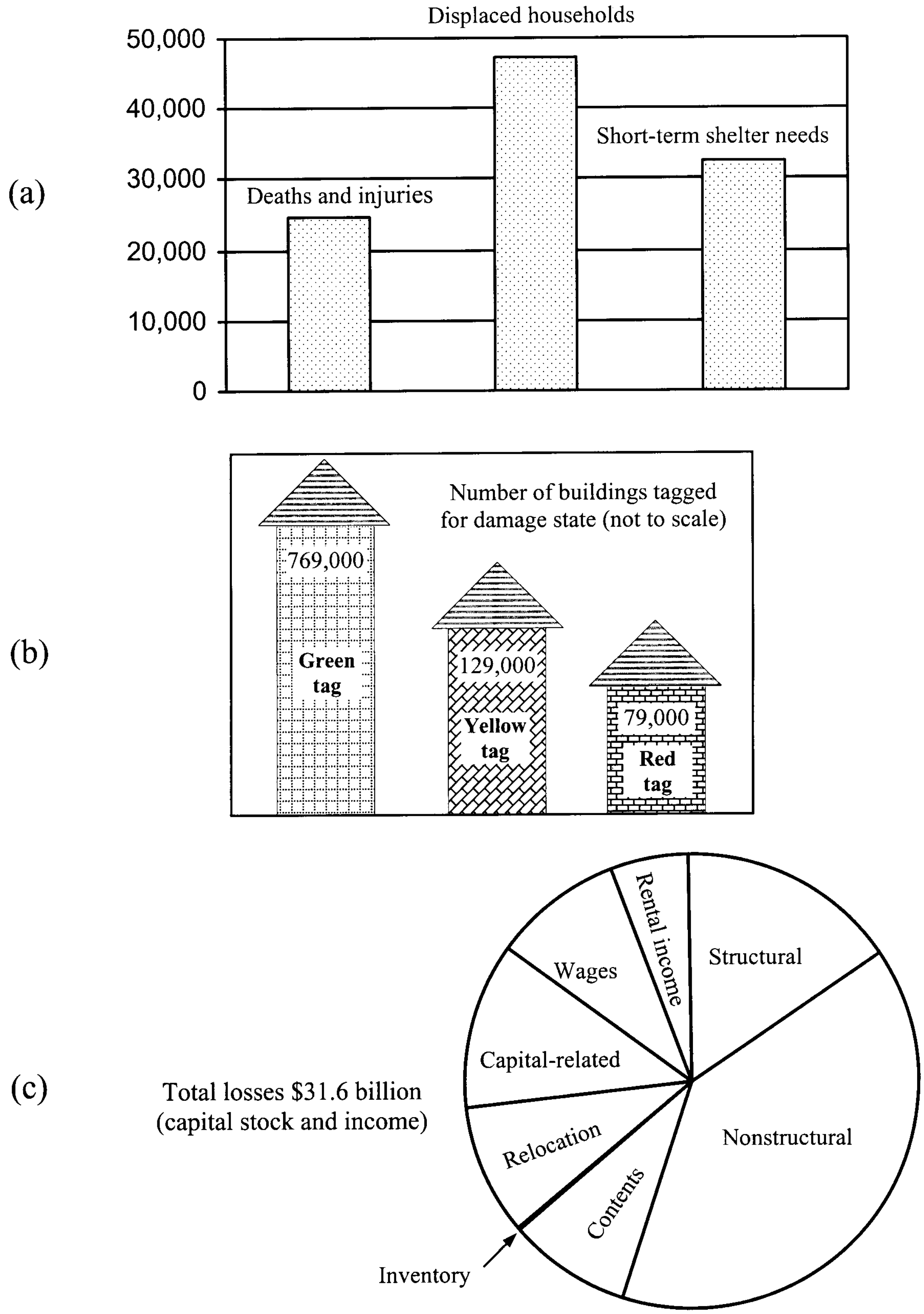


Figure 4. 500-year return interval damage and loss estimates: (a) Social losses for individuals and households. (b) Number of buildings by damage tags: green tag = building has been inspected, no restrictions on use or occupancy; yellow tag = off limits to unauthorized personnel; red tag = unsafe, not to be entered or occupied. (c) Direct economic losses to buildings.



(Continued from page 128)
million tons. The debris is categorized under two types: The first type of debris is easily movable with bulldozers and includes brick, wood, glass, building contents, and other materials. The second type of debris falls in large pieces, such as steel members or reinforced concrete elements.

SUMMARY

The preliminary results from this study suggest that there is a serious risk in Oregon from both a M8.5 Cascadia event and 500-yr probabilistic ground motions. Studies of the M8.5 event indicate that over 10 billion dollars of building damage and about 7,000 casualties or more will be inflicted. The 500-yr ground motion studies indicate losses of more than 30 billion dollars, which is considerably higher than the M8.5 model. The 500-yr study produces higher losses because the modeled hazards span the entire state (i.e., offshore subduction zone and local inland earthquakes). Results from this study can be used to help increase earthquake awareness, stimulate mitigation and risk reduction action (e.g., strengthening facilities), support and set policies and legislation, and develop emergency response plans.

FUTURE STUDIES

Future studies for Oregon may involve evaluating additional earthquake scenarios, specialized hazards (e.g., tsunami inundation, liquefaction, and slope stability), and expanded inventory data and focused study regions, such as counties. Inventory data may include unreinforced masonry structures, which are currently not included in the default database, or a more accurate inventory of schools or emergency facilities. Development of a more complete inventory would provide more accurate inventory damage and loss estimates.

ACKNOWLEDGMENTS

Special thanks are extended to Stuart Nishenko of FEMA and Jawhar Bouabid of Risk Management Solutions, Inc., for their thoughtful reviews. My sincere appreciation goes to John D. Beaulieu of DOGAMI and William M. Elliott of the City of Portland for their support of this study. Thanks also to Klaus Neuendorf and Neva Beck for their assistance in producing this paper. Research was supported by State of Oregon funds.

REFERENCES

Building Seismic Safety Council, 1997, NEHRP recommended provisions for seismic regulations for new buildings and other structures, 1997 ed.: Washington, D.C., Federal Emergency Management Agency Publications FEMA 302 (Part 1–Provisions), 337 p. and FEMA 303 (Part 2–Commentary), 362 p., 32 maps.

Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M., 1996, National Seismic Hazard Maps; documentation, June 1966: U.S. Geological Survey Open-File Report 96-532, 110 p. See also Internet website at http://geohazards.cr.usgs.gov/eq/

National Institute of Building Sciences, 1997, HAZUS: Earthquake loss estimation methodology, technical manual (prepared for Federal Emergency Management Agency): Washington, D.C., NIBS Document 5201, 3 vols., var. pag.

Risk Management Solutions, Inc., 1997, HAZUS97: Earthquake loss estimation methodology, user's manual (prepared for National Institute of Building Sciences under a cooperative agreement with the Federal Emergency Management Agency): Washington D.C., NIBS Document 5200, var. pag.

Sadigh, K., Chang, C.-Y., Abrahamson, N.A., Chiou, S.J., and Power, M.S., 1993, Specification of long-period ground motions: Updated attenuation relationships for rock site conditions and adjustment factors for near-fault effects, *in* Proceedings of ATC-17-1 Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control: Redwood City, Calif., Applied Technology Council, p. 59–70.

Wang, Y., 1998, Earthquake damage and loss estimate for Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–98–3.

Wang, Y., Weldon, R., and Fletcher, D., 1998, Creating a map of Oregon UBC soils: Oregon Geology, v. 60, no 4. p. 75–80.

Whitman, R.V., Anagnos, T., Kircher, C.A., Lagorio, H.J., Lawson, R.S., and Schneider, P., 1997, Development of a national earthquake loss estimation methodology: Earthquake Spectra, v. 13, no. 4, p. 643–661.

Yamaguchi, D.K., Atwater, B.F., Bunker, D.E., Benson, B.E., and Reid, M.S., 1997, Tree-ring dating the 1700 Cascadia earthquake: Nature, v. 389, p. 922–923.

Youngs, R.R., Chiou, S.-J., Silva, W.J., and Humphrey, J.R., 1997, Strong ground motion attenuation relationships for subduction zone earthquakes: Seismological Research Letters, v. 68, no. 1, p. 58–73. □

Hells Canyon subject of new book

Islands & Rapids. A geologic story of Hells Canyon, is an exciting new book by retired U.S. Geological Survey geologist Tracy Vallier. It is published by Confluence Press, Lewis-Clark State College, Lewiston, Idaho.

Vallier's book tells the geologic history of the region but also serves as a field guide and entertains the reader with natural and human history and the author's own reminiscences. It has four maps and many photographs.

The book sells for $25 and can be purchased from the Nature of the Northwest Information Center. See back cover of this issue for ordering information. □