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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: U.S. Geological Survey Workshop on Probabilistic Hazard and Risk Assessment in the Earth Sciences (20.01402.461—Expenses paid by USGS)

DATE/PLACE: November 16–17, 1999, U.S. Geological Survey, Golden, Colorado

AUTHOR: Charles B. Connor

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AUTHOR: Charles B. Connor

PERSONS PRESENT: Chuck Connor (CNWRA), Ute Dymon (Kent State University), Bill Roberds (Golder Associates), Allen Bradley (University of Iowa), Manu Lall (Utah State University and Columbia University), Daniel O'Connell (U.S. Bureau of Reclamation), and 14 USGS scientists from Water Resources (WRD) and Geologic Divisions (GD)

BACKGROUND AND PURPOSE OF TRIP:

The goal of this workshop was to bring together experts in probabilistic hazard and risk assessment for earthquakes, floods, landslides, volcanoes, increase awareness of the tools used to assess hazard and risk across discipline, and determine if a common framework for assessing risks from different hazards can be developed. The Center for Nuclear Waste Regulatory Analyses (CNWRA) staff attended primarily to assess how the volcanic hazard models for the proposed high-level radioactive waste repository at Yucca Mountain, developed at the CNWRA, compare with hazard models developed in other disciplines by the U.S. Geological Survey (USGS) and related organizations. In addition, the meeting provided an excellent opportunity to learn more about the state-of-the-art in seismic hazard assessment, flooding, and landslides. Skip Vecchia (WRD) chaired the meeting. Vecchia outlined several specific objectives, including:

- Improve communication between experts in geologic hazards assessment
- Describe current state-of-the-art
- Consider how analyses can become more consistent across discipline
- Develop recommendations for future USGS policy
- Produce a publication of short papers summarizing the state-of-the-art in hazards assessment at a level accessible to nonexperts

Vecchia also posed a series of questions at the outset of the meeting:

- What probability models are most appropriate (e.g., when and how should extreme events be considered)?
- What are the best or most appropriate temporal models?
- What are the best or most appropriate spatial models?
- What is the best or most appropriate way to portray natural and model uncertainty?
- What can we do to improve communication of hazard and risk?

Joesph Jones (WRD) indicated that the meeting is part of an initiative to better understand and mitigate hazards in the Tacoma, Washington area, where numerous natural hazards must be managed. This is a five year initiative within the USGS to perform a cross disciplinary hazard analysis. The initiative grew out of the realization that local governments must contend with myriad hazard and risk assessments and that in general there is resistance to cross-discipline attempts to clarify hazard and risk assessments.

The meeting was divided into two parts. First, 14 speakers presented their abstracts summarizing the state-of-the-art in hazards assessment in their disciplines. Abstracts of these talks are attached. Second, roundtable discussions were held to discuss commonality and important differences in approach to hazard assessment. Abstracts from the meeting presentations are attached.

SUMMARY OF PERTINENT POINTS:

Three speakers summarized flood hazard in engineering practice. Allan Bradley (University of Iowa) summarized temporal models in flood assessment. He indicated that many of the methods have been used for more than 50 yr and that it is often difficult to revise methods of hazard and risk assessment in floods because these methods have become standard for estimating insurance tables and developing policy. Bradley discussed probability models for flood magnitude, focusing on peak of the flood event, and peak-over-threshold models. Alternatively, the largest event in a given year is used to develop time series. Exceedance probability is then estimated using statistical fits to these series, such as Weibull and log-Pierson Type III models. Basically, nonhomogeneous Poisson models are used because of seasonality in the time series. At ungauged sites, several approaches are used to estimate time series, including regional flood frequency and rainfall-runoff approaches. Design storms, leading to design floods, are then developed for some return period, such as 100 yr. Significant problems have emerged with this approach related to how to treat extreme events. Bradley described difficulty in forecasting flood impact on dams and nuclear power plants. Furthermore, nonstationary in time series is increasingly an issue, due to change in climate and change in land use.

Brent Troutman (WRD) discussed floods as spatial processes. Troutman discussed spatial characterization of floods in terms of a marginal density function Q(x), where x is a point and Q(x) is a regionalized measure of flood magnitude, perhaps peak-over-threshold. Two methods are used to estimate Q(x). The first defines an index flood, where Q(x) is marginalized by "total" drainage area only. A second method commonly used is a quantile regression approach, in which several basin characteristics (i.e., parameters) are estimated by regression. Both methods are in use today and both suffer serious shortcomings. For example, parameters may vary significantly within large basins, and both do not characterize extreme floods in large basins adequately. Physical models of stream flow, precipitation, and runoff are not in widespread use for long-term flood frequency estimation. The index flood model was introduced in volcanology by Iverson et al. (1998, Geological Society of America Bulletin vol. 110) to model lahars on Cascade volcanoes, where parameters are estimated from past lahars characteristics and digital elevation models.

Upmanu Lall (Utah State University / Columbia University) suggested that it is inappropriate to parameterize flood processes. He prefers to model flood frequency using nonparametric models that depend on nonlinear dynamics of climate. Lall argued that flood frequencies are a reflection of a highly nonlinear system that freely oscillates, in the sense that climate, and therefore precipitation and flooding, change mode without external forcing. As an example, Lall presented climate models in which 40 yr duration El Nino Southern Oscillations occurred. He illustrated that such an event would dramatically change flood frequency in North America. Lall concluded that there is little use for frequency estimates solely based on historical flood gauge data and illustrated this point by the high frequency of "one hundred year" floods in the United States during the last decade. Lall also argues that natural variation in flood frequency and extreme events are only understood by recognizing and modeling the underlying physical processes. Essentially, the best we can do in temporal probability estimates is diagnose nonstationary in flood frequency relative to slow climate mode changes.

Three talks on landslides were given. William Roberds (Golder Associates) gave a very general talk on methods of parameterizing landslide likelihood and the economics of mitigation. Rich Bernkopf (USGS) discussed cost-benefit analyses for landslide mitigation using a binary statistical regression. Bernkopf illustrated his talk with a development of a hazard and risk assessment, hindcasting the Loma Prieta earthquake and resulting damage. This was accomplished using ArcInfo and insurance company data bases. Essentially, Bernkopf argued for the use of conditional probability density functions for analysis of risk, and casting results in economic terms using the Utility function. Randy Jibson (USGS) analyzed the distribution of 11,000 landslides that followed the 1994 Northridge earthquake. Based on these data, Jibson developed a Weibull distribution failure model, depending on dynamic slope stability and earthquake shaking intensity. These reduce to a single parameter: Newmark's displacement parameter. There was a lot of discussion about whether parameters estimated using this technique following the Northridge earthquake could then be used to estimate future likelihood of failure on the same slopes.

Art Frankel and colleagues gave a general overview of the USGS national seismic hazard maps and associated products. The seismic hazard maps are derived from three components. Spatially smoothed historical earthquake data sets are the first component. The smoothing of the maps is done using an arbitrary (eye-balled) smoothing parameter, although Frankel gave the impression that other techniques were used as well. Second a regional background area is defined in which the probability of seismic hazards is set at some low value. Third, hazards are estimated based on specific faults. Probabilities based on these three maps were summed and normalized. Basically, this approach is entirely empirical. Much discussion about the national seismic hazard maps focused on identifying who they are for. Frankel indicated that they are for civil engineers for use in building construction, rather than general risk assessment. For this reason, the maps depict peak horizontal ground accelerations and spectral response. If the maps were designed for general risk assessment and hazard mitigation, they might also depict the probability of ground acceleration reaching a particular level, but they do not.

Three talks were given related to volcanology. Connor presented an overview of methods in volcanic hazard assessment, largely developed as part of NRC work. Uncertainty exists in forecasts of eruption timing, magnitude, and consequences. It is critical to express this uncertainty in probabilistic volcanic hazard assessments. There are numerous approaches to illustrating uncertainty, but two which are particularly successful are hazard curves, which show the likelihood a given event will exceed a given magnitude, and hazard maps, which contour hazards. Probabilistic volcanic hazards assessments utilize data from geologic studies, numerical simulations and monitoring activities. For example, a tephra hazard curve for the city of Leon, Nicaragua, illustrates the probability of tephra accumulation to a given thickness, facilitating disaster planning. Hazards can be represented as annual probability, conditional probability, or screening distance value. Annual probabilities include the likelihood of a volcanic eruption within a given year, and the range of consequences of volcanic eruptions, such as the amount of tephra that might accumulate in a particular area. Conditional probabilities assume, for instance, that the likelihood of a volcanic eruption is unity. Thus, the probable consequences of an eruption may be evaluated independently, and cast as a probability tree. Screening distance values are worst case scenarios that bound the upper limit of potential consequences of volcanic activity based on reasonable, conservative assumptions.

Manuel Nathenson (USGS) discussed temporal forecasting methods based on the Weibull distribution and mixed exponential distributions without reference to physical models. Roger Delinger present his work on development of lahar hazard models using numerical simulation of lahars, coupled to parameter estimation techniques similar to simulated annealing methods. Delinger suggested that these techniques are appropriate for modeling lahars and related phenomena at Mt. Rainier, but this modeling is not yet completed.

In addition to these discipline-specific talks, Dan McConnell (U.S. Bureau of Reclamation) and Ute Dyman presented overviews of needs in hazard assessment. McConnell reiterated the need for physical models that accurately portray geologic processes in hazard assessment. Dymon discussed the basic elements that should be present in hazard maps and her previous work in formulating evacuation plans for nuclear facilities.

SUMMARY OF DISCUSSIONS:

As the presentations ran long, discussions were somewhat limited. Discussions focused on commonalities. Everyone agreed that physical bases for probability models are of fundamental importance and that temporal probability models that ignore the underlying physical processes are insufficient. It was agreed that spatial probability models can be standardized. As a whole, the group felt that the greatest commonalities between the hazard disciplines were in volcanology and floods, because of the similarity of issues related to lahars. It was noted that floods and seismology had developed similar methods for addressing long-term recurrence and that these methods are now mature. It was felt that earthquakes and floods have the least in common in terms of spatial probabilistic assessments. The group concluded that the seismologists were doing the best job of communicating hazards assessments and making static probability estimates. The group concluded that volcanologists are doing the best job of dynamic hazards assessment, in the sense that hazard and risk assessment is updated during periods of volcanic unrest.

IMPRESSIONS/CONCLUSIONS

The meeting was successful in bringing together people from across disciplines to discuss methods in hazard assessment. The group did not make much headway in addressing the general questions and concerns outlined by Vecchia at the outset of the meeting. It is clear that CNWRA methods in volcanic hazard assessment are comparable to techniques developed in flood, earthquake, and landslide mitigation, and outpace some of the techniques currently used in these disciplines.

PROBLEMS ENCOUNTERED

None

PENDING ACTIONS:

Connor will contribute a short (5–8 page) paper on probabilistic volcanic hazards assessment. Connor also agreed to contribute to Ute Dymon's paper, which will discuss the necessary components of hazard maps.

SIGNATURES:

B. C

Charles B. Connor

11/22/99

Date

CONCURRENCE SIGNATURE AND DATE:

H Lawrence McKague

H. Lawrence McKague
Manager, Geology and Geophysics

11/22/99

Date

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Budhi Sagar
Technical Director

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Date

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Workshop on Probabilistic Risk Assessment for Earthquakes, Floods, Landslides, and Volcanoes

November 16-17, 1999

U.S. Geological Survey Building
Colorado School of Mines Campus
1711 Illinois Street
Golden, Colorado

Sponsored by the U.S. Geological Survey Urban Hazards Initiative

Purpose

The purpose of this workshop is to bring together experts in probabilistic hazard and risk assessment for earthquakes, floods, landslides, and volcanoes, increase awareness of the tools used to assess risk across the different hazards, and determine if a common framework for assessing risk from the different hazards can be developed.

Participants

Organizer

Skip Vecchia, U.S. Geological Survey, Bismarck, North Dakota

Speakers

William Bakun, U.S. Geological Survey, Menlo Park, California
Richard Bernknopf, U.S. Geological Survey, Menlo Park, California
A. Allen Bradley, University of Iowa, Iowa City, Iowa
Chuck Connor, Southwest Research Institute, San Antonio, Texas
Roger Denlinger, U.S. Geological Survey, Vancouver, Washington
Art Frankel, U.S. Geological Survey, Golden, Colorado
Randy Jibson, U.S. Geological Survey, Golden, Colorado
Upmanu Lall, Utah State University, Logan, Utah
Manuel Nathenson, U.S. Geological Survey, Menlo Park, California
Daniel O'Connell, U.S. Bureau of Reclamation, Lakewood, Colorado
David Perkins, U.S. Geological Survey, Golden, Colorado
William Roberds, Golder Associates, Redmond, Washington
Brent Troutman, U.S. Geological Survey, Lakewood, Colorado
Rob Wesson, U.S. Geological Survey, Golden, Colorado

Guests

Joseph Jones, U.S. Geological Survey, Tacoma, Washington
Ute Dymon, Kent State University, Kent, Ohio
Harry McWreath, U.S. Geological Survey, Reston, Virginia

Schedule

Tuesday, November 16, 1999

8:00 – 8:30 Welcome, Introductions, Opening Remarks
- Skip Vecchia and Joseph Jones

8:30 – 10:00 Flood Risk Assessment

"Flood Hazard Assessment in Engineering Practice"
A. Allen Bradley

"Characteristics of Floods as a Spatial Process"
Brent Troutman

"Low Frequency Climate Variability and Changing Flood Risk"
Upmanu Lall

10:00 – 10:15 Break

10:15 – 11:45 Landslide Risk Assessment

"Landslide Risk Assessment: An Overview"
William Roberds

"Stochastic Landslide Forecasting Models: Case Studies in Policy Analysis"
Richard Bernknopf

"A Modeling Procedure to Produce Probabilistic Seismic Landslide Hazard Maps"
Randy Jibson

11:45 – 1:00 Lunch

1:00 – 2:30 Earthquake Risk Assessment

"USGS National Seismic Hazard Maps and Associated Products"
Art Frankel
David Perkins

"Spatial Correlation of Earthquake Hazard and Loss"
Rob Wesson

"Earthquake Probabilities in the San Francisco Bay Area"
William Bakun and David Schwartz

2:30 – 2:45	Break
2:45 – 4:15	Volcano Risk Assessment "State-of-the-Art-and-Science in Probabilistic Volcanic Hazard Assessment" Chuck Connor "Probabilities of Volcanic Eruptions and Applications Involving Recent USGS Hazard Assessments" Manuel Nathenson "Robust Estimates of Debris Flow Hazards on Volcanoes" Roger Denlinger and Daniel O'Connell
4:15 – 4:30	"Obstacles on the Road to Consistent Hazard Assessment" Daniel O'Connell
4:30 – 5:00	Discussion of the "Big Picture" and Formation of Workgroups Skip Vecchia

Wednesday, November 17, 1999

8:00 – 9:00	Workgroups meet individually to discuss similarities and contrasts between specialty areas
9:00 – 9:45	Workgroups summarize findings from individual meetings
9:45 – 10:00	Break
10:00 – 11:30	Further discussion, develop overall recommendations and findings of the workshop, outline format of proceedings
11:30	Adjourn

Topic: Flood Hazard Assessment in Engineering Practice

A. Allen Bradley
Iowa Institute of Hydraulic Research, University of Iowa, Iowa City, Iowa

Flood hazard assessment using probabilistic methods is the basis for many planning and design decisions, including the management of land in flood prone areas (e.g., the 100-year floodplain) and the design of hydraulic structures (e.g., levees). The concepts used in probability-based flood design are based on traditional probabilistic models of floods, which assume that floods are generated by a random stationary process. This presentation describes the probability models commonly-used to describe flood magnitudes. Although there has been considerable debate in the literature over the choice of probability distributions and the estimation of parameters from flow records, a standard statistical method for flood quantile estimation is routinely used for engineering design within the United States. Still, the majority of problems of practical importance require estimates of the changes in flood quantiles associated with land use modifications (urbanization) or flow regulation (by flood control reservoirs). Streamflow measurements are seldom available at these sites for statistical analysis; even if they were, nonstationarity due to changes in the underlying flood distribution would make past observations inconsistent with future conditions (for which the predictions are needed). This presentation also describes some of the common rainfall-runoff based approaches used for flood hazard assessment, and approaches for estimating the upper bound to flood discharges needed for the design of high-hazard structures.

Characteristics of floods as a spatial process

Brent Troutman

River flow extremes constitute a complex random process in both space and time. In this presentation, some basic characteristics of flood flows considered as a spatial process are reviewed and discussed. Of particular interest are both marginal and joint distributional properties of annual peak flows at a collection of points in some large region. Two widely used regionalization methods for modeling the dependence of the marginal distribution of annual flood peaks on drainage area -- the index-flood method and regional quantile regression -- are compared. In addition, problems associated with characterizing spatial correlation of flows are discussed, and generalized least squares as used by USGS to account for spatial correlation in quantile regression is briefly introduced. Finally the problem of estimating regional flood probabilities, with the goal of assessing frequency of occurrence of flow extremes somewhere in a large region, is discussed. Examples are presented showing how storm rainfall and network properties affect this frequency, and how this frequency may be estimated using annual peak flow data.

Abstract: Low frequency climate variability and changing flood risk

Upmanu Lall

Flood frequency analysis, as traditionally practiced, is marked by an assumption that annual maximum floods conform to a stationary, independent, identically distributed random process. These assumptions are at odds with the growing recognition that low frequency climate variations such as the El Nino Southern Oscillation systematically change the probabilities of seasonal and extreme daily rainfall, and hence of floods, in different regions of the world. Ongoing work on the diagnosis of such changes in flood series will be presented, focusing on two case studies. The implications of such analyses will be discussed in the context of (a) interpretation of the historical flood record, (b) situations in which it may be useful to estimate conditional flood risk, (c) possible statistical methods for estimating flood risk.

Landslide Risk Assessment: Extended Abstract

William Roberds, Golder Associates

Landslides can occur in different forms, ranging from individual rock falls to large creep failures, depending on site conditions (e.g., topography, geologic structure, shear strength, pore pressures, loads), some of which in turn are affected by various processes and events (e.g., earthquakes, precipitation, erosion, excavation). Such landslides can have significant consequences (e.g., casualties, property damage, and socio-economic impacts such as loss of service), depending on their characteristics (e.g., timing, location, size, mobility, runout, etc.) and on the vulnerability of people, structures and infrastructure to those landslide characteristics. Such undesirable consequences can be prevented or at least reduced through various actions designed to: a) prevent landslides from occurring (e.g., by installing drains or support, scaling or flattening the slope); b) reduce their severity if they do occur (e.g., by installing debris barriers); and/or c) reduce the vulnerability of potentially affected people/structures/infrastructure (e.g., controlling development, warning/evacuating people, strengthening structures, maintaining contingency plans). However, some of these actions can be very expensive to implement (in financial terms as well as in worker safety and socio-economic terms) and may prove to be either ineffective or unnecessary. The objective for any site or, even more importantly, a set of sites should be to identify and implement those actions (if any) which are most cost-effective, appropriately trading off the various implementation "costs" and landslide consequence reductions ("benefits").

However, for any action (including no action), the occurrence of landslides at a site and the characteristics/consequences if they do occur cannot generally be predicted with certainty beforehand, due to inherent uncertainties in: a) the site conditions/processes/events and in the vulnerability of people/structures/infrastructure, a combination of stochastic variability (which is not reducible) and ignorance (which is reducible through more information); and b) the relationships of instability, landslide characteristics and consequences to the site conditions/processes/events and the vulnerability of people/structures/infrastructure, a combination of simplifications and approximations.

The uncertainties in whether one or more landslides will occur at a site, and in the consequences if they do occur ("risks"), need to be adequately considered when deciding on possible actions. Such risks can be assessed in many ways, differing widely in effort/cost, accuracy and defensibility. Fundamentally, each method is a combination of the following attributes: a) site-specific or averaged over a set of sites; b) qualitative or quantitative; and c) comparative or absolute. Although qualitative and/or comparative methods may be adequate for ranking or screening slopes and possible actions for slopes, a site-specific, absolute, quantitative method is generally needed for making optimal, defensible decisions on actions. However, such quantitative methods can vary significantly in level of detail, ranging from: a) direct assessments of the frequency of landslides and their consequences; to b) detailed models of various modes of instability, runout and consequences which in turn rely on direct assessments of specific input parameters. Direct assessments (at any level) can be: a) statistically driven (if a representative data set is available); b) based on judgment (consistent with available data); or c) a combination of the two. Similarly, the models can be: a) empirically-based (which requires substantial data from similar situations relating outcomes to observable factors, e.g., geologic units); b) theoretically-based (which requires the assessment of engineering parameters, e.g., peak pore pressure); or c) a combination of the two. For example, probabilistic dynamic simulation models can be used to predict peak pore pressure, or rockfall or debris flow runout characteristics.

The appropriate method to use for risk assessment on a particular project depends on a variety of factors, primarily the "value" of increased accuracy in making decisions and increased defensibility in justifying those decisions. Other factors include: a) the availability of relevant engineering and empirical data, and the cost associated with acquiring additional data; and b) the availability of tools and expertise (e.g., regarding stability, runout and damage models, and objective and subjective probability assessments), and the cost associated with improvements. Several case studies and tools are briefly discussed by the author, as well as by the other session authors, to illustrate these concepts.

Stochastic Landslide Forecasting Models: Case Studies in Policy Analysis

R.L Bernknopf, USGS and Stanford University

Policy initiatives to reduce landslide losses are analyzed in a decision framework where benefits and costs are identified and evaluated from society's perspective to promote public safety. In addition, there is a second objective to ensure that policies are implemented in an efficient manner. Cost-benefit analysis can help decide the economic value of a mitigation project. Three landslide-hazard models have been developed that utilize binary-choice statistical regression to make predictions of the probability of a physical-state change. The models are based on Earth Science Information (ESI) for: (1) construction-induced landslides in Cincinnati, OH, (2) earthquake-triggered landslides in Santa Cruz, CA, and (3) rainfall-triggered debris flows in Oakland, CA.

In the Cincinnati case, mitigation rules based on the Uniform Building Code were evaluated that are spatially selective. In the second case, landslides triggered by the 1989 Loma Prieta earthquake caused significant losses. By examining different structures of information for estimating the probability of a landslide, the economic impact of two styles of ESI for earthquake-hazard mitigation is compared. In the third case, a space-time probability model is applied for rainfall-triggered debris flow events. The model is demonstrated in the Oakland-Berkeley hills in the San Francisco Bay Region. This model provides the basis for hazard announcements and planning emergency response for a future hazardous event.

The utility associated with the ESI is to forecast the probability of the occurrence of landslides and to assist in identifying the "best" mitigation strategy a, where $a \in A$ mitigation options. The payoff $u_s(a, \theta)$ is based on the environment s, where $s \in S$ states of the environment, the action a, and θ which is an index of informational uncertainty, where $\theta \in \Theta$ information structures. In θ, $p_{s(k)\gamma_\theta}$ is the conditional probability of a landslide in location k, $k \in K$ locations, predicted by hazard assessment $\gamma = \gamma(g, h, t)$, where $g \in G$ geologic, $h \in H$ hydrologic, $t \in T$ topographic attributes respectively. The conditional proability of hazard is combined with values at risk and applied in a policy analysis aimed at optimizing the allocation of resources.

A MODELING PROCEDURE TO PRODUCE PROBABILISTIC SEISMIC LANDSLIDE HAZARD MAPS

Randall W. Jibson

Analysis of the distribution of the more than 11,000 landslides triggered by the 1994 Northridge, California, earthquake has facilitated developing modeling procedures that estimate the probability of slope failure as a function of dynamic slope stability (critical acceleration) and earthquake shaking intensity. Combining data sets that describe the geology, topography, ground shaking, and slope-material properties in a dynamic slope-stability model based on Newmark's permanent-deformation (sliding-block) analysis yields estimates of coseismic landslide displacement from the Northridge earthquake in each 10-m grid cell. The modeled displacements are then compared with the digital inventory of landslides triggered by the Northridge earthquake to construct a probability curve that estimates probability of failure ($P(f)$) as a function of Newmark displacement (D_n, in cm):

$$P(f) = 0.335[1 - \exp(-0.048\, D_n^{1.565})].$$

This equation was calibrated using data from six 7½' quadrangles near the 1994 epicenter. Once calibrated, the probability function can be applied to estimate the spatial variability in failure probability in any ground-shaking conditions of interest. The resulting digital hazard maps can be updated and revised with additional data that become available, and custom maps that model any ground-shaking conditions of interest can be produced when needed.

This method uses a deterministic, physical model of slope failure to make empirically calibrated estimates of failure probability. For the model to be rigorously probabilistic, the variability and uncertainty of the model parameters must be quantified. Gathering the types of data that will be necessary to make this quantification will be a huge challenge and should be a primary focus for the future.

USGS National Seismic Hazard Maps and Associated Products

**A.D. Frankel, C.S. Mueller, E.V. Leyendecker, S.C. Harmsen,
R.L. Wesson, T.P. Barnhard, F.W. Klein, D.M. Perkins, N.C. Dickman,
S.L. Hanson, and M.G. Hopper**

U.S. Geological Survey
MS 966, Box 25046, DFC
Denver, CO 80225

The USGS recently completed new probabilistic seismic hazard maps for the United States. These hazard maps form the basis of the probabilistic component of the design maps used in the 1997 edition of the NEHRP Recommended Provisions for Seismic Regulations for New Buildings prepared by the Building Seismic Safety Council and published by FEMA. The maps depict peak horizontal ground acceleration and spectral response at 0.2, 0.3, and 1.0 sec periods, with 10%, 5%, and 2% probabilities of exceedance in 50 years, corresponding to return times of about 500, 1000, and 2500 years, respectively. We outline the methodology used to construct the hazard maps. There are three basic components to the maps. First, we use spatially-smoothed historic seismicity as one portion of the hazard calculation. In this model, we apply the general observation that moderate and large earthquakes tend to occur near areas of previous small or moderate events, with some notable exceptions. Second, we consider large background source zones based on broad geologic criteria to quantify hazard in areas with little or no historic seismicity, but with the potential for generating large events. Third, we include the hazard from specific fault sources. We use about 450 faults in the western U.S. (WUS) and derive recurrence times from either geologic slip rates or the dating of pre-historic earthquakes from trenching of faults or other paleoseismic methods. Recurrence estimates for large earthquakes in New Madrid and Charleston SC were taken from recent paleoliquefaction studies. We used logic trees to incorporate different seismicity models, fault recurrence models, Cascadia great earthquake scenarios, and ground-motion attenuation relations. We present deaggregation plots showing the contribution to hazard at selected cities from potential earthquakes with various magnitudes and distances. In addition to paper and electronic versions of the hazard maps, we have produced CD-ROM's with programs to lookup seismic-hazard and seismic-design values by latitude and longitude or zipcode. Our website (http://geohazards.cr.usgs.gov/eq) contains a comprehensive set of seismic hazard-related products, including seismic hazard maps, earthquake catalogs, fault parameter table, GIS export files, hazard look-up by zipcode, gridded hazard values, spatial deaggregation of hazard for 100 cities, and interactive hazard maps.

State-of-the-Art-and-Science in Probabilistic Volcanic Hazard Assessment

Chuck Connor, Southwest Research Institute, 6220 Culebra Rd, San Antoni, Tx, 78238-5166, email: cconnor@swri.edu

The last fifteen years has seen a dramatic improvement in forecasting of volcanic eruptions, in large part driven by the efforts of USGS scientists. Volcanologists have developed a comprehensive understanding of the nature of volcanic phenomena and have used this understanding to mitigate hazards. For the first time, physical and empirical models have been introduced as tools in volcanic hazard assessments – giving volcanologists the potential to quantify eruption hazards using measurable parameters. Better approaches to hazard mapping and the communication of hazards are emerging. These improvements mean that, in the United States, volcanic eruptions are less likely to produce unexpected and disastrous results than they were in the past.

Nevertheless, the demands society places on volcanic hazards assessments are increasing at least as fast, as evinced by population growth around volcanoes and the construction of facilities that require extremely low geologic risk. Like many natural phenomena, volcanic eruptions are difficult to evaluate in terms of the relative significance: the probability of volcanic eruptions is often very low compared to the scale of human experience and the consequences of volcanic eruptions are often comparatively high. Furthermore, volcanic eruptions are complex phenomena, producing many and varied hazards: ranging from long-term gas emissions to devastating volcanic debris avalanches and lahars. Unlike many natural hazards, volcanic eruptions are very often preceded by periods of unrest, often lasting months or years. These volcano crises require flexible hazards and risk assessments.

Uncertainty exists in forecasts of eruption timing, magnitude, and consequences. It is critical to express this uncertainty in probabilistic volcanic hazard assessments. There are numerous approaches to illustrating uncertainty, but two which are particularly successful are hazard curves, which show the likelihood a given event will exceed a given magnitude, and hazard maps, which contour hazards. Probabilistic volcanic hazards assessments utilize data from geologic studies, numerical simulations and monitoring activities. For example, a tephra hazard curve for the city of Leon, Nicaragua, illustrates the probability of tephra accumulation to a given thickness, facilitating disaster planning. Hazards can be represented as annual probability, conditional probability, or screening distance value. Annual probabilities include the likelihood of a volcanic eruption within a given year, and the range of consequences of volcanic eruptions, such as the amount of tephra that might accumulate in a particular area. Conditional probabilities assume, for instance, that the likelihood of a volcanic eruption is unity. Thus, the probable consequences of an eruption may be evaluated independently, and cast as a probability tree. Screening distance values are worst case scenarios that bound the upper limit of potential consequences of volcanic activity based on reasonable, conservative assumptions.

Probabilities of Volcanic Eruptions and Applications Involving Recent USGS Hazards Assessments

Manuel Nathenson
U.S. Geological Survey
Menlo Park, California 94025

An underlying assumption of USGS hazards assessments for the Cascades is that the probability of volcanic eruptions may be treated as a Poisson process. Time histories for some volcanoes match this assumption well. In order to calculate an annual or 30-year probability for an eruption, the relation for the recurrence rate is used. For a Poisson process, this relation is obtained from the exponential distribution for the probability that an eruption will occur in a time T less than or equal to the interval time t:

$$P\{T \leq t\} = 1 - e^{-\mu t} \approx \mu t, \quad \text{for } \mu t \text{ small,}$$

where μ is the mean occurrence rate of events per year. Since occurrence rates are small in the Cascades, the approximate relation shown is normally used. For the case of lava flows from isolated vents covering an area a in a volcanic field of total area A, a factor $p = a/A$ can be factored in as $\mu t p$ to account for the probability of areal coverage. This analysis assumes that the occurrence of vents are homogeneous in space within the defined area of the volcanic field.

The properties of a Poisson process include the characteristic that the conditional probability of waiting till an eruption occurs does not depend on the time that we have already waited only on the time that is in the future. For some volcanoes, the time history contains disparate time intervals between eruptions, with some being short and others being much longer. In this case, other probability distributions are a more accurate representation of the data, and the conditional probability for these distributions does depend on the time since the last eruption. The Weibull distribution introduced by Bebbington and Lai (1996) has mixed results in dealing with these disparate intervals. An alternate distribution is the mixed exponential

$$P\{T \leq t\} = 1 - p_1 e^{-\mu_1 t} - p_2 e^{-\mu_2 t}$$

where p_1 is the fraction of short intervals, μ_1 is the average occurrence rate for the short intervals, and p_2 and μ_2 are the same parameters for the long intervals. The basic notion embodied in this relation is that there are two states, one involving short intervals and a second involving long intervals. The probability of an eruption occurring in each of these states is governed by an exponential distribution. The mixed-exponential distribution appears to match the available data reasonably well and resolves a conceptual problem for volcanoes with disparate eruption time intervals.

Some examples of time histories with disparate eruption time intervals are: Mullineaux's (1974) data for eruption times for tephra layers at Mount Rainier have three long intervals (>2000 years) and seven short intervals (<600 years). Mullineaux's (1996) data for Mount St. Helens has one interval of 8600 years, one of 1500 years, and 34 less than 640 years. Donnelly-Nolan and others (1990) data for Medicine Lake volcano has one interval of 7700 years, one of 1640 years, and 13 less 780 years. The Weibull and mixed exponential distributions agree much better with the Medicine Lake data set than does the exponential distribution. The conditional probability that there will be an eruption in the next 30 years is 2.5 % for the Weibull and mixed exponential distributions compared to the estimate using the exponential distribution of 3.7 %. Estimates at other times since the last eruption differ from that for the exponential by larger factors.

ROBUST ESTIMATES OF DEBRIS FLOW HAZARDS ON VOLCANOES

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Debris flows are common on volcanoes, and pose a significant hazard that persists long after eruptive activity has ceased. Hazard estimates must incorporate both model uncertainties, which relate deposits to the magnitude of the flow that created them, and data uncertainties, which relate here to the ability to estimate deposit age and volume. While the uncertainty in age of debris flow deposits is commonly constrained by C14 dates on organic matter. the uncertainty in volume is usually greater than the volume estimate. Currently we rely on crude estimates of volume based principally on thickness of debris flow deposits on floodplains. These crude estimates of volume could be better constrained by physical modeling, which would route flows through a given drainage to determine what volume corresponds to each deposit as well as provide the relation between runout distance and volume.

For hazard assessment applications, the critical issue is not the estimation of a complete record of all flows, but rather the frequency and potential magnitudes of flows large enough to exceed the safe conveyance capacity of the system. The bounds on volume and age in the geologic record are direct indicators of the frequency of the largest actual flows. A Bayesian methodology developed for flood hazard estimation (O'Connell,1999) has been modified for use with debris flows, and is applicable to non-volcanic debris flow hazards as well. The Bayesian approach naturally incorporates both nonexceedence and exceedence information over time using likelihood functions in a unified probabilistic flow-frequency analysis. The method includes both frequency model and data estimation uncertainties to derive Bayesian estimates of the annual probability that a debris flow of a given size will occur on a particular volcano. Application of this methodology to the debris flow record for Mt. Rainier, Washington, indicates that debris flows large enough to be hazardous to the town of Ortiz are likely to occur more frequently than previous analyses would indicate.

Obstacles on the Road to Consistent Probabilistic Hazard Assessment

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Probabilistic hazard estimation goals require extrapolation beyond the limits of historical observation. Extrapolation requires either physical understanding of the system or extending the observational record. In earthquake hazard estimation there are physical bases for using the truncated Gutenberg-Richter magnitude-frequency relation for low probability events. While comparable physical bases for magnitude-frequency have not been found for floods, landslides, and volcanic eruptions, the geologic record contains abundant information about the occurrence, or the lack of occurrence, of large magnitude/low probability events. However, there is incomplete understanding of the physics governing seismic wave, water, and sediment routing processes during extreme events for all these systems. This makes probabilistic hazard assessment difficult.

Determinism and bias are other factors that undermine the goal of probabilistic hazard assessment. Characteristic earthquake models based on fault mapping are a deterministic approach relative to using distributed or "smeared" source zones to estimate seismic hazards. Virtually all extreme peak discharge estimates for floods are derived from indirect estimates that often exhibit substantial biases toward extreme values that suggest a consistently conservative bias. Extreme event probabilities based solely on short observational records produce substantial biases when the physical processes representing extreme behavior are completely absent from the record.

Natural variability and "nonstationarity" are serious concerns when making hazard predictions. Probabilistic hazard assessment is viewed by the public, and most users, as making hazard predictions. Does process variability represent nonstationarity or random phase periodicity? Earthquake prediction has not worked well so far for earthquake hazard estimation. Time-dependent hazard assessment may become viable for some small dimensional systems representing integrated processes like lake surface elevations. However, for large dimensional point processes like earthquakes and floods the stochastic assumption is probably inescapable for probabilistic hazard assessment in the next few years. What's needed to bridge the knowledge gap is substantial new basic science research and physical understanding that requires collecting detailed, long-term geological and geophysical data. Thus, the U.S.G.S. can not simply be a group of applied consultants. Advances in probabilistic hazard assessment require a renewed commitment to extract new information from the geologic record. Without a strong U.S.G.S. commitment to sustained data collection, detailed field investigations, and long-term basic science, applied hazard assessment efforts will run out of fuel.