Report of the
Scientific Earthquake Studies Advisory Committee
of the Department of the Interior
to the Director of the United States Geological Survey

2006

The Scientific Earthquake Studies Advisory Committee (SESAC) of the Department of the Interior is issuing this annual report for 2006 to the Director of the United States Geological Survey (USGS) for submission to Congress. The report describes the Committee's activities during 2006 and addresses policy issues and matters relating to the participation of the USGS in the National Earthquake Hazards Reduction Program (NEHRP). We believe this report (and previous years' reports) will be particularly useful to the NEHRP Advisory Committee on Earthquake Hazards Reduction, currently in the final stage of being established.

SESAC MANDATE

The Scientific Earthquake Studies Advisory Committee was appointed and charged, through Public Law 106-503, to review of the USGS Earthquake Hazard Program's roles, goals, and objectives; assess its capabilities and research needs; and provide guidance on achieving major objectives and the establishment of performance goals.

ACTIVITIES OF THE COMMITTEE DURING 2006

The SESAC met three times:

1. Meeting in Reston, Virginia, March 6 and 7. Objective: Review the overall direction of the USGS Earthquake Hazards Program for the current year and for the future, with emphasis on defining opportunities for future growth and strategies for balancing program needs against increasing resource limitations. The committee also received an update on USGS and NOAA activities in support of the President's tsunami warning initiative, the USGS participation in the National Science Foundation's EarthScope project, the USGS hazards initiative, and plans for a re-chartered National Earthquake Prediction Evaluation Council. The SESAC welcomed three newly appointed members: Jim Dieterich, from University of California, Riverside; Art Lerner-Lam, from Columbia University; and Vicki McConnell, from the Oregon Department of Geology and Mineral Industries. This was the final meeting for three departing SESAC members, Ron Eguchi, Paul Segall, and Bob Smith

2. Meeting in Golden, Colorado, July 6 and 7. Objective: Examine the USGS role in translating hazard information into a risk framework; provide a review of USGS geohazard program coordination.

3. Meeting in Albuquerque, New Mexico, October 30 and 31. Objective: Review the activities and function of the USGS Albuquerque Seismological Laboratory (ASL) and the USGS role in the Global Seismographic Network. Review the direction of the USGS Earthquake Hazards Program, with emphasis on tsunami hazard mitigation and warning efforts**.**

4. Other activities:

   - On April 18, SESAC chairman Cluff testified at a Senate Field Hearing in San Francisco, called by the Honorable Senator Jim DeMint, Chairman, Subcommittee on Disaster Prevention and Prediction, U. S. Senate Committee on Commerce, Science, and Transportation. The hearing was part of the 100th Anniversary Commemoration of the Great 1906 earthquake. Activities for the 1906 Earthquake Commemoration were organized by the 1906 Alliance (Earthquake Engineering Research Institute, Seismological Society of America, California Governor's Office of Emergency Services, U. S. Geological Survey, Western States Seismic Safety Policy council, and others).

     Cluff informed the committee members (Senator DeMint and Senator Boxer) on earthquake science and engineering issues identified in the recommendations of the 2005 SESAC report, with emphasis on the need to increase work on multiple hazards; the Southern California demonstration project; and the instability of the San Francisco Bay delta levees, particularly during a large San Francisco Bay Area earthquake. Senator Barbara Boxer seemed especially concerned and pledged to work with Senator DeMint to press for the support needed to address these seismic safety problems.

   - On May 12, SESAC chairman Cluff, Ellis Stanley, Emergency Preparedness Department of Los Angeles, and David Applegate, USGS, briefed congressional staffers from the House Science Committee and Senate Commerce, Science and Transportation Committee, on the recommendations from the SESAC 2005 report and related matters. This event was the third segment of a USGS 2006 Congressional Briefing Series **(www.usgs.gov/solutions)**.

   - On June 27, SESAC chairman Cluff participated in a meeting with the Government Accountability Office (GAO) held at the USGS Menlo Park, California office. The purpose of the meeting was to review with the GAO the Earthquake Hazards Program in the context of the challenges in understanding earthquake hazards and progress made in contributing to reducing earthquake risks.

REVIEW OF THE USGS EARTHQUAKE HAZARDS PROGRAM

The various accomplishments of, issues pertaining to, and opportunities for the USGS Earthquake Hazards Program identified and reviewed at our March, July, and October meetings are discussed below.

USGS coordination with the new NEHRP lead agency

During the March 6 and 7 SESAC meeting the committee heard from NEHRP lead agency representative Shyam Sunder, Deputy Director of the National Institute of Standards and Technology (NIST) Building and Fire Research Laboratory, who described NIST's plans for carrying out its new duties as the designated lead agency in the short term, despite the lack of new funds from Congress. NIST has set up a NEHRP office headed by Jack Hayes, who came to NIST from the U.S. Army Corps of Engineers Construction Engineering Research Laboratory in Champaign, Illinois. NIST is covering the bulk of the cost of the office but is also receiving contributions from the other NEHRP agencies (USGS, NSF and FEMA). Former USGS Earthquake Hazards Program (EHP) Coordinator John Filson's participation in NEHRP lead agency activities is fulfilling USGS's in-kind contribution to manage NEHRP. Sunder asked for the committee's input on the need for NEHRP and was answered that the earthquake hazard requires a special focus or runs the risk of being lost within the current multi-hazard focus. It was suggested that NIST seek input from the regional earthquake consortia regarding federal-state linkages necessary for policy development and implementation

USGS Participation in the Global Seismographic Network

Background:

The Global Seismographic Network is a global distribution of high-fidelity earthquake monitoring instruments supplying data in real time in support of USGS missions in earthquake detection and notification, disaster management, hazards assessments and loss reduction, and earthquake research. The GSN is a joint program between the USGS and the National Science Foundation (NSF), and is coordinated under a USGS-NSF Memorandum of Understanding through a shared governance structure with the Incorporated Research Institutions for Seismology (IRIS), an NSF-funded consortium of US universities with programs in earthquake science. The GSN is jointly deployed, operated, and maintained by the USGS's Albuquerque Seismological Laboratory and by the University of California, San Diego. The ASL is responsible for approximately two-thirds of the network. USGS's partners in GSN have contributed, approximately, an additional $60 million over the last twenty years, illustrating the leverage produced by this partnership for USGS.

Inaugurated in 1986, the GSN is the successor network to the World Wide Standard Seismographic Network (WWSSN) and experimental digital networks, and operates some of the most advanced seismological instrumentation, telecommunications and data management systems ever deployed in the service of earthquake monitoring and research. Now composed of 138 stations, on every continent – with several more installations

planned for 2007 – the GSN is crucial to the NEIC's ability to accurately locate and characterize earthquakes throughout the world. The high-fidelity seismic wave data returned from the GSN, particularly the on-scale recording of one of the world's largest earthquakes in December 2004, enables the NEIC to quickly and accurately measure the size of an event – a critical factor in tsunami warning and disaster response. The great dynamic range and geographic distribution of the GSN enables the NEIC routinely to locate accurately earthquakes as small as magnitude 5 globally No other international, open network of seismometers can perform at this level.

Consequently, the NEIC has become the *de facto* international authority on earthquake notification, for both US and international stakeholders, placing the USGS in a visible international leadership position in earthquake monitoring, and supporting US humanitarian and strategic objectives in international disaster response and recovery. As an open network, with no restrictions on access to real-time data, the GSN expresses the USGS's position on the free and open exchange of seismological data, and provides a technically transparent global infrastructure for international partners to use to build their own regional, high-performance earthquake monitoring networks to supplement the global capabilities. These regional developments leverage the investments in the GSN to extend state-of-the-art monitoring capabilities at lower cost to countries and regions most at risk from earthquakes. This infrastructure has enabled the USGS to respond positively to requests from USAID, for example, to assist in the development of regional networks and training of network operators in countries receiving US disaster assistance. This further leverages the USGS and NSF investments in the GSN.

The GSN represents one of the most visible examples of the USGS partnership with the US academic seismology community, especially in the use of high-quality waveform data for research. One of the most important and pressing examples is the need for the NEIC to provide quick and accurate estimates of earthquake size and complexity – the "source mechanism" – for the purpose of evaluating probable impacts on life and property, assisting with early warnings for tsunamis, and forecasting damaging aftershocks. Progress in this area is being made through the USGS's external grants program, which enables the transfer of basic research results in rapid source characterization to the operational regime of the NEIC. This program has also brought academic researchers to the NEIC and has fostered closer and therefore more productive collaborations with the academic community than would have otherwise occurred.

The USGS uses the GSN as one of its primary contributions to the Global Earth System of Systems (GEOSS) as part of the set of tasks related to disaster mitigation. To a certain extent, these tasks codify what the USGS, particularly the ASL and NEIC, is already doing. The GEOSS framework, including the U.S. Group on Earth Observations component, is an additional way for the USGS to promote its accomplishments in earthquake monitoring and hazards mitigation on an international stage. It is worth noting that the GSN is one of the few examples of *in situ* monitoring that can claim such global success.

The GSN is a member of the international Federation of Digital Seismographic Networks (FDSN), an international organization of network operators supporting standards-driven data exchange and common instrumentation protocols. Together with GEOSS, USGS

participation in the FDSN promotes international coordination and efficiencies, and high visibility for USGS operations with foreign partners.

Issues:

Increasing costs of operations and maintenance: While the GSN is now nearly built out to its original design specification and there are efficiencies of scale, the operational costs of the GSN continue to exert budget pressures. The GSN has taken steps to contain costs, such as specifying and deploying standardized instrumentation, but instrument amortization (replacement) costs are not adequately funded. Consequently, there is short-term need to increase the amortization budget to 15-20% of the total operations and maintenance (O&M) budget. Additionally, there needs to be continued expenditure to upgrade the telecommunications infrastructure of the GSN so that all stations can be communicated to the NEIC in real-time at high bandwidth. There are a few remaining dial-up connections which should be replaced, for example. In steady state, amortization and replacement costs should be closer to 10% of the O&M. Sharing the operations and maintenance burden with international partners and participating countries is being explored *ad hoc*, but is at times an effective strategy to reduce costs.

Funding opportunities for international coordination: GEOSS and FDSN are not funding mechanisms, and care must be taken that USGS management wisely parameterize international interactions for staff. Alternative funding mechanisms, such as support from USAID, are also important.

Earthquake data product reconciliation: While the NEIC is the *de facto* international authority for earthquake characterization and notification, it is not *de jure*, and there remains the issue of how to reconcile earthquake reports by the different agencies with their own global or regional responsibilities for earthquake monitoring. The USGS is in a very strong position and may have the convening authority to take the lead in international discussions for earthquake parameter reconciliation.

Common technical performance goals for global and regional networks: Similarly, reconciliation of earthquake data products requires a strong knowledge of the performance attributes of different networks. The USGS, particularly the NEIC, should continue to work with the GSN and other operators to develop standards-based network assessment tools and implement them across networks.

Free and open data exchange and problematic countries: Several countries are recalcitrant with respect to free and open data exchange. The USGS should continue to press these countries, particularly India and China, through existing channels, on free and open real time data exchange. One mechanism, for example, is the existing USGS-NSF-China cooperative agreement, where such discussions could be formalized.

Use of supplemental data from other networks for enhancing NEIC and other USGS operations: The NEIC is exploring the use of data from other networks and arrays to supplement the GSN, both regionally and globally, for certain mission-critical operations. This should be encouraged.

Caribbean network expansion in support of a tsunami warning system for the region needs to be finished.

Support of the mission of tsunami warning centers: The committee is impressed with the increasing level of cooperation between the NEIC and the tsunami warning centers. It is important that the warning centers recognize the contributions that the USGS and its partners are making to the rapid characterization of tsunamigenic earthquakes, especially with GSN and other high-fidelity waveform data.

Expansion of the external grants program: The committee is impressed by the expansion of the external grants program to promote the transfer of source characterization research results to the operational environment of the NEIC. This type of performance should be encouraged.

USGS Earthquake Activities at the Albuquerque Seismological Laboratory

The SESAC endorses the careful work that is being done by Lind Gee, Bob Hutt, and their staff at ASL to test optimal siting strategies for GSN, ANSS Backbone, and EarthScope seismic stations, and to optimize the stability of the STS-2 instrument by enhancing its thermal insulation and counteracting the effects of thermally induced tilt. The SESAC also endorses the work that is being done to archive the WWSSN film chip seismograms, and recommends that this archive be made accessible to the research community.

Translating USGS Hazards Information into a Risk Framework

The SESAC endorses the research that the USGS is undertaking to improve the information that it provides for input into HAZUS and other loss estimation tools. Potential applications include improved input into HAZUS; providing national seismic risk maps in addition to or as an alternative to national seismic hazard maps; and development of a web tool for risk assessment of wood frame houses. SESAC recommends that, in developing its web-based tool, the USGS consider the availability of site-specific information on soils, and take care not to provide information that is in conflict with the code requirements of local jurisdictions.

The SESAC encourages the development of risk-targeted ground motion maps as a means for enhancing the ways in which risk is judged by both the public and private sectors, and suggests that the needs of potential users and potential actions from them be carefully considered in its development.

EarthScope Opportunities for the USGS Earthquake Hazards Program

The USGS is an active partner in the National Science Foundation's EarthScope Program, which is designed to gain insight on the structure and dynamics of the North American continent. Because this insight is key to understanding earthquake and volcano hazards, USGS scientists are integral parts of all three components of EarthScope – the San Andreas Fault Observatory at Depth (examining the fault with directional drilling into the zone where earthquakes ruptures begin), US Array (imaging the Earth's interior with seismic instruments), and the Plate Boundary Observatory (measuring strain with global positioning system and other geodetic instruments). NSF funding for EarthScope

has covered costs of equipment that will help to complete the Advanced National Seismic System national Backbone that is operated by the USGS.

The EarthScope Program is evolving as it moves into the fourth year of its five-year construction phase for facilities, but the changes within NSF are likely to have little impact on the participation of the USGS in the program. NSF is phasing out the EarthScope Facilities Office in Washington, D.C, which helped to coordinate activities of the three components of the program during initial facility construction, and, beginning in 2007, will fund an EarthScope National Office based initially at a university in the western United States. This office will assist in education and outreach activities and support EarthScope-related efforts in information technology. The EarthScope Program Committee, which has provided external advice to NSF, is being replaced by an EarthScope Steering Committee.

Whereas funding for the EarthScope facilities is on track through NSF's Major Research Equipment and Facilities Account, funding for science projects and education and outreach efforts that take advantage of the EarthScope equipment has suffered from essentially flat budgets at NSF in recent years. Various initiatives to significantly increase NSF's budget over the next few years have been proposed by the Administration, House, and Senate. For EarthScope to achieve its goals, substantial increases are needed to cover costs of operations and maintenance of equipment as it is deployed over the next 15 years and for the science projects and education and outreach efforts. The Committee believes that the USGS earthquake and volcano hazards programs will benefit immensely from increases to NSF's budget for EarthScope.

The Committee recommends that the USGS take full advantage of EarthScope data and equipment.

The USGS should use data from EarthScope's seismic instruments, which are providing opportunities to more accurately locate and measure earthquakes and to provide details on velocity structure, and the USGS should use EarthScope's geodetic data as input into probabilistic seismic hazard analysis. In terms of equipment, the USGS should work with its partners who operate regional seismic networks to optimize network performance through the adoption of key US Array seismometers and/or sites. The USGS and its regional network partners should determine the amount of funding that is necessary to meet performance standards for detection thresholds, accuracy of location and depth, and percentage of time that stations are operational. The Committee believes that full funding of ANSS would provide the USGS with the necessary resources and that adoption of selected US Array transportable instruments and/or sites is likely to result in considerable cost savings.

The Committee further recommends that the USGS use its external grants program to work with academic and other partners who propose to use EarthScope data, instrumentation, and information to further the USGS missions in earthquake hazard assessment, monitoring and risk reduction, and fundamentals of earthquake physics.

Advanced National Seismic System

Significant improvements have been made in the Advanced National Seismic System (ANSS) during the past year, including 24/7 operations and updated software for event processing at the National Earthquake Information Center (NEIC), development of new products for rapid dissemination of information after an event, introduction of performance standards for the regional networks, and selection of six buildings and three bridges for instrumentation.

The Committee continues to be concerned however, that without additional resources, ANSS development will stall by 2008. Much of the development activities during the past two years were carried out using supplemental funds from the President's tsunami initiative, but these funds expired at the end of FY 2006. USGS has done an excellent job of leveraging opportunities to expand the system under constrained budgets, but many pressing needs will not be met as development money gives way to rising operational costs. For example, the number of buildings and other structures scheduled to be instrumented by 2007 is far shy of what is needed to support the development of improved building codes and design/rehabilitation standards. Early warning technology, already developed and implemented in several other countries, needs to be fully prototyped and tested in at least one high-risk U.S. city. Dense instrumentation arrays in close proximity to active faults and development of geotechnical arrays are also viewed as priorities for ANSS.

Recent events, such as the tsunami in Sumatra, Hurricane Katrina, and the commemoration of the 1906 San Francisco earthquake highlight the importance of situational awareness immediately after an extreme event. Within California, the California Integrated Seismic Network (CISN) provides a high level of service and serves as an exemplar for post-event awareness. However, the level of service provided by regional networks throughout the US is not uniform. As discussed in the 2005 annual report, all ANSS regional networks need to be fully modernized and supported!

The Hawaii earthquake of 15 October 2006 serves as an example of how outdated equipment and event processing software at a regional network can impact event response. The initial reported magnitude of 4.6 made by the regional network was based on the duration magnitude, which significantly underestimated the moment magnitude of 6.7 calculated by NEIC. In addition, most of the strong motion instruments in Hawaii are film recorders without telemetry or communications capabilities. The data from these instruments were not retrieved until days after the event, and therefore, did not contribute to the emergency response. Many of the records available immediately after the event went off scale, and did not provide an adequate characterization of the earthquake. This situation is not unique to Hawaii and underscores the urgency of completing ANSS.

Of equal concern, USGS is not taking full advantage of *current* opportunities to leverage facilities developed by the National Science Foundation, such as EarthScope and NEES, because sufficient funding is not available. Two specific examples include the opportunity to fully develop ANSS regional seismic monitoring by transitioning

EarthScope Transportable Array stations to the ANSS regional networks; and the opportunity to use the NEES mobile facilities (geotechnical and structural shakers) to build metadata for ANSS free-field and instrumented-structure sites.

As the committee has discussed in the previous four annual reports, full funding for ANSS is a key element in reducing the risk from earthquakes that will strike the United States. The committee strongly supports full funding of this initiative.

National Earthquake Prediction Evaluation Council

In 2004 and 2005, the Committee strongly urged that the National Earthquake Prediction Evaluation Council (NEPEC) be re-established to serve as a forum for review of earthquake predictions and probabilistic forecasts of earthquake activity. The committee is pleased to note that NEPEC has been reauthorized and met twice in 2006 with Jim Dieterich as chair. In 2007 NEPEC will provide external scientific review of the long-term probabilistic earthquake forecast of the Working Group on California Earthquake Probabilities (WGCEP). The working group is jointly organized by the USGS, the Southern California Earthquake Center, and California Geological Survey and receives partial funding from the California Earthquake Authority (CEA). CEA will use the WGCEP study as input to setting earthquake insurance rates in California. Aspects of the study are also being incorporated into the 2007 revision of the National Seismic Hazard Map. Also in 2007, NEPEC will organize a workshop to gather information on the current status and understanding of research into periodic strain events discovered to occur in the Pacific-Northwest subduction zone and similar areas. These events, which are thought to occur as silent slip events in the subduction zone, apparently stress the seismogenic portion of the subduction zone and may be associated with periods of elevated risk of earthquakes.

USGS GEOHAZARD PROGRAM COORDINATION

At its July meeting in Golden, the SESAC reviewed the coordination among the USGS geohazard programs (Earthquake Hazards Program, Landslide Hazards Program, Volcano Hazards Program, Global Seismographic Network, Geomagnetism Program). We were asked to do so in order to assist those programs as they address the Office of Management and Budget (OMB) recommendation to "evaluate initial efforts to coordinate hazards investments across landslide, earthquake, and volcano activities." We understand that this report meets one of the milestones set to address that recommendation.

Since the committee was established to provide guidance for the Earthquake Hazards Program, presentations focused on landslide and volcano activities. After an introduction from Dave Applegate, reflecting his role of coordinating the geologic hazards programs, the committee heard presentations from Landslide Hazards Program Coordinator Peter Lyttle, Volcano Hazards Program Coordinator Jim Quick, and Geologic Hazards Team Chief Scientist Jill McCarthy, whose staff are funded by four of these five programs. In addition, the committee reviewed a number of budgetary and planning documents

prepared by the programs as well as documents prepared in response to this and other OMB recommendations.

We are pleased with the overall progress that USGS has made toward internally coordinating its hazards efforts, including the establishment of the Senior Science Advisor position with coordination responsibilities across the USGS hazard activities. While there is more progress to be made, it is also important to recognize that there are differences in how these hazards are addressed.

This letter report focuses on the interactions across the hazards, especially between the two largest programs: the Earthquake Hazards Program and the Volcano Hazards Program. The committee's evaluation has not included the Geomagnetism Program, which is the smallest of the five geohazard programs ($2 million per year budget). However, the committee notes the complementary efforts that have gone into applying the investments in networking and software development by the Earthquake Hazards Program to geomagnetic monitoring systems.

It is important to underscore that the challenge of hazard activity coordination extends well beyond the USGS. There has been some excellent progress in coordinating across Federal agencies that deal with hazards and disasters. In particular, the committee lauds the work to enhance tsunami monitoring and warning systems through USGS and NOAA's National Weather Service (NWS) and the work for debris flow monitoring within the Landslide Hazard Program and the NWS. The anticipated work with FEMA regarding risk assessment and risk determination will be most useful if it addresses national and regional trends and develops tools that can be incorporated by state and local governments and agencies.

Southern California Multi-Hazard Demonstration Project and San Francisco Bay Area

The committee applauds the USGS for moving ahead on a multi-hazard demonstration project in Southern California. This project will provide information for emergency managers for cities and counties, utilities and infrastructure owners, private companies, and federal government agencies for scenario planning. The initial focus will be on integrating existing research to generate scenarios of coupled hazards, such as earthquakes triggering wildfires, or storms that cause coastal erosion and debris flows in wildfire burned areas. In its 2005 report, the committee strongly encouraged the USGS, the Secretary of the Interior, the Office of Management and Budget, and Congress to move forward vigorously with the Natural Hazards Initiative in the USGS fiscal year 2007 budget.

The SESAC encourages the demonstration project to expand the multi-hazard and geographic scope to eventually include the San Francisco Bay Area multi-hazards as part of this effort; this was part of the SESAC recommendation #1 in the 2005 annual report. This topic was discussed during the April 18, 20006 Senate Field Hearing in

San Francisco, where the Senate committee seemed especially concerned and pledged to press for the support needed to address these seismic safety problems in California.

We recommend the USGS undertake a complete analysis of the consequences of catastrophic earthquakes in the San Francisco Bay Area and in Southern California to identify where and when the breaking points for an extreme earthquake disaster in California will be. The lessons learned in this demonstration project would be applicable to all national extreme disasters. The action plan to conduct multi-hazard demonstration projects a sound concept when the goals of the project are well defined. The devil will be in the details, of course. The committee emphasizes the need to identify specific policy decisions that could be better informed by this project, and to engage infrastructure owners in the project.

One of the challenges for the USGS program coordinators is to quantify the benefits-to-cost of avoiding disasters and expediting recovery. Indirect costs and the inability to count lives actually saved require developing proxy benchmarks for performance measurements. The committee suggests that the multi-hazards demonstration projects should include research goals to address determination of benefit-to-cost ratios for indirect losses and that this work be closely coordinated through their local partners.

Landslide Hazard Program

There is a legacy of fractionation within the USGS hazards programs in their dealing with the process of landslides. The Volcano Hazard Program long ago claimed volcano-induced mass movement as part of their program, and the Earthquake Hazard Program claimed co-seismic landslide hazards in their program. Other USGS programs have also laid claim to areas of landslide research. It is not evident to an outside reviewer that there is much, if any, program coordination or science or technology sharing between these various programs for landslide hazard characterization and mitigation. It is imperative that the USGS Landslide Hazards Program take a lead role in coordinating these many disparate efforts within the Survey in order to improve this situation.

The committee applauds the recent work to incorporate volcano monitoring and information dissemination expertise into debris flow monitoring in southern California – this is a move in the right direction to avoid redundancy and confusion. As noted above, the partnerships being developed in southern California with the National Weather Service hold the potential for a major advance in the Survey's ability to generate valuable to be expanded to include other at-risk areas of the Nation.

Integration of Earthquake Hazard and Volcano Hazard Activities

The EHP comprises seven regional USGS offices, including the National Earthquake Information Center in Golden, CO, eight earthquake monitoring regions supported by local university-based programs, a national backbone earthquake monitoring network, internal research, an external grants program, and a public outreach component and information products. The VHP comprises five volcano observatories and similar national coordination and external community involvement. Because volcanoes and earthquakes are tectonically related and geographically correlated, it is natural to suggest that there be administrative and operational overlap between the programs.

However, from a risk reduction standpoint, earthquake and volcano hazards are distinct phenomena with different vulnerability profiles and early warning possibilities, requiring specialized hazard and risk assessment and customer outreach. Further, though volcano and earthquake monitoring networks use similar technologies, they are very different operationally and use different analytical methods. For example, volcano monitoring networks also use technologies such as "gas sniffers" that are not relevant to earthquake monitoring. The following sections outline the scope of differences.

Earthquakes and volcanic eruptions are characterized in different ways: The occurrence of earthquakes along fault segments (both mapped and unmapped) suggests a distributed geographic framework for assessing hazard. Additionally, the area directly impacted by a particular earthquake is a function of earthquake source characteristics, and seismic wave propagation through the local/regional geology. Earthquake hazard assessment thus depends on understanding the potential locations of medium-to-great earthquakes on particular fault segments and the amplifying and attenuating effects of the local terrain and geology on ground shaking. Particular events are also of relatively short duration, occurring at most over a few minutes, and usually lead to aftershock sequences that comprise individual, smaller events occurring days to weeks afterward.

In contrast, volcanic eruptions initiate in relatively localized areas, which for the most part are well known. The area of impact depends on the type of eruption, its explosive size, and the dispersal of debris and lava flows over land or ash in the atmosphere. Eruptions may be accompanied by earthquakes and tremor, but these are more indicative of the progress of the eruption rather than threats by themselves. Eruptions vary in duration, can extend for years, and do not necessarily decay in time like aftershocks. A local understanding of topography and wind direction is important in assessing volcanic risk, and mass movement and weather conditions need to be updated and monitored for each eruption. Volcanic risk assessment includes mapping previous eruptions and understanding the dynamics of debris flows and mass wasting events in the local topography.

Moreover, volcanologists claim (with a track record of some successful predictions) that individual volcanoes exhibit precursory behavior that with proper monitoring can provide a semblance of early warning extending over several hours, days or even weeks.

Earthquake early warning as it is currently formulated depends on rapid detection of the event and the inherent delays in wave propagation, providing at most a few tens of seconds of warning.

The monitoring networks needed for earthquakes and volcanoes, though using similar instrumentation (seismometers, for example), are deployed and operate very differently. Earthquake monitoring networks must combine international, national, regional and local in situ observations, and thus are multi-scale. Volcano monitoring networks are very much specific to the particular volcano or volcanic source under observation, and are much more localized. In some cases, such as in Cascadia and Alaska, volcano monitoring and earthquake monitoring networks can be partially integrated to improve coverage, but the analysis of volcanic events still diverges sufficiently from the analysis of ordinary earthquakes that different operational requirements accrue.

The different phenomenologies indicate that there are non-overlapping operational requirements during the course of an event, in early warning, and in the characterization of potential source regions. Earthquakes must be identified in a matter of seconds (locally), and ground-shaking measurements from local instrumentation must be acquired, analyzed and integrated with other observations in near-real-time. Volcanoes usually give more warning, but a more diverse assortment of readings must be assimilated and integrated into a data product or prediction of a catastrophic eruption. For example, local and regional atmospheric conditions must be assessed, especially if there is the potential for an ash cloud to interfere with aircraft. The FAA asks for 18-hour warnings five minutes after an eruption is predicted. These analytical differences require differently trained operational personnel working under time constraints that are different from those of the NEIC.

Recognizing this, the EHP and VHP managers have implemented different threat warning regimes. The five volcano observatories will be using a unified threat assessment system. The earthquake monitoring regions operate in different tectonic environments, obviating a strictly uniform approach.

Risk assessments are different: Volcanic eruption risks and earthquake risks are different. An important component of earthquake risk in the United States is the fragility of buildings and infrastructure, with secondary risks associated with the loss of livelihoods and economic disruption. A majority of the aggregate earthquake risk profile in the U.S. is associated with urban areas in the West and Alaska. In contrast, except in the Pacific Northwest, the direct risk from volcanic eruptions and debris flows in more geographically compact, and affects more isolated, less densely populated areas (notwithstanding the stunning visual impact of a volcanic eruption in progress which, unlike earthquakes, is often captured by the media as it is taking place). A significant component of volcanic risk arises from the dispersal of ash into the atmosphere, which can disrupt population and agricultural centers far from the source and affect aviation.

The different risks require different assessment methodologies, including different aspects of fragility and economic impact, and different analysis of monitoring data.

Relationship to emergency management and responders: While it is likely that EHP and VHP operations will interact with the same emergency personnel and first responders, the information provided to them by each program will be very different in style and timing. Both programs will need to be fine-tuned to local conditions and circumstances, and both will need to interact with national-level officials, but the relationships between information and action will be different. Again, the EHP and VHP will each have to maintain distinct expertise in the development of outreach and emergency response interactions.

Integration and overlap: Areas of possible integration include suggestions related to coherent data and information exchange, and presenting a more uniform interface to the public and other stakeholders. Also, in particular in areas where volcanic and earthquake hazards are co-located, several suggestions are made for monitoring network operations.

Network operations and data exchange: Some basic instrumentation and telecommunications infrastructure can be shared in areas where volcano and earthquake monitoring networks overlap. The relatively localized volcano monitoring networks can piggyback on the more extensive telecommunications and telemetry backbone needed for the more distributed earthquake monitoring instrumentation. In some places, bandwidth requirements for continuous high-frequency monitoring may exceed backbone capacity, but this is likely to evolve. To promote scientific collaborations between volcanologists and seismologists, the volcano data should be integrated into the existing data management centers that archive earthquake data and make it available to investigators. There are few technical barriers that would prevent this from occurring. Protocols for data sharing should be designed to ensure that the appropriate analysis is done when large earthquakes are associated with volcanic activity. Some of the event location, array processing and waveform analysis techniques designed for earthquake characterization could be installed in the volcano observatories. The real-time analysis system (HYDRA) under development at the National Earthquake Information Center should be evaluated for applications in the volcano observatories. This is a considerable and useful software investment by the EHP that could have value to the VHP. Associated or complementary geophysical data should also be archived in the data management centers. Coordination and sharing of real-time seismic and geodetic monitoring data would enhance the effectiveness of both programs.

Risk identification and assessments: While the risk phenomenology is different, certain baseline assessments and data are needed by both the VHP and the EHP risk assessment enterprises. In particular, base maps of buildings, infrastructure, topography, geology, hydrography and so on could all be assimilated and aggregated into a common base risk mapping system. The VHP and EHP would contribute unique overlays. The VHP and EHP could share a common GIS unit, subject to considerable design and rectification of real-time needs.

Aggregate multi-hazard risk assessment: The public awareness and response to geophysical risk in some regions of the country should not discriminate between

volcanoes and earthquakes -- or other hazards -- in the process of developing meaningful mitigation strategies and the resources to implement them. For example, landslides and debris flows on Mount Rainier, which could affect the Seattle-Tacoma area, could be triggered by an earthquake, volcanic eruption, shallow intrusion that melts ice, or extreme weather events. Thus the VHP and EHP should work with the other hazard programs to establish uniform risk metrics and present a more uniform profile to policymakers and other stakeholders.

Training and outreach to emergency management (EM) personnel in non-operational modes: While the information needs and interventions of EM personnel responding to volcanic eruptions or earthquakes might be different, they will most likely be the same local and community institutions. Thus this particular stakeholder group should have a uniform interaction with USGS personnel and offices providing information. Before a disaster, the VHP and EHP should establish a common means of communicating with EM personnel and offices. This should include explicit design of the means to distribute authoritative information in the event of a disaster. In many cases, state and local EM personnel rely upon their state geological surveys to interpret technical information from the USGS geohazards groups. The USGS should always include state geological surveys in their communications with state and local officials.

Merged External Grants Programs: The EHP benefits from a well-established peer-reviewed extramural grants program, which closes the gap between basic research and applications, and provides a steady supply of highly trained individuals ready to work in government, in academia, and in the private sector. Therefore, the various hazard programs should consider ways in which individual grants programs can merge and complement one another.

Strengthening the National Volcano Hazards Program: The Volcano Hazard Program consists of five volcano observatories that operate as separate, and very individual, entities. This situation is a result of both the ad hoc nature of the creation of the observatories and the timing of their various creations. It is not entirely bad as the scope of volcano hazards and the geographic locations are quite extensive and demanding; however, to the public and the outside observer it often appears that there are five volcano hazard programs, not one. The development of a unified alert system is a major step forward in changing this perception.

The committee strongly supports the recent work to quantify the volcano hazards on a national level and develop a comprehensive plan for monitoring and disseminating volcano hazard and risk information through the National Volcano Early Warning System (NVEWS) process. It is important for the Volcano Hazard Program to strengthen internal continuity and coordination before there can be more extensive cross-program coordination.

In that light, one aspect of the NVEWS process needs to be re-evaluated, and that is the recommendation to develop a separate 24/7 volcano monitoring operation. More consideration needs to be given on how this goal might be coordinated across existing

hazards monitoring activities, particularly in light of the recent standing up of a 24/7 operation at the National Earthquake Information Center.

The Volcano Hazards Program has very good coordination with the Earthquake Hazards Program in jointly operating the seismic monitoring in most volcanic areas and should be encouraged to continue searching for beneficial cooperation in all the regions that contain volcanic hazards. This coordination in particular recognizes the need to avoid redundancy in technology and the importance of cooperating on research projects.

RECOMMENDATIONS

The following activities have the highest potential to reduce earthquake losses in the United States over the next five years:

1. **Development of National Risk-Targeted Ground Motion Maps**.
The SESAC encourages the development of risk-targeted ground motion maps as a means for enhancing the ways in which risk is judged by both the public and private sectors, and suggests that the needs of potential users and potential actions from them be carefully considered in its development.

2. Full Funding of ANSS
As stated in past Committee reports, the SESAC strongly recommends to the Director of USGS that full funding of the ANSS at the level authorized in the current NEHRP legislation be appropriated. The USGS must make a commitment to work through the Department of the Interior and the Office of Management and Budget to ensure that this objective is met.

3. Expedite the Southern California Multi-Hazards Demonstration Project
The SESAC endorses the decision by the USGS to proceed with a multi-hazard demonstration project in Southern California. In addition, the SESAC encourages the demonstration project to expand the multi-hazard scope to eventually include the San Francisco Bay Area multi-hazards as part of this effort.