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April 7, 2008

Dr. Mark Myers, Director
U.S. Geological Survey
12201 Sunrise Valley Drive, Mail Stop 100
Reston, VA 20192

Dear Director Myers:

On behalf of the members of the Scientific Earthquake Studies Advisory Committee (SESAC), I present the committee's sixth annual report on the U.S. Geological Survey (USGS) Earthquake Hazards Program for transmission to Congress, the Department of the Interior, and USGS's federal partner agencies in the National Earthquake Hazards Reduction Program (NEHRP).

The committee met twice in 2007, hearing presentations from USGS staff, partners and stakeholders. As stated in our report, the USGS Earthquake Hazards Program faces challenges and opportunities that are almost unprecedented over its 30-year duration. Meeting these challenges, and capitalizing on these opportunities, should be the highest priorities for the Earthquake Hazards Program. The SESAC has four primary recommendations:

1. As stated in past Committee reports, the SESAC strongly recommends 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.
2. The SESAC endorses the decision by the USGS to proceed with a multi-hazard demonstration project in Southern California first funded by Congress in FY 2007 and recommends that these efforts will be both strengthened and sustained. The SESAC encourages the demonstration project to expand the multi-hazard scope to include other high-risk areas as part of this effort.
3. It is imperative for the USGS to develop a comprehensive monitoring, analysis and research program to study the significance of episodic tremor and slip events -- one of the most exciting geophysical discoveries since the plate tectonics revolution. It is especially

important to better understand the significance of this phenomenon with respect to changes of earthquake probability.

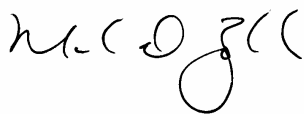
4. The ability of the USGS to meet a number of critical mission components is seriously threatened by the steady decrease in the number of research scientists actively engaged in the Earthquake Hazards Program. Hence, through hiring and direct support, it is essential for the USGS to be able to fulfill its mission for providing critical earth science research within NEHRP.

Although the attached report covers the committee's activities in 2007, developments in the new year underscore the challenges faced by the program, in particular the February release of the President's budget for fiscal year 2009. The budget eliminates the current year's increases for the multi-hazards initiative and Global Seismographic Network. It cuts deeply into the program's support for external research.

This committee has consistently emphasized the importance of maintaining and enhancing the external component of the earthquake program. The committee's 2006 annual report noted that: "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." The 2005 report stated: "Many of the advances in earthquake hazard assessments, monitoring, and notification now put into practice were made possible by research supported through the National Earthquake Hazard Reduction Program... It is imperative the program receives funding to continue to support and coordinate internal and external research." Likewise, the current and previous report both emphasize the value of the multi-hazard demonstration project and call for expansion, not contraction, of this important initiative.

As you prepare your budget for fiscal year 2010, the committee hopes that you will shift from your present course and focus on building this tremendously important program. The USGS has a great opportunity to seize.

Best regards,



Mark D. Zoback
Benjamin M. Page Professor of Earth Sciences

cc: Scientific Earthquake Studies Advisory Committee members
Peter Lyttle, Acting Associate Director for Geology
Linda Gundersen, Chief Scientist for Geology
David Applegate, USGS Earthquake Hazards Program

Annual Report for 2007 of the Scientific Earthquake Studies Advisory Committee to the Director of the U. S. Geological Survey

The Scientific Earthquake Studies Advisory Committee (SESAC) is issuing this annual report for 2007 to the Director of the U. S. Geological Survey (USGS) for transmission to Congress. The report describes the Committee's activities during 2007 and addresses policy issues and matters relating to the participation of the USGS in the National Earthquake Hazards Reduction Program (NEHRP). Committee members are listed in Appendix I at the end of the report.

Introduction

Since establishment of the National Earthquake Hazard Reduction Program in 1977 (Public Law 95-124), the mission of the USGS within NEHRP has been: *to develop effective measures for earthquake hazards reduction, promote their adoption, and improve the understanding of earthquakes and their effects on communities, buildings, structures, and lifelines, as well as to provide the Earth science content needed for achieving these goals through research and the application of research results, through earthquake hazard assessments, and through earthquake monitoring and notification.*

Despite decades of inadequate funding and steady erosion of scientific personnel and technical support staff, the USGS can still claim to have the foremost earthquake science program in the world. The SESAC is pleased to report that thanks to its extraordinarily dedicated and hard-working staff, the USGS Earthquake Hazards Program continues to meet its statutory missions, if not without increasing difficulty. This said, the SESAC is struck by the degree to which this program faces challenges and opportunities that are almost unprecedented over its 30-year duration. Meeting these challenges, and capitalizing on these opportunities, should be the highest priorities for the Earthquake Hazards Program. The SESAC has four primary recommendations:

1. Today, the USGS produces in real-time, or near real-time, an unprecedented suite of Web-based information products on earthquake effects that assist disaster response agencies. ShakeMap, ShakeCast and the Prompt Assessment of Global Earthquakes for Response (PAGER) system provide specific, detailed information on earthquake effects that could not have been imagined at the time of the 1989 Loma Prieta (63 fatalities, \$10 billion in losses), 1994 Northridge (60 fatalities, \$40 billion in losses) and the 1995 Kobe, Japan (6,400 fatalities, \$150 billion in losses) earthquakes. Capabilities were improved substantially with funding provided following the 2004 Sumatran (230,000 fatalities) earthquake and tsunami. Within the context of the NEHRP strategic plan, currently in preparation, the USGS *monitors and rapidly reports on earthquakes and their shaking intensity in the United States and abroad.* The only mechanism for the USGS to be able to continue to carry out this mission and continue to provide the types of data products that will dramatically lower earthquake effects is through **full funding of the Advanced National Seismic System (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.
2. The devastating fires during the summer of 2007 in Southern California give obvious testimony for all disaster response entities to be able to respond to hazards threatening large populations centers, be it the result of earthquakes, volcanic eruptions, fire or flood. It is critically-important to **build on the successful 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 first funded by Congress in 2007 and recommends that these efforts will be both strengthened and sustained. The SESAC encourages the demonstration project to expand the multi-hazard scope to include other high-risk areas as part of this effort.
 3. The documentation of non-volcanic tremor and associated deep, episodic aseismic slip events in a number of subduction zones around the world represents one of the most exciting geophysical discoveries since the plate tectonics paradigm was firmly established in the 1960's. Now referred to as ETS (episodic tremor and slip), this remarkable geophysical phenomenon has been particularly well-documented in the Cascadia subduction zone that threatens the Pacific Northwest and western British Columbia. Deep episodic tremor has now been found beneath the San Andreas Fault in central California. It is imperative for the USGS **to develop a comprehensive monitoring, analysis and research program** to study the significance of ETS events and understand their significance with respect to changes of earthquake probability.
 4. The ability of the USGS to meet a number of critical mission components are seriously threatened by the steady decrease in the number of research scientists actively engaged in the Earthquake Hazards Program. From a high of over 400 staff supported in the 1980's to 220 at the end of 2007, this decrease has made it increasingly difficult for the program to meet its steady-state responsibilities of monitoring and reporting. It is also becoming increasingly difficult to continue the development of innovative data products such as ShakeMap, ShakeCast and PAGER and state-of-the-art national and regional seismic hazard maps. More importantly, when new scientific discoveries are made, such as the discovery of episodic tremor and slip, it is nearly impossible for the remaining USGS research staff to play the critical role appropriate for the USGS in carrying out the necessary research. Hence, **through hiring and direct support, it is essential for the USGS to be able to fulfill its mission for providing critical earth science research within NEHRP.**

SESAC MANDATE

The Scientific Earthquake Studies Advisory Committee was appointed and charged, through Public Law 106-503 re-authorizing NEHRP, to review 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 2007

The SESAC met twice. The first meeting, held in February 12-13, 2007, at USGS headquarters in Reston, Virginia, included briefings on the USGS Earthquake Hazards Program and strategic planning, status of teams supported by the program, NEHRP partnership, national seismic hazard maps, National Earthquake Prediction Evaluation Council (NEPEC), and Southern California Multi-Hazards Demonstration Project.

The second meeting was held on September 5-6, 2007, in Paso Robles, California. The meeting, which included a site visit to the San Andreas Fault Observatory at Depth (SAFOD) in Parkfield, focused on a review of USGS geodesy and deformation activities, the future of USGS activities at Parkfield, and briefings on the Advanced National Seismic System (ANSS), NEPEC, national seismic hazard maps, and the demonstration project. The ANSS Steering Committee, a subcommittee of SESAC that provides guidance on network modernization, met twice in 2007. A summary of its activities is included in this report.

In addition to these meetings, SESAC Chairman Mark Zoback serves as an *ex officio* member of the newly established Advisory Committee on Earthquake Hazards Reduction, which was established by the 2004 re-authorization of NEHRP to provide guidance to all four NEHRP agencies. He attended the committee's October 23-24, 2007, meeting held at the USGS National Earthquake Information Center in Golden, Colorado.

In the sections that follow, this report expands upon the four recommendations summarized above and addresses a number of topics of particular import to the USGS Earthquake Hazards Program. These include:

- The activities and recommendations from the ANSS Steering Committee;
- The National Earthquake Prediction Evaluation Council (NEPEC) review of time-varying earthquake probabilities in California and of implications of episodic tremor and slip in the Pacific Northwest;
- Progress on the Multi-Hazards Demonstration Project in Southern California;
- The status of staff planning in the teams supported by the program;
- USGS interactions with its partner NEHRP agencies;
- Revitalizing the once world-leading USGS role in geodetic research and monitoring;
- Development of earthquake early warning systems (and how they might be used);
- The status of developing a new generation of national seismic hazard maps; and

- An overview of earthquake research plans in the Parkfield area.

ANSS Steering Committee Report

The ANSS product PAGER (Prompt Assessment of Global Earthquake Response) provides an unprecedented opportunity for assessing the impact an earthquake has on the nearby population and infrastructure. PAGER has become the focal point of activity for many products of ANSS (Figure 1). It allows the many outputs of the monitoring system, from earthquake locations to ShakeMap, to feed into a product that relates directly to the impact on people, which will allow policy makers and response leaders to anticipate and react to the severity of the situation.

The development of PAGER, as well as the accuracy of its assessments, relies on the results of basic research in many areas. For example, the accurate description of the earthquake itself, in terms of its location, geometry and slip is critical to forecasting the extent of shaking. The shaking has to be coupled with loss models —empirical and analytical— and population densities to assess the impact on the environment. Of course, all of this information has to be passed on to the emergency responders and the policy makers to ensure that the response is appropriate for the situation.

During the past year, two earthquakes occurred that provided ANSS with opportunities to evaluate the effectiveness of recent targeted improvements to the system. In the Caribbean, the last of the nine new broadband stations funded after the Indonesian earthquake and tsunami of 2004 was installed last fall. All of the new stations were operational for the magnitude 7.4 Martinique earthquake on November 29, 2007. With the full complement of regional stations, NEIC had a first automatic location in just over one minute, with a final reviewed solution at 12 minutes after origin. This final solution triggered PAGER warnings and activated the NEIC’s extensive call list just 14 minutes after origin.

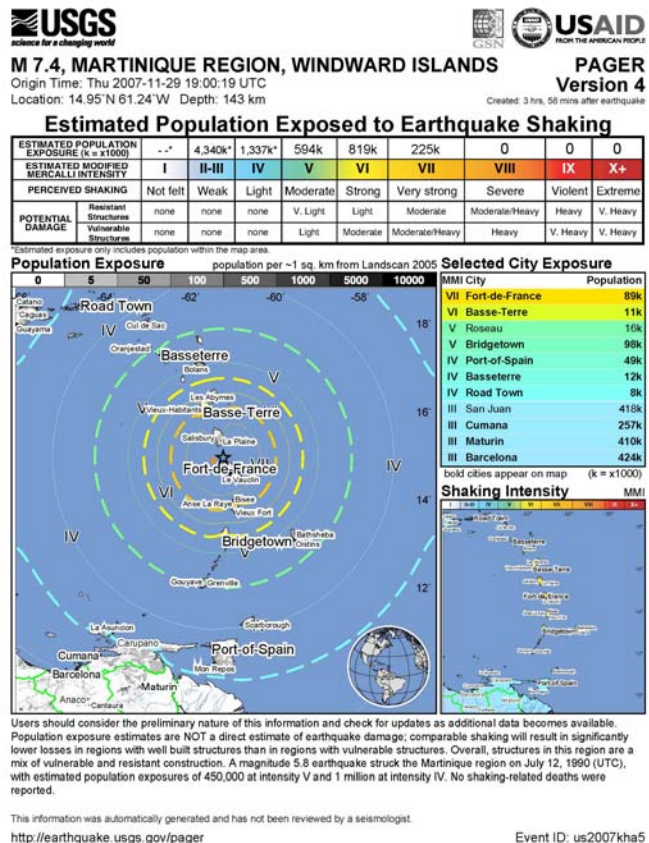


Figure 1. Example of PAGER output.

On October 30, 2007 the Alum Rock, California, earthquake of magnitude 5.4 provided a robust test of improvements to California Integrated Seismic Network (CISN) software. The upgraded software performed very impressively, with over 84,000 distributed messages detailing the final location and magnitude at 5:46 minutes after origin. A first motion focal mechanism, moment tensor solution from Berkeley, "Did You Feel It?" page, and a statement of aftershock probabilities were all posted to the web within the next 5 minutes. There were 63,858 Internet responses to "Did You Feel It?" following this event. With the exception of a delay in posting the ShakeMap, caused entirely by web server problems, the Alum Rock earthquake has provided the USGS with a thorough test of the upgraded CISN software that validates ANSS plans to upgrade CISN software at other data centers.

In addition to these rapid web-posted products, the Alum Rock event demonstrated the viability of the new Center for Engineering Strong Motion Data, jointly operated with the California Geological Survey. The Northern California Network has now pushed all of their recorded strong motion data automatically to this new Center, making virtually all unprocessed strong motion data available within the first 11 minutes following an event.

ANSS has completed the installation of accelerometers and other recording instrumentation in eight structures (2 buildings in the San Francisco Bay area, 2 buildings in the Los Angeles area, 2 buildings and 1 bridge in Anchorage, and 1 bridge in Missouri). Seven more structures (6 buildings and 1 bridge) will be completed in 2008 and 2009. A large number of accelerometers have been -- or will be -- placed throughout each of these structures in order to sufficiently capture their dynamic response during weak, moderate and strong earthquake ground motions. Such information will enable structural engineers to more accurately assess structural performance and improve seismic design standards. Unfortunately, because dense arrays of instruments are needed to fully capture the required response data, the cost of instrumenting a structure is much higher (by an order of magnitude) than the cost of instrumenting a single free field ground-motion station. Therefore, unless substantially more funds are made available, including funds for continual maintenance, the ANSS structural monitoring goals for continued expansion cannot be met, and the program will stagnate. This statement applies, in turn, to the ANSS regional networks, which are struggling to modernize their aging infrastructure and take advantage of opportunities such as conversion of temporary USArray station deployments into permanent network additions.

The committee remains concerned about the management of the National Strong Motion Project (NSMP), which should play an important role within ANSS in support of the earthquake engineering community. If USGS is to fully implement the ANSS vision for structural monitoring and collection of critically needed ground motion data, this project may need to be restructured and its staffing expanded. The Committee is enthusiastic about the potential for expanding ANSS products and tools for engineers, and encourages USGS to pursue a PAGER-like approach in this area.

All of the momentum that ANSS has gained, despite its under-funded mandate, is now in danger of being lost, since ANSS will fail to reach its stated operational goals and full

complement of instruments. The projected ANSS budgets will allow at most a status quo of the ANSS activities. This program was the most highly rated of all major investments in the Department of the Interior in 2007, and yet it continues to struggle with a budget that is about one sixth of what is needed in order for it to be successfully and fully implemented. ANSS is on the cusp of becoming one of the research jewels in the USGS, but it cannot be expected to reach its goals without adequate funding.

National Earthquake Prediction Evaluation Council Activities

Following a recommendation from this committee, the USGS reestablished the National Earthquake Prediction Evaluation Council (NEPEC) in 2006 to serve as a forum for review of earthquake predictions and probabilistic forecasts of earthquake activity. The NEPEC provides advice to the Director on these matters, and keeps the SESAC informed of its findings through its Chair, SESAC member Jim Dieterich. In 2007 NEPEC provided external oversight of the review process for the long-term probabilistic earthquake forecast of the Working Group on California Earthquake Probabilities (WGCEP) and hosted a workshop to gather information on research into periodic strain events discovered to occur in the Pacific-Northwest subduction zone.

Episodic tremor and slip

The Cascadia subduction zone, which extends along the Pacific Northwest coast from southern British Columbia to northern California, is understood to be the source region of great subduction earthquakes. The megathrust interface is locked to depths of about 25 kilometers, and aseismic slip at greater depths transfers stress onto the locked portion, building toward the next great earthquake. Evidence has emerged in recent years that periodic aseismic slip events occur near the base of the locked zone. These events extend hundreds of kilometers along strike and tens of kilometers down dip along the megathrust, and are associated with subtle reverberatory seismic signals known as tremor. These episodic tremor and slip (ETS) events occur every few months, and are now recognized along most of the length of the Cascadia subduction zone as well as in Japan and elsewhere. Inasmuch as each ETS event loads the locked part of the megathrust, understanding their role in promoting, if not triggering, future large earthquakes is an important and scientifically intriguing challenge. This has become a subject of intense research and the rapid progress in understanding the characteristics of ETS can be attributed to the remarkable improvements in the volume and quality of seismic and geodetic data from the USGS, Canada, and especially from the Plate Boundary Observatory component of EarthScope.

The USGS and the Oregon Department of Geology and Minerals Industries hosted a workshop in Portland in May 2007, at which NEPEC received briefings on the current state of scientific research on ETS and engaged emergency management officials in discussions of the policy implications of ETS and how the scientific and emergency management communities should deal with information suggesting elevated earthquake risk. NEPEC has formulated several recommendations, including: that the USGS explore means for improving the coordination and focus of its studies on the temporal variations

of tectonic activity within the subduction zone, with the aim of developing a means of assessing this behavior and flagging any anomalies or changes that might occur; that the USGS assume a leadership role in this field, including the designation of an individual to promote coordination; that the USGS convene workshops to facilitate communication among researchers active in this field; and that, should any significant changes or anomalies in the current pattern of behavior be observed, the USGS focus immediate attention on assessing the importance of this change for future seismic activity and defining national needs for a comprehensive ETS monitoring system in Cascadia and other parts of the country where ETS may be occurring.

Working group on California Earthquake Probabilities

The NEPEC was asked by the USGS to provide oversight of the review process for the Working Group on California Earthquake Probabilities (WGCEP) assessment of the probabilities of future earthquakes in California. The WGCEP project is a joint undertaking of the USGS, the California Geological Survey and the Southern California Earthquake Center, with support from the California Earthquake Authority. The results of this project will provide the basis for the time-independent characterization of earthquake hazard to be used in the USGS National Seismic Hazard Map (NSHM), and as a time-dependent model to be used by the California Earthquake Authority in setting rates for residential earthquake insurance. Additionally, based on experience with previous working group studies it is expected that this assessment will provide the basis for a variety of earthquake mitigation and response activities. NEPEC provided similar oversight to previous WGCEP projects in 1988 and 1990. A NEPEC subcommittee attended meetings of the WGCEP and received briefings from the Working Group's Scientific Review Panel, two members of which are also members of NEPEC.

The current assessment updates previous studies, incorporates major methodological developments, and provides the first comprehensive state-wide coverage of seismic hazards. NEPEC has stated that the formal review processes established by the WGCEP and its Management Oversight Committee were appropriate and professional. NEPEC members provided comments on a draft version of the WGCEP report, and the Council has scheduled a review of the final document in order to verify that the important concerns raised in review were addressed by the Working Group, and to provide the USGS with advice on the quality of the analysis and on what avenues of research will be most fruitful in improving the earthquake rupture forecasts that will underlie future USGS hazard products.

Multi-Hazards Demonstration Project in Southern California

The committee received updates on this activity at both meetings in 2007 as this is an important new thrust for the Earthquake Hazards Program. During 2007-2008, the major activity of the Multi-Hazard Demonstration Project is the development of an earthquake planning scenario for southern California. The scenario is a multi-disciplinary effort that includes input from seismologists, geologists, engineers and lifeline operators.

The scenario assumes a magnitude 7.8 earthquake on the southern San Andreas Fault. Fault rupture begins near the Salton Sea and propagates northwestward past San Bernardino to just north of Palmdale. Ground motions have been calculated based on the assumed rupture and predict strong long-period ground motions imparted to the Los Angeles basin could cause considerable damage to high-rise and older mid-rise buildings. The general distribution of building damage is also being evaluated. Projected casualties and economic and social consequences are being assessed for incorporation into the document.

The fault rupture crosses several major lifeline corridors, such as the Palmdale/Highway 14, Cajon Pass, San Geronio Pass and the Interstate-10 Highway area near Indio. Highways, rail lines, natural gas and petroleum product pipelines, power transmission lines, and optical fiber lines converge at these corridors. Damage to one element can cause delays in repairing the damage to the others. The limited time allotment of the scenario project does not permit detailed analysis of liquefaction and landslide hazards throughout the southern California planning area. As part of the demonstration project, however, detailed ground failure analyses were conducted in the vicinity of these lifeline corridors. This will permit lifeline operators to evaluate downtimes with a more complete damage assessment in these critical areas than is possible elsewhere.

The report is scheduled to be released on May 5, 2008. Damage assessments from the scenario will be incorporated into the 2008 southern-California-wide Golden Guardian emergency response exercise, which will occur in mid-November, 2008 and last for several days. The committee suggests that USGS should emphasize this as a planning event, not necessarily the most likely or historic but leading to an awareness of the consequences with attributes that are useful for planning.

A primary focus of new Earthquake Hazards Program External funding in FY 2007 is directed toward the Southern California Earthquake Center's (SCEC) Southern San Andreas Fault Evaluation (SoSAFE) project to better define the fault's slip rate and earthquake history of the past 2000 years. Preliminary funding has enabled the extension of the earthquake history at several sites to six previous events and identified a whole new set of keystone sites. The committee compliments the SoSAFE effort for instituting a rigorous in-field scientific review process while paleo-seismic trenches are open.

Staffing

At its meeting in Reston, the committee heard presentations from the chiefs of the Western Region Earthquake Hazards Team and Central Region Geologic Hazards Team, which together represent the bulk of the internal funding commitment of the Earthquake Hazards Program.

For the western team, the committee was told that meeting salaries was a major challenge with the result that even after a buy-out in 2006, there is little or no hiring taking place. The committee is concerned about the overall age of the staff as the team needs to be able to plan for the future of projects. This is particularly troubling in that the buy-outs were

designed to eventually allow new staff to be hired. The committee is concerned about the lack of continuity between older staff and replacement hires. While the committee recognizes the value of the emeritus program, it can only work if there are replacements coming on board. The committee is also concerned about the lack of a staffing plan for the western team and intends to examine this matter further in 2008. The ANSS National Strong Motion Project is a particular concern as is the lack of engineering expertise.

From a staffing perspective, the Geologic Hazards Team in the Central Region is clearly in a different place from the Earthquake Hazards Team. Different demographics have led to substantial turnover in recent years, and the committee compliments the team for having moved through this transition by following a staffing plan to prioritize new hires and achieve a good balance of scientists, operations, and support staff, so scientists have the support they need. The committee is particularly pleased to hear that students and post-doctoral appointments are being used to engage early-career scientists and generate a pool of talent for permanent positions. That said, continued funding challenges make key components of the Geologic Hazards Team highly dependent on funding from other Federal agencies. One important example is the staff working with financial support U.S. Nuclear Regulatory Commission on license applications.

NEHRP Activities

At the Reston meeting, the committee received an update on NEHRP activities from NEHRP Director Jack Hayes with the National Institute of Standards and Technology. The committee is pleased that the Interagency Coordinating Committee (ICC), comprised of agency heads along with the heads of the White House Office of Science and Technology Policy and Office of Management and Budget, enables follow-up from agency leadership so that working-level issues move forward. The committee is also pleased that the NEHRP-wide external Advisory Committee for Earthquake Hazards Reduction (ACEHR) has been established and began meeting in 2007. The chair of SESAC is an ex officio member of ACEHR, and several former SESAC members are now on ACEHR. The committee applauds the efforts to establish NEHRP priorities for strengthening interagency activities, but is concerned that key focus areas such as lifelines are not included in the areas of interest. The committee encourages joint workshops as a way to set joint research agenda and show that NEHRP is greater than the sum of its parts. The proposed scenario workshop is an appropriate topic; to be effective scenarios need to involve local jurisdictions and state agencies in their development.

The Role of Geodesy in the USGS Earthquake Hazards Program

SESAC recognizes the prominent role of geodesy in the USGS Earthquake Hazards program and believes that geodetic observations and research will continue to be necessary to fulfill the Program's mission and to better understand the full range of earthquake behavior. Obtaining and using real-time multi-parameter deformation data is essential to meeting the USGS hazard reduction responsibility. It is important that the USGS maintain its geodesy scientific program in parallel with monitoring and event response.

The role of EarthScope's Plate Boundary Observatory (PBO) in USGS monitoring and response must be defined. While PBO offers the advantage of many new instruments and routine processing for some scientific needs, PBO's objectives are related to fundamental research and not hazard response. USGS needs greater accuracy and overall system robustness to fulfill its roll for hazard alerts. A solution may be to choose priority PBO sites for hardening, improved telemetry and reduced latency in data streaming in order to effectively augment USGS capabilities, especially with respect to real-time data transmission, analysis and interpretation. This will require resource allocation to take advantage of PBO assets.

The USGS geodesy program faces serious challenges of dwindling staff and aging equipment. Adequate staff and monetary support must be allocated in order to fulfill the USGS monitoring and response role, but the extent of this role needs to be more accurately defined to take the Program into the future.

- **SESAC recommends that the USGS Earthquake Hazards Program develop a white paper that clearly defines the future goals of the USGS in geodetic program in carrying out its programmatic mission within NEHRP and the staffing and budget requirements to achieve those goals.**

Earthquake Early Warning

Outside of the United States, significant progress has been made in the development of earthquake early warning systems during the last few years. Designed to provide alerts ahead of the arrival of strong shaking in heavily populated areas, such systems are currently active in five countries (Japan, Mexico, Turkey, Italy, and Romania) and are under development in six others (Taiwan, Iceland, Switzerland, Greece, Egypt, and India). The European Union's SAFER (Seismic eArly warning For EuRope) project is a consortium of 23 partners from 14 European and other countries to develop and implement earthquake early warning technologies to provide alerting capabilities for the cities of Naples, Istanbul, Cairo and Athens.

The Japan Meteorological Agency (JMA) initiated an Earthquake Early Warning service in October, 2007. This service provides advance announcement of the estimated intensities and expected arrival times of strong shaking. Warnings are aimed at mitigating earthquake-related damage by triggering counter-measures such as promptly slowing down trains, controlling elevators, and avoiding rock falls/landslide areas. Warnings by JMA are provided through various media outlets such as TV, radio, and the Internet. In addition, a Japanese cell phone company is offering earthquake warnings through an "Area Mail" feature that provides quick emergency reports delivered to mobile phones in a specific area, with dedicated ring tones and messages used to alert the user to an impending emergency.

In the United States, pre-prototype earthquake early warning tests are being conducted by member institutions of the California Integrated Seismic Network (CISN, a regional

component of ANSS), as part of a three-year program funded by the USGS. In 2007, a near-real-time version of the *ElarmS* seismic analysis algorithm was implemented at UC Berkeley to evaluate its performance in terms of warning accuracy and timeliness. In addition to using the first few seconds of P-wave arrivals to rapidly estimate earthquake magnitude, ElarmS now also incorporates components of ShakeMap to produce an *AlertMap*—a map of the predicted peak ground motion—which is updated every second during the course of an earthquake.

On October 30, 2007, the magnitude 5.4 Alum Rock earthquake near San Jose, CA, was the largest earthquake to occur in the San Francisco Bay region since the 1989 Loma Prieta earthquake. One second after the earthquake was detected, ElarmS estimated the magnitude and other parameters necessary for the first AlertMap. Within 15 seconds, data from approximately 90% of the Bay area seismic stations had been processed. This test demonstrated the potential for issuing an alert in San Francisco (43 miles northwest of the epicenter) before the ground shaking was felt. Accuracy can be improved and warning times reduced by deploying additional stations and fast telemetry along fault zones.

While early warning systems are currently being tested in California, the societal benefits may be even more pronounced in other earthquake-prone parts of the country. In the central and eastern US, strong ground motions are felt over significantly larger areas than in California, enabling both a larger area and longer lead times for alerts ahead of strong shaking. Since these areas are less resistant to earthquake shaking, such alerts may be relatively more important for loss reduction. However, a significant increase in the instrumentation density in that region would be required for early alerts to become a reality.

Despite the progress being made in the CISN tests, opinions vary widely as to the benefits of earthquake early warning systems, both relative to other program efforts and relative to cost. Much work remains to be done before this technology could be confidently used as part of a national program for earthquake public safety. The CISN effort must ultimately address questions of effectiveness, user needs and cost-benefit. The USGS and its CISN partners should study those systems developed in other countries to learn how such systems are used and their applicability to the US.

- **SESAC recommends that USGS continue to support research on earthquake early warning systems but not at the expense of other important research and assessment efforts.** A thorough investigation of the feasibility of earthquake alerting in the United States must include carrying out a comprehensive assessment of how such information would be used by local and state entities (police, fire and disaster-response departments), utilities, private companies and other end-users. Discussion of early warning systems is only justified if we continue to develop a state-of-the-art national earthquake monitoring capacity through the ANSS. As in past reports, SESAC affirms its recommendation that ANSS receive the highest priority for funding and implementation.

It is also worth noting that early warning can be viewed as an emerging technology for rapid warnings for many types of emergencies. While the details of earthquake early warning are specific to earthquakes, the operation of sensor networks, real-time data analysis, and rapid notification can be expanded to cover other types of natural and man-made emergencies that fall within the USGS mission.

USGS National Seismic Hazard Maps

The USGS recently completed its update of the National Seismic Hazard Maps. These maps update the 2002 maps and incorporate new ground-motion attenuation models, geologic and seismologic studies of faults and seismicity, and geodetic strain data. The maps are for 2%, 5%, and 10% probabilities of exceedance in 50 years for peak horizontal ground acceleration and spectral acceleration at seven periods on firm-rock site conditions. Draft maps were released for expert review in May 2007 and for public comment in June 2007. Preliminary maps were released on the USGS website in late 2007.

There are very considerable changes to the ground motion levels in the 2007 maps as compared with the 2002 maps. These changes are significant for engineering design and have been discussed at several regional workshops. The Central and Eastern United States hazard is typically about 10% smaller along the eastern seaboard than the 2002 hazard due to the new attenuation relations used. The changes to the hazard in the Western United States are more substantial. The hazard in the Pacific Northwest has increased by 15 to 30% due to the new Cascadia magnitude-frequency distribution and from updating the attenuation relations. Throughout coastal California and the Basin and Range, the spectral accelerations at a period of 0.2 seconds (s) are generally 10 to 20% smaller than the 2002 values for a hazard level of 2% probability of exceedance in 50 years. At a period of 1.0 s the reduction is even larger, on the order of 20 to 30%. These changes are predominantly due to the use of the Next Generation Attenuation (NGA) ground motion models developed by the Pacific Earthquake Engineering Research Center. Because of the changes generated by the NGA models, a peer-review panel was assembled to consider their use in developing the seismic hazard maps. Despite the impact on the hazard maps, the peer-review panel concluded that NGA represents the best science to date and that the new models should be included. The significant changes to the hazard levels, particularly the reductions to the hazard, have raised concerns within the engineering community because of the worry that the hazard levels are very volatile and may go up again in the next round of hazard maps.

The next steps for the National Seismic Hazard Maps include their finalization, their use in developing design maps of Maximum Considered Earthquake ground motion for use in building codes, and eventual adoption in building codes. The process of adoption into the building codes involves a series of steps, including adoption first by the NEHRP Provisions (expected in 2008), then by American Society of Civil Engineers (ASCE) 7 (expected in 2010 or 2011), and eventual adoption by the International Building Code (expected 2012).

As the USGS now stands at the beginning of a new revision cycle for the National Seismic Hazard Maps, it is the ideal time for important research to be undertaken to address technical issues and new research directions related to the hazard maps. For example, there are inconsistencies between physics-based simulations of ground motions and the empirical NGA ground motion models that should be addressed. Also, developments in vector representations of ground-motion hazards, in which ground motion is represented by two or more parameters, should be considered as they have the potential to improve the accuracy of predicting building response.

- **SESAC recommends that the USGS identify and initiate new research projects that are critical for the development of the next generation of seismic hazard maps.**

The Future of the USGS Parkfield Experiment

At the Paso Robles meeting, the committee held a discussion led by Bill Ellsworth, former Chief Scientist of the Earthquake Hazards Team, on the long-term role of USGS at Parkfield, where the committee went on a field trip the following day. He began by noting that what goes on at Parkfield does not stay at Parkfield but has been broadly applied elsewhere with pioneering efforts in the application of geodetic methods to mapping fault movement at depth, real-time monitoring, and strategic partnerships with the California Geological Survey (CGS) and California Office of Emergency Services for public education and warning. The National Science Foundation has also joined with the USGS to support a number of Parkfield experiments and monitoring systems, including the borehole seismic network operated by U.C. Berkeley, and numerous EarthScope-related activities.

The San Andreas Fault at Parkfield is the most densely instrumented fault in the world because of the pattern of $M \sim 6$ earthquakes that recur every 20 to 30 years. During the 2004 magnitude-6 event, the extensive strong-motion network operated by the California Geological Survey recorded the highest peak acceleration ever observed and a spread of peak accelerations that in a single event covered the whole range expected for all magnitude-6 quakes. Ellsworth described the seismic structural investigations to understand geologic controls on rupture with applications to the Hayward fault as well as the results from tripod LIDAR showing that post-seismic deformation represented a significant amount of the total moment release. Many of the first scientific results were published in a special issue of the *Bulletin of the Seismological Society of America*, and data captured in 2004 and beyond will continue to fuel research for many years to come.

The committee sees scientific value in continuing the experiment but urges the USGS to consider a number of issues in doing so. Questions to be considered are what has been learned, what benefits have accrued to the scientific community and to emergency management, whether it is worth waiting for another magnitude-6 event, and what USGS investments should be going forward. The reloading period offers a unique opportunity to study the complete Reid elastic rebound cycle using InSAR and other types of geodetic data. New instrumentation includes an increased density of continuous GPS stations

through EarthScope, including former USGS stations that are now part of PBO Nucleus; PBO has also installed borehole strainmeters to the south that include seismometers.

The California Geological Survey's plans for its strong-motion instrumentation include upgrading the original Parkfield Array, cooperative work underway with the USGS south of Parkfield in the California Valley, and site velocity measurements being performed in the nearby Turkey Flat area. The original array was instrumented with film-recording strong-motion instruments for the purpose of recording an event of the magnitude of the Parkfield 2004 earthquake. That event represented the harvest of two decades of work, and of waiting, at the Array. After that event, it was important to think through the future purpose of the Array, with potential results ranging from abandonment through upgrade. A decision was made to take an intermediate approach, upgrading to medium-resolution (12-bit) recorders with relatively low power requirements. About half of the Array has been upgraded to date, with a late 2009 completion target for the entire Parkfield Array.

An important cooperative effort with the USGS and Caltech is underway in the California Valley south of the Parkfield Array along the San Andreas Fault. One model for the next Fort Tejon-type earthquake has it starting in the area south of Parkfield, and rupturing southward toward San Bernardino. Thus, in the California Valley an important joint array is coming on line, after nearly two years of effort. The Pasadena USGS office has been working with CGS staff to develop an across-the-fault array at Parkfield, incorporating and upgrading pre-existing stations. This set of stations is expected to produce a very interesting set of data when an earthquake occurs. Many of the stations in the Parkfield Array have become more important in seismological research because of the data recorded during the 2004 event. As a result, and as part of a larger effort, USGS has a field program underway to measure near-surface S velocities, or Vs30, at both CGS and USGS stations in the area.

USGS long-term planning for modernization needs to keep in mind that while the marginal cost to keep systems running is not high, replacement costs could be substantial. The USGS should also consider where it would do another Parkfield-scale experiment were funds available. Previous studies have recommended a similar experiment in southern California, and the ongoing Multi-Hazards Demonstration Project represents an opportunity to enhance the near-fault recordings there, building on previous investments made by USGS in the Coachella Valley following the 2002 Denali Fault, Alaska event. The ANSS Steering Committee has recommended additional instrumentation for the Southern San Andreas Fault.

If the USGS is to obtain close-to-the-fault strong-motion recordings for large events, it should be looking globally, and the same applies for obtaining near-field geodetic data with fault displacement representing a major issue for lifeline operators. To reduce costs, USGS should consider the value of robust but triggered strong-motion and GPS sensors for this type of near-fault experiment.

Appendix I. Membership of Scientific Earthquake Studies Advisory Committee

Mark Zoback, *Chairman***
Stanford University

Ralph Archuleta**
University of California Santa Barbara
(Chair, ANSS Steering Committee)

James Dieterich*
University of California Riverside
(Chair, National Earthquake Prediction Evaluation Council)

Art Lerner-Lam*
Columbia University

Vicki McConnell*
Oregon Department of Geology and Mineral Industries

Stuart Nishenko**
Pacific Gas & Electric

John Parrish**
California Geological Survey

Ellen Rathje**
University of Texas at Austin

Garry Rogers**
Geological Survey of Canada

* Term to be completed in February 2009.

** Term to be completed in February 2010.