

Report for 2008-2009 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 bi-annual report for calendar years 2008 and 2009 to the Director of the U. S. Geological Survey (USGS) for transmission to Congress. The report describes the Committee's activities during 2008-2009 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. Recent earthquakes have demonstrated the value of USGS rapid post-event information products, which emergency responders and the public have come to rely upon. For the USGS to be able to continue to carry out its mission and continue to provide essential data products to dramatically lower earthquake effects requires ***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. In addition, SESAC continues to recommend that the USGS support research and development on Earthquake Early Warning (EEW) systems. Implementation of a state-of-the-art national earthquake monitoring capacity (ANSS) will benefit all aspects of earthquake information collection and dissemination and is essential for deployment of EEW systems.

2. SESAC is pleased to note the immense public participation in the Great Southern California ShakeOut preparedness exercise. With approximately 5 million individuals, dozens of local, state and federal agencies and hundreds of schools, businesses, hospitals and other institutions participating in ShakeOut, it represents a key achievement of the USGS Multi-Hazards Demonstration Project. This exercise, and its subsequent expansion to a statewide annual exercise, demonstrates the many benefits resulting from focusing on partnership development and effective delivery of scientific information to the public. A key part of the ShakeOut's success was the scientifically credible scenario that USGS and its partners developed for a major rupture on the southern San Andreas Fault, making the consequences real enough to drive action. The scenario approach and exercise should serve as a model for future earthquake scenarios in other at-risk US cities. ***SESAC is pleased to see USGS expand its multi-hazard initiative to the Pacific Northwest and encourages further expansion to include other high-risk areas of the Nation.***

3. The documentation of repeated episodes of non-volcanic tremor and associated deep, 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 (for 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 and the constraints on probable characteristics of future megathrust earthquakes in Cascadia.

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 fewer than 250 full-time equivalents at the end of 2009, this decrease has made it increasingly difficult for the program to meet its 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 2008-09

The SESAC met three times during the period of this report. The first meeting, held in February 19, 2008, at USGS headquarters in Reston, Virginia, included discussions with then USGS Director Mark Myers and NEHRP Director Jack Hayes, and staff briefings on the USGS Earthquake Hazards Program, status of teams supported by the program, and a review of future directions for USGS seismic hazard assessment, discussing plans both for the next generation of the national seismic hazard maps and for the time-dependent California statewide earthquake rupture forecast.

The second meeting was July 31-August 1, 2008, at the USGS Menlo Park center in Menlo Park CA. Discussion topics included the multi-hazards demonstration project, Hayward Earthquake commemoration activities, draft geodesy white paper, and reviews of international risk assessment programs, the ANSS steering committee report, and an Episodic Tremor and Slip workshop report.

The third meeting was February 2-3, 2009, at the University of Washington. The primary focus of the meeting was an overview of USGS earthquake activities in the Pacific Northwest. The committee heard from USGS staff about new research pathways as well as user perspectives on putting USGS science to work. One highlight of this meeting was to hear directly from a variety of stakeholders in the Seattle area and to learn of the many benefits they are deriving from close interactions with the USGS on issues related to urban seismic hazards. These individuals represented various local governmental organizations and engineering companies engaged with risk reduction activities in the region. The committee also had a tour and briefing at the University of Washington's Pacific Northwest Seismic Network facilities. The committee heard updates from the earthquake program and the primary teams supported by the program. They heard about lessons learned from the Great Southern California ShakeOut and received updates on seismic risk maps, the ANSS Steering Committee.

The ANSS Steering Committee, a subcommittee of SESAC that provides guidance on network modernization, met twice in 2008 and twice in 2009. 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.

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 platforms for testing predictions;
- The USGS scientific response to the 2008 Wenchuan earthquake;
- Progress on the Multi-Hazards Demonstration Project in Southern California and expansion of multi-hazard projects to other regions;
- Research on earthquake early warning systems;
- Update on developments in episodic tremor and slip research activities; and
- The status of staffing in the teams supported by the program and future workforce planning.

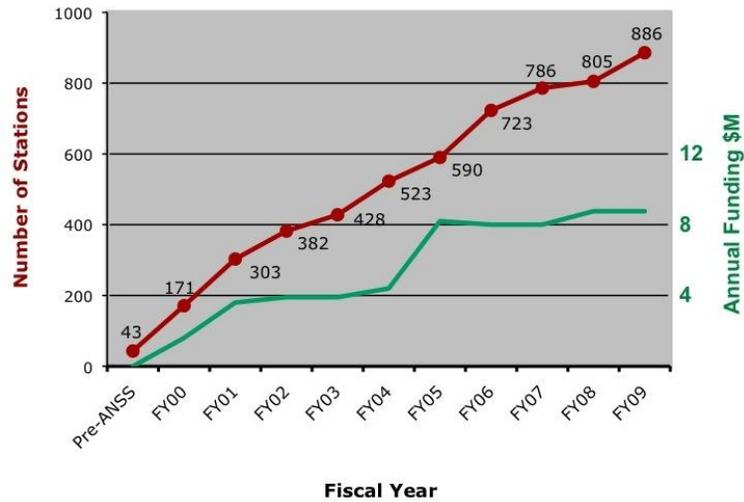
ANSS Steering Committee Report

The Advanced National Seismic System (ANSS) is the highest-scoring major information technology capital investment made in the Department of the Interior. The 2008 Strategic Plan for the National Earthquake Hazards Reduction Program (NEHRP) emphasizes full funding of the ANSS is a necessary strategic priority in order for NEHRP to fulfill its mission.

Figure 1 shows the growth of ANSS stations and funding from inception through 2009 (not including funding to ANSS through the American Recovery and Investment Act, received mid-way through FY 2009 and being spent primarily in 2010 and 2011). Despite nearly level funding since 2005, the number of ANSS stations has continued to grow –primarily through leveraging by States and other agencies. The sharp increase in stations achieved in FY 2009 (from 805 to 886) came as a result of investment by USGS in a new, low-cost, strong-motion sensor called NetQuakes, which promises to dramatically lower the costs of capitalizing and maintaining the system. This came about through a USGS “Venture Capital” investment in seismic sensor technology.

New seismic stations were installed along the southern San Andreas Fault in 2008-2009, both as part of the USGS Multi-hazards Demonstration Project and in response to the ANSS Steering Committee’s recommendation to improve opportunities to record close-in strong ground motion. The southern San Andreas Fault last experienced a major earthquake about 1680. A hypothetical rupture on this section of the San Andreas Fault was the centerpiece of the USGS organized “Great Southern California Shakeout” exercise for emergency response to a major earthquake. ANSS strong motion sensors were also installed in the Pacific Northwest.

Figure 1. Growth of ANSS Stations Since Inception



In addition to modernizing network stations within ANSS, the program targets putting sensors in buildings, bridges and other structures of engineering interest for instrumentation to record the response of structures during earthquakes. ANSS embarked on this aspect of the program beginning with 11 structures (bridges, buildings and a port) in Alaska, California, Missouri, Tennessee, Utah, Washington and Puerto Rico. The instrumentation of these structures is now complete. While important, these structures represent a small fraction of the expected number envisioned under the authorization of ANSS. However, without any increase in funding, there are no current plans to instrument more structures.

New opportunities to enhance both the networks and structure instrumentation were begun in 2009 in cooperation with the Veterans Administration (VA) and with the U.S. Nuclear Regulatory Commission (USNRC). The VA has funded USGS to install, as part of ANSS, dense sensor arrays in its medical facilities in areas of very-high and high seismic risk. Fifty-six buildings have been identified as high-priority for seismic instrumentation that will include free-field sites as well as strong-motion sensors within the structures. All of the recorded data will be publicly available through ANSS. However, the long-term operation and maintenance for the instrumentation has not been funded. In addition to the VA, the new USNRC Seismic Research Plan 2008-2011 has a section that would support instrumentation under ANSS. Most of the instrumentation would be in the central and eastern U.S. where the vast majority of nuclear power plants exist. The USNRC has funded USGS to evaluate seismic monitoring needs in the central and eastern U.S.; that study will be completed in 2010.

ANSS has continued its efforts to ensure that the strong shaking during earthquakes is comprehensively recorded and made available to scientists and engineers for thorough analysis and interpretation of earthquake shaking effects buildings, critical facilities, lifelines and infrastructure. An important development in 2008 was the Center for Engineering Strong Motion Data (CESMD), which was developed jointly with the

California Geological Survey to provide a combined database and web portal for access to all US strong motion data, and with plans to include worldwide strong motion data. The data from worldwide networks are invaluable for the assessment of earthquake effects. Thus, a full integration of the data from large magnitude earthquakes is a priority within ANSS, and the CESMD will build a sustainable product line for the engineering community within ANSS. USGS has also reorganized the National Strong Motion Project (NSMP) to streamline the collection of strong motion data and increase its role in instrumentation of structures.

The most successful product line within ANSS has been the development of ShakeMap and PAGER (Prompt Assessment of Global Earthquake Response). Following the devastating magnitude-7.9 Wenchuan earthquake in China (May, 2008), PAGER loss models (which are in development) were used to estimate losses within hours of the event, on the order of 50,000 deaths, a number sadly borne out (~69,000 as of July 15, 2008) following this tragic event. Maps from PAGER and ShakeMap were printed in many of our nation's most prestigious newspapers and shown on television networks. The Wenchuan earthquake generated over 500 million hits on USGS servers at the National Earthquake Information Center (NEIC) in the 10 days following the earthquake.

By 2008, ANSS had reached equilibrium, with a minimal capital budget and an annual budget of about \$8.76 M, approximately one sixth of its planned operating budget. Nonetheless, it has furthered the development of products for the public and for the professional communities. It has also streamlined its operations and successfully developed partnerships that can assist in ensuring that the U.S. is well monitored in the event of a large earthquake. However, without an infusion of capital for purchasing new seismic stations and instrumentation for structures along with an increase in its operating budget, ANSS cannot meet the goals outlined in its Congressional authorization and in the NEHRP and USGS strategic plans, and the economic benefits of the system will not be realized.

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, who is also a member of the SESAC. Jim Dieterich served as NEPEC Chair from 2006 until 2009. Terry Tullis of Brown University took over as Chair beginning in the summer of 2009. NEPEC meetings and recommendations are summarized on the USGS web site <http://earthquake.usgs.gov/aboutus/nepec/>. In 2008 NEPEC reviewed the earthquake forecast of the Working Group on California Earthquake Probabilities (WGCEP), and reviewed progress in the testing of proposed earthquake prediction methods. These activities are described below. In addition, NEPEC members attended a workshop on Episodic Tremor and Slow slip (ETS) that spawned from an earlier NEPEC meeting on that subject and recommendations, summarized in our

2007 letter, that USGS assume a leadership role in the study of ETS and explore means for improving the coordination and focus of its studies of temporal variations of ETS and their possible implications for damaging earthquakes. See our [earlier/later] section on ETS for more on this topic.

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. As described in our 2007 report, the WGCEP project is a joint undertaking of the USGS, the California Geological Survey and the Southern California Earthquake Center (SCEC), with support from the California Earthquake Authority. Early in 2008 the Working Group completed a major report on their Uniform California Earthquake Rupture Forecast (UCERF v.2; <http://www.scec.org/ucerf/>). Earthquake probabilities provided the basis for the time-independent characterization of earthquake hazard in the USGS National Seismic Hazard Map (NSHM), and as a time-dependent model used by the California Earthquake Authority in calculating revised rates for residential earthquake insurance. A NEPEC subcommittee attended meetings of the WGCEP and its Scientific Review Panel, reporting to USGS that the review processes established by the WGCEP were appropriate. As a final step, the NEPEC reviewed the UCERF draft report in early 2008 to verify that the important concerns raised in review had been addressed by the Working Group. NEPEC provided similar oversight to previous WGCEP projects in 1988 and 1990, and will do so again as the Working Group undertakes a new phase of model development in 2010-2012.

At its fall, 2008 meeting the NEPEC was briefed by WGCEP Chair Ned Field on strengths and weaknesses of the UCERF v2 report, and engaged him in a discussion of avenues of research that are most likely to improve the models that underlie the Survey's flagship earthquake probability and hazard products. Field explained that the UCERF model represents "best available science," but is extremely complex and unwieldy, with several unsatisfying features that were inherited from earlier efforts. Field listed a number of potential improvements to the method that should motivate future work. Field urged aggressive development of software for physics-based simulation of regional earthquake behavior as an example of new approaches that push the envelope. In discussion, Council members stressed the importance of earthquake rupture forecasts and hazard maps as flagship products, and that USGS must continue to push their improvement. Noting that it will be about three years before methods must be decided upon for the next update to the national seismic hazard maps, members urged USGS to take advantage of this time to encourage multiple, competing approaches, using the USGS grants program to encourage free thinking.

Testing of earthquake prediction methods

The NEPEC received updates at its fall meeting on the Collaboratory for the Study of Earthquake Predictability (CSEP; <http://www.cseptesting.org/>). This international

research collaboration was initiated by the Southern California Earthquake Center, building on an earlier joint project with the USGS, to foster rigorous application of the scientific method to the field of earthquake prediction research. CSEP testing centers provide resources to run earthquake prediction computer programs, to conduct prospective prediction experiments, and to evaluate the predictive strength of proposed methods. SCEC developed the first testing center with support from the Keck Foundation, and additional testing centers have been developed abroad. The current CSEP activities focus on comparative testing of prediction methods based on seismicity, an approach optimized to achieve useful statistics in a short time and to provide insight into whether seismicity holds prediction clues that transcend those captured in standard aftershock clustering models. SCEC leaders believe that the CSEP methods may be broadly applicable to the rigorous testing of a broader suite of model-based earthquake occurrence and hazard forecasts, and has indicated its intention to seek financial support from USGS in the future.

In a letter to USGS, the Council voiced support for the rigorous hypothesis testing promoted by CSEP, while pointing out several ways in which the CSEP testing center could evolve to become more useful to you in your Stafford Act role. The NEPEC believes it appropriate that USGS play a part in supporting CSEP. However, given the highly constrained budget of the USGS Earthquake Hazards Program, it is unlikely that the USGS can provide sole support at the level needed to sustain this effort. Lastly, the NEPEC urged that USGS researchers interested in earthquake occurrence, statistics, forecasting and prediction take advantage of the methods and facilities developed by CSEP.

2008 Wenchuan Earthquake Response

The 12 May 2008 Wenchuan Earthquake ($M_w = 7.9$) in China was a significant and devastating earthquake from which much can be learned. This event is particularly important to our understanding of earthquake processes and effects, because it was a large magnitude earthquake in an intraplate region, it is somewhat analogous to the type of events that occurred in the New Madrid Seismic Zone of the Central US in 1811-1812.

The Wenchuan earthquake demonstrated the value of USGS rapid earthquake response products, including ShakeMap and PAGER (Prompt Assessment of Global Earthquakes for Response). Due to difficulty of access to the affected region, there was a paucity of technical information available about the earthquake immediately after the event. ShakeMap and PAGER played an important role in filling that gap and assisting disaster relief organizations. The relief director for Save the Children stated that the information from PAGER was speeding up their in-country response activities by several days by quickly identifying the hardest-hit areas.

Technical interactions with Chinese officials and the China Earthquake Authority (CEA) included a delegation led by NEHRP Director Jack Hayes (from the National Institute of Standards and Technology) to meet with Chinese officials in Beijing in June, 2008. This meeting led to an invitation from the CEA for teams of US government and academic

scientists to visit the epicentral area. As a result, the USGS sent multiple researchers to China to investigate various characteristics of the earthquake, including faulting and earthquake-induced landslides. These interactions have led to additional funding for landslide studies of the earthquake from the U.S. Agency for International Development's Office of Foreign Disaster Assistance (OFDA). The USGS also supplied very high resolution satellite imagery and interpretation to the Chinese through the International Charter for Space and Major Disasters, and the Chinese embassy requested USGS assistance on a number of technical issues.

The 2008 Wenchuan Earthquake proved to be a seminal event in developing relationships between the USGS and the China Earthquake Authority. It is anticipated that joint research of this earthquake between the USGS and CEA will continue for many years

Multi-Hazard Demonstration Project and the Great Southern California ShakeOut

In late 2006, the USGS proposed the greater Southern California region as the site for its first Multi-Hazard Demonstration Project. The project was organized and led by Dr. Lucile M. Jones as chief scientist and the USGS staff based in Pasadena, California. In 2007, Congress appropriated funding for the Demonstration Project. As the Project name describes, the impact upon the region from a variety of hazards would be analyzed and their impacts demonstrated in the form of individual scenarios. The purpose of these scenarios is to identify the physical, social and economic consequences of a major disaster to the region.

The focus of the first of these scenarios was a magnitude 7.8 earthquake on the southernmost portion of the San Andreas Fault between the Salton Sea and extending northward to Lake Hughes (approximately 300 km). This segment of the San Andreas was selected because it has not ruptured in over 300 years; whereas other portions of the San Andreas Fault have a recurrence interval of about 150 years. Over 300 individuals with an assortment of specialties contributed their expertise to the development of the scenario.

Methods of calculating the strong ground motion impacts created by this earthquake were significantly different from those of the past, which typically used attenuation relations that relied upon estimations of fault magnitude and distance from a fault. In this new scenario, physics-based ground motion simulations were derived from computer modeling applications that accounted for distinct variables such as specific site characteristics, directivity of wave propagations and radiation patterns.

The resulting assortment of physical damage to the affected region is interesting and impressive. In addition to the strong ground shaking predicted to occur throughout the region, the scenario recognized that surface offsets along the San Andreas Fault would sever lifelines where they crossed the Fault at 1,289 locations (roads, data lines, pipelines, railroads, power lines, aqueducts, etc.). Secondary hazards included widespread surface liquefaction problems, and the activation of between 10,000 and 100,000 landslides. More than 600,000 buildings would suffer some damage. Property

losses to structures and their contents, from both primary earthquake ground shaking and as many as 1,600 resultant fires, amounted to \$113 Billion.

Business and commercial losses would reach another \$100 Billion. On the human side, it is estimated that there would be 1,800 deaths, over 50,000 injured requiring some type of hospitalization, and more than 250,000 homeless. Societal impacts would be long lasting.

Details on how the scenario's findings and conclusions were derived were published in *The ShakeOut Scenario*, USGS Open File Report 2008-1150, Version 1.0. (California Geological Survey Preliminary Report 25), published in May 2008 (<http://pubs.usgs.gov/of/2008/1150/>).

As the M 7.8 Earthquake Scenario report was nearing completion, the State of California was gearing up for its biennial Golden Guardian emergency response exercise. In 2006, the Golden Guardian '06 Emergency Response Exercise was focused on the San Francisco Bay area and based upon a repeat of the M 7.9 San Francisco Earthquake of 1906. The USGS made major contributions to the success of that exercise. The Governor's Office of Emergency Services (OES) (recently reorganized into the California Emergency Management Agency, CalEMA), coordinator of the Golden Guardian drills, elected to use the recently completed USGS southern San Andreas Fault rupture scenario as the basis for its Golden Guardian '08 Emergency Exercise in Southern California.

During this same time, the Earthquake Country Alliance was being formed through the coordinated efforts of the USGS and the Southern California Earthquake Center (SCEC) located at the University of Southern California and funded principally by the USGS. The Earthquake Country Alliance became an association composed of businesses, schools, local governments, and local and regional community organizations. The purpose of the Alliance was to promote awareness of earthquake dangers to communities and encourage education and preparedness on everyone's part by means of community actions.

Through the combined efforts of the USGS, the Earthquake Country Alliance based at SCEC, and the California OES, the Golden Guardian '08 Emergency Response Exercise expanded into the largest earthquake drill in United States history, which was advertised as the *Great Southern California ShakeOut*.

On November 11, 2008 the Golden Guardian '08 exercise commenced, ostensibly with the "rupture" of the southern San Andreas Fault at 10:00 A. M. local time. As a part of the ShakeOut, more than 5 million participants including individuals, families, schools, businesses, and government agencies actively engaged in some portion of the emergency drill. While thousands of school children practiced survival techniques in the classroom, hospitals, fire departments, emergency coordination centers, and businesses drilled in rescue and recovery operations. Also in conjunction with the ShakeOut, the City of Los Angeles hosted a three-day International Earthquake Conference.

The USGS operated two earthquake clearing houses: the main clearinghouse at its Menlo Park Campus, and a clearinghouse “field station” at the USGS Pasadena facility. As a dynamic part of the exercise, the USGS placed the simulated earthquake on a special Internet Web page of the California Integrated Seismic Network (a part of the Advanced National Seismic System), where the main earthquake and thousands of aftershocks could visually be tracked as they “occurred” along the San Andreas Fault. Scenario ShakeMaps were also generated and displayed. USGS and CGS geologists coordinated field sightings using shared systems as they reported the scope of simulated damage at various locations around Southern California. The OES State Emergency Operations Center at Mather Field, its Regional Emergency Operations Center at Los Alamitos, and the CGS Event Response Center in Sacramento, were all activated and participated in the exercise. The *ShakeOut Scenario* provided a thought-provoking study of the scale of the damaging effects of a large magnitude earthquake on a densely populated metropolitan region—a region that likely is better prepared for earthquakes than any other metropolitan region in the U. S. The scenario’s wide acceptance by professional first-responders and government decision makers as the basis for an actual emergency drill attests to its thoroughness of scope and the solidity of its scientific, engineering, and socio-economic findings.

Earthquake Early Warning

UCERF v2, the Unified California Earthquake Rupture Forecast published in 2008 reported that the probability of a magnitude 6.7 or larger earthquake in California during the next 30 years is greater than 99%. The forecast further indicated that the faults with the greatest probability of large earthquakes are the southern San Andreas Fault near Los Angeles and the Hayward Fault near Oakland and San Francisco. With more than 25 million people at risk from earthquakes along these faults, the concept of Earthquake Early Warning (EEW) represents a new and promising strategy for public safety and mitigation.

Prototype earthquake early warning tests are currently being conducted in California 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, the largest earthquake to occur in the San Francisco Bay region since the 1989 Loma Prieta earthquake, provided a test for the *ElarmS* system. One second after the earthquake was detected, *ElarmS* estimated the magnitude and other parameters necessary for the first AlertMap. This test demonstrated the potential (once delays that accrue at the seismic stations

are eliminated) for issuing an alert as early as 12 seconds before strong ground motions would reach San Francisco, 43 miles northwest of the epicenter. Within 15 seconds of detection, data from approximately 90% of the Bay area seismic stations had been processed, revealing a complete picture of the distribution of ground shaking throughout the Bay area.

In southern California, the magnitude 5.4 Chino Hills earthquake on July 29, 2008 provided Caltech with a real-time test of 2 EEW algorithms it has been evaluating as part of the CISN program (the *Virtual Seismologist* and $\tau_c - P_d$). Los Angeles City Hall, which is located about 30 miles from the Chino Hills epicenter would have received 6 sec warning based on the configuration of the current CISN network. Performance testing of EEW software by the CISN group has highlighted the technological limitations of current instrumentation and telemetry for rapidly issuing early warnings. Overall accuracy can be improved and warning times reduced by deploying additional stations along fault zones and utilizing faster telemetry and data processing systems. EEW represents the 'real-time' end of a spectrum of earthquake information products, all of which depend on a robust and reliable national seismic system (ANSS).

The 2009 American Recovery and Investment Act provided support for the USGS that includes \$19.2M of one-time funding for the modernization of ANSS components by replacing older instruments with state-of-the-art, robust systems across the highest earthquake-hazard areas of the nation. The collateral benefits of this modernization will include faster transmission of on-scale recordings that can be used for the EEW program.

While EEW 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.

Following larger earthquakes, EEW systems will be invaluable as potentially damaging aftershocks occur during the emergency response and recovery phase. An EEW system that was established immediately following the 1989 Loma Prieta earthquake helped emergency responders during the cleanup of collapsed freeways in Oakland, CA, approximately 60 miles north of the epicenter. When large aftershocks occurred, this system provided ~ 20 s of warning for workers to evacuate from potentially hazardous locations. Similar portable systems could be deployed following all significant US earthquakes near urban areas as an additional demonstration/ application of EEW technology.

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 to overall cost. Much work remains to be done before this technology can be confidently used as part of a national program for earthquake public safety. While scientific and technological advances are occurring in the United States and throughout the world, comprehensive assessments and examples of how such information would be integrated into current risk mitigation programs and used by local and state entities (police, fire and disaster-response departments), utilities,

private companies and other end-users to improve situational awareness and reduce earthquake losses need to be updated. In the transportation sector, for example, Japan's EEW systems have already demonstrated their value in slowing down high-speed trains before the onset of strong ground shaking. In contrast, no public policy framework for the preemptive, precautionary shutdown of gas and electric utility systems has been established in the United States. Liability issues for utility directed shutdowns include the increased social risks due to post-earthquake loss of power and gas. The USGS and CISEN partners should study how the EEW information is used in other countries.

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.

Episodic Tremor and Slip Monitoring and Research Opportunities

The recently discovered phenomena of episodic tremor and slip, or ETS as it has become known, is now recognized as important part of the active plate boundary process that may have significant implications for refining earthquake hazard estimates, particularly in the Cascadia subduction zone that threatens the Pacific Northwest. SESAC continues to urge the USGS to develop a comprehensive monitoring, analysis and research program using a range of seismological and geodetic tools to study ETS events and understand their significance. We commend the USGS for its leadership role in co-sponsoring two workshops on ETS. A workshop on "aseismic slip, tremor and earthquakes" in February, 2008 brought together key researchers, educators and emergency management personnel to improve research coordination, assess hazard implications and capitalize on the education and outreach opportunities that this repeating phenomena presents. The workshop in March 2009 brought together key researchers to assess the state of knowledge of ETS in Cascadia and map out future research.

Overall, SESAC believes that it is critical for the USGS *to be fully engaged in comprehensive monitoring, analysis and research of this fascinating phenomenon* and to understand the significance of ETS with respect to changes of earthquake probability and the constraints on probable characteristics of future megathrust earthquakes in Cascadia.

Team Staffing

Over the past several decades, the Earthquake Hazards Program has continuously struggled to do more with fewer staff. As noted above, there are currently about half as many individuals working in the program as in the 1980's yet the USGS has had dramatically increased responsibilities for monitoring, data analysis and providing real time information products. SESAC strongly believes that the centers supported by the Earthquake Hazards Program are seriously understaffed.

The most significant impediment to hiring is the cumulative effect of flat program funding for salaries and modest cost-of-living increases making it possible to only replace a fraction of the number of individuals that leave the program through retirement or attrition. The lack of adequate funding makes it difficult for the program-funded centers to fully carry out their missions, to maintain continuity in the research program and to move into new research areas. Both the Earthquake Science Center based in Menlo Park and the Geologic Hazards Science Center based in Golden find it necessary to raise funding from outside the Earthquake Hazards Program to cover basic needs.

It is important to note that staff demographics are very different in the Earthquake Science Center and the Geologic Hazards Science Center. The Earthquake Science Center (until recently the Earthquake Hazards Team) has a relatively old work force, with about half the scientific staff eligible for retirement within 5 years. The Geologic Hazards Science Center (was Geologic Hazards Team) has a healthier demographic profile having already had many retirements over the past 5 years and the opportunity to add young and mid-career scientists.

We note that Goal 6 of the USGS Science Strategy is to "Develop a Flexible and Diverse Workforce for the Future". SESAC recommends that this goal should be defined in terms of specific and immediate objectives and benchmarks to be tracked and reported based on the state of the USGS staffing at this time.

Appendix I. Membership of 2008-2009 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