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

December 2004

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

SESAC MANDATE

The Scientific Earthquake Studies Advisory Committee was appointed and charged, through Public Law 106-503, to advise the Director of the United States Geological Survey on matters relating to that agency's participation in the National Earthquake Hazards Reduction Program. The charge includes review of the USGS Earthquake Hazard Program's roles, goals, and objectives, assessment of its capabilities and research needs, guidance on achieving major objectives, and establishment of performance goals.

ACTIVITIES OF THE COMMITTEE DURING 2004

The SESAC met three times:

1. Meeting in Reston, January 21 and 22. 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.
2. Meeting in Memphis, June 3 and 4. Objective: Review the direction of the USGS Earthquake Hazards Program in the Central and Eastern United States, with emphasis on the creation, communication, and use of seismic hazard analyses in the region.
3. Meeting in Jackson Hole, September 13 and 14. Objective: Review the direction of the USGS Earthquake Hazards Program in the Intermountain West, with emphasis on the effectiveness of partnerships in establishing the ANSS-Teton and Eastern Idaho Seismic Network.

On February 23, SESAC members Cluff, Wood, and Jordan briefed staffers of a combined House and Senate Science Committee on the recommendations from the

SESAC 2003 report. Briefly, the SESAC recommended the USGS Earthquake Hazards Program

1. Rigorously pursue full funding of the Advanced National Seismic System (ANSS) at the level authorized in the current NEHRP legislation,
2. Improve its ability to closely coordinate its research activities with complementary programs in other parts of the Federal government, and
3. Allow ample budget and more flexible strategies for learning from future earthquakes and coordinate post-earthquake investigations with the Interagency Coordinating Committee on Earthquake Hazards Reduction.

The ANSS National Steering Committee, a subcommittee of SESAC, held meetings on May 13 and 14 and November 18 and 19. SESAC member Sharon Wood chairs the Steering Committee; SESAC member Jon Price serves on the Steering Committee.

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 January, June, and September meetings are discussed below.

Five-Year Plan

The SESAC has reviewed the progress leading toward the Earthquake Hazards Program's Five-Year Plan for 2004-2008, and will complete its review as one of the objectives of the first 2005 SESAC meeting, presently scheduled for January 11 and 12 in Reston.

Senior Leadership Position

The SESAC is very pleased to acknowledge the completion of the USGS process to find a highly respected and visionary leader for the senior leadership position, which now will encompass earthquakes, landslides, and volcanoes. Selection of David Applegate in February as the Senior Science Advisor is greatly appreciated. Applegate's experience and credibility, not only in the science and engineering fields, but also in the political arena, is well established. The SESAC applauds the selection.

Advanced National Seismic System (ANSS)

The Committee reiterates its concerns, raised in the 2002 and 2003 SESAC annual reports, that the level of support for the Advanced National Seismic System (ANSS) is not sufficient. Funding is needed to modernize and expand earthquake monitoring nationwide, particularly in vulnerable urban areas, and to meet the goals of monitoring and providing rapid emergency response for large U.S. earthquakes, as well as related tsunami seismic sources on the west coast, including Alaska and Hawaii. The Committee still believes that ANSS funds should be appropriated at the amount authorized by Congress and that the USGS, the Department of the Interior, and the Office of

Management and Budget should include a request for funding of the fully authorized $35 million in the Administration's budget.

The San Simeon, California, earthquake (magnitude 6.5 on 22 December 2003) tested ANSS and the related California Integrated Seismic Network. Overall, the system performed well, although the accuracy of early information about the earthquake was compromised by the lack of near-source observations. Because the nearest telemetered stations were well outside the epicentral region, the initial ShakeMaps under-estimated the intensity of the shaking south of the epicenter. To be truly useful to the emergency response and recovery efforts, more instruments are needed.

Opportunities exist for partnerships between the USGS and local governments and businesses, which may be able to share in the costs of deploying instruments in their jurisdictions. The effectiveness of cooperation in establishing the ANSS-Teton and Eastern Idaho Seismic Network was well demonstrated at our September meeting in Jackson Hole. The Wyoming example demonstrates that the seismological community, emergency managers, universities, and state and local officials can be vocal and effective supporters.

To date, the USGS has installed more than 500 ANSS stations throughout the United States. Regional stations have been upgraded, and new ANSS backbone stations have been installed. ShakeMap is now operational in Anchorage, Salt Lake City, and the Los Angeles, San Francisco, and Seattle areas. The ANSS has reached a significant milestone in that the USGS is now locating earthquakes of magnitude 3.5 or larger everywhere in the conterminous United States; however, to collect the ground motions and structural responses vital to respond to urban hazards requires greater density in metropolitan areas. With additional funding, many additional earthquake-prone cities will have this capability, which has immediate applications in emergency response to earthquakes and other major disasters (including terrorism) that could cause damage to buildings and other structures. ShakeMaps and the ability to broadcast these maps with ShakeCast also are increasingly important components of estimating losses using the HAZUS model developed by the Federal Emergency Management Agency, thereby speeding Federal response to a disaster.

Support for the acquisition and installation of several backbone stations (both upgraded stations and new sites) will be provided by the USArray component of NSF's EarthScope Program, but long-term maintenance of these stations must be the responsibility of the USGS and included in the ANSS budget. The partnership between the USGS and the NSF on the EarthScope Program is an excellent example of complementary missions in basic and applied science. Overall, taxpayers save money because the two agencies are working together and avoiding duplication of effort. The Committee is encouraged by the formation of a joint EarthScope-USGS working group on data management and products. However, funding for EarthScope will end after 10 years, and the USGS should plan for the possibility of taking long-term responsibility for the stations. Whereas EarthScope is a science experiment, the USGS, under the Stafford Act, has responsibility for monitoring and issuing warnings.

A working group within the ANSS National Steering Committee (a subcommittee of the SESAC) is helping to define standards for the accuracy of hypocenters and magnitudes. Additionally, an ANSS Structural Instrumentation Guideline Committee has been formed by the Steering Committee to prepare guidelines that will

- Identify and set priorities for specific engineering needs that can be addressed by earthquake data collected through structural monitoring (of buildings, infrastructure, and other engineered structures, such as dams, landfills, and earth embankments)
- Provide procedures to identify candidate structural monitoring projects
- Provide criteria for evaluating and setting priorities for ANSS funding
- Provide recommendations on ANSS structural monitoring procedures and practices for instrument installation and operation, data access and distribution, data utilization, and informational and educational activities.

A National Research Council (NRC) committee is in the process of completing a report on the economic benefits of improved seismic monitoring. The SESAC anticipates the report of the NRC committee will be helpful in making the case for funding ANSS at the fully authorized level.

Earthquake Hazards Program in the Central and Eastern United States

In June, the SESAC met in Memphis, Tennessee, to review the USGS Earthquake Hazards Program in the Central and Eastern United States. Guests from the region expressed concerns associated with the seismic hazard maps for the New Madrid Seismic Zone. The Kentucky Geological Survey expressed frustration due to the large gap that appears to exist between what is known about the seismic hazard and the public policy being developed to minimize the risk. They expressed the need for consensus-building efforts during the process of hazard-map development. They said both the engineering community and the public-policy makers in the Central United States need simpler and more applied explanations of the earthquake hazards in this area.

There are a number of reasons why assessing earthquake hazards in the Central and Eastern U.S. is particularly difficult. Faults responsible for the large earthquakes typically are not exposed at the earth's surface, and recurrence intervals between great earthquakes may be much longer than the historical record, making it difficult to estimate average inter-event times. Also, it is more difficult to predict shaking levels for scenario earthquakes in the mid-continent region. Because there are fewer earthquakes in the Central and Eastern U.S., the distribution of shaking with distance from moderate to large quakes is not well known.

Despite these problems, certain advances in understanding have been made, particularly in the New Madrid Seismic Zone. During the winter of 1811-1812, the mid-continent was struck by three large earthquakes—just how large has been a matter of considerable debate. Previous estimates ranged up to greater than magnitude 8. Reexamination of historical records and more accurate assessment of population distributions and local site

effects now suggest magnitudes in the mid 7s. The pattern of seismicity during the past few decades outlines two strike-slip fault zones trending down the middle of a failed Precambrian rift. It appears that deformation has repeatedly focused on these zones of weakness over geologic time. The 1811-1812 earthquakes caused massive liquefaction of fluid-saturated Mississippi valley sediments. This left extensive sand deposits throughout the region of greatest shaking. USGS and USGS/NEHRP-funded geologists have uncovered equally extensive, but older sand deposits, interpreted as having been caused by prehistoric quakes. Dating of these sand deposits suggests that quakes of a size comparable to the 1811-1812 events have occurred several times in the past, roughly every 500 years or so. Seismic reflection data show that the cumulative displacement along faults in the Mississippi embayment may not exceed a few hundred meters. There is some evidence indicating that slip accelerated in late Holocene time, suggesting the New Madrid Seismic Zone in some way responded to stress alterations associated with glacial unloading.

Intraplate earthquakes are relatively infrequent worldwide and consequently in the U.S., as well. To study intraplate seismicity, the USGS needs to maintain the capability to study similar events internationally. Whereas each earthquake has its unique characteristics, much insight can be gained from studying comparable events abroad, such as the Bhuj earthquake in India. The USGS, together with external partners, must continue to collect pertinent data—paleoseismic, seismic, and geodetic. They should strive to develop a working model for intraplate seismicity. The association of intraplate seismicity with failed rifts suggests that current deformation is localized along preexisting fault zones within the crust.

The USGS faces distinct challenges in the Central and Eastern U.S., because there is insufficient staffing to work adequately in all areas of moderate to high seismic hazard. Considerable attention has been given to the New Madrid Seismic Zone. Very little work, beyond supporting regional seismic networks, has been done in the Eastern U.S., where even a moderate earthquake could be devastating. Puerto Rico has the highest seismic hazard in the Central and Eastern U.S. and paleoseismic work there has made a significant contribution to improving hazard maps. Yet, at current levels of funding, the USGS has not been able to address adequately the earthquake hazards in Puerto Rico and the U.S. Virgin Islands.

Through discussions at the Memphis meeting, it was evident that the state policy makers, consultants, and scientists working in the hazard area need to clearly understand the USGS map products, participate in their development, and be able to use them properly in their seismic-safety decisions. A strong consensus-building process can serve as a means for all interests to gain a fundamentally sound understanding on which to properly frame policy decisions. The SESAC supports the inclusion of local experts in the process of assessing the earthquake hazards and assessing building stock vulnerabilities. This will lead to a better understanding of the associated risks in any given area.

It was obvious to us that the staffing level at the USGS office on the University of Memphis campus that serves the Central and Eastern U.S. is not adequate for the many tasks before it. Within the context of their 5-year plan, the SESAC would like to see the

USGS develop a "master plan" for work in the New Madrid Seismic Zone to better focus research efforts and work products to increase the knowledge base, decrease uncertainty, and allow the region to better prepare for earthquakes. Long-term goals, project prioritization, and a clear identification of "core business" would give this office better direction. If the plan is a collaborative effort, it will help satisfy frustrated policy makers and help solidify the science community. It will also focus the scientists on the areas of technical agreement so they can work together constructively to resolve technical differences. The New Madrid Seismic Zone has long suffered from negative public debate on the hazards, and that has weakened support for advancing the science.

Earthquake Hazards Programs in Intermountain West

The September SESAC meeting began with a field trip of the Jackson Hole area, including the Teton fault, a newly installed ANSS station, and the Jackson Lake Dam. SESAC member Bob Smith led the field trip; participants included representatives from the Department of the Interior, the National Park Service, and the USGS, meeting speakers, and SESAC members.

On September 13, Bennett W. Raley, Assistant Secretary for Water and Science, spoke to the Committee and guests from the perspective of the Department of the Interior. He stated that the natural hazards program is clearly a mission for the USGS, but that there was strong competition from other national programs, such as health care and homeland security. Although he did not anticipate budget improvements for the USGS over the next 5 years, he urged creativity and patience.

The SESAC was pleased that USGS Director Chip Groat could attend the meeting and provide his perspective. He said that everyone has concern for levels of funding, and, working with the Department of the Interior, they have done everything they could to restore cuts. They had asked for the full $35 million funding for ANSS, and were given a small bump up. He said Interior was not the only department that was struggling with no new money, and in a flat budget situation, there is even less money due to inflation.

There was trepidation when Director Groat informed the SESAC that the USGS budget attrition had caused him to rethink the direction of the USGS. To maintain viable programs for the future, the USGS is planning to concentrate on a focused initiative for multiple years. Director Groat believed a truly focused effort would result in something for almost everyone. To generate support and create partnerships, the program would have to be highly visible and capture the imagination of the American people. Two issues were being considered as having the proper level of attraction: water availability and natural hazards. The SESAC members, collectively and individually, expressed their support for a hazards initiative, pointing out that strong local support already exists in many areas, and that a hazards initiative would encompass most water issues.

Guest speakers included partners in the installation of the Advanced National Seismic System in the area, who described their involvement in the process. The installation of this new network was a noteworthy collaboration between Teton County, the Wyoming

State Geological Survey, the National Park Service, the Geologists of Jackson Hole, the University of Utah, the Bureau of Reclamation, and the USGS. That evening, the SESAC was privileged to attend the formal inauguration of the ANSS-Teton and Eastern Idaho Seismic Network at the home of Peter Ward, USGS emeritus, where we viewed telemetered data from the new network.

Ten new near-real-time, broadband and strong-motion seismograph stations were installed along the Teton fault near Jackson Hole, Wyoming, and near similar faults in eastern Idaho. They were sited based on their proximity to the faults, optimal distribution to accurately monitor seismicity throughout the area, site noise, telemetry options, and ease of servicing. One site, near a populated area, has proved to be a popular fieldtrip spot for school children throughout the valley. Seven of the ten seismic stations involved reoccupation of former Bureau of Reclamation stations. All the stations are identical in their infrastructure setup, acquisition and processing hardware, and telemetry systems. Importantly, these stations also are identical to those operated and maintained by both the University of Utah Seismograph Stations and the USGS, which allows for flexibility in determining how to operate them long-term under the ANSS. In conjunction with other regional seismograph stations operated by the USGS, the University of Utah, Brigham Young University-Idaho, the Idaho National Environmental Laboratory, the Montana Bureau of Mines and Geology, and the Wyoming Geological Survey, the new stations provide basic seismic monitoring of western Wyoming and eastern Idaho through the USGS and University of Utah Seismograph Stations monitoring systems.

EarthScope Opportunities for the USGS Earthquake Hazards Program

EarthScope has begun to expand seismic and geodetic observational capabilities in the western United States that will provide key information for the USGS earthquake research and monitoring goals. In the past 2 years, EarthScope has begun to populate USArray, a mobile seismic array, and the Plate Boundary Observatory network of Global Positional System receivers and strain meters. The resulting information is vital to understanding the structure, evolution, and crustal deformation of North America, as well as providing data on earthquake and volcano processes. In addition, components of existing western United States GPS networks, initially funded under NSF and other grants, are being transferred and coordinated into the overall Plate Boundary Observatory. These stations will provide important geodetic coverage on active fault zones and tectonic deformation of the entire western U.S.

The USGS is regarded as a partner with EarthScope in its operations and research. These cooperative efforts are demonstrated by USGS scientists' participation on the San Andreas Fault Observatory at Depth drilling project. In cooperation with the USGS, EarthScope has responded to several earthquake and volcano emergencies. These include the installation of GPS stations in the epicentral area of the 2004 Parkfield magnitude 6 earthquake, on Mount St. Helens volcano, and on Augustine volcano. In addition, the USArray station deployment plans were rearranged to densify seismic coverage in the 2003 San Simeon magnitude 6.5 earthquake area.

This cooperation is commendable. EarthScope seismic and GPS arrays are future sources of important data on earthquakes in the United States that the USGS should incorporate into its monitoring and research plans. We recommend the USGS become a more integral participant in EarthScope by

- Continuing to support USGS scientists and provide technical support in the San Andreas Fault Observatory at Depth project
- Incorporating data from the seismic and geodetic arrays into USGS monitoring systems
- Involving USGS scientists more broadly in use of EarthScope data
- Actively seeking collaborative research with university scientists in research and hazard topics of common interest.

The EarthScope USArray has begun station deployments in California and the Pacific Northwest. These broadband seismographs, while operating for up to 1.5 years in a particular region, provide seismic data that complement the ANSS data, as well as providing additional information for several USGS-funded regional seismic arrays. Together with USGS seismic networks, the USArray, and Plate Boundary Observatory expand the sources of new earthquake information on such features as the San Andreas fault, the Cascadia subduction zone, and the interior of the western U.S. These efforts materially benefit the USGS earthquake monitoring and research objectives, especially at a time when resources are limited.

Earthquake Prediction

In our 2003 report, the Committee noted a resurgence in research on short-term earthquake prediction and encouraged the USGS to reestablish the National Earthquake Prediction Evaluation Council (NEPEC), as authorized under the National Earthquake Hazard Reduction Act of 1981. Here we reiterate the Committee's position on the status of prediction research and expand our recommendations in the light of events that have occurred during the past year, which included a highly visible earthquake prediction in southern California.

In January 2004, UCLA released a statement to the press that a team led by one of its faculty members, Professor V. I. Keilis-Borok, had predicted an earthquake of magnitude 6.5 or greater somewhere in a 12,400-square-mile region of southeastern California before September 5, 2004. The prediction was based on his algorithm that identifies patterns of seismicity before previous large earthquakes and then searches for similar patterns in recent seismicity; when such patterns are found, he issues an alert of a predetermined duration—in this case, 9 months—for the region that contains the pattern.

Keilis-Borok and his colleagues had previously announced (though not through the press) two predictions using this algorithm, one in Japan and one in central California. Both were satisfied by earthquakes having appropriate magnitudes in the stated space/time prediction windows—the magnitude 8.1 Hokkaido event of September 25, 2003, and the magnitude 6.5 San Simeon event of December 22, 2003. Owing to these apparent

successes, their southern California prediction generated tremendous public interest within the state and received extensive media coverage worldwide.

A workshop involving about 40 experts was convened at the Southern California Earthquake Center on February 20 to evaluate the prediction and its underlying method. The workshop was attended by the eight-member California Earthquake Prediction Evaluation Council (CEPEC), which issued an advisory to the governor in early March. This report drew the following conclusions:

> *"The Keilis-Borok methodology appears to be a legitimate approach in earthquake prediction research. However, the physical basis for the prediction put forward by the authors has not been substantiated, and they have not yet issued enough predictions to allow a statistical validation of their forecasting methodology. Continued research along these lines may lead to useful forecasts. Although the analysis has matured to the point of generating provocative scientific results, the absence of an established track record and the sensitivity of the results to input assumptions leaves CEPEC uncertain of the robustness of the prediction made using patterns of small earthquakes. This uncertainty, along with the large geographic area included in the prediction, leads CEPEC to conclude that the results do not at this time warrant any special public policy actions in California."*

In the run up to the September 5 expiration date, media and public interest again peaked as it became clear that Keilis-Borok's prediction might be a false alarm. (There was also some confusion that September 5 was the specific date of the prediction, rather than the end of the prediction interval.) The post-prediction press coverage generally expressed disappointment in what was widely viewed as a failure,[1] but it also provided an opportunity to remind the public of the need for earthquake preparedness as well as emphasizing the intrinsic difficulty of the prediction problem.

The recent experience in southern California supports the lessons that have been drawn from other predictions. The public views prediction to be the central goal of earthquake research, and they have high expectations that science will deliver reliable predictions. However, viable prediction methods have not yet been achieved and may not be feasible any time soon. Indeed, some experts believe that earthquakes are inherently unpredictable. Deterministic prediction of fault ruptures on short time scales of days to weeks—the specificity most people want—may be precluded by the chaotic nature of brittle deformation in Earth's crust. Furthermore, the utility of earthquake prediction schemes in protecting public safety is not obvious (the disruption caused by false alarms might exceed the societal benefit from valid predictions).

For these reasons, most current research focuses on long-term forecasting (on time scales of decades to centuries), where significant progress has been made, as opposed to intermediate-term prediction (on time scales of months to years), where the issues of

[1] A front-page story in the Los Angeles Times on September 8, entitled "Science is left a bit rattled by the quake that didn't come," stated that the Keilis-Borok technique "appears to be just one more in a long line of prediction methods that haven't worked reliably—to the disappointment of many."

predictability are more controversial. Such methods are intrinsically probabilistic in nature, and their statistical complexity makes them difficult for the public to understand and evaluate.

In this active research environment, authoritative evaluations of predictions and prediction experiments need to be made in a timely manner to guide state, local, and federal governmental response, and to manage public expectations. CEPEC played a positive role in advising the public and state government in the recent southern California prediction. This experience underscores the need for an active National Earthquake Prediction Evaluation Council as the forum to review predictions and resolve scientific debate before public controversy or misrepresentation. The Committee supports the USGS efforts to reestablish a NEPEC equipped with adequate resources to perform this role.

Balanced Program

Earthquake prediction issues emphasize the need for the USGS to engage in fundamental research to assess the predictability of damaging earthquakes. This requires a physics-based understanding of earthquake initiation and propagation, and of the processes that control the eventual size of ruptures and damaging ground motion. Such research requires theoretical and laboratory studies, as well as sophisticated numerical simulations.

Although it is difficult to recommend programs when there is no new funding, the Committee believes several truths should not be forgotten. Real-time response efforts are important, but without parallel efforts in basic earthquake research, applied methodology will suffer in the end. If support for ANSS and ShakeMap, for example, undermines support for the basic research that is the lifeblood of the program long term, the USGS Earthquake Hazards Program will become nothing but a monitoring function. Without parallel research, both related to the advancement of instrumentation and on basic earthquake physics, the network will become underused and outdated. Basic earthquake research must remain a core component of the USGS program to continue to achieve the important recent developments we have seen, such as stress-transfer theory, time-dependent hazard assessment, and improved dynamic models of earthquake sources.

In November, Director Groat announced that in 2007, the USGS would be pursuing a natural hazards agenda. The Committee anticipates there will greater flexibility for the Earthquake Hazards Program in the future, and particularly recommends ample budget and more flexible strategies for learning from future earthquakes. The occurrence of large earthquakes, such as the recent Sumatra earthquake and tsunami, provides scientists and engineers with unexpected opportunities to study the behavior of dangerous faults and their damaging effects.

RECOMMENDATIONS

We believe there are three especially important and high-priority recommendations for the USGS Earthquake Hazards Program at this time.

1. The Committee continues to strongly recommend to the Director of the 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 Committee supports the USGS efforts to reestablish the National Earthquake Prediction Evaluation Council to serve as the forum to review predictions and resolve scientific debate prior to public controversy or misrepresentation, so decision makers are not mislead by unfounded short-term earthquake predictions. The Committee encourages the USGS to support an active NEPEC equipped with adequate resources to perform this role.
3. The Committee stresses the need for balance in the Earthquake Hazards Program. The USGS must maintain the learning from future earthquakes, hazard mapping, earthquake geology, and earthquake physics components of the program. The USGS should not become simply a monitoring agency.