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February 13, 2012

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

Dear Director McNutt,

On behalf of the members of the Scientific Earthquake Studies Advisory Committee (SESAC), I present the committee's combined annual report for 2010-2011 on the U.S. Geological Survey (USGS) Earthquake Hazards Program for transmission to Congress, the Department of Interior, and the USGS's federal partner agencies in the National Earthquake Hazards Reduction Program (NEHRP).

During this period the committee met three times. Twice you presented your views about the status of the Earthquake Hazards Program. In addition the committee heard from various personnel within the USGS as well as external members of the scientific and engineering communities who have had direct involvement in the Earthquake Hazards Program. It is clear that the expectations for the USGS in earthquake hazards are expanding while at the same time there is steady state, or diminishing, funding. As evidenced by induced earthquakes, by the Louisa County, Virginia earthquake and the great Tohoku, Japan, earthquake, the effect of earthquakes is complex and potentially devastating. The USGS has always moved forward in trying to mitigate the effects through monitoring, basic research, and education of the public. In order to provide guidance on the distribution of resources while meeting the new challenges that lie ahead, the committee makes four principal recommendations:

1. The Advanced National Seismic System (ANSS) must be completely built out and fully functional. Monitoring earthquakes is crucial to our understanding of the seismic hazard and risk. With recent moderate magnitude earthquakes in Virginia, Texas, Oklahoma, Arkansas it is clear that there is a need to examine the density of seismic stations in the central and eastern U.S. Recordings of ground shaking are the basic data for essential products—earthquake location, shake maps, PAGER alerts, early warning, amplification maps, etc. The monitoring network is the backbone of seismic research. In 2011 the reauthorization of NEHRP within Senate Bill S 646 and the House Bill H.R. 1379 included specific funding for ANSS. These funds are no longer considered in the reauthorization of NEHRP H.R. 3479. Every effort has to be made to impress upon the Office of Management and Budget and the members of Congress that without a fully operational ANSS the foundation of earthquake research and mitigation is itself at risk.

2. The Louisa County, Virginia, earthquake and its aftershocks are of paramount importance to our understanding of the earthquake hazard in the eastern U.S. While there are few recordings close to the epicenter, the rapid response of installing portable instruments allows for a more detailed investigation. Had this earthquake occurred closer to a metropolitan area, one could certainly imagine damage ($8-$12 billion) such as that experienced by Christchurch on February 22, 2011 from a M 6.1 earthquake on a fault that almost went under the city. Because the Louisa County earthquake could be the prototypical earthquake for the eastern U.S. and because there is very limited data for earthquakes of this magnitude

in the eastern U.S.. it is imperative that the USGS maximize its understanding of the cause and consequences of this earthquake.

3. Induced seismicity has come to the forefront of public attention with the effort to extract the maximum amount of hydrocarbons and with the potential expansion of geothermal exploration. These activities are known to induce earthquakes, most are small magnitude but some can reach moderate magnitudes, as did several events of the last year. However, any policy with respect to induced seismicity may involve multiple agencies, such as the Department of Energy, Environmental Protection Agency and agencies within states where activities that induce seismicity are regulated. The role of the USGS is to monitor earthquakes, but with limited resources and the expansion of activities that induce earthquakes, the USGS should examine the scope of its monitoring and research capabilities and policies with respect to induced seismicity.

4. With the increased use of geodetic systems, e.g., Global Positioning System (GPS), Laser Imaging Detection and Ranging (LIDAR) (system), Interferometric Synthetic Aperture Radar (InSAR), the USGS will have to decide on the level of support for geodetic measurements and where it can most optimally add to the USGS mission within NEHRP. Geodetic measurements have been a primary component of the NEHRP program. With the new technologies the USGS is not the major supporter of the data acquisition and analysis, but has opportunities to leverage significant investments by other agencies.

The attached report provides a broader perspective on the USGS's Earthquake Hazards Program. There are many issues, such as the interaction between the National Science Foundation's EarthScope program and USGS seismic and geodetic monitoring, the development of strategies for assessing the predictability of earthquakes, the interaction between the USGS and state agencies in monitoring of induced seismicity, the continued USGS efforts in responding to damaging earthquakes.

As one prepares for the budget negotiations it will be critical to impress upon the Department of Interior, the Office of Management and Budget and the Congress that earthquakes are apolitical and can occur almost anywhere. To mitigate the damage from future earthquakes the USGS must record, analyze and understand the earthquakes that occur in the present.

With warm regards.

Ralph J Archuleta

Ralph J. Archuleta
Professor of Earth Science

cc: Members, Scientific Earthquake Studies Advisory Committee
David Applegate, Associate Director, Natural Hazards
John Filson, Acting Program Coordinator, Earthquake Hazards

Report for 2010-2011 of the Scientific Earthquake Studies Advisory Committee To the Director of the U. S. Geological Survey

This is the report of the Scientific Earthquake Studies Advisory Committee (SESAC) to the Director of the U. S. Geological Survey (USGS) for transmission to Congress. This report covers the calendar years 2010 and 2011. It addresses policy issues that arise through the USGS's role in the National Earthquake Hazards Reduction Program (NEHRP). The members of SESAC are listed in Appendix 1 at the end of this report.

INTRODUCTION

To provide the context for our report we reiterate the mission of the USGS within NEHRP: *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.*

In 2010-2011, earthquakes, both big and small, have impacted the global society and reinforced the basic need for a greater understanding of the underlying physics of the earthquake process and earthquake effects. On January 12, 2010, a magnitude 7.0 earthquake struck Haiti resulting in greatest loss of life (316,000) from an earthquake since 1556. This earthquake is not unusual in its magnitude; it did not have unusual secondary effects such as an unquenchable fire or an enormous tsunami. It simply occurred near a heavily populated city whose infrastructure was poorly built to withstand the intensity of shaking caused by the earthquake. Even Japan, a country that has long recognized its earthquake hazard and is probably best prepared, was caught off guard by the March 11, 2011, magnitude 9.0 Tohoku earthquake and the resulting tsunami. The cost of this earthquake and tsunami is expected to exceed $309 billion. Lessons are learned from earthquakes of all sizes. For example, the M 7.0 Darfield, New Zealand earthquake of September 4, 2010, caused much less damage to Christchurch than the smaller, but closer, M 6.3 earthquake of February 22, 2011. Both earthquakes occurred in a region that had almost no prior seismic activity, and certainly no earthquakes of such magnitude in recorded history. Similarly the M 5.8 earthquake of August 23, 2011, in Louisa County, Virginia, brought home the real threat of earthquakes in the eastern U.S. It is the largest event in the central and eastern U.S. since the 1897 Giles County, Virginia, earthquake, also estimated to be M 5.8; the Louisa County earthquake was the largest earthquake in the contiguous U.S. in 2011. While the tectonically active western U.S., Alaska and Hawaii had their usual number of earthquakes in 2011 there also were earthquakes with magnitudes 4.0-5.6 in what are normally seismically quiet areas of Oklahoma, Texas and Colorado. The seismic activity throughout the world and in particular the U.S. reinforces the basic premise underlying NEHRP that all of the U.S. must be prepared for damaging earthquakes. These earthquakes and the damage they have caused make it all the more critical that the USGS maintain its leadership role as defined within its NEHRP mission statement.

The pressure for the USGS to do more is increasing in this time of flat or decreasing appropriations for the USGS. We applaud the USGS's commitment to its programs that provide almost immediate notification of earthquakes 24/7, develop state-of-the-art hazard maps, respond immediately to significant earthquakes in the U.S., incorporate new technologies for measuring the Earth's deformation before, during and after earthquakes, and maintain a vision for reducing the risk to and improving the resiliency of the nation. How can the USGS sustain its preeminent role in earthquake studies, monitoring, advancing new technologies without any substantial increase in its funding is a question that is on the near horizon.

While we fully acknowledge that resources are already spread thinly over the programs, we also know that the USGS must continue to look ahead and meet the challenges that affect the nation's response to earthquakes. As such we make the following recommendations.

1. The Advanced National Seismic System (ANSS) must be completely built out and fully functional. Monitoring earthquakes is crucial to our understanding of the seismic hazard and risk. With recent moderate magnitude earthquakes in Virginia, Texas, Oklahoma, Arkansas it is clear that there is a need to examine the density of seismic stations in the central and eastern U.S. Recordings of ground shaking are the basic data for essential products—earthquake location, shake maps, PAGER alerts, early warning, amplification maps, etc. The monitoring network is the backbone of seismic research. In 2011 the reauthorization of NEHRP within Senate Bill S 646 and the House Bill H.R. 1379 included specific funding for ANSS. These funds are no longer considered in the reauthorization of NEHRP H.R. 3479. Every effort has to be made to impress upon the Office of Management and Budget and the members of Congress that without a fully operational ANSS the foundation of earthquake research is itself at risk.

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4. With the increased use of geodetic systems, e.g., Global Positioning System (GPS), Laser Imaging Detection and Ranging (LIDAR) (system), Interferometric Synthetic Aperture Radar (InSAR), the USGS will have to decide on the level of support for geodetic measurements and where it can most optimally add to the USGS mission within NEHRP. Geodetic measurements have been a primary component of the NEHRP program. With the new technologies the USGS is not the major supporter of the data acquisition and analysis, but has opportunities to leverage significant investments by other agencies.

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 2010-2011

The SESAC met three times during the period of this report: 1) USGS headquarters, Reston, Virginia, January 26, 2010; 2) California Institute of Technology (Caltech), Pasadena, California, November 4-5, 2010; and 3) Incorporated Research Institutions in Seismology (IRIS), Washington D.C., November 2-3, 2011.

The first meeting of January 26, 2010, was shortly after the M 7.2 Haiti earthquake. USGS Director Marcia McNutt provided an overview of the USGS response to this catastrophe. The Haiti earthquake was a natural segue into the USGS activities with respect to earthquakes, such as, support for the ANSS, evaluation of earthquake forecasts, financial impact of expected earthquakes, and a prognosis for increased funding given the increased demands being put on USGS resources. Other topics included preparation for the bicentennial of the New Madrid earthquakes as well as the current state of knowledge about the probability of earthquakes in the central US. At this meeting the committee brought up the critical role that the USGS has in monitoring induced seismicity. As noted by Chair Mark Zoback, the Department of Energy (DOE) has asked the American Rock Mechanics Association (ARMA) to advise them on seismic issues. For intergovernmental issues, it would seem more natural that DOE would have asked the USGS for its advice. Bill Leith, USGS, provided an overview of how the American Recovery and Reinvestment Act (ARRA) funds were being used to improve the USGS capabilities for monitoring earthquakes and improving the nation's ability to react to earthquakes. Among the topics was the improvement in network operations that will allow development of a prototype earthquake early warning (EEW) in California.

The second meeting on November 4-5, 2010, started with a discussion of induced seismicity. Chair Zoback announced that the National Research Council is doing a study on the matter. The progress of the ANSS was examined. Through funding from ARRA the ANSS was moving forward in seismic monitoring. However, concerns were raised about how the monitoring of engineered structures was progressing. In this arena there are new technologies that may allow for a more robust and cost effective means of monitoring. These technologies have to be evaluated to be sure that the data are of the quality that is expected of ANSS sites. The question of whether ANSS should absorb the management of the USGS GPS networks was raised. This did not seem practical given the limited resources in both personnel and funding that currently exist for ANSS. Because the meeting was held in Southern California, the committee heard reports from Professor Mark Simons of Caltech on the partnership between the USGS and Caltech. Besides the obvious collaboration on seismic networks, Simons discussed Caltech's proposed collaboration between Caltech, the NASA Jet Propulsion Laboratory (JPL) and the USGS. A key element would be the use of JPL's Advanced Rapid Imaging and Analysis (ARIA) Center for Natural Hazards to provide near real time assessment of damage following earthquakes. Ken Hudnut, USGS Pasadena, provided an overview of the operations that are executed through the Pasadena office, such as the multi-hazard initiative, the Southern California Earthquake Hazard Assessment and the Southern California Earthquake Monitoring Project. Lucy Jones, USGS Pasadena, provided details of the multi-hazard project. Tom Brocher, USGS Menlo Park, and Jill McCarthy, USGS Golden, discussed the state of the operations overseen by the two regions.

Advanced National Seismic System (ANSS)

The following is taken verbatim from a report of November 2011 by Bill Leith of the USGS to Senator Barbara Boxer. It is a concise summary of what the committee has been informed about over the past three meetings.

"The Advanced National Seismic System (ANSS) is an investment by the U.S. Geological Survey (USGS) to improve the recording and reporting of earthquakes in the United States. The fully deployed ANSS will provide the data on ground shaking from earthquakes required to deliver timely and accurate early warnings, notifications, and impact statements, to prepare national seismic hazard assessments, and for cost-effective, earthquake-resilient engineering design and construction practices. First authorized by Congress in 2000, ANSS is planned as a modern 7,100-station seismic network, including:

- a 100-station national "backbone" network (completed in 2006 with support from the National Science Foundation (NSF), as part of the *EarthScope* facility);
- 1,000 high-quality, regional seismic stations in areas of moderate to high earthquake risk, designed to provide accurate information on earthquake locations, depths and magnitudes and to faithfully record information that can be used to develop complete fault models and time histories for large earthquake sources;
- 3,000 strong motion recording stations in 26 of the nation's highest-risk urban areas, for the purpose of recording damaging strong shaking and the generation of *ShakeMaps*, loss estimates, and related products for emergency response;
- 9,000 sensors (3000 equivalent stations) in buildings, bridges and other "lifeline" structures, designed to collect data on how the nation's infrastructure performs during major earthquakes, data that are greatly lacking from historical earthquakes.

<u>By the end of FY 2011, ANSS was 30% completed</u> (1754 ANSS stations and one 24x7 operational center). American Recovery and Reinvestment Act funding, allocated by USGS in 2009 for ANSS modernization, resulted in significant progress toward the modernization of older stations and the upgrading of communications and data centers. At expected 2012 budget levels, ANSS development will cease, and the system will remain at its current operational level.

To complete the system, the following additional investments would be needed:

- Structural Instrumentation: the ANSS requirements document calls for extensive instrumentation of buildings, bridges and other structures in areas of high earthquake risk. This is the least developed component of ANSS: 9,000 data channels are needed, and instrumentation installed through FY2011 is 1164 channels.

• Expanded Urban Monitoring: the ARRA funding was targeted for the modernization of existing seismic stations, but not for an expansion of the networks. To meet the ANSS requirements, an additional 1,700 stations are needed; these will be deployed in the highest-risk urban areas of the nation.

• Earthquake Early Warning (EEW): Alerts prior to the arrival of strong shaking are planned as an outcome of the full deployment of ANSS, for those areas of the country for which EEW is feasible. This month, the Gordon and Betty Moore Foundation pledged $6 million in grants to universities partnering with the USGS to complete the current research and development phase, but full *implementation* of EEW will require further investment in regional monitoring networks, communications, data centers and 24x7 operations.

• Data Management: Currently, a large proportion of the data management needs of the system are being accommodated through the IRIS Data Management System, funded by NSF. At full implementation, USGS would need to assume this funding responsibility, as well as the task of developing seamless data and product access for ANSS.

A 2005 cost-benefit study of ANSS by the National Research Council concluded that the economic benefits of the improved national system outweigh costs by approximately 10:1. The quantitative economic benefits in just one benefit area (performance-based seismic design) exceed the cost of deploying the entire system.

Current ANSS operations cost approximately $24 million per year. To achieve full implementation of ANSS – and gain the full projected economic benefits – USGS estimates that annual funding needs to be doubled and remain at that level (i.e., approximately $50 million per year).

More information on ANSS is available on the web at: earthquake.usgs.gov/anss."

Earthquake Early Warning

SESAC notes that USGS funded research in EEW has made significant progress and recommends that the USGS continue to support research and development on Earthquake Early Warning (EEW) systems as a natural product of a fully implemented ANSS. In light of significant new private funding from the Gordon and Betty Moore Foundation to universities to enhance EEW research and develop prototype systems, the USGS must clearly define its role as a national agency as the operational implementation of EEW systems move closer to reality. The appointment of a full time EEW coordinator by the USGS is a positive step.

It is clear from the Japanese experience during the March 2011 magnitude 9.0 Tohoku earthquake that when a dense network of modern seismographs is in place, early warning algorithms can be effective. Although the Japanese system did not work perfectly, warnings appeared on television screens and on mobile phones before strong shaking arrived, and trains were successfully stopped without incident. SESAC continues to recommend that the full implementation of ANSS is an important step towards an effective EEW system.

While scientific advances in EEW methodology in the United States, Japan and other countries are encouraging, much remains to be done before EEW technology can be confidently used as part of a national program for earthquake public safety. How such information would be effectively used by local and state entities (police, fire and disaster-response departments), utilities, private companies and other end users, as part of a national mitigation strategy, remains unclear. USGS must be part of the discussions that define the role of EEW in a national context.

Response to the Louisa County, Virginia Earthquake

The August 23, 2011 M5.8 Louisa County Virginia earthquake is the largest instrumentally recorded earthquake in eastern North America since the 1988 M5.9 Saguenay, Canada earthquake. The USGS must take full advantage of this rare opportunity to gather as much information possible regarding seismic hazard in the eastern United States. The USGS, along with cooperating universities, has already amassed critical data from aftershocks. Aftershock data and main shock recordings from permanent regional stations have provided information about the main shock location and fault plane orientation, moment tensor solution, stress drop, rupture radius, and amount of slip. Comparisons can also be made between observed and predicted ground motions at distances exceeding 100 km.

The short-term response by the USGS should focus in the aftershock region and include continued monitoring of aftershocks to determine parameters that are important for the national seismic hazard maps (e.g. aftershock decay rate and ground attenuation), detailed geological mapping, systematic searches for liquefaction and paleoseismic features, and reprocessing of available seismic reflection lines. Geologic mapping should incorporate aeromagnetic and gravity data; NE trending, linear magnetic anomalies extend through the region and may be indicative of major subsurface faults. New potential field data should be collected and, possibly, LIDAR to help delineate past earthquake scarps. Detailed surface mapping may not reveal the causative fault for the Louisa County earthquake but a high-resolution seismic reflection line across the epicentral region may link aftershocks to a specific fault or fault system.

The long-term response of the USGS should involve a broader understanding of the seismic hazard that faces the central and eastern US. Clearly, monitoring should continue in the Central Virginia Seismic Zone (CVSZ) at a level that will provide adequate near-source ground motions and fault rupture parameters should another damaging earthquake occur. Regionally, the ANSS backbone interstation spacing should be reduced in order to record near-source ground motions for moderate-to-large central and eastern US earthquakes. The passage of USArray through the region will provide short-term densification and every effort should be made to keep as many TA stations as possible. In addition, netQuake instrumentation should be installed wherever possible. Site effects should be determined for all ANSS stations to better predict the amount of ground shaking in future earthquakes. If the Louisa County earthquake can be associated with Mesozoic extensional faults, then it would be prudent to map and possibly monitor similar faults in close proximity to major urban areas in the eastern US. Distinct regions of low-level seismic activity in the central and eastern US have been identified on the national seismic hazard maps. As in the case of the CVSZ, a concerted effort should be made to understand why these seismogenic regions exist and if they pose an elevated risk of a future, damaging earthquake.

USGS Role in Earthquake Response

Over the last two years the USGS has responded to a significant number of earthquakes, including the 2010 Haiti earthquake, the 2010 Maule, Chile earthquake, the 2011 Louisa County (VA) earthquake, and others. The responses have involved a large range of activities, including coordination planning with the NEHRP agencies and other agencies considering responses and sending technical personnel to the field to install instrumentation and make technical assessments. These activities have taken a significant amount of staff time. Currently, there is no clear decision making process that the USGS follows to determine its level of response when an earthquake occurs. It is time for the USGS to evaluate whether its responses to these previous earthquakes have been appropriate, and to develop a plan for deciding its response to future earthquakes.

Additionally, the NSF is no longer supporting EERI's Learning from Earthquakes reconnaissance efforts. This program has coordinated earthquake responses focused on engineering aspects, and the loss of funding has left a void with respect to engineering issues. The NSF has decided to use competitive RAPID grants to support large numbers of groups to respond to an earthquake to investigate specific issues in engineering, social science, and earth science. However, coordination between these efforts has been lacking. In the past, EERI has provided coordination between various reconnaissance groups. Perhaps funding from FEMA or NIST could fill the void left by the loss of NSF funding for the EERI Learning from Earthquakes program. This would improve the coordination of reconnaissance efforts, in particular in the engineering area.

Induced Seismicity

During the last few years, the practice of hydraulic fracturing (fracking) and wastewater injection has become a national concern on several fronts. Several states have either banned fracking or the treatment, disposal or storage of wastewater from hydraulic fracturing pending further studies (e.g., Pennsylvania, New York, New Jersey) or have issued legislation requiring industry operators to list the content and concentration of chemicals used in waste water injection in deep wells (e.g. Colorado, Wyoming, Arkansas, Texas, Pennsylvania). In addition, induced seismicity or triggered earthquakes have become a concern for local communities as evidenced by the reaction to recently felt earthquakes in southern Colorado, Ohio, Oklahoma, and Arkansas.

The development of new energy resources that utilize these injection techniques has become tied to national policies of energy independence and economic growth. As these practices spread throughout the central and eastern United States, concerns about the proximity of Underground Injection Control (UIC) wells to active seismic zones or to critical facilities (e.g. hospitals, schools, or nuclear power plants) based on their perceived potential to induce or trigger damaging earthquakes will become more of an issue.

There are approximately 144,000 "Class II" (wells associated with oil and gas production) wastewater disposal wells in the United States, but only a very small fraction of them have induced earthquakes that are large enough to be of concern to the public. The fact that most of these injection wells have not caused earthquakes of any consequence underscores the need for a better understanding of why larger events have occurred and the development of mechanisms to mitigate their occurrence in the future.

What is the appropriate role of the USGS in this field? Should the USGS limit itself to just doing the basic science to understand the cause of the seismicity? Who monitors the seismicity? Are there criteria to be set that can be used to set policy as opposed to working on a case-by-case basis?

As the nation's earth science agency, the USGS plays a critical role in the national strategy to identify new energy resources and develop energy independence. The issues surrounding induced seismicity have already engaged USGS scientists involved in the NEHRP program. The USGS has a long and active history in studying induced seismicity – extending from the Denver Rocky Mountain Arsenal earthquakes in the mid-1960's to current investigations with university partners to monitor earthquakes in Arkansas, southern Colorado, Oklahoma, and Ohio.

Rather than monitor the seismicity at every wastewater and geothermal injection project in the United States, SESAC recommends that the USGS continue to apply their expertise, as part of the NEHRP program, to develop an improved understanding of how fluid injection induces seismicity. These studies would form the basis for technical guidelines and procedures that can be used and referred to by state, local and Federal regulators as well as industry to evaluate the likelihood of induced seismicity at waste fluid injection, geothermal and planned carbon sequestration sites. A sound technical understanding can, in turn, inform policy decisions regulating the proximity of these projects to population centers and critical facilities. The USGS has already partnered with the EPA and DOE on these issues and SESAC endorses their continuation cooperation and interaction.

SESAC recommends that technical guidelines and procedures address issues such as:

- The determination of proposed injection site stress fields and fault geometries.
- Standards and procedures for monitoring of seismic activity before, during and after injection.
- Identification of the necessary parameters to be monitored for induced seismicity (e.g., volume, rate, porosity, permeability).
- The ability to predict the induced seismicity correlated with these parameters.
- The ability to control those parameters as a way to mitigate the potential hazards associated with injection.

USGS and the NSF EarthScope/USArray

EarthScope/USArray has contributed directly to establishing and/or upgrading a total of 59 of the ~100 stations of the ANSS Backbone network. One of the goals of EarthScope is to have a permanent backbone network of approximately 100 equally spaced stations across the conterminous US to serve as a reference for the 400 station Transportable Array (TA) as it crosses the continent. Since this goal matches the USGS requirements for ANSS Backbone Network, the creation of the USArray Reference Network was developed as a joint effort between USGS, IRIS and NSF. During the construction phase of EarthScope, USArray contributed a total of $6M to establish or upgrade 39 ANSS Backbone stations (including construction and installation costs, 44 broadband sensors and DAS's, 35 strong motion sensors and associated power and communication systems). Following the EarthScope construction phase, all permanent equipment for these 39 stations was transferred from NSF to USGS. Funding limitations prevented the USGS from establishing the remaining stations of the ANSS Backbone to bring the total reference network to the required 100 stations, so EarthScope and IRIS agreed to "advance deploy" an additional 20 TA stations, primarily in the central and eastern US, to fill in gaps in permanent station coverage in these regions. Seventeen of these are completely new stations using the standard TA equipment and vault design. These will continue to be operated by USArray until the USArray project is completed in 2018.

As it traverses the lower-48 states, the USArray Transportable Array has provided uniform coverage, a significant increase in station density (400 stations at 70 km spacing) and lower detection threshold in many regions. During the ~2 year deployment for each of the 400 TA stations, this has allowed regional networks, the NEIC and university groups to carry out special studies of low-level seismicity, high-resolution crustal and source modeling and to establish baseline/reference models that will improve future studies of regional seismicity. This is especially important east of the Rocky Mountains, where previous coverage and station density in the Central and Eastern US has been poor or non-existent. The USArray network currently straddles the Mississippi River from the Canadian Border to the Gulf of Mexico and will continue eastward until the final station removal is completed in 2015.

In order to provide continuing coverage and a USArray "legacy", IRIS/USArray has arranged with NSF to establish a station "adoption" program, whereby interested regional networks, states, universities or other organizations can acquire operating TA stations for the cost of hardware replacement, providing the operators are willing to have the data continue to flow openly to the IRIS DMC and NEIC in real-time. To date, 45 complete stations have been "adopted" under the arrangement, primarily in WA, OR, AZ, CO and PA (an additional 29 vaults have been adopted and instrumented with non-TA equipment).

Similar arrangements for systematic adoption of even "one-in-four" of the TA stations in the central and eastern US would provide a major increase (up to 200 stations) in the permanent coverage of this poorly monitored region. With a modest investment the hardware at these sites could be augmented (e.g., adding accelerometers, increasing the sample rates) to accommodate special ANSS needs. For the past three years, IRIS has been actively seeking to develop large-scale station adoption arrangements with the USGS, the Nuclear Regulatory Commission and State Geological Surveys to bring about this important improvement in coverage for the central and eastern US. Except in Pennsylvania (where 4 stations have been advance-deployed and adopted), response to-date has been disappointing. Unless transition arrangements can be developed within the next year, it is likely that this unprecedented opportunity for improvement in the ANSS will be lost.

Station deployment of the USArray/TA is expected to commence in Alaska in 2014. Current plans call for 291 stations to operate during 2014-2018 at approximately 85 km spacing throughout interior Alaska, the Aleutians and adjacent Canada. Arrangements for station adoption can result in similar improvements in coverage for this highly active seismic region, but only if plans can be developed and agreed to now.

Leveraging the large EarthScope investments made by NSF provides a unique opportunity to make a significant step forward in the goals of ANSS. SESAC and the ANSS Steering Committee are strongly encouraged to become actively engaged in pushing to see the TA legacy turned in to a permanent improvement in ANSS and US earthquake monitoring.

Partnerships with States

ANSS. Funds that are provided by various states, whose own seismic networks contribute to the completeness of the ANSS, are not counted in the ANSS support. However, funding for at least two contributing states with large regional networks – California and Nevada – has been dramatically reduced. Where the USGS had been facing a "hold the line" situation with insufficient funds to provide for expansion of the designed system, it is now faced with an actual reduction in overall available funds and degradation in overall ANSS performance. It is unlikely, in the foreseeable economic future, that the states will be able to replace their lost funds without seeking other, non-legislative sources. The California Geological Survey's Strong Motion Instrumentation Program (CGS-SMIP) contracts with several state agencies and some local agencies (water districts, harbors, etc.) to place network instruments and support maintenance of those instruments by CGS-SMIP.

Induced Seismicity. The most common cause of induced seismicity is the injection of fluids under pressure into the subsurface; and the most common reasons for this injection are: geothermal production, waste liquids disposal, carbon dioxide sequestration, and fracking methods for enhanced oil and gas recovery. As occurrences of induced seismicity from these industrial/commercial operations increase, and the general public becomes more "aware" of this seismicity, the USGS likely will be called upon to comment on the cause and predictability of continuing "annoying" or "damaging" induced seismic events.

Because these industrial/commercial activities are carried out under permits issued by the states, the states may be encouraged to require these commercial activities to install seismic monitoring arrays in and around areas of potential induced seismic activity. Since many fracking issues appear related, also, to drinking water concerns, perhaps the U. S. Environmental Protection Agency could be encouraged to require seismic arrays for commercial operations that potentially cause induced seismicity. EPA could delegate this Federal authority to state agencies, much as it does petroleum-drilling permits. The USGS would receive data from these commercially sponsored arrays allowing the USGS to study and comment on induced seismic events.

Geodetic Monitoring (GPS)

Data from continuous and campaign GPS measurements contribute significant information that USGS needs to meet its goals of understanding seismic hazard, providing information about earthquakes, and responding to events. Interseismic strain is a function primarily of long-term fault slip rates and the seismogenic depth or creep distribution on faults. Thus, measurements made by GPS, InSAR or other methods can be used to estimate quantities that relate directly to the buildup of stress within the crust in preparation for future earthquakes. Coseismic and postseismic displacements are used to constrain earthquake source models, along with lithospheric and asthenospheric rheology and stress transfer. Rapid or real-time displacements measured by continuous GPS networks can be used for rapid source assessment. Real-time displacements also have obvious applications for tsunami warning. They probably have only a limited application to earthquake early warning except in unusual circumstances (extremely large events). Some of these applications of GPS data have a long history within the USGS Earthquake Hazards program. Others are newly mature and have been implemented to some degree. Real-time applications are maturing and likely will become ready for operational implementation within a few years; some would argue that they are ready now.

USGS has opportunities to expand the scope and depth of its use of GPS data. In an era of tight budgets, any expansion may be difficult, but it would be useful to have a plan for expansion in case opportunities arise. USGS has supported the operation of GPS networks of varying sizes in several regions, including California, the Pacific Northwest, Intermountain West, and Mid-continent (New Madrid). USGS decided several years ago to restrict future GPS network support to those already being supported, which means that additional regions like Alaska or other parts of the central or eastern US have never had USGS-supported GPS networks. In the meantime, the National Science Foundation has built the Plate Boundary Observatory (PBO). Officially, the NSF EarthScope program that supports the operation of PBO sunsets in 2018, so there may be a long-term need for USGS to take over operation of some parts of PBO that are of special interest to USGS. Most people in the US geodetic community believe that NSF will continue operation of all or most of PBO beyond that point, but that is not guaranteed and there is no formal NSF commitment to do so. This makes it timely for USGS to evaluate how well the combination of PBO and USGS-supported networks meet USGS needs, how USGS would respond if NSF funding for geodetic networks was significantly reduced or redirected, and whether USGS needs additional data that it might support the acquisition of itself.

Raw GPS data needs to be analyzed to estimate site positions in order to make it useful for earthquake studies. This is somewhat different from seismic data, in which the output of the seismometer is already a measure of ground motion. This means that processed GPS position time series, either for static daily positioning or high-rate displacements, are derived products that are subject to change when the original data are reprocessed. This needs to be considered when archiving and using data, and also in the future for integrating real-time GPS displacement streams with seismic data. USGS currently supports processing of GPS data in-house, both at USGS and Menlo Park. SESAC did not discuss these efforts in detail. USGS could choose to do standard GPS processing in-house for all of the data of interest to USGS by building on these present capabilities. Alternatively, it could contract to this function to UNAVCO or emulate UNAVCO's approach for PBO (UNAVCO contracts the data processing for PBO to two analysis centers plus an analysis coordinator). Contracting small parts of the processing to several independent network operators is not a good strategy for the classic daily static positioning problem, but it is less clear how to handle potential future real-time analysis. At present, real-time analysis software can handle only a limited number of stations at a time, and it may be advisable to integrate future real-time displacement streams with the regional seismic data streams. If so, this has implications for who should operate given sites and how data flow should be handled.

USGS has the opportunity to make use of a great deal of data and products provided by other agencies, mainly NSF and NASA, but also NOAA to some extent. In addition to retrospective use of data from sites operated by those agencies, as mentioned above, streams of real time data and the orbits and other products needed to use them are available. All PBO GPS sites in Cascadia stream real time data. NASA and foreign agencies, mainly working through the International GNSS Service (IGS), provide additional real-time data or product streams. USGS should watch of developments in this area closely, because the capability for precise real-time GPS anywhere in the world is likely only a few years away, and the USGS can probably exploit this for its own uses with a modest cost investment. As the real-time GPS technology matures further, the USGS may look for partnerships in supporting real-time data from sites that currently do not provide it.

Data archiving for GPS data is another issue. Some USGS GPS data has been archived at the Northern California Earthquake Data Center. Some USGS continuous GPS sites are currently archived at UNAVCO. The Volcano Hazards Program is already paying UNAVCO on a per site basis. An USGS-wide solution may be desirable, combining resources from all of the Hazards programs, and such a solution might be more cost-effective. It is worth examining whether USGS should support archiving at UNAVCO on a more systematic basis, to compare the cost (presumably negotiable if done Hazards program wide) vs. the cost to do the job properly in house.

National Earthquake Prediction Evaluation Council (NEPEC)

Several NEPEC activities and plans are summarized here. The first concerns seismicity in the central US. In the spring of 2011, NEPEC convened an "Independent Expert Panel on New Madrid Seismic Zone Earthquake Hazard." We were lucky to convince a group of outstanding of scientists with a variety of relevant expertise to serve. The panel members were chosen to have no vested interests in the outcome of their review. They received input in writing and in face-to-face meetings with a variety of scientists, some having previously expressed strong opinions. The panel wrote a succinct 25-page report that contains their charge, their membership, their activities and procedures, an executive summary and their more-detailed assessment of the seismic hazard. The report is available at http://earthquake.usgs.gov/aboutus/nepec/reports/NEPEC_NMSZ_expert_panel_report.pdf, and a letter forwarding the report to the director of the USGS is available at http://earthquake.usgs.gov/aboutus/nepec/reports/NEPEC_LettertoMcNutt4-18-11.pdf.

The panel found that despite considerable uncertainties about the underlying origins, nature and history of earthquakes in the region, the seismic zone is at significant risk for damaging earthquakes, which must be accounted for in planning and development. The panel also examined the USGS national seismic hazard maps and the process by which they are produced and updated. They concluded that the hazard maps employ a scientifically sound, carefully implemented, open, and consensus-based process that incorporates a range of scientific data, views and interpretations, and represents the best means available to refine hazard estimates. Although the report acknowledges that uncertainties in our knowledge are sufficiently broad that the current USGS national hazards maps could somewhat overestimate the seismic hazard within the New Madrid Seismic Zone (NMSZ), the panel recommended that the 2008 national maps should continue to be used until they are updated in 2013. NEPEC hopes the report of our expert panel will be helpful for long-term and emergency planners facing societally relevant decisions in the New Madrid area. Significant seismic hazard in the NMSZ and broader central US region is evident.

Part of the focus of a NEPEC meeting in Seattle in November, 2011 was on how to interact with emergency planners and managers if some geologic event occurred that the scientific community believed could be a precursor to a major damaging earthquake, either in the Cascadia subduction zone or in the upper plate. NEPEC is convening a subcommittee to compile a list for the Pacific Northwest of possible damaging earthquakes and geologic events that might presage them. With such a compilation in hand, the plan is to hold a meeting with the community of emergency planners and responders to see what kinds of messages they would like to receive from the scientific community were various potentially premonitory events to occur. Out of this we hope will come better communications with the emergency planning and response communities as well as a number of prepared specific messages that could be transmitted on short notice in response to various anticipated potentially premonitory events.

One issue that NEPEC is anticipating will occupy its attention in the future is the role that Operational Earthquake Forecasting (OEF) may play in the field of earthquake prediction. Were a robust and effective automated system of OEF to be developed it would have many advantages over the current situation in which time-consuming human interpretation is involved before an earthquake forecast or warning can be issued. NEPEC hopes that a robust OEF system can be developed. The role of NEPEC in OEF the next few years is likely to be one of helping evaluate community progress toward OEF, its reliability and usefulness, and how and whether it might eventually replace the actions of groups such as NEPEC and its California equivalent, CEPEC. If OEF becomes well developed, then it will be important to determine what role, if any, NEPEC might continue to play in advising on a any dramatic increase in earthquake probability that were to emerge from a OEF forecast.

NEPEC and SEPEC met jointly in November, 2010 and one item on our agenda was hearing from Nancy Baumgartner, USGS Deputy Ethics Counselor, and Jessica Kirschbraun, California Emergency Management Agency, concerning the legal status and issues for NEPEC and CEPEC members in light of the criminal charges brought against prediction researchers and officials in Italy. The conclusion is that if members are acting in their capacities as members of NEPEC, then they are legally free from liability for their actions.

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