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July 28, 2015

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

Dear Director Kimball,

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

This report is based on the SESAC meetings during 2014 and 2015.

Twice a year we listen to reports from USGS personnel about the state-of-health of EHP. There are recurring themes that are major concerns to SESAC:

- There are new initiatives that provide excellent opportunities for EHP to gain a more profound understanding of earthquake hazards or mitigate their effects. Each of these is added to the EHP portfolio without commensurate funding. The base funding for EHP has hardly changed since its inception in the 1970's.
- The blueprint for monitoring earthquakes in the US–USGS Circular 1188–was written in 1999. It is in the process of being updated. The next generation of instrumentation and monitoring strategies require a progressive document.
- The basic infrastructure for monitoring earthquakes consumes nearly 50% of the entire EHP budget. It has become a zero-sum game between gaining more data and doing the research to understand the significance of data when the funding level stays flat.

There are emerging opportunities as well as the concomitant challenges for EHP:

- Earthquake Early Warning (EEW) is an initiative that has support in the public, in some state agencies and in Congress. It is an initiative made possible by having the density of seismic stations, modern telemetry, and computational resources, within a fully developed Advanced National Seismic System. The development of EEW has been in collaboration with university partners. In the

final analysis the USGS will be the agency that will be responsible for sending the alert. Even in a limited region such as southern California it is clear that were EHP to operate EEW as a 24/7 operation there would be dire consequences, i.e., no funding for other critical elements within the EHP.

- Induced seismicity provides opportunities for understanding earthquakes and their effects at a different scale. It has also exposed a new segment of the population to their effects. Thus there is a greater awareness of earthquakes being phenomena that are not limited to the western US. EHP is expected to monitor these earthquakes, do the research to find the underlying cause(s) to mitigate the effects, and assess the hazard. There is a need for partnerships if the EHP is to fulfill its obligation of monitoring earthquakes in the US. Current expectations for the EHP are underfunded; a new program in EHP that focuses on induced seismicity meets the needs of the nation but comes at the expense of other worthwhile programs in EHP. In itself the new program on induced seismicity does not have the resources it needs.
- The 2011 Mineral, Virginia earthquake as well as seismicity, some of it induced, has heightened the public's awareness of the seismic hazard in the central and eastern US (CEUS). Yet, the seismic hazard in the CEUS is poorly understood. The adoption of the 160 Transportable Array stations will provide more data about some aspects (path effects) of the hazard. There are open questions about the strength of shaking should the CEUS have a magnitude 6.5 or greater earthquake. The USGS must take the lead in developing a strategy for improving our understanding of the seismic hazard in the CEUS.
- The National Earthquake Information Center (NEIC) has become the persona for the USGS in its response to earthquakes. It provides rapid, accurate and in-depth information about earthquakes across the world 24/7. NEIC has been proactive in providing estimates of shaking intensity (ShakeMap), losses, both financial and life (PAGER-Prompt Assessment for Global Earthquake Response), damage (ShakeCast) that are routinely expected following any damaging earthquake. As these tools become embedded in the full suite of information packages, the need to make such tools robust to any failure, be it hardware or personnel, requires redundancy in the staff and equipment.
- There are other significant directions that the EHP might pursue such as urban hazard maps, operational earthquake forecasting, expanding geodetic networks, establishing seismic arrays that consist of thousands of sensors, etc. Each opportunity can provide more mitigation, but each comes with a cost both in capital and in personnel.

These opportunities and challenges will not disappear. SESAC recommends that you do all that you can to take advantage of the opportunities.

- Be sure that the new blueprint for monitoring earthquakes includes a vision for the future and addresses monitoring across the nation.
- Develop a funding strategy at the highest USGS level for monitoring and analyzing induced seismicity.
- Develop a funding strategy at the highest USGS level for Earthquake Early Warning that will allow for a natural and rapid expansion from a regional system to a nationwide system.

- Continue to build on the success of NEIC in providing products that are readily available following significant earthquakes. The nation and the world first turns to NEIC whenever there is a noteworthy earthquake.
- Strengthen the partnerships with NSF and other federal partners within NEHRP as well as universities and private industry.

Attached is a report that expands SESAC concerns about the health of the EHP. Succinctly, the USGS EHP has met its expectations exceedingly well. Its success has naturally led to even greater expectations in monitoring earthquakes and mitigating the seismic hazard with only miniscule increases in resources–budget or staff. As a business plan an ever-expanding scope of activities without additional resources is untenable.

SESAC appreciates the dedication, expertise and professionalism of the USGS EHP personnel. The information and reports SESAC receives are of the highest quality. Anyone who looks into the EHP will recognize that the EHP has been a highly successful program. We want that success to continue for a safer and more resilient nation.

We know that you have many irons in the fire. Earthquakes may not occur every season, but they present a real hazard every day. SESAC is always open to hearing from you regarding the Earthquake Hazards Program. If we can assist you in any way, please ask.

With warm regards,

Ralph J. Archuleta, Chair of SESAC
Professor Emeritus of Seismology

cc: Members, Scientific Earthquake Studies Advisory Committee
David Applegate, Associate Director, Natural Hazards
William Leith, Program Coordinator, Earthquake Hazards Program

Scientific Earthquake Studies Advisory Committee
Report for 2015
To the Director of the U. S. Geological Survey
And to the Congress of the United States of America

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 on the USGS Earthquake Hazards Program (EHP) covers SESAC meetings of May 29 and 30, 2014, and January 28 and 29, 2015. This report calls attention to issues that affect the effectiveness of the EHP both short-term and long-term. The USGS EHP is a core agency within the National Earthquake Hazards Reduction Program (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. The members of SESAC are listed in Appendix B at the end of this report.

Introduction

To provide the context for this report the Committee reiterates:

* the **Mission of NEHRP**:

  "*To develop, disseminate, and promote knowledge, tools, and practices for earthquake risk reduction—through coordinated, multidisciplinary, interagency partnerships among the NEHRP agencies and their stakeholders—that improve the Nation's earthquake resilience in public safety, economic strength, and national security*"

* the **Mission of USGS Earthquake Hazards Program (EHP)** within NEHRP:

  "*To provide and apply relevant earthquake science information and knowledge for reducing deaths, injuries, and property damage from earthquakes through understanding of their characteristics and effects and by providing the information and knowledge needed to mitigate these losses". The USGS role in NEHRP is thus to provide Earth sciences information and products for earthquake loss reduction.*

* the **Goals of the USGS' EHP**:

  1. *Improve earthquake hazard identification and risk assessment methods and their use;*
  2. *Maintain and improve comprehensive earthquake monitoring in the United States with focus on "real-time" systems in urban areas;*
  3. *Improve the understanding of earthquakes occurrence and their effects and consequences.*

SESAC met May 29, 30, 2014 at the USGS Geologic Hazards Science Center on the campus of the Colorado School of Mines, Golden, Colorado. SESAC held a second meeting on January 28, 29, 2015 at the Southern California Earthquake Center on the University of Southern California

campus, Los Angeles, California. The agenda and list of attendees for the two meetings is given in Appendix A.

The May 2014 meeting covered EHP activities in Earthquake Early Warning (EEW), monitoring and analysis of likely induced earthquakes in the regions with widespread fluid injection, the upcoming transfer of 160 stations from the National Science Foundation to the USGS EHP in the central and eastern US, and a reflective/prospective view of the EHP's research and operations as it looks to the next decade.

The January 2015 meeting focused primarily on earthquake monitoring which consumes about 50% of the EHP budget. The data acquired from monitoring earthquakes are the fundamental building blocks for almost every major product delivered by the EHP. The backbone of earthquake monitoring in the US is the Advanced National Seismic System (ANSS) which includes the US National Seismic Network USNSN), the National Strong Motion Program (NSMP) and various regional networks supported by the USGS. The USGS also shares in the support of the Global Seismographic Network (GSN) to improve observations of earthquakes throughout the world. The GSN is a cooperative network between the NSF funded Incorporated Research Institutions for Seismology (IRIS) and the USGS. The primary analytical and reporting center for EHP is the USGS National Earthquake Information Center (NEIC) which has placed increasing emphasis on new information products and has been operational 24/7 as a result of increased funding following the 2004 Sumatra earthquake.

At the January meeting, SESAC also looked at the development of EEW, inclusion of induced seismicity into the National Seismic Hazard Map, operation/maintenance of the 160 stations in the central and eastern US, and the potential of operational earthquake forecasting.

Summary of Principal Issues

The foundation for EHP is monitoring earthquakes. New initiatives such as induced seismicity, seismic hazards in the eastern US, and earthquake early warning among others bring fresh ideas and renewed enthusiasm for the mission of EHP. The critical concept that must always be considered is that earthquakes have a time scale from decades to millennia. New initiatives require sustained support on a decadal time scale. Moreover the fundamental data come from networks of instrumentation, communication channels and computational capacity to process the information. All of these require a commitment to diversified workforce and funding for long-term maintenance, upgrades and operation.

Looking ahead the SESAC anticipates that the EHP will face challenges where Congress, Department of Interior and the Director of the USGS will need to provide support:

1. The Advanced National Seismic System (ANSS) has been served well by an initial planning document (USGS OFR 1188) that is now almost two decades old. To remain effective ANSS must be refreshed and augmented with new monitoring strategies that take advantage of new technologies and instrumentation. SESAC strongly encourages an

internal activity underway within EHR to develop an updated version of the ANSS plan to define current needs and help guide future investments.

2. Hydraulic fracturing, deep-well injection, carbon sequestration, and geothermal energy are potentially major contributors the future US energy portfolio. These activities can lead to increased seismicity; however, the need to respond to potentially induced seismicity puts severe demands on the EHP both in monitoring and in accounting for such seismicity in the national hazard maps. Because these activities are likely to increase in the future, the EHP needs a sustained effort that is well supported at all levels in order to understand the phenomenon and possibly mitigate the seismic hazard.

3. Earthquake Early Warning (EEW) has moved to the forefront of the public's interest in earthquake mitigation. EEW is a product that results from a fully developed ANSS. However, the density of stations, the redundancy in communication and computational effort as well as being both operational and reliable 24/7 requires more capital cost and more operational costs than has been budgeted. SESAC emphasizes that EEW cannot be made functional at the expense of the entire EHP. There must be a substantial increase in the base budget for EEW to perform as expected.

4. On a six-year cycle the EHP produces the US National Seismic Hazard Maps (NSHM). In that these maps directly affect *a trillion dollars per year* in new building inventory they may be the single most important EHP product. The US National Seismic Hazard Maps integrate most of the EHP primary efforts such as the ANSS, paleoseismic investigations, seismicity, ground motion research, geodesy, etc. Among several potential variations to the NSHM the EHP has been exploring the possibility of urban seismic hazard maps—maps with greater detail that take into account the local geology, basins, topography. While such an undertaking could provide better estimates of the hazard, the effort would greatly expand the workload that can only be accommodated by an increase in the workforce and available resources.

5. Seismic hazards in the central and eastern US (CEUS) are not well understood putting a large fraction of the US population at risk. EHP, as part of an interagency agreement, will gradually assume the operation and maintenance of 160 stations in the CEUS that were installed by IRIS as part of the National Science Foundation's EarthScope Transportable Array. This enhanced capability is a significant improvement over the quality and density of previous observational systems in the CEUS, however, like the new emphasis on induced seismicity and EEW, this renewed thrust into the hazards of the CEUS has been put under the EHP umbrella without sufficient long-term resources.

6. The EHP has maintained an extraordinary balance between fundamental and strategic research. Consequently it has developed products that are indispensable to the public, policy makers, professional groups and to the overall scientific community. There is no question that ShakeMap is quickly accessed following each major earthquake or that PAGER (Prompt Assessment of Global Earthquakes for Response) provides an almost immediate, reliable estimate of damage and fatalities for earthquakes throughout the world. The US National Seismic Hazard Maps are indispensable to seismic mitigation.

As these products evolve they require more expertise from computer scientists, earthquake engineers, statisticians, etc. Thus the diversity of the EHP workforce will need to evolve without diminishing the scientific workforce that provides the impetus for new ideas and products.

The EHP has rightfully been recognized for its exemplary efforts directed toward its dual mission of monitoring earthquakes and understanding seismic hazards to help mitigate seismic risk. Its success has initiated new projects and expanded the existing ones that are the foundation upon which the new projects were launched. There has been no commensurate increase in either the budget or the workforce. As a business plan this is untenable.

The SESAC urges Congress, the Office of Management and Budget, the Department of Interior and the Director of the U.S. Geological Survey to consider the impact that constrained funding has in of stifling the Earthquake Hazards Program. A severely damaging earthquake will occur in the US; it is only a matter of time. To assess what might have been done after the earthquake is like buying fire insurance after the house has burned down. The Earthquake Hazards Program has proven that it is fiscally conservative while being entrepreneurial in initiating new programs to meet the changing needs of the nation. It is time to recognize that the Earthquake Hazards Program must have funding that is commensurate with the expectations placed upon it.

Topics

Advanced National Seismic System (ANSS)
The National Steering Committee of the Advanced National Seismic System identified as a top priority an update of the vision and plan for ANSS. The original plan was published in 1999, and in the meantime ANSS has been partly built out, technologies have changed, and science and engineering needs and priorities have evolved. Cecily Wolfe and John Filson at the USGS have developed a draft document – Advanced National Seismic System, Accomplishments, Status, and Plans – that celebrates ANSS achievements, documents progress since its inception, and lays out the goals and priorities for the next decade, many of which would require new funding to achieve. ANSS is currently seeking input from the broader scientific and engineering community, as well as from the NEHRP agencies and others.

The NSC sees a need for the USGS to develop better capabilities to field and analyze portable deployments, both for future aftershock sequences, and also because existing permanent networks are too sparse to appropriately monitor induced sequences. While enhanced monitoring of the central and eastern US is welcome, ANSS cannot take over the operation of CEUSN stations and assure their long-term operations without additional new funding. The NSC recommended that the Puerto Rico Seismic Network be allowed become a participant in the ANSS as a self supporting network, contingent on their being able to meet ANSS standards and implementation policies. The Commonwealth of Puerto Rico is an unincorporated territory of the United States (U.S.), having almost 4 million U.S. citizens living in a region of high earthquake and tsunami hazard. At the same time the NSC is concerned with the recent defunding of some regional seismic networks, which reflects the limitations of the EHP base budget. The current funding climate has led to increases for specific initiatives without increases in the base budget. The committee views the base ANSS capabilities as important and is concerned by this situation.

Finally, as part of the update of the vision document, the NSC recommends that structures to be monitored be thoughtfully chosen such that they are representative of commonly used building types. An alternative to instrumenting structures would be to deploy dense arrays of free field instruments in urban areas, so engineers can have more precise ground motion information at the buildings that are damaged in a major earthquake.

National Seismic Hazard Maps
The current USGS National Seismic Hazard Maps (NSHM) are a direct application of the USGS Earthquake Hazards Program (EHP) Mission Statement: “To provide and apply relevant earthquake science information and knowledge for reducing deaths, injuries, and property damage from earthquakes through understanding of their characteristics and effects and by providing the information and knowledge needed to mitigate these losses.” Used nationwide by professional communities to design infrastructure, develop emergency response plans, and identify social vulnerabilities, these maps provide the best estimate of earthquake hazards across the nation and are an invaluable resource to society. The importance of these maps cannot be overstated. They directly affect nearly a trillion dollars of new construction annually (Figure 1).

There are a number of other products related to the NSHM that have been suggested. Among them are Urban Seismic Hazard Maps (USHM). Would USHM prove beneficial? In a broad

context, USHMs would provide similar information, only to a specified metropolitan area. Confined to a restricted geographical area by definition, USHMs could account for refined level of detail in local geological structure, basin geometry, topography and soil and site conditions.

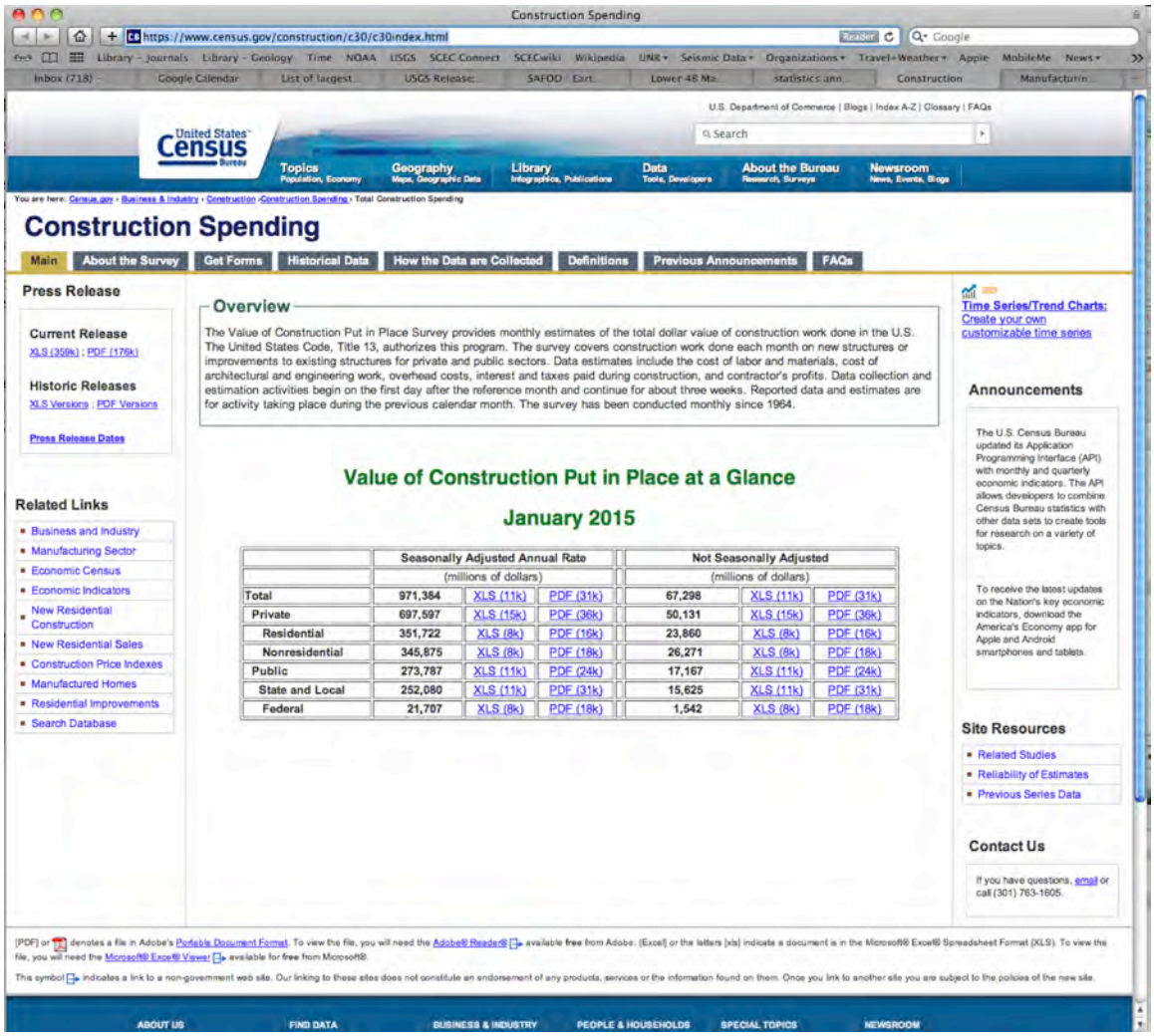

Figure 1. Screen shot of a page from the US Census on construction spending, accessed March 12, 2015.

To be useful and remain relevant, development of USHMs entails the following:

- Identification of
    - specific regional requirements: liquefaction, building fragility, rupture forecasts
    - local resources able to assist with scientific data
    - local authoritative agencies: EMA, City/County Agencies, Professional Groups
- Collaboration and cooperation of the identified interest groups
- Production of the maps in a useful format: paper, electronic, web based
- Maintenance and regular updates to the maps

The current NSHM is produced from the 2008 USGS hazard model; the 2014 USGS hazard model is under consideration for adoption. Consensus groups—representing a nationwide cross

section of highly qualified scientists, engineers, and other interested professionals—determine how the latest research and remaining uncertainties are handled in the hazard model. The process requires multiple levels of discussion and allows for unrestricted public comment. This process minimizes interest group influences while encouraging cross-discipline dialogue from all user groups. However the process takes years and does not lend itself to frequent updates of the maps.

When hazard mapping is brought down to a regional level, the vast majority of current consensus group participants would most likely decline to participate in development of USHM that are outside of one's own geographic area. More sophisticated modeling techniques that are only practical on an urban scale are likely to generate a significantly more profound effect on the hazard estimates, and by extension the end user's products. When two maps exist, there are bound to be questions. Given a NSHM and an USHM of the same region, which map will control: The map that produces the least or greatest hazard? Where the two maps overlap, if hazard contours are not in agreement, which map will control? The decision will have significant cost implications to local economic development, with the lesser cost option typically resulting in design for a lower hazard.

In considering USHMs and other potential products that might be limited to specific regions: what should EHP's role be given the potential growth in demand for relevant USHMs? Resources are finite, so only a limited number of metropolitan areas would receive USHMs. The greater number of USHMs, the more dependent each region would be on their local resources to update and maintain those maps. Even considering local development and production, the EHP must have a role in every USHM to maintain the integrity of the information provided. From an engineering perspective, Urban Seismic Hazard Maps must be subject to the same rigorous guidelines and rules applied to the National Seismic Hazard Maps.

Currently, National Seismic Hazard Maps are an established authoritative USGS product. There are many other suggestions for improvements and modifications to the National Seismic Hazard Maps. There are limited resources within the EHP. Thus each new product must have a priority and a business plan as to how such products will be developed and maintained over the decades of their usefulness.

Hydraulic Fracturing, Deep-well Injection

Induced seismicity, especially that caused by the disposal of high volumes of waste saline waters produced from oil and gas well hydraulic fracturing activities and dewatering operations, has become a major topic of concern for some petroleum producing states and for the EHP. Induced seismic events caused by high volume / high pressure disposal of waste water resulting from oil and gas well stimulation operations, although proportionately very minor to date, continue to present an area of growing concern to the EHP. Since 2008, petroleum operation related induced seismic events in Oklahoma alone have increased by ten times. The number of earthquakes in Oklahoma with magnitude greater than 3.0 surpasses the number of naturally occurring tectonic magnitude 3 earthquakes recorded in California.

Of concern to the EHP is how to quantify and present the hazards and risks associated with induced seismicity. The recently published 2014 National Hazard Map presents earthquake hazards from naturally occurring tectonic earthquakes on a national scale, but omits the impacts

of human triggered induced seismic events such as those in Oklahoma and other central and eastern states.

In November 2014, a National Seismic Hazard and Risk Assessment Steering Committee, chaired by John Anderson, convened in Oklahoma City and addressed some of the issues of presenting induced seismicity in a meaningful manner. The outcome of this workshop is described by Petersen et al. (2015; http://pubs.usgs.gov/of/2015/1070/). The Steering Committee has initially supported the omission of human triggered seismic events from the National Hazard Map because of the transient nature of this induced seismicity. The workshop report explores the sensitivity of hazard models to alternative ways of treating the rates of induced earthquake, uncertainties in the present and possible future locations of these events, uncertainties in the maximum magnitude that might be induced, and uncertainties in ground motions. Regardless of the alternative approaches to modeling these induced earthquakes, all of the models show large increases in the probabilistic seismic hazard in the affected areas. New products currently envisioned by EHP will be applicable for only limited time periods (e.g. one year), require frequent (e.g. annual) updates, and address user needs beyond those of the traditional national hazard maps, including the concerns of emergency management, of local residents who experience of common small "nuisance" earthquakes, and of engineers' need to evaluate the resilience of existing structures in light of potential rapid variability of the annual seismic hazard.

At the present time, the EHP faces a shortage of adequate field instruments and necessary staff to effectively monitor areas impacted by induced seismicity, and of necessary staff to create and update products that communicate the results to the public. Issues related to induced seismicity are likely to continue well into the foreseeable future and should be a focus of future funding and research opportunities.

Earthquake Early Warning

The underlying premise of Earthquake Early Warning (EEW) is that with a sufficient density of stations and high-speed telemetry, a computer algorithm can detect, locate, assign a magnitude and send an alert to regions in the vicinity of an earthquake faster than the arrival of shaking. The time difference between the alert and the shaking can range from 0 seconds to 100's of seconds depending on where the earthquake is happening and where the alert is received. While humans might not be able to do much with only a few seconds of warning, there are many automated systems that can respond. That response can mitigate the severity of the shaking.

EEW is a consequence of comprehensive monitoring in real-time with a sufficient density of stations—a fully developed ANSS. EEW is highly visible to the Congress as well as the California Legislature. As SESAC has commented before, EEW is not a project that can be instituted within the current EHP budget. EHP has prepared a budget for the implementation of EEW on the west coast. Ignoring the additional capital costs, the operating budget for this one area is roughly 30% of the entire EHP budget. This operational cost is *in addition* to EHP's current monitoring budget. SESAC reiterates that there must be a separate budget augmentation if EEW is to be implemented.

Congress has allocated $5M toward EEW. This support, while needed, continues the dilemma for the EHP in that the funds are well short of what it will take to implement EEW in the western US (see table below). Only one area of California (southern California) might be equipped for an operational EEW with the additional $5M.

West Coast Implementation Cost	California	Pacific Northwest	West Coast (CA+PNW)
One-Time Construction costs	$23M	$15M	$38M
Annual Operation and Maintenance	$12M	$5M	$17M

Includes:

- Infrastructure upgrades, operation and maintenance
- Adds personnel to bring network staffing up to robust levels, operate new EEW 24/7, and test and monitor system performance
- Support for continued R & D

Does not include current network funding.

National Earthquake Information Center (NEIC)

The public face of the EHP is NEIC — over 150 million page views in 2014. For any major earthquake in the world (e.g., Nepal, M_W 7.8, April 25, 2015, 1,671,008 page views within 24 hours) or strongly felt earthquake in the US (e.g., South Napa, California, M_W 6.0 August 24, 2014, 5,176,365 page views within 24 hours) the public turns to NEIC and its web pages for the most recent, informative information.

Following the 2004 great Sumatra earthquake the NEIC became a 24/7 operation with two operational centers: the primary is at the USGS NEIC headquarters on the Colorado School of Mines, Golden, CO; the backup is at the Denver Federal Center. Since 2008 the NEIC has significantly enhanced the quality and breadth of the products it provides as part of its rapid characterization of national and global earthquakes ranging from as small as M 4.8 to the largest M>9.0. For most of the US and Europe reliable magnitudes are available within 5-10 minutes; for almost everywhere else in the world the NEIC provides a stable magnitude within 25 minutes. This information is critical when earthquakes occur near populated areas. Realizing that large magnitude earthquakes represent the release of energy over a finite-sized fault, which directly affects the felt area and is more diagnostic of where strong shaking is likely to occur, NEIC is improving its methods to produce images of the fault within hours of the event. This leads to better estimates of damage and fatalities that are broadcast through PAGER (Prompt Assessment for Global Earthquake Response), an NEIC product.

NEIC activities are closely coordinated with national and international partners in seismic station operation and reporting. The various partners within the US responsible for ANSS station operation provide data and event parameterization to NEIC in real time and protocols are in

place to acknowledge the "authoritative source" for earthquake reporting in each of the primary US regions. Global earthquake reporting by the NEIC relies on the Global Seismographic Network (GSN) as the primary backbone network, but this is heavily supplemented by numerous national and regional networks around the world that contribute data in real time to NEIC. The expanded use of real time data from numerous international sources not only improves NEIC location capabilities but also provides continuous checks of station operation and improves the quality of data being provided by these contributed stations.

Besides improving locations and magnitudes of earthquakes across the globe, NEIC has developed more precise locations and magnitudes for earthquakes in the central and eastern US (CEUS) by taking advantage of the NSF transportable array as it moved across the CEUS. This is critical as more earthquakes are located in the CEUS, which is monitored by permanent seismic networks that have few stations for large regions. Data from the ANSS backbone stations as well as the newly acquired 160 TA stations flows into NEIC providing a permanent network for CEUS stations. These stations though can saturate, i.e., the amplitude of the ground motion can exceed the capacity of the instrument to stay on scale. This is the case for the strongest shaking—the shaking most likely to cause damage. Looking forward the instrumentation at each site will have to be supplemented with strong-motion recorders. This of course will increase the capital cost as well as the operational cost, but it is necessary to understand the seismic risk in the CEUS.

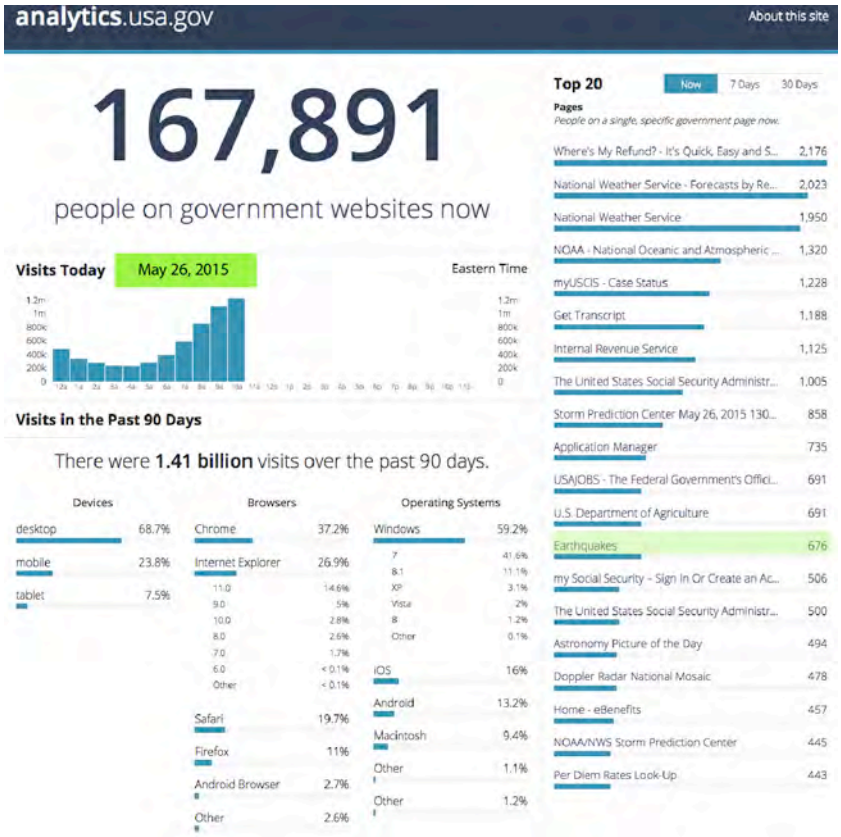

Figure 2. Modified screenshot of web activity on US government sites for May 26, 2014. Green rectangles added to emphasize the day and the ranking of NEIC—Earthquakes.

Earthquake Hazards Program External Dependencies

For its information products related to earthquake activity and earthquake hazards the EHP depends heavily on outside capabilities. This arises from extensive collaboration between EHP, other federal agencies and the academic community that is a significant strength of US programs in earthquake seismology. These highly leveraged collaborations provide cost savings and add diversity, but require vigilance to track balance and sustainability of various agency investments. One critical dependency is the National Science Foundation supported facilities: Seismological Facilities for the Advancement of Geosciences & EarthScope (SAGE) and Geodesy for the Advancement of Geoscience & EarthScope (GAGE). SAGE is managed by the Incorporated Research Institutions for Seismology (IRIS); GAGE is managed by UNAVCO—a consortium of universities to further the science and education in geodesy. Real time and archived seismic data within SAGE are essential for research into hazards in every part of the country. Geodetic data gathered largely by the NSF Plate Boundary Observatory were used to improve the 2014 National Seismic Hazard Maps. The second critical dependency is the regional seismic networks (RSN) that are key contributors to the Advanced National Seismic System (ANSS). In addition to the essential core USGS support, the RSN are supported heavily by the research universities, sometimes with university or state support and sometimes with additional outside contracts and grants. As part of an interagency agreement involving USGS, NSF and USNRC, USGS will gradually assume responsibility for support of 160 stations of the Transportable Array (TA) (a component of EarthScope) to enhance seismic coverage in the central and eastern US. This network, the Central and Eastern US Seismic Network (CEUS-SN), was installed and has been operated for the past ~5 years by IRIS with full support from NSF/EarthScope. The NSF support will cease by the end FY18. It is important that a strong case be made for the utility of this network, its importance in studies of central and eastern seismicity and the necessity of providing increased USGS base support for ANSS to ensure its long-term operational support. Without increased support, the severe underfunding of the RSN, which has already forced the USGS to defund four networks, could become a crisis as supporting the CEUS_SN requires more USGS funds after NSF support ends.

EarthScope is a major observational program that has been funded by the National Science Foundation. Funding commenced in 2003 but is expected to sunset in 2018. The EarthScope observatories can be divided into three major components: USArray, Plate Boundary Observatory (PBO), and the San Andreas Fault Observatory at Depth (SAFOD). The EarthScope seismic data are archived and distributed by the IRIS data management center (DMC). The geodetic data are archived and disseminated by UNAVCO. The EHP projects have benefitted enormously from all three EarthScope components. These projects include both research and information products.

It is important to note that monitoring of earthquake locations is a shared activity of several regional seismic networks (RSN) and the USGS. Thus EarthScope dependencies are not limited directly to USGS, and USGS dependencies are not limited to EarthScope. The regional seismic networks and the National Earthquake Information Center in Golden require a broad distribution

of seismic stations in order to locate all the important earthquakes[1] accurately. Outside of the most populous regions of California, the NSF Transportable Array (TA) stations of EarthScope greatly enhanced the network coverage and significantly improved the nations ability to locate and study earthquakes while those stations were in place.

EarthScope data are used in making the National Seismic Hazard Map. To continuously improve the maps requires the best available data, so that hazards are neither underestimated, nor overestimated. This goal requires two types of data that are provided by seismic monitoring.

- One is reliable information about the distribution and magnitudes of earthquakes, as generated by regional seismic networks and ANSS. Waveforms from RSNs are archived at the IRIS DMC. In some cases, relocation of past earthquakes is necessary with the use of these data, so continuation of the DMC is essential for this application.
- The second is obtained from the waveforms recorded by the seismic monitoring stations, in order to improve models for the amplitudes of ground motions caused by each earthquake. These waveforms are archived at the IRIS DMC. This research is not done in real time like earthquake locations but rather as subsequent research. At present there is considerable uncertainty in our best estimates of ground motions from earthquakes. In many cases, we suspect that this uncertainty is costly, driving up the ground motion requirements in the building codes. A case might be made that the uncertainty is greatest in the areas where the monitoring is sparse, i.e. outside of coastal and southern California.

The re-competition of SAGE and GAGE facilities is thus very consequential to the EHP. These two facilities require funding of about $37M/year—about 2/3 of the EHP annual budget. The EHP cannot do all that it does without partners who can shoulder some of the total effort needed to monitor earthquakes and mitigate seismic risk. NSF (along with IRIS and UNAVCO as EarthScope operators) is a significant collaborator with USGS in a balanced portfolio of earthquake research, monitoring and reporting. It will be important to continue to carefully track these external dependencies as changes occur in both USGS and NSF funded earthquake programs over the next five years.

[1] The definition of important earthquakes depends on the application. Development of the National Seismic Hazard Map requires all earthquakes with magnitude $M_W \geq 2.7$ in the eastern US. In the eastern US, smaller earthquakes can be important if they are in a location where they are being felt, for their capability to delineate the locations of active faults, or because they are induced by human activity.

Appendix A: 2015 SESAC Report

May 29, 30, 2014
Attendees: SESAC
Ralph J. Archuleta, Chair, John Anderson, Greg Beroza, Julie Furr, John Parrish, Christine Powell, David Simpson, Terry Tullis (by phone on day 1) (Appendix A)

USGS EHP: William Leith, Mike Blanpied, Harley Benz, Bill Ellsworth (for Tom Brocher), Ned Field, Lind Gee (by phone), Gavin Hayes, Keith Knudsen, Elizabeth Lemersal (by phone), Jill McCarthy, Mark Peterson, David Wald, and Cecily Wolfe (by phone).

Guest: Jack Hayes (NIST), Director of National Earthquake Hazards Reduction Program (NEHRP)

AGENDA MAY 29-30, 2014

Scientific Earthquake Studies Advisory Committee (SESAC)
May 29-30, 2014
USGS National Earthquake Information Center, Room 535 Golden, Colorado

May 29th - Thursday

8:45	Meet-n-greet	
9:00	Introductions, Agenda, SESAC business	Ralph Archuleta
9:15	Program overview and 2014-2015 budgets	Bill Leith
10:00	Science Center SOH reports	Tom Brocher, Jill McCarthy
10:30	Break	
11:00	National Maps Steering Committee Report	John Anderson Mark Petersen
11:30	ANSS Steering Committee Report	Greg Beroza, CecilyWolfe
12:00	Lunch	
13:00	Global Seismographic Network	Lind Gee (Phone), Cecily Wolfe
13:30	Future direction of the NEIC	Gavin Hayes
14:15	ANSS Products	Dave Wald
15:00	Break	
15:30	UCERF3 and time dependent faulting models	Edward Field
16:00	Earthquake Likelihood Forecasting	Mik Blanpied
16:30	NEHRP update	Jack Hayes
17:00	Adjourn	
19:00	Group dinner	

May 30th - Friday

8:45	Meet-n-greet	
9:00	2016-2020 Strategic Planning - Introduction	Bill Leith
9:30	Science Center perspective - ESC	Bill Ellsworth
10:00	Science Center perspective - GHSC	Jill McCarthy
10:30	Break	
10:45	Issues and Opportunities, 2016-2020 (structured discussion)	
12:00	Lunch	
13:00	Executive Session - 2 hours	
15:00	NEIC Tour	
16:00	adjourn	

January 28, 29, 2015

Attendees: SESAC
Ralph J. Archuleta, Chair, John Anderson, Greg Beroza, Julie Furr, John Parrish, Janiele Maffei, David Simpson, Terry Tullis (by phone on day 1)

USGS EHP:
William Leith, Mike Blanpied, Paul Earle, Doug Given, Rob Graves, Keith Knudsen, Jill McCarthy, Jessica Murray, Cecily Wolfe.

Guests: Greg Anderson (by phone), NSF EAR Program Director; Nancy Baumgartner, USGS ethics officer; Jack Hayes (NIST) (by phone), Director of National Earthquake Hazards Reduction Program (NEHRP); Tom Jordan, Science Director for SCEC.

AGENDA JANUARY 28-29, 2015

Scientific Earthquake Studies Advisory Committee
Boardroom, Southern California Earthquake Center (SCEC) Headquarters, University of Southern California (USC)
3651 Trousdale Parkway #167 Los Angeles, CA 90089

Wednesday Jan. 28th

8:30	Meet---and---greet	
8:45	welcome and introductions	Ralph Archuleta
8:50	federal advisory committee roles and responsibilities	Nancy Baumgartner
9:30	Current program status and initiatives (FY15)	Bill Leith
10:15	Broader NEHRP activities and issues	Jack Hayes (phone)
10:30	break	
10:45	ANSS Standing Committee Report	Greg Beroza
11:15	National Hazard & Risk Standing Committee Report	John Anderson
11:45	Discussion	
12:00	Lunch	
1:00	Memphis code developments	Julie Furr
1:30	SCEC 5 Planning and Central Coast Project	Tom Jordan

2:30	Earthquake early warning 3---year planning	Doug Given
3:00	Discussion	
3:15	break	
3:45	Subduction Zone Observatory proposal	Mike Blanpied
4:15	Beyond EarthScope	Greg Anderson (phone) & Bill Leith
5:00	Discussion	Committee
6:30	Adjourn	
7:00	Group Dinner—	Lab Gastropub

Thursday Jan. 29th

8:45	Meet---and---greet	
9:00	Earthquake Monitoring current and future /w discussion	Cecily Wolfe
10:15	break	
10:30	Geodetic Monitoring current---and---future /w discussion	Jessica Murray
11:15	NEIC current---and---future /w discussion	Paul Earle
12:00	Lunch	
1:00	Executive Session	Committee
3:30	Adjourn	

Appendix B

SESAC Committee May 2014

Ralph Archuleta, Chair, Professor, University of California, Santa Barbara, CA
John Anderson, Professor, University of Nevada, Reno, NV, Chair of the National Seismic Hazard and Risk Steering Committee
Greg Beroza, Professor, Stanford University, Stanford, CA, Chair of the USGS Advanced National Seismic System (ANSS)
Julie Furr, MS, Professional Engineer, Chad Stewart and Associates Engineering, Inc., Lakeland, TN
John Parrish, Ph.D., California State Geologist, Sacramento, CA
Christine Powell, Professor University of Memphis, TN, Center for Earthquake Research and Information (CERI)
Terry Tullis, Professor Emeritus Brown University, Providence, RI, Chair of the National Earthquake Prediction Evaluation Council (NEPEC)
David Simpson, Ph.D, Past President of the Incorporated Research Institutions for Seismology (IRIS), Washington DC

SESAC Committee January 2015

Ralph Archuleta, Chair, Professor Emeritus, University of California, Santa Barbara, CA
John Anderson, Professor, University of Nevada, Reno, NV, Chair of the National Seismic Hazard and Risk Steering Committee
Greg Beroza, Professor, Stanford University, Stanford, CA, Chair of the Advanced National Seismic System (ANSS)
Julie Furr, MS, Professional Engineer, Chad Stewart and Associates Engineering, Inc., Lakeland, TN
Janiele Maffei, MS, Structural engineer, Chief Mitigation Officer of the California Earthquake Authority, Sacramento, CA
John Parrish, Ph.D., California State Geologist, Sacramento, CA
Terry Tullis, Professor Emeritus, Brown University, Providence, RI, Chair of the National Earthquake Prediction Evaluation Council (NEPEC)
David Simpson, Ph.D, Past President of the Incorporated Research Institutions for Seismology (IRIS), Washington DC