# Scientific Earthquake Studies Advisory Committee SESAC

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 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.*

# Scientific Earthquake Studies Advisory Committee
# SESAC

Membership:

Professor Emeritus **Ralph Archuleta**, Chair, University of California, Santa Barbara, CA

Professor **John Anderson**, Chair of the National Seismic Hazard Map Committee, University of Nevada, Reno, NV

Professor **Greg Beroza**, Chair of the USGS Advanced National Seismic System (ANSS), Stanford University, Stanford, CA

Ms. **Julie Furr**, Chad Stewart and Associates Engineering, Inc., Lakeland, TN

Ms. **Janiele Maffei**, Chief Mitigation Officer of the California Earthquake Authority

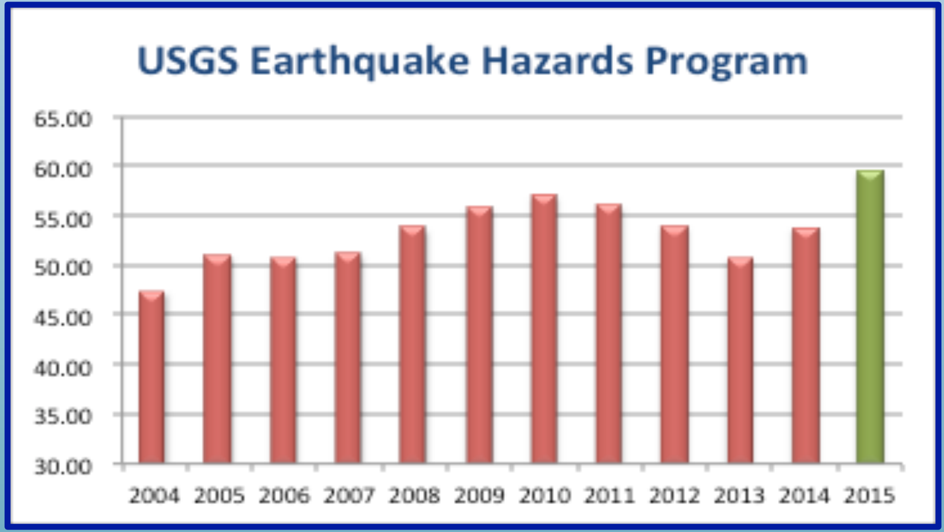
Dr. **John Parrish**, California State Geologist, Sacramento, CA

Professor Emeritus **Terry Tullis**, Chair of the National Earthquake Prediction Evaluation Council (NEPEC), Brown University, Providence, RI

Dr. **David Simpson**, Past President of the Incorporated Research Institutions for Seismology (IRIS), Washington DC

# Earthquake Hazards Program FY2015

+$5M for earthquake early warning
+$0.7M for induced seismicity




The level of funding has hardly changed since the initial level in 1977 when NEHRP was first authorized.

# Primary Topics Under Discussion by SESAC

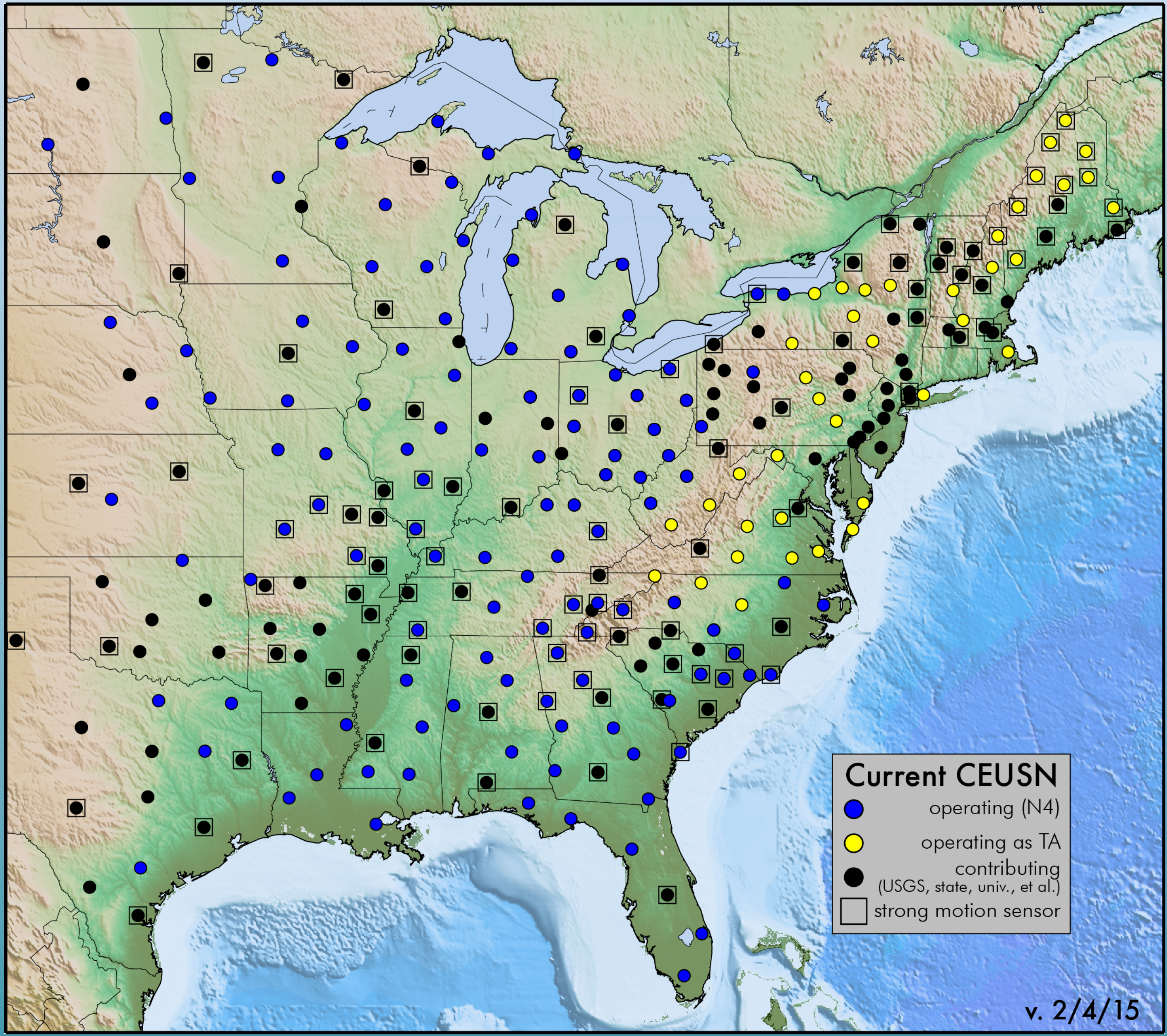
**1. Development of ANSS**

a. USGS Circular 1188 (1999) was the original justification for ANSS. It is being rewritten to reflect the issues in monitoring for the next decade.
b. The USGS is absorbing the transfer from NSF of 160 USArray stations in the CEUS. This was a multiagency plan involving the USGS, the Office of Science and Technology Policy, the Office of Management and Budget, the National Science Foundation (NSF), the Department of Energy, and the Nuclear Regulatory Commission. Issue: How will the USGS cover the expense (~$1,242K/yr) of the long-term operation of these stations?
c. Current funding highlights and supports specific initiatives, e.g., earthquake early warning (EEW), induced seismicity, transfer of USArray stations, but there are no concurrent increases in the base budget.
d. Structural monitoring is a key component of ANSS. It is expensive to monitor a structure. The ANSS committee is considering the cost/benefit of having dense arrays of free field instruments in urban areas versus instrumentation of single structures.

# Acquisition of 160 new stations in CEUS

Increased sampling rate compared to standard TA station (100sps real-time & 200sps triggered)

62 Strong motion sensors added in higher hazard areas



# Primary Topics Under Discussion by SESAC

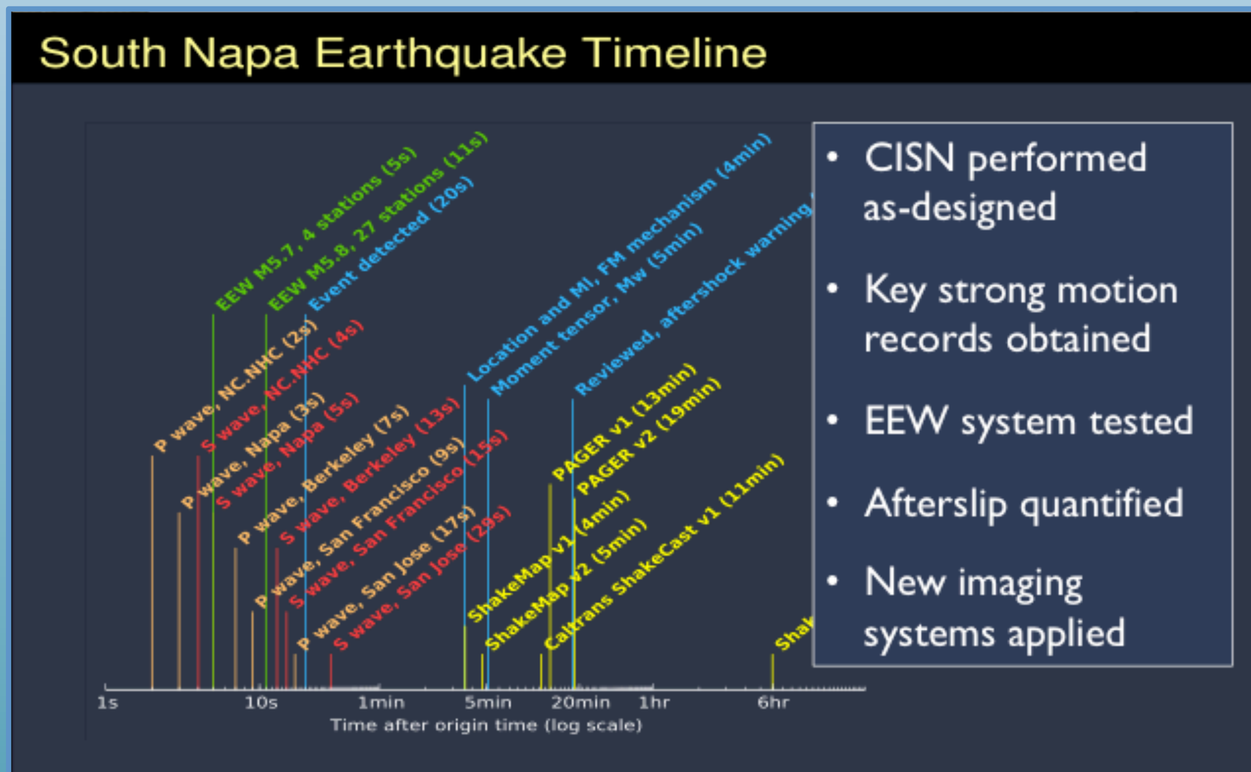
**2. Earthquake Early Warning**

a. In FY 2014 the USGS received $850K in new funding to support EEW, bringing base funding to $1.5M. In 2015, Congress added an additional $1.5M in one-time funding. The estimated operational cost for the west coast is $16.1M. This is in addition to the current network operational costs. The one-time construction cost is $38M. (SESAC report to ACEHR in August 2014).

b. The State of California has supported EEW and there is a special committee looking at how it would be funded on an annual basis. At the time of the SESAC meeting in January 2015, there was no solution.

c. USGS Open-File Report 2014-1097: Technical Implementation Plan for the ShakeAlert Production System—An Earthquake Early Warning System for the West Coast of the United States.

# South Napa Earthquake Timeline



# Primary Topics Under Discussion by SESAC

**3. Hydraulic Fracturing**

a. In FY 2014 the USGS received $1M in new funding to support research on induced seismicity. In 2015 the amount was $700K. This brings total funding for induced seismicity research and monitoring to $2.5M.
b. Oklahoma is the most active state in the continental US for earthquakes greater than M > 3.0.
c. How should induced seismicity be incorporated into national seismic hazard maps? This question has the highest priority of the National Seismic Hazard & Risk Steering Committee.

# Induced Seismicity

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GEOPHYSICS

# *Coping with earthquakes induced by fluid injection*

Hazard may be reduced by managing injection activities

*By* **A. McGarr,[1*] B. Bekins,[2] N. Burkardt,[3] J. Dewey,[4] P. Earle,[4] W. Ellsworth,[1] S. Ge,[5] S. Hickman,[1] A. Holland,[6] E. Majer,[7] J. Rubinstein,[1] A. Sheehan[5]**

Large areas of the United States long considered geologically stable with little or no detected seismicity have recently become seismically active. The increase in earthquake activity began in the mid-continent starting in 2001 (*1*) and has continued to rise. In 2014, the rate of occurrence of earthquakes with magnitudes (*M*) of 3 and greater in Oklahoma exceeded that in California (see the figure). This elevated activity includes larger earthquakes, several with $M > 5$, that have caused significant damage (*2*, *3*).

POLICY

To a large extent, the increasing rate of earthquakes in the mid-continent is due to fluid-injection activities used in modern energy production (*1*, *4*, *5*). We explore potential avenues for mitigating effects of induced seismicity. Although the United States is our focus here, Canada, China, the UK, and others confront similar problems associated with oil and gas production, whereas quakes induced by geothermal activities affect Switzerland, Germany, and others.

These injection activities include (i) disposal of wastewater by injection into deep formations; (ii) injection of water or $CO_2$ into depleted reservoirs for enhanced oil recovery (EOR); (iii) hydraulic fracturing (fracking) to enable production of oil and gas from low-permeability reservoirs; (iv) injection of supercritical $CO_2$ into deep formations for permanent carbon capture and storage (CCS); and (v) injection into geothermal reservoirs to replenish water lost to steam production or to develop enhanced geothermal systems (EGS).

Although only a small fraction of disposal wells have been associated with induced earthquakes large enough to be felt, there are so many disposal wells that this contributes significantly to the total seismic hazard, at least in the mid-continent (*1*, *2*, *6*). EOR has been associated with earthquakes as large as *M*4.5, but felt earthquakes are rare (*7*). For the most part, fracking induces only micro-earthquakes (too small to be felt), although there have been a few felt earthquakes (*8*). CCS may pose future seismic hazards (*9*), but few projects are under way, and the largest earthquakes have been too small to be felt at the surface. Geothermal fields and EGS sites are few in number and, within the United States, limited to western states where earthquakes up to *M*4.6 have been associated with geothermal production (*10*).

Wastewater injection directly into the crystalline basement has induced earthquakes of particular notoriety [e.g., in the Denver region during the 1960s (*11*)]. EGS case histories (e.g., the Deep Heat Mining Project in Basel, Switzerland) show that injection of water into crystalline basement is likely to result in significant earthquake response (*10*, *12*).

> ***"Developing a hazard model for earthquakes induced by industrial activities is key to determining effective ways to mitigate their damaging effects."***

Most disposal wells inject not into basement but into sedimentary layers of high permeability and porosity, targeted because of their ability to accept fluid, with little or no earthquake response (*13*). For some cases, however, effects of fluid injection were not confined to the target formation but were communicated to greater depth along a preexisting fault, as evidenced by earthquake locations in the basement (*14*) and simulated by numerical modeling (*15*).

Large volumes of injected wastewater may be required for an earthquake response that includes events large enough to be felt, or even damaging (*5*). The magnitudes of the largest induced earthquakes in some sequences correlate with the volume of injected fluid. Nonetheless, there is debate as to whether injected volume is the key factor that limits maximum magnitude (*6*) or whether it is controlled by the size of a nearby fault and its relation to the contemporaneous stress state, as is the case for natural earthquakes. Although faults evidently play at least several possible roles that affect the likelihood of inducing felt earthquakes, most of these faults are only detected when they are imaged by well-located induced earthquakes (*3*, *14*).

**SEISMIC HAZARD MODELS.** The long-term (50-year) model for seismic hazard in the United States, which sets design provisions in building codes, intentionally excludes, as much as possible, contributions from induced earthquakes (*16*). Developing a corresponding model for earthquakes induced by industrial activities is key to determining effective ways to mitigate their damaging effects. But to do so requires taking account of some essential differences between induced and natural seismicity.

Natural seismicity is usually assumed to be independent of time in assessing its hazard. Seismicity induced by fluid injection, in contrast, varies with time, often because of changes in injection rate. When a project is terminated, the rate of induced earthquakes diminishes with time, often in an irregular way (*11*). The spatial distribution of injection also changes as oil and gas production declines in one region and increases in another. These realities rule out simply combining induced and natural earthquake sources to develop a model for setting seismic safety provisions for new construction, the traditional application of the hazard model. Instead, a separate 1-year hazard model for induced earthquakes is being developed and will be updated frequently (*17*).

Thus, it is important to be able to determine whether an earthquake sequence was induced or natural, so as to avoid inappropriate earthquake input to either hazard model. This is not always straightforward. Induced and natural earthquakes appear similar when observed on seismograms. If an injection activity and an earthquake sequence correlate in space and time, with no known previous earthquake activity in the area, the earthquakes were likely induced (*11*, *18*). Some sequences are more challenging. There may be a lengthy delay between the start of injection and the first detected earthquakes or an offset of many kilometers between the injection site and earthquakes (*5*). Adding to the difficulties are enigmatic

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# Primary Topics Under Discussion by SESAC

**4. National Seismic Hazard Maps**

a. How should induced seismicity be incorporated into national seismic hazard maps is the highest priority of the National Seismic Hazard Map Committee.
b. Are urban hazard maps a logical extension of the National Seismic Hazard Map?
c. A fundamental issue is characterization of basins nationwide. In particular, how is the hazard characterized for periods greater than 1.0 s.

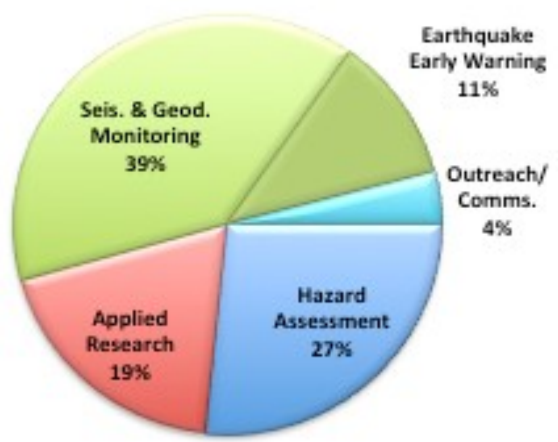
# Primary Topics Under Discussion by SESAC

**5. Priorities within the USGS: Balance Between Monitoring vs Research/Hazard Assessment**

EHP FY2015 Budget by Program Element

Total FY15 budget is $59.5 M

External funding Will be $16.35M for grants & cooperative agreements




Induced seismicity increase assigned to Applied Research

# Primary Topics Under Discussion by SESAC

**5. Priorities within the USGS: Balance Between Monitoring vs Research/Hazard Assessment**

a. Two new initiatives that will require additional funding to support capital and operations: EEW and Induced Seismicity
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c. How large of a footprint should GPS monitoring be within the USGS? The USGS operates 141 continuous GPS sites of which 64 are co-located with seismic stations. USGS is examining its scientific plan for geodesy.
d. Is "operational earthquake forecasting" a new thrust in the USGS?
e. Global seismic network had funds for purchasing new borehole instruments. This year the administration requested funds to install them in 2016-2018.

# Primary Topics Under Discussion by SESAC

**6. NSF Plans for SAGE/GAGE — recompetition for 2018**

a. SAGE: Seismological Facilities for the Advancement of Geosciences & EarthScope. SAGE is managed by the Incorporated Research Institutions for Seismology (IRIS). Within the SAGE facility, the IRIS Data Management Center is essential to the USGS EHP and the seismological community.
   i. Repository for all Global Seismic Network data
   ii. Archives all the data from the ANSS Backbone
   iii. Archives data from most regional networks (all non-Calif.)

b. GAGE: Geodesy for the Advancement of Geoscience & EarthScope. GAGE is managed by UNAVCO—a consortium of universities to further the science and education in geodesy.
   i. Repository for geodetic data: GPS, InSAR, LiDAR
   ii. USGS has relatively few GPS stations; geodetic research on deformation is dependent on GAGE.

c. These facilities will be re-competed in 2017, as EarthScope will sunset in 2018.