Origins of a National Seismic System in the United States

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ABSTRACT

This historical review traces the origins of the current national seismic system in the United States, a cooperative effort that unifies national, regional, and local-scale seismic monitoring within the structure of the Advanced National Seismic System (ANSS). The review covers (1) the history and technological evolution of U.S. seismic networks leading up to the 1990s, (2) factors that made the 1960s and 1970s a watershed period for national attention to seismology, earthquake hazards, and seismic monitoring, (3) genesis of the vision of a national seismic system during 1980–1983, (4) obstacles and breakthroughs during 1984–1989, (5) consensus building and convergence during 1990–1992, and finally (6) the two-step realization of a national system during 1993–2000. Particular importance is placed on developments during the period between 1980 and 1993 that culminated in the adoption of a charter for the Council of the National Seismic System (CNSS)—the foundation for the later ANSS. Central to this story is how many individuals worked together toward a common goal of a more rational and sustainable approach to national earthquake monitoring in the United States. The review ends with the emergence of ANSS during 1999 and 2000 and its statutory authorization by Congress in November 2000.

Electronic Supplement: Charter of the Council of the National Seismic System (April 1993).

INTRODUCTION

In February 1993, some 50 seismologists representing the major seismic networks in the United States met in Lakewood, Colorado, to adopt a charter for the Council of the National Seismic System (CNSS), a cooperative action aimed at coordinating for the first time national, regional, and local seismic monitoring throughout the Nation. Why did this happen? Why did independent network operators, setting aside self-interest and varied concerns, come together to commit to a more rational and sustainable approach to national earthquake monitoring for the common good? Some were enthusiastic about unified national seismic monitoring. Some were willing to cooperate but reluctant to lose autonomy over their network operations. All were concerned with modernization and stable future support of seismic networks. Whatever their individual views, at the end of the day they agreed to join together and work toward establishing a national system, and eventually they succeeded. We believe this is a story worth telling.

The seeds of a national system were sown in 1980 and took decades to bear fruit: 13 years to form a first-generation national system with the CNSS, seven more years to gain a congressional mandate for establishing and operating a modernized and standardized national seismic system, and still longer to successfully implement a truly functional system. This article reviews the history of the developments that led to the current national system, placing particular importance on the period between 1980 and 1993. We also describe how the CNSS formed the organizational foundation and impetus for the subsequent launching of the Advanced National Seismic System (ANSS). This article begins with background information on the history and technological evolution of seismic monitoring in the United States, followed by a description of events during the 1960s and 1970s that paved the way for national policymaking relating to U.S. observational seismology. Our narrative of events tracing the origins of a national seismic system unfolds in four time frames: 1980–1983, 1984–1989, 1990–1992, and 1993–2000.

Our narrative follows the waypoints provided by government documents and by reports from the Committee on Seismology of the National Academy of Science's National Research Council (NRC). That said, our review is also influenced by our perceptions and memories from taking part in many of the activities that shaped the national system. We recognized this hazard when we began writing but reasoned it was worth risking, if only to provide those currently working toward the goals of the ANSS an account, however biased, of what it took to get things started.

BACKGROUND (1887 TO THE 1990S)

In this section, we sketch the historical evolution of seismic monitoring in the United States, and we describe changes in technology that influenced the character of seismic networks as they existed in the 1990s when they became the building blocks of our NSS. Various chapters in Lee *et al.* (2002, 2003) along with the U.S. national and institutional reports in Compact Disc (CD) #2 therein are rich sources of historical and technical detail. From the beginning, academic institutions have played a prominent role in earthquake monitoring and research in the United States. Early history includes the installation in 1887 of low-magnification mechanically recording seismographs at the University of California, Berkeley (Bolt, 1989), the establishment between 1900 and 1928 of seismographic stations by the Society of Jesus at 15 Jesuit colleges and universities located throughout the United States (Udias and Stauder, 1996), and the installation of Wood–Anderson short-period seismographs at seven sites in southern California in the 1920s to form a regional network (Kanamori *et al.*, 2003). This Wood–Anderson network and the ensuing introduction of Richter's earthquake magnitude scale in 1935 were influential in leading to the systematic recording and study of local earthquakes and regional seismicity (Lee and Stewart, 1981). In 1936, there were 56 seismographic stations operating in the United States and its then territories of Alaska, Hawaii, and Puerto Rico; 43 of the stations were operated by 33 academic institutions (Heck, 1936, chapter 7; see McComb, 1936, for descriptions of typical instrumentation).

Within the Federal government, the U.S. Weather Bureau was charged with seismological investigations (collecting and publishing earthquake reports) from 1914 to 1925 (Heck, 1936, p. 57). In 1925, the responsibility for seismological work of the government was transferred to the U.S. Coast and Geodetic Survey (USCGS; Heck, 1929). Early USCGS activities in seismology included the operation of several seismographic stations, some jointly with academic institutions (Heck, 1936, chapter 7); initiation of the well-known series, United States Earthquakes, beginning with the year 1928; and the establishment in 1931 of a strong-motion instrumentation program in California (Kisslinger and Howell, 2003, p. 10). The first issue of the familiar Preliminary Determination of Epicenters was published by the USCGS in 1940 (Sipkin *et al.*, 2000).

The Modern Era

Observational seismology in the United States entered a new era in 1960, spurred by a pressing national need for the surveillance of nuclear testing. Resulting national policy developments led to, among other things, the creation in 1960 of the World-Wide Standardized Seismograph Network (WWSSN), the first global network of modern seismographs having standard design and uniform recording characteristics (Oliver and Murphy, 1971; Peterson and Hutt, 2014). The USCGS was tasked to install and operate the WWSSN and to manage the collection, preliminary analysis, and distribution of data. In 1965, there were 26 WWSSN stations operating in the contiguous United States (Peterson and Hutt, 2014, table 2.1, figure 2.1), forming a nationwide but spatially nonuniform network of collocated short-period and long-period seismographs. Monitoring the Nation's seismicity was about to improve dramatically with the growth of regional seismic networks (RSNs), stimulated in the 1960s and 1970s by plate tectonics and earthquake source studies, increasing concern for seismic hazards and the possibility of earthquake prediction (Agnew, 2002).

RSNs in the United States in the 1960–1970 era either evolved into or began as telemetered microearthquake networks, designed to locate local earthquakes of very small magnitude with high location accuracy. The focus on smaller earthquakes was driven, in part, by the need to define the geometry and mechanics of active tectonic and volcanic structures for research and hazard assessment. Telemetered seismograph systems were implemented by Jerry Eaton at the Hawaiian Volcano Observatory in the 1950s and by Don Tocher at Berkeley in 1961–1963 (Lee and Stewart, 1981, p. 8; Okubo *et al.*, 2014). After joining the U.S. Geological Survey (USGS), Eaton played a foundational role in the mid-1960s in designing and creating the USGS Central California Microearthquake Network, which became a model for microearthquake networks and monitoring practice elsewhere (Lee and Stewart, 1981). These networks typically consisted of tens to hundreds of high-magnification short-period stations, generally with only a single-component vertical sensor with limited bandwidth and dynamic range, continuously transmitting data to a central recording facility. A survey in the early 1980s (NRC, 1983) counted 47 separate regional and local seismic networks operating ~1600 stations in the United States; academic institutions operated 28 of the networks.

The evolution of digital technology, computers, and software after the 1960s had a profound impact on instrumentation, data transmission, and data processing associated with global, regional, and strong-motion seismology (e.g., Lee, 2002). After the mid-1990s, the digital communication network of the Internet vastly facilitated the collection, exchange, analysis, archiving, and distribution of earthquake data and information products. One can follow the advancement of a typical RSN, particularly from the late 1960s into the 1990s, by reading the thorough description by Okubo *et al.* (2014) of the history of seismic monitoring systems at the Hawaii Volcano Observatory—from analog recording on multichannel film recorders (Develocorders) and manual data analysis to automated, near-real-time event detection and data processing. Similarly, see Hutt *et al.* (2002) regarding the evolution of technology from the analog WWSSN to the current global digital seismic network.

Another key development in U.S. network seismology was the creation of the National Earthquake Information Center (NEIC) as the national data center and archive for earthquake information. The NEIC was established in 1966 in Rockville, Maryland, within the Department of Commerce (motivated, in part, by USCGS data-handling responsibilities for the WWSSN) and eventually was relocated to Golden, Colorado, at the time of its transfer to the USGS in 1973 (Sipkin *et al.*, 2000). Snapshots of the character of NEIC operations in the 1990s are given by Buland (1993) and Sipkin *et al.* (2000).

Prospective Building Blocks for a National System in the 1990s

To set the stage for our main story, U.S. network seismology in the 1990s was replete with both potential and challenges. High-quality stations with very broadband high-dynamic range seismometers and digital recording systems were beginning to be installed in U.S. seismic networks in the late 1980s: in northern and central California as part of the Berkeley Digital Seismic Network (Bolt *et al.*, 1988; Romanowicz, 2003), in southern California as part of the TERRAscope project of the California Institute of Technology (Caltech; Kanamori *et al.*, 1991), and in the central and eastern United States as part of a U.S. National Seismograph Network (USNSN) planned by the USGS (Massé *et al.*, 1989; Buland, 1993). The potential of U.S. network seismology was also highlighted by the advent of real-time earthquake information systems in the early 1990s to meet emergency-response needs for rapid notification and situational awareness (Kanamori *et al.*, 1997). Two groundbreaking projects were Caltech/USGS Broadcast of Earthquakes (CUBE) in southern California (Kanamori *et al.*, 1991, 1997) and Rapid Earthquake Data Integration (REDI) in northern and central California (Gee *et al.*, 1996). In the mid-1990s, a further development was the transformation of the Southern California Seismic Network into a "ground-motion seismic network" by the incorporation of strong-motion instrumentation enabled by TriNet, a cooperative partnership between the USGS, Caltech, and the California Division of Mines and Geology (Hauksson *et al.*, 2003). A revolutionary outcome was the creation in 1997 of the first TriNet "ShakeMaps," automated maps produced within a few minutes of an earthquake depicting the severity and distribution of instrumental ground motion and shaking intensity (Wald *et al.*, 1999). The distinction between weak-motion and strong-motion seismic monitoring had become blurred, driven both by the need of seismic networks to record moderate and large earthquakes on scale and by the need for rapid assessment of earthquake impact.

Eventually, strong-motion instrumentation would become a fundamental part of a national seismic system: accelerometers and accelerographs were gradually integrated into conventional seismic networks, autonomous strong-motion programs would become partners in the system, and structural seismic monitoring would become a core part of the system's mission. In the 1990s, the available building blocks for a national system primarily were the emergent USNSN, existing RSNs, and the NEIC. In 1993, the USNSN had a projected number of about 60 broadly spaced high-quality digital stations, each equipped with both broadband seismometers and accelerometers, and was designed to provide uniform national-scale coverage (Buland, 1993). Spatially dense coverage of areas of moderate-to-high seismicity throughout the Nation was still reliant on RSNs. However, despite major advances in California, most RSNs were handicapped with outdated instrumentation and other problems, as we later discuss. Although the potential building blocks for a national system existed in the 1990s, modernization of most RSNs persisted as a major issue, and standardization and coordination of operations among the separate multi-jurisdictional building blocks posed greater challenges.

DEVELOPMENT OF NATIONAL PROGRAMS (1960S AND 1970S)

The period during the 1960s and 1970s was a watershed for national attention to seismology, earthquake hazards, and seismic monitoring—initially catalyzed by both the VELA UNIFORM program and the great Alaska earthquake of 1964 and later by the 1971 San Fernando, California, earthquake. In 1959, anticipating the national need to ensure international compliance with a comprehensive nuclear test ban, the Department of State convened the Panel on Seismic Improvement chaired by Lloyd Berkner (see Table 1 for the membership of selected panels and working groups discussed in the text). The Berkner panel report, entitled "The Need for Fundamental Research in Seismology" (Department of State, 1959), recognized that the challenges of detecting and identifying underground nuclear explosions would not be solved until many fundamental problems in seismology were addressed through basic research and improvements in data quality and availability. The influential panel report guided the development of the VELA UNIFORM program, "the greatest jump in American support of seismology in the 20th century" (Kisslinger and Howell, 2003, p. 7), including well-funded research ($8.5 million in 1960) for studies on the "generation and propagation of seismic waves" (Romney, 1985). (All dollar values cited herein are nominal values unadjusted for inflation.) A key recommendation of the Berkner panel report was a major improvement in seismic instrumentation in order to produce the data needed for basic research in seismology. This was achieved through direct follow-up actions that created the WWSSN.

On 26 March 1964, a magnitude 9.2 earthquake occurred beneath Prince William Sound along the southern coast of Alaska (USGS, 1965–1970). The disastrous megathrust earthquake and resulting tsunami, at a time of expansion of the field of seismology instigated by the VELA UNIFORM program, bolstered calls for increased U.S. funding for research on earthquake prediction, earthquake physics, earthquake engineering, and related topics. Among these moves was a report of the NRC's Committee on Seismology, which called for a national program in seismology totaling about $500 million over a 10-year period (NRC, 1969). Although the NRC's recommendation of a national program was not acted upon by Congress, the Alaska earthquake motivated the USGS to establish in 1966 a National Center for Earthquake Research in Menlo Park, California. One significant outgrowth was the USGS Central California Microearthquake Network, mentioned earlier. Recall that the NEIC was also established in 1966. In 1970, the NEIC was transferred to the newly formed National Oceanic and Atmospheric Administration (NOAA), which had subsumed the USCGS within the Department of Commerce. In the early 1970s, related activities of the NOAA and USGS programs raised questions regarding the need and justification for two Federal earthquake programs. In 1973, agreement was

Table 1
Selected Working Groups and Participants

Year	Working Group	Participants
1959	Panel on Seismic Improvement	Lloyd Berkner (Chair), Hugo Benioff, Hans Bethe, Maurice Ewing, John Gerrard, David Griggs, Jack Hamilton, Julius Molnar, Walter Munk, Jack Oliver, Frank Press, Carl Romney, Kenneth Street, John Tukey
1969	NRC report on Seismology: Responsibilities and Requirements of a Growing Science	Jack Oliver (Chair), Clarence Allen, Bruce Bolt, Anton Hales, Eugene Herrin, Benjamin Howell, Donald Hudson, Sidney Kaufman, Carl Kisslinger, James Wilson
1980	NRC Panel on Local, Regional and National Seismograph Networks	Bruce Bolt (Chair), Edward Chiburis, Robert Crosson, Robert Herrmann, Hiroo Kanamori, Paul Pomeroy, David Simpson, Robert Smith, Don Tocher, Mihailo Trifunac
1983	NRC Committee on Seismology report on Seismograph Networks: Problems and Outlook for the 1980s	Thomas McEvilly (Chair), Keiti Aki, Allin Cornell, Paul Jennings, Hiroo Kanamori, Karen McNally, Peter Molnar, Paul Richards, Robert Smith
1985	*Ad Hoc* Committee on Regional Networks (ACORN)	Leadership committee: David Simpson (Chair), Walter Arabasz, John Davies, Carl Johnson, Doug Johnson, Arch Johnston, Steve Malone, Woody Savage
1987	Alta I	Meeting participants: Walter Arabasz, William Bakun, James Brune, Rob Clayton, Robert Crosson, William Ellsworth, John Filson, Thomas Hanks, Thomas Heaton, Robert Herrmann, Arch Johnston, Hiroo Kanamori, Robert Massé, Elaine Padovani, David Simpson, Robert Smith, Wayne Thatcher
1990	NRC Panel on Regional Seismic Networks	Arch Johnston (Chair), Walter Arabasz, Gilbert Bollinger, John Filson, Robert Herrmann, Lucile Jones, Hiroo Kanamori
1989	National Seismic System Science Plan	Authors: Thomas Heaton, Don Anderson, Walter Arabasz, Ray Buland, William Ellsworth, Stephen Hartzell, Thorne Lay, Paul Spudich
1991	Alta II	[49 participants from 16 states and British Columbia representing 24 seismic networks, the USGS, IRIS, and the private sector]

NRC, National Research Council; USGS, U.S. Geological Survey; IRIS, Incorporated Research Institutions for Seismology.

reached between the two agencies involved to transfer all NOAA earthquake research and operations, including personnel, to the USGS.

The San Fernando Earthquake and National Earthquake Hazards Reduction Program

Momentum for a national program was revived by a damaging magnitude 6.6 earthquake that occurred on 9 February 1971 in southern California, near San Fernando (USGS and NOAA, 1971). The urban impact of this earthquake, particularly the heavy damage it inflicted on critical facilities and infrastructure, propelled a concerted effort by scientists, engineers, government officials, and a few politicians to call for a national program to study, assess, and reduce earthquake risks. Initially, nothing much came of these efforts until Vice President Nelson Rockefeller pushed for the formation of a panel to make recommendations for expanded earthquake and earthquake engineering research. The panel was headed by Guy Stever, then head of the National Science Foundation (NSF), and Nathan Newmark, a distinguished engineer at the University of Illinois. The resulting Newmark–Stever report (NSF and USGS, 1976) laid out three options for increased funding for the USGS and NSF, with the latter's share directed mostly to earthquake engineering. The report plus the interest of high-level government officials led to substantial funding increases for the USGS and NSF, about $20 million each, in 1978 (Hamilton, 2003).

Congress passed legislation to establish a national earthquake program in 1977 after years of advocacy by earthquake scientists and engineers. On 7 October 1977, President Carter signed the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124) creating the National Earthquake Hazards Reduction Program (NEHRP). The legislation authorized funding for the NSF, the USGS, and the National Bureau of Standards. The authorized funding levels for 1978 were consistent with the existing program levels in NSF and USGS, including the increases resulting from the Newmark–Stever report. The 1977 Act did not define specific roles for the participating agencies; rather, it laid out broad research elements with an emphasis on earthquake prediction and earthquake-resistant design and construction.

Network Funding in the Late 1970s

The formation of NEHRP was a major milestone, but challenges remained for U.S. network seismology. Seismic monitoring was not specifically mentioned in the original 1977 NEHRP legislation, and access to NEHRP funds for RSNs was problematic. NSF objectives, for example, focused on basic earthquake and earthquake engineering research, precluding proposals for support of seismic monitoring. USGS objectives also posed hurdles. With new total annual funding of about $30 million in 1978 upon the formation of NEHRP, the USGS began an expanded program of earthquake research. At this time, about 25% of USGS funding for earthquake studies was committed to external projects, mostly at universities; the remaining funds supported internal research and operations. The USGS external funding element allowed support for RSNs, but chiefly to provide data for specific earthquake-related research topics. To gain this support, regional network operators had to compete on an annual basis with all other proposals to the USGS external research program. This situation created difficulties because the USGS proposal review panels often did not view network operations as research. In some cases, a research proposal based on data from a specific regional network was recommended for funding, but support for the operational expenses of the network was not. Financial support for most RSNs at this time was unstable at best.

Another important source of financial support for RSNs in the late 1970s warrants mention. When the U.S. Nuclear Regulatory Commission (USNRC), a successor agency to the U.S. Atomic Energy Commission, began operation in January 1975, reactor safety in earthquakes was a major concern. At the time, 80 of the current 99 U.S. commercial nuclear power reactors either had operating licenses or construction permits, with all but six of the reactors (then and now) sited in the central and eastern United States (CEUS), east of the Rocky Mountains (see USNRC, 2015). Consequently, the USNRC had a major interest in seismicity and seismic hazard in the CEUS. To aid its mission of regulating the safety of nuclear power plants, the USNRC began to contribute support to the development and operation of RSNs at several eastern academic institutions with existing programs in seismology. About 1978, the USNRC and the USGS made an informal agreement whereby the USNRC would support RSNs in the CEUS, whereas the USGS supported those in the western United States. The USNRC, however, was not committed to long-term earthquake monitoring in the CEUS. In fact, it raised the issue of the useful lifetime of a seismic network and pressed the seismological community to address this question. The course of U.S. network seismology would be altered by changes in USNRC financial support in the 1980s.

ENVISIONING A NATIONAL SEISMIC SYSTEM (1980–1983)

The vision of a rationalized and optimized system of national seismic monitoring was first developed by the Panel on National, Regional, and Local Seismograph Networks of the NRC's Committee on Seismology (see Table 1). The panel, chaired by Bruce Bolt, produced a report entitled "U.S. Earthquake Observatories: Recommendations for a New National Network" (NRC, 1969). A primary recommendation of the report was the development of a new National Digital Seismograph Network of some 36 high-quality stations evenly distributed throughout the United States to supplement coverage by existing RSNs. The panel also recommended, among other things, continued support and modernization of RSNs, four ocean-bottom observatories, and incorporation of strong-motion sensors into the new national network. Of the 14 recommendations in the report, the most important by far, in our view, was the adoption of the concept of an "integrated United States Seismograph System (USSS)" that would incorporate all of the observational elements recommended. The report also urged that a strong base of Federal and State funding be established to sustain the operations of all elements of the system. These recommendations proved seminal in developing monitoring policies for the future, but their timing in 1980 was ill-starred. New constraints in Federal funding soon appeared and "potentially disastrous cuts [were] nearly imposed in earthquake studies by several agencies in the fall of 1981" (NRC, 1983, p. 4).

The funding crisis of 1981 and increasing budget constraints for their support of seismic networks prompted several government agencies to ask the NRC to convene a workshop to assess the status, problems, and future of U.S. seismographic networks. The NRC Committee on Seismology, chaired by Tom McEvilly (see Table 1), organized the workshop and produced a report entitled "Seismograph Networks: Problems and Outlook for the 1980s" (NRC, 1983), based in part on a questionnaire sent to RSN operators. The report reviewed the problems faced by global and regional networks as well as the concept of a national network. In the report, the Committee on Seismology endorsed the Bolt panel's idea of an integrated USSS, but it recognized the difficulty of obtaining funding to implement the concept. Moreover, the state of affairs of RSNs did not appear conducive for using them to build a USSS. The McEvilly report's assessment of the status of RSNs was candid and somewhat daunting. In part, it reads (NRC, 1983, p. 2f)

> *Regional network operations are beset with problems falling into three categories: functional definition, funding difficulties, and operational problems. Functional definition is the planned lifetime for a network, and a realistic estimate of it needs to be provided. Funding difficulties are of two types: a lack of stability on a year-to-year basis, and the vulnerability of research funding being decreased to maintain network operations in times of fiscal stress when research funding is mixed with operational costs of the network. Operational problems are seen in the lack of coordination among networks, the need for a more standardized data base management system, and a growing obsolescence of network equipment. These problems are interrelated and difficult to order in importance.*

The report recommended that regional networks of "planned, limited lifetime" be subject to periodic performance review, that funding agencies acknowledge the research importance of regional network data, that operations be coordinated, and that data be collected and archived in standard formats. Additionally, the report recommended that "a good faith effort must be made to remove the serious vulnerability of research support in the packaged funding practice" (NRC, 1983, p. 24). They were saying that network operations and associated research should be funded separately. Annual piecemeal funding of network operations through multiple research proposals was not working. In 1983, USGS management changed the funding arrangements for its external earthquake research projects from conventional contracts to grants, providing a more flexible and more user-friendly context for supporting and conducting research. Consistent with a recommendation of the McEvilly report, the USGS also changed the funding instruments for regional network operations from annual contracts to separate multiyear cooperative agreements, providing increased stability for these efforts. The cooperative agreements reflected the following realities: longer-term funding commitments were needed for network stability, network data were fundamental to addressing many research problems, and network operations in fact were cooperative efforts. Many regional networks received partial support from State and other Federal sources.

OBSTACLES AND BREAKTHROUGHS (1984–1989)

The time period from 1984 to 1989 was marked by some tough challenges as well as first steps by the U.S. network seismology community toward a national system. In 1984, academic research interests took a bold action in forming the Incorporated Research Institutions for Seismology (IRIS), a consortium of U.S. universities, for the purpose of implementing initiatives with NSF support for new national facilities to support seismological research (Smith, 1986). The three elements of the IRIS program were the Global Seismographic Network (GSN), Program for the Array Seismic Studies of the Continental Lithosphere (PASSCAL), and a Data Management Center (DMC). Significantly, IRIS provided the leadership and focus needed to stabilize the operations and support of global seismic networks. In time, the availability of digital data from the worldwide stations of the GSN greatly benefited the NEIC, and IRIS has had a tremendous positive impact on the science of seismology in the United States and worldwide. However, in 1984 when IRIS's founders opted not to include regional seismic monitoring within the IRIS program, the decision was consequential for U.S. network seismology. RSNs operated by IRIS member universities (as well as by the USGS) were left to find some other umbrella organization for critically needed modernization and stability. It is important to note that some individuals involved in the early years of IRIS development and leadership worked constructively within the seismological community to advance the interests of RSNs. The most notable of these were Dave Simpson and Tim Ahern, presently president emeritus of IRIS and director of IRIS Data Services, respectively.

Ad Hoc Committee on Regional Networks: Beginning of a Regional Network Coalition

In 1985, a crisis arose when the USNRC announced a phased termination of its financial support for RSNs in the CEUS, prompted both by budget cuts impacting the USNRC and by the agency's reluctance to maintain long-term support for seismic monitoring. (A similar crisis had arisen in 1981, but the USNRC reconsidered cutting network support after a strong (mb 5.7) earthquake in New Brunswick on 9 January 1982 was widely felt in the northeastern United States.) The combination of the USNRC announcement and the IRIS developments placed RSNs both in the CEUS and the western United States in a vulnerable position. Regional network operators started to self-organize in an attempt to control, or at least influence, their destiny. In the fall of 1985, in conjunction with the annual meeting of the Eastern Section of the Seismological Society of America (SSA) in Knoxville, Tennessee, Dave Simpson of Columbia University and Bill Ellsworth of the USGS convened a symposium and workshop on "Regional Seismographic Networks: Past, Present, and Future" under the auspices of the NRC Committee on Seismology. The Knoxville meeting was a landmark for regional network seismology. A later report (NRC, 1990) summarized the 1985 meeting as follows:

> *More than 100 seismologists attended the meeting, representing the vast majority of the more than 50 regional networks in the United States, and all expressed concern for future support. A dramatic result of the Knoxville meeting was a ground swell of consensus, enthusiasm, and commitment for addressing in a coordinated way the multifold problems faced by regional networks. The participants unanimously agreed that out-of-date instrumentation was the greatest source of scientific handicap and frustration for network seismologists…*

The meeting was a start. Desirable technological advances in RSNs were explored, but how were resources going to be found for new instrumentation? Operational issues were identified, such as the need for common standards, new network recording systems and software, and mechanisms for efficient data exchange and archiving. In reality, these issues would become staples for RSN working groups for years to come. Perhaps most critically, the meeting forced regional network operators to begin squarely facing the burden of providing sound documentation and compelling justification for the continued operation of RSNs. What do they contribute? Are they worth the cost? What is their scientific justification? Indeed, the question of whether RSNs in the United States had a future would continue right up to the formation of ANSS (Arabasz, 1998). It seems fair to say that in the 1980s there was a tension in the U.S. seismological community between basic researchers and network seismologists, with the former including some prominent critics of the value of RSNs. The Knoxville workshop gave rise to the *Ad Hoc* Committee on Regional Networks (ACORN, see Table 1), an independent grassroots attempt to coordinate and focus the activities of those concerned with the future of RSNs. During 1985–1987, ACORN activities included discussion forums at national society meetings, presentations before national committees, and the exchange of information on software and instrumentation developments (Simpson, 1987). Eventually, USGS-sponsored meetings of network operators in 1987 and 1989 (discussed below) gave rise to other working groups that superseded ACORN.

Beginning of a National Network

Before the USNRC announced in 1985 that it would phase out its support of RSNs in the CEUS in 1985, it had informally asked the USGS to assume responsibility as the supporting agency for these networks. USGS managers concluded, after reviewing current obligations and financial resources, that the USGS could not assume this additional burden. Nevertheless, both the USGS and the USNRC recognized the importance of continuous baseline seismic monitoring for future seismic-hazard assessments in the CEUS. Ultimately the USNRC offered to provide support to the USGS to develop, for the eastern half of the nation, a limited version of the national network envisioned in the Bolt panel report. The USNRC offered to provide the USGS with $1 million a year for five years, mostly for hardware, for this purpose, and an interagency agreement (reproduced as appendix B in NRC, 1990) based on this concept was signed in 1986. The USGS was criticized for sacrificing, as it appeared, the fate of CEUS regional networks by striking a separate agreement with the USNRC. At the time, the USGS did not have the funding to support these RSNs without eliminating ongoing projects, and the existing political climate was not favorable for any funding increases for earthquake science within the Department of the Interior. USGS managers were convinced that the USNRC had made an irreversible decision to withdraw support for the regional networks and that the offer to support development of an alternative monitoring approach in the CEUS was the best choice available. With USNRC concurrence, the USGS used the funding to develop what it termed the USNSN, intentionally avoiding the word "system" in an attempt to make clear that it was not intended to meet the full requirements of the proposal in the Bolt panel report. The USGS technical design features and network objectives were formalized in a planning document (Massé *et al.*, 1989) that envisaged expanding the USNSN concept to a 150-station network covering the entire conterminous United States. Viewed in hindsight, the USNRC had provided the spark needed to start implementation of a national system.

Consensus on a Way Forward, "Alta I"

During 8–10 July 1987, the USGS convened a meeting at Alta, Utah, to informally review the scientific and technical status of USGS-supported networks and to discuss their future course. The USGS was at a critical point in planning the USNSN, and it also was at the planning stage for a new 3-year cycle of cooperative agreements for RSNs. The 17 participants (9 from universities, 8 from the USGS) were involved variously in network operations, their support, or in research based on network data (see Table 1). Evolving plans for the USNSN and its uncertain implications for RSNs dominated the discussions. Was the USGS about to "federalize" U.S. network seismology? The growing operational costs of RSNs, especially for telemetry, were problematic. After insightful discussions of network technology, science, and policymaking—and a declaration by the USGS that they were firmly committed to university RSNs—a defining moment was reached that made Alta I a tipping point. There was consensus on a way forward: development of a National Seismic System (NSS) including both a national element (the USNSN) and regional elements (RSNs). The satellite telemetry scheme of the USNSN could be a cost-effective way of interfacing with RSNs (Simpson, 1987). Further, there was unanimous agreement that a science plan for the national system had to be written.

Tom Heaton led a team in developing a "National Seismic System Science Plan" (Heaton *et al.*, 1989). Apart from outlining the fundamental concepts and scientific goals of the system, the document made a compelling case for the present and future scientific value of RSNs and their role in an integrated national system. The plan complemented the Bolt panel report and demonstrated the scientific potential of a national system, anticipating applications such as earthquake early warning. Supporters and skeptics of a national system had been urging the publication of such an explanatory document since 1980.

NRC Panel on Regional Networks and a Consequence of the Loma Prieta Earthquake

In late 1987, the NRC Committee on Seismology established a Panel on Regional Networks, chaired by Arch Johnston (see Table 1), "to evaluate the health and status of regional seismograph networks." The NRC published a report of this panel entitled "Assessing the Nation's Earthquakes: The Health and Future of Regional Seismograph Networks" (NRC, 1990). The principal recommendations in the report were for Federal agencies to stabilize funding for seismic networks with long-term support for operations and modernization, for the USGS to complete the USNSN in the east and extend it to the western United States, and for the Federal government to pursue the development of an integrated national system as envisioned in the Bolt panel report. The report asserted that the USGS should take the lead in pursuing these recommendations. Appended to this report was a paper by Dave Simpson on technical strategies for revitalizing RSN data gathering, many of which were later adopted.

The next earthquake of consequence for national earthquake policy occurred on 17 October 1989, about 100 km south of San Francisco, California, near the town of Loma Prieta in the Santa Cruz Mountains (USGS, 1994–1998). The earthquake, which was the most damaging to strike the United States since the San Fernando earthquake, led to an increase in funding to the USGS and NSF for earthquake research and monitoring. In 1989, the appropriated funding for the USGS Earthquake Hazards Program was $\sim$ $35 million, as it had remained since 1983. This level was increased to $\sim$ $47 million in 1990 and to $50 million in 1991. The USGS used a portion of this added funding to increase support to CEUS regional networks impacted by the USNRC reduction. This was a significant step. At last, for better or worse, the responsibility for support (or partial support) of many of the major RSNs was being taken on by one Federal agency.

PUSHING AHEAD TO A NATIONAL SYSTEM (1990–1992)

In the early 1990s, considerable time and effort was spent trying to reach community consensus on how to achieve coordination among RSNs and how to integrate them into a national system. A cautious approach was needed to engage all players and keep them "at the table." The reauthorization of NEHRP (Public Law 101-614) on 16 November 1990 clarified somewhat the USGS statutory role in national seismic monitoring. Among the responsibilities assigned to the USGS within NEHRP was the charge to "monitor seismic activity"; the legislation specifically stated that the USGS "shall … operate a National Seismic Network (and) support regional seismic networks, which shall complement the National Seismic Network." Two reports provided policy guidance to the USGS: the report of the Panel on Regional Networks (NRC, 1990) and a January 1991 report of the USGS Review Panel on Regional Seismograph Networks (John Filson [chair], Andy Murphy, Jim Whitcomb, George McMechan, David James, Carl Stepp, and Gerardo Suarez). The latter report advised that RSNs "should be supported, operated, and managed" in the context of an NSS and that "the USGS must establish a standing coordination mechanism or body for the national system."

In June 1991, the USGS sponsored a meeting of seismic network operators at Alta, Utah (informally referred to as Alta II). The meeting was organized by Al Lindh of the USGS and Bob Smith of the University of Utah to address major technical and funding issues faced by RSNs and, at their suggestion, to discuss forming a consortium of regional network operators. The meeting was attended by 49 individuals representing network seismology in academia, the USGS, IRIS, and the private sector (see Table 1). In a sense, the meeting was Knoxville 1985 redux: "It's time to do something about solving the problems of regional seismic networks!" But this time there was palpable determination for follow-up action. Four working groups were formed to pursue progress on sensors and telemetry, recording systems, data centers and formats, and coordination with the USNSN. Further, a steering committee was formed (Walter Arabasz [Chair], John Davies, Egill Hauksson, Arch Johnston, Al Lindh, and Arthur Snoke) with two main tasks: first, by the time of the April 1992, SSA Annual Meeting in Santa Fe, facilitate forming a "Consortium of U.S. Regional Networks" (CUSRN), envisioned as a partnership of government, academic, and private network operators; and second, organize open forums for network seismologists at the October 1991 Eastern Section SSA Annual Meeting in Memphis and the December 1991 American Geophysical Union (AGU) Fall Meeting in San Francisco in order to keep the Alta II process alive and to get more community input on the intended consortium.

The Memphis and San Francisco forums were well-attended, and at each forum there were progress reports from the Alta II working groups and lively discussions about the proposed consortium. The discussions in San Francisco were more focused and substantive. Where would a "home" be found for the proposed CUSRN? Three options were formed: (1) organize under and as part of IRIS, (2) form a self-governing body with the USGS providing "secretariat" services and other support, or (3) form a completely independent body. Option 2 appeared, tentatively, to be the preferred choice of the attendees, in view of realities that the USGS was a key funding source, operated the largest seismic networks, and had the mission of national seismic monitoring. But the attendees also had an eye on how coordination with IRIS might be helpful in the areas of data management and archiving and in instrumentation development. Before the meeting was closed, Arabasz, Filson (representing the USGS), and Dave Simpson (representing IRIS as its new president) agreed to refine organizational models for the CUSRN for further consideration by the network community at large.

In mid-January 1992, Arabasz, Filson, Simpson, and Arch Johnston (invited to represent eastern networks) met to brainstorm practical options for the CUSRN. A key concern was finding an effective linkage between RSNs and a national system. Coordination was needed not only among RSNs but also between regional and national network operations. They came up with a proposal having three elements. First, form a coordinating council for an NSS (provisionally termed "the National Seismic System Coordinating Council") that would be organized by the USGS (IRIS was reluctant to be diverted from its focus on basic science). Because this body would deal with a national system it would involve RSNs. This council would be charged with coordinating the development of a national system and with providing leadership in resolving relevant issues as they arose. Second, stimulate the formation of an independent cooperative association of regional and local seismic networks, either formal or informal, along the lines of the proposed CUSRN, to provide a forum to promote interchange of technical and scientific concepts and developments. Finally, form working groups under the national council to address specific operational issues. Arabasz distributed this proposal to the network seismology community in advance of an announced community forum on "U.S. Regional and Local Seismic Networks" at the upcoming SSA Annual Meeting.

The special forum was held on 15 April 1992 at the SSA Annual Meeting in Santa Fe, and about 100 individuals attended. Reports on network-related technical issues were presented by the four Alta II working groups followed by reports from IRIS representatives on prospective interactions between IRIS and regional/local networks. A presentation by Tim Ahern, manager of the IRIS DMC was particularly significant and encouraging: the archiving of regional network data into the DMC did not pose as formidable a task as first feared, and IRIS could provide modest support for conversion of regional network data into Standard for Exchange of Earthquake Data (SEED) format developed by the Federation of the Digital Seismic Networks. This signaled a potentially big step forward for data exchange and archiving of RSN data.

Filson presented and led discussion of the concept of a coordinating council for the NSS coupled with a separate cooperative association of regional and local network operators (i.e., CUSRN). Filson made four principal points. (1) He stated the willingness of the USGS to take the lead in forming a national council. (2) He noted the key issues that needed to be addressed, including representation, leadership, voting privileges, and funding for council operations. (3) He indicated the possible conflicts in trying to form an organization that was inclusive and transparent yet capable of making and acting on decisions—drawing a distinction between general council participation for informational and discussion purposes and voting participation for decision making and implementation. (4) He indicated that these issues should be addressed by establishing a charter for the council. Group discussion led to strong consensus support for forming the proposed council. There were no vocal advocates for forming a separate CUSRN; rather, it seemed that most of the concerns of regional and local network operators could be sufficiently addressed within the proposed council. The forum ended with general agreement to proceed with the development of the council and a governing charter, and the Alta II steering committee was dissolved. The USGS took advantage of the 1992 AGU Fall Meeting in San Francisco to convene one more community forum on forming an NSS. Filson presented the principal elements of a draft charter for the national coordinating council, followed by questions and discussion. The meeting was well-attended and enthusiasm was evident for pushing ahead to form the governing body for a national system. The forceful consensus was "Enough talk, let's get on with it!"

REALIZING A NATIONAL SYSTEM (1993–2000)

The Council of the National Seismic System

On 19 February 1993, the USGS convened a formational meeting of the NSS in Lakewood, Colorado (Arabasz and Malone, 1995). Approximately 50 persons attended this meeting representing most, if not all, of seismic network operations—national, regional, local, and strong motion—in the United States. At last, most of those responsible for monitoring and reporting seismic activity throughout the country were together in the same room to discuss and adopt a plan for their collective future. The meeting lasted for one full day and chiefly focused on the structure of proposed cooperation among network operators. By the end of the meeting, there was agreement to form a CNSS, and a draft charter for the CNSS was discussed. Filson was elected the first Chair of the Council for a 2-year term and Arabasz was elected Vice-Chair. An executive committee was formed consisting of John Ebel, Bill Ellsworth, Arch Johnston, Egill Hauksson, Steve Malone, Bill Menke, Bob Page, and Barbara Romanowicz. By April 1993, a formal charter for the CNSS was agreed to by the executive committee and was circulated to network representatives for signature. The text of the charter is given in Ⓔ the electronic supplement of this article. Reading it now more than two decades later, the text seems overly formal, but the charter successfully met the needs and concerns of the organizations participating in council activities. Eventually, 30 institutions and agencies (listed in the electronic supplement) joined the Council. Upon reflection, the CNSS charter, relying as it did on consensus agreement and without an empowered central authority, had the same weaknesses as the Articles of Confederation at the time of our Nation's founding. But both documents served a valuable purpose. Commitment to cooperate had to come first before governance (whether through the ANSS or the U.S. Constitution) could then be established.

From CNSS to the Vision of an ANSS

The NSS that was created with the formation of the CNSS was a first-generation structure, the union of existing seismic networks operated by the Council members. In words borrowed from USGS Circular 1188 (USGS, 1999), it was at best "an uneven patchwork of loosely confederated networks with different equipment, operations, products, and funding sources." Transforming what existed into a modern and truly functional system required new funding and was to take more than another decade and not achieved until implementation of the ANSS.

The respective chairs and vice-chairs who provided leadership of the CNSS were Filson and Arabasz (1993–1995), Arabasz and Steve Malone (1995–1997), Malone and Harley Benz (1997–1999), and Tom Heaton and Lind Gee (1999–2001), when the transition of CNSS to ANSS was completed. Early during the CNSS, working groups were formed to explore software development and implementation, data acquisition methods, strong-motion/engineering geology, data distribution and archiving, and rapid earthquake response. In 1996, a CNSS Composite Catalog was created, hosted by the Northern California Earthquake Data Center at Berkeley.

A number of developments made 1997 a pivotal year for the evolution of the NSS. In February 1997, Joan Gomberg, Barbara Bogaert, Walter Arabasz, and Steve Malone convened a groundbreaking USGS/CNSS workshop in Memphis, Tennessee: "U.S. Seismic Networks and the National Seismic System—Taking Connectivity and Performance to the Next Level." As a follow-up to the workshop, a CNSS white paper in May 1997, "A Framework for Advancing the National Seismic System (NSS)," authored by Walter Arabasz, Ray Buland, Bill Ellsworth, and Lind Gee, outlined short-term, intermediate-term, and long-term performance goals for accelerating development of the NSS. Converging circumstances that spurred the white paper included a USGS 5-year plan (1997–2002) calling for an effective NSS by 2000; increased expectations for Federally funded projects raised by the Government Performance and Results Act; the imminence of a national-scale consortium being formed to meet strong-motion needs of the U.S. earthquake engineering community (described in the next paragraph); increased expectations by users for rapid earthquake information based on the CUBE, REDI, and TriNet projects in California; and the inauguration of Consolidated Reporting of Earthquakes and Tsunamis (CREST), a project involving six CNSS seismic networks along the Pacific coast to support earthquake and tsunami risk mitigation.

In April 1997, the earthquake engineering community held a seminal workshop in Monterey, California, sponsored by the U.S. Committee for Advancement of Strong Motion Programs (CASMP) and NSF resulting in the report "Vision 2005 for Earthquake Ground Motion Measurements in the United States" (Borcherdt *et al.*, 1997). The 43 workshop attendees predominantly included earthquake engineers but also several seismologists. One of the significant outcomes was an estimate that as many as 7500 strong-motion instruments were needed on a national scale to provide the data needed for improving earthquake safety in the United States. This report was important because it gave, for the first time we believe, the scale of the strong-motion instrumentation needed to meet engineering needs. Another outcome was the intent to create a Consortium of Organizations for Strong-Motion Observation Systems (COSMOS). The charter for COSMOS was written in December 1997.

Perhaps the most critical development in 1997 was the appearance of a key provision in Congress's reauthorization of NEHRP for FY1998 and FY1999. Under Public Law 105-47, enacted 1 October 1997, the USGS was directed, within one year, to "provide for an assessment of regional seismic monitoring networks in the United States." The assessment was to include needs and projected costs, notably targeting "the need to update the infrastructure used for collecting seismological data for research and monitoring of seismic events in the United States" and "the need for expanding the capability to record strong ground motions, especially for urban area engineering purposes."

In response to the directive of Public Law 105-47, the USGS convened a 3-day workshop in early June 1998 in Denver, Colorado, to assess the requirements for U.S. seismic monitoring. In addition to CNSS members, the workshop purposefully included representatives from the earthquake-engineering and emergency-management communities as well as the broader seismology community. Key topics for focused discussion were data requirements for regional and national seismic monitoring; engineering/strong-motion data requirements; emergency response requirements; monitoring strategies and network interaction; and the needs of basic and applied science for data from seismic networks. The workshop succeeded in characterizing the current status of U.S. seismic monitoring, requirements and justifications for updating and improvements, and the basic outlines of the report requested by Congress. Armed with this information and broad community input, Harley Benz, Filson, Arabasz, and Lind Gee, by the end of 1998 had drafted a report that laid out the vision of an ANSS: "An Assessment of Seismic Monitoring in the United States: Requirement for an Advanced National Seismic System" (USGS Circular 1188, USGS, 1999). This document drew upon many of the concepts developed by the strong-motion community in the 1997 CASMP report. The ANSS report was submitted by the USGS to the Congress in the spring of 1999. Closing the arc from vision to reality of the ANSS lay ahead—authorization, funding, structuring, and implementation.

Launching the ANSS

In late 2000, Congress formally authorized the establishment and appropriation of funds to the ANSS (the statutory terms for the ANSS were the Advanced National Seismic Research and Monitoring System). Relevant legislative text in Title II ("Earthquake Hazards Reduction Authorization Act of 2000") of Public Law 106-53, enacted on 13 November 2000, reads as follows:

> *The Director of the United States Geological Survey shall establish and operate an Advanced National Seismic Research and Monitoring System. The purpose of such system shall be to organize, modernize, standardize, and stabilize the national, regional, and urban seismic monitoring systems in the United States, including sensors, recorders, and data analysis centers, into a coordinated system that will measure and record the full range of frequencies and amplitudes exhibited by seismic waves, in order to enhance earthquake research and warning capabilities.*

Additional text in the legislation instructed the Director of the USGS, not later than 90 days after the date of the law, to provide Congress with a 5-year management plan for the enhanced system, including "annual cost estimates for both modernization and operation, milestones, standards, and performance goals, as well as plans for securing the participation of all existing networks in the Advanced National Seismic Research and Monitoring System and for establishing new, or enhancing existing, partnerships to leverage resources." Further, the law authorized appropriations for ANSS at the level of $38 million for FY2002 and at comparable substantial levels annually through FY2006. Authorizing appropriations is not the same as actually appropriating money. The amount appropriated for ANSS development in FY2002 was $3.9 million. This built upon earlier funds appropriated to the USGS for new urban strong-motion instruments ($1.6 million for FY2000 and $2.0 million for FY2001) that effectively provided the start-up funding for ANSS (see USGS, 2003, pp. 135–136). (ANSS funds come from an appropriation to the USGS for the Earthquake Hazards Program.) Sixteen years beyond the enactment of Public Law 106-503, the full capitalization of ANSS and the securing of sufficient operating funds remain ongoing challenges. Nonetheless, through successful partnering and leveraging of funds, immense progress has been made in transforming what existed before 2000 into a multipurpose modernized NSS. One unexpected opportunity for enhancing ANSS arose with the American Recovery and Reinvestment Act (ARRA) of 2009, under which seismic and geodetic monitoring activities supported by the USGS received an additional $19 million of one-time support for equipment modernization. An NRC report on the economic benefit of improved seismic monitoring (NRC, 2006) helped secure the ARRA funding.

The history of implementing ANSS is another story. Many organizational hurdles and entrenched positions had to be overcome (see Malone, 1999). We will conclude our present review by describing some developments during 1999 and 2000 that relate to the emergence of ANSS prior to its formal authorization. In the 106th Congress, the language of Public Law 106-503, cited above, first appeared in a House bill (H.R.1184) that was passed on 21 April 1999 and was then referred to the Senate one day later. Before USGS Circular 1188 was officially submitted to Congress in the spring of 1999, congressional staffers had been briefed on the vision and scope it described for ANSS and were favorably impressed. This led to the inclusion of legislative language in H.R.1184 for authorizing ANSS. Without these actions ANSS authorization would have been delayed at least three years. The most compelling argument to Congress in support of ANSS was that there already existed a foundational basis on which to coordinate and build an NSS, namely the CNSS.

As events unfolded, Senate action on H.R.1184 was delayed. A counterpart NEHRP bill (S.1639) including the authorization of ANSS was introduced in September 1999 but was not passed by the Senate until October 2000, becoming Public Law 106-503 enacted the next month.

After H.R.1184 was passed by the House in April 1999 but before it became law, the USGS proactively moved ahead to begin forming a management plan for ANSS. A 2-day workshop on the "Implementation of the Advanced National Seismic Research and Monitoring" was held in Beaver Creek, Colorado, in August 1999. Broad stakeholder interests were represented by 49 participants from the USGS, CNSS, COSMOS, IRIS, State geological surveys, State and Federal emergency management agencies, and the private sector. The meeting resulted in the outline of an implementation plan and management structure for ANSS that called for a national steering committee to provide overall direction, an ANSS manager to be responsible for implementation, and regional coordinators and committees for regional implementation and guidance. The USGS continued moving ahead and created an interim national steering committee, which first met in February 2000 in Albuquerque, New Mexico. The 14 committee members represented CNSS and other groups that had a stake in ANSS. The transition from CNSS to a new partnership structure for managing an enhanced NSS was under way.

EPILOGUE

Congressional authorization of a national seismic system in November 2000 was the end result of two decades of striving by seismic monitoring interests in the United States. Although it might have been easier to design an NSS from scratch (assuming the availability of funds to build such a system), those involved recognized that the system needed to be built on and evolve from existing facilities, capabilities, and interests. This decision was both practical and political, and it has ongoing benefits because ANSS continues to rely on partnering to supplement Federal funding. The framers of the CNSS charter tried to mold diverse interests into an organization that respected existing roles but provided a vision of a shared future and a framework for realizing that future. An observation by Joseph Ellis describing the founding of our Nation aptly applies here as well, "No one present at the start knew how it would turn out in the end" (Ellis, 2002, p. 5). The level of enthusiasm for the concept of a national system varied among network seismologists. Some worried that centralization would jeopardize their autonomy, flexibility in their network operations, or competition for network funding. Some felt a stronger affinity to their region than to a national structure. Each had advanced to a different level of trust in the USGS. But all recognized the need to work together to survive and perhaps thrive. The realization of the ANSS, and subsequent increased support for national and regional monitoring, vindicated this approach (although, in truth, not for every network).

To advance ANSS, hard work still needs to be done under challenging circumstances. New demands and priorities arise while there are still unmet seismic monitoring needs in many parts of the Nation. Under the ANSS Management Plan, the ideal of ANSS governance as a consensus-driven community enterprise coexists with the fact that the USGS must justify and answer for the expenditure of federal funds for implementing ANSS. The USGS must also oversee the performance and day-to-day technical operations of ANSS as its system manager. All these circumstances understandably give rise to tensions, many of which are not new and will likely persist to some degree. In ANSS, supporting the common good is critical, but it requires building mutual trust (a long-term process) and shared goals (set collectively).

Many of those originally involved in the formation of a national seismic system have now either retired or moved on to other positions. A few are deceased. Sustaining the operation and societal contributions of the current system is now in the hands of a new generation. As the new generation faces future technological, financial, and organizational challenges, perhaps our story will encourage its members to do so in a spirit of good will and compromise and to take a long view—the legacy of those who provided the foundation for the new generation to build upon.

DATA AND RESOURCES

No data were used in this article. Information presented is variously from cited sources, archival materials in the authors' personal files, and the authors' recollections from their involvement in many of the events and developments described.

ACKNOWLEDGMENTS

We pay special tribute to all those, mentioned or unmentioned in this article, who in ways small and large contributed to making a national seismic system a reality. This includes thanks to individuals who served on the National Research Council (NRC) Committee on Seismology and its panels during the formative years of developing the national system and whose guiding reports were crucial. Credit is also due to members of the NRC staff, with particular recognition to the late Joseph W. Berg, Jr., an NRC staff member who worked tirelessly on behalf of seismological interests in the United States. We also thank our coauthors of a 2005 summary of the origins of the Advanced National Seismic System (Filson *et al.*, 2005): Harley Benz, Ray Buland, Lind Gee, Steve Malone, and David Oppenheimer—all of whom were closely involved over many years in shaping the policies and practice of national earthquake monitoring. In this regard, we also acknowledge the efforts and contributions of Bill Ellsworth. Harley Benz, Lind Gee, and Dave Simpson gave us helpful comments on an early draft. John Ebel, editor of the Historical Seismology section of Seismological Research Letters (SRL), provided careful reviews and insightful comments that greatly helped to improve the article. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Published Online 9 November 2016